ICQEM 18

"A better world with Quality!"

3rd International Conference on Quality Engineering and Management

July 11-13, 2018

Universitat Internacional de Catalunya

Barcelona, Spain

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Foreword

Welcome to the 3rd International Conference on Quality Engineering and Management

After the successful organization of the **1st** and **2nd International Conference on Quality Engineering and Management**, in 2014 and 2016, it is our pleasure to welcome you to the conference **3rd edition** at the Universitat Internacional de Catalunya in Barcelona.

The **ICQEM 2018** is an international forum to present and discuss the progresses in the Quality Management, Quality Engineering and Organizational Excellence fields. Consequently, since the beginning, the conference covers different topics as: Standards, Continuous Improvement, Supply Chain Quality Management, Management Systems, Six Sigma, Quality Tools, Quality Management in Higher Education, Quality Management in Services, Total Quality Management, Organizational Excellence and The Future of Quality.

This conference provides the unique opportunity to share the latest insights of academic and industrial research on Quality Engineering and Management and Organizational Excellence, as well as to experience the unique environment of Barcelona, a city which has been at the heart of the artistic, cultural and scientific development since many years.

The ICQEM18 includes keynote speeches, parallel technical sessions, workshops and a number of social and networking events, including a conference dinner. The 2018 edition **keynote speakers** will include:

- **Mats Deleryd -** CEO & President, Swedish Institute for Quality, Sweden
- **Jaume Ribera -** Professor of Operations Management, IESE Business School, Spain
- **Marianna Sigala -** Professor, University of South Australia, Australia
- **Malcolm Tight -** Professor, Lancaster University, UK

Approximately 80 full papers have been submitted and almost 65 were accepted for presentation, after review from the Conference Scientific Committee. Some of these papers were selected by the Scientific Committee to be considered for a special issue that will be published by the International Journal of Quality and Reliability Management (SCOPUS indexed journal). Papers accepted correspond to authors from all around the world, with more than 20 countries represented at this level. Therefore, a warm acknowledgment to all speakers and authors is well deserved – **Thank You!**

We must acknowledge the institutional support received from the Universitat Internacional de Catalunya (UIC Barcelona), Universitat de Girona, School of Engineering of the University of Minho, University of Coimbra, Portuguese Association for Quality, ALGORITMI Research Centre, Research

Network on Management Standards, Cempalavras and Brazilian Society of Quality and Excellence in Management.

Let's take advantage of this great opportunity and make with your contributions an event with Quality, shared and built by such a top level group of participants!

We thank you for your participation and welcome you to Barcelona!

Universitat Internacional de Catalunya, July 11, 2018

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Frederic Marimon
Universitat Internacional de Catalunya

Conference Local-Chair

Martí Casadesús
Universitat de Girona

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Papers index

Submitted papers

Circular Economy: Challenges for the Supply Chain

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ABSTRACT

Purpose - The purpose of this paper is to enhance the difficulties the supply chain will face to implement Circular Economy (CE), as opposed to linear economy, since all interested parties have different thoughts about it, and are not convinced of its cost-benefit.

Design/methodology/approach - The paper is based on the attendance of a relevant congress in Amsterdam on the subject, combined with literature review and participation in discussions about the creation of the CE Nucleus at the Federal University of Rio de Janeiro (UFRJ).

Findings - Main finding refers to the lack of awareness of stakeholders on the importance of CE for sustainability: enterprises, suppliers, governments and society do not assign priority for the concept and its tools.

Research limitations/implications - since CE is a new strategy, its practice is limited to a few developed countries, where society is aware of its relevance. This means that experience is limited, hence available literature is relatively scarce, especially regarding challenges.

Practical implications - the success of the implementation of CE depends upon the mind set of people in general, thus requiring a strong communication effort to convince all parties of its importance. Examples of good practices and reference literature are provided as motivation.

Social implications - CE has a direct connection with sustainability, hence its direct social implications regarding optimization of the utilization of Earth resources.

Originality/value - Due to the limited worldwide experience on CE, especially in developing countries, the paper will provide guidance for its application for all stakeholders.

Keywords: circular economy, supply chain, challenges

Paper type: General review

INTRODUCTION

According to the Ellen MacArthur Foundation [1], Circular Economy (CE) "is an economy that is restorative and regenerative from its design, aiming to maintain the products, components and materials with its greater utility and its greater value throughout the time, distinguishing between the technical and biological cycles". Many other definitions have been coined by specialists working in the area. The emphasis is always on a "cradle to cradle economy", with the formation of closed feedback loops.

On the other hand, the recent international standard ISO 20400, on sustainable procurement [2], refers to a series of activities to explain the CE concept:

- Identification of alternative methods of meeting demand, such as outsourcing, using services or leasing instead of execution with own resources;
- Aggregation and/or consolidation of demand;
- Sharing of use between divisions or organizations;
- Incentive to the recycling, repair or reuse for another purpose of used goods;
- Define whether outsourcing is necessary and how to extend the scope of responsibility for labor and environmental practices along supply chains;
- Use of recycled/ renewable materials.

If this list is thoroughly analyzed, it will be clear that each item represents a challenge to the supply chain.

The standard also emphasizes that resources are kept as long as possible to extract their maximum value, and waste can be considered as an alternative resource.

This paper, although recognizing the vast field and the specific needs and requirements of each supplier chain, is intended both to present difficulties for CE implementation, and on the other hand provide possible solutions through discussion, referenced literature and practical examples. A micro-vision at organization level, an example of an industrial park or zone (meso-level) and a macro-approach at national level is presented, in order to cover possible actions to be initiated by all stakeholders.

DIFFERENT CHALLENGES FOR DIFFERENT SUPPLY CHAINS

This paper is based on networking and on information gathered during the first International Congress on Circular Procurement in Amsterdam on 20-22 April 2016 [3], and on the experience of the Author participating in the implementation of the CE Nucleus at the Federal University of Rio de Janeiro and related activities. Working as a Consultant of several national and transnational organizations in Brazil and abroad gave also the opportunity to observe CE practices in different stages.

Of course, challenges to the supply chain to introduce CE practices are quite different, depending upon several issues, as discussed in general terms at the Amsterdam Congress:

- the sustainability in general and CE specifically awareness level of each country, including both the degree of importance population (see item 3.2, beforelast paragraph as an example, The Netherlands x USA) as well as business assign to CE; this will influence behavior of individuals and corporations, and public policies issued by governments; these policies in turn could include incentives such as tax breaks to firms adhering to its practices
- the size of the supplier (and of the purchaser), and the products and services it provides, as well as market competition issues; small companies will not have power to influence its supply chain, which can include bigger partners
- the existence or not of reverse logistics scheme and facilities provided by the company, and marketing strategies offering advantages such as discounts when used products are turned back for recycling or remanufacturing
- the type of product: if due to the advancement of technology new models of a certain product present advantages such as lower energy consumption, remanufacturing is not applicable; in these cases, disassembly for use of components or materials is the right CE practice; however, since for instance ICT equipments usually contain dangerous substances, care should be taken to avoid harm to people handling them or to the environment [4]
- the existence of national, regional or local laws and regulations related to the environment [5]; there are cases where, for instance, manufacturers directly or through their sales representatives including shops must take back products when they reach their life end
- economical factors: adopting CE practices can mean the need of additional facilities, and the relevant costs can be a burden, especially for a small company (see Fig. 1); governments in these cases could provided subsidized credits to make feasible the necessary investments
- the availability of cost-effective technologies to introduce a CE practice

- the customer base: are the customers individuals, or other companies? are they willing or prepared to recognize and prefer a supplier adopting CE practices as their contribution to a more rational use of Earth resources?
- company leadership: is top management actually conscious of the importance to adopt CE practices, and willing to demonstrate to all levels that this is actually top priority, encouraging all employees to think circular from the very initial phases of design and development of products and services?

THE ROLE OF INTERESTED PARTIES (STAKEHOLDERS)

CE is the result of an attitude or culture that needs to be developed by all stakeholders: government, business, development institutions and society in general; they need to be informed, or rather enlightened and motivated, that it is imperative for the preservation of humanity's future, not simply a fad. The cultural question, therefore, requires specific treatment since the practice of CE forces a paradigm shift. It is important to emphasize the importance of government and the private sector integrating thoughts about the impacts of the acquisition approach across the procurement cycle, from design, delivery, use and disposal (including reuse, re-purposing, and recycling).

Collaboration within organizations and with the market is also important in identifying priority categories where supply and material supply chains can move from open or linear to circular or closed, reducing life cycle costs and impacts.

Of course, a top priority is the amount of plastic materials that contaminates large areas ashore and, in the seas, already considered catastrophic. The subject is also calling the attention of university graduates, for instance the use of plastics for packaging and its problems and possible solutions [6].

Society

How society in general as a whole, represented by individuals integrating their thoughts to form public opinion, will influence positively the introduction of CE practices in a country? And what are the challenges to the supply chains they generate?

The first difficult challenge is the consumerism society, namely whether individual customers easily buy the CE concept. By the way, there is very little literature, if any, regarding the obstacles CE will face regarding people purchasing habits of, for instance, the newest model of a cell phone, and other electronic gadgets. Many consumers, provided they have enough money, will desperately look for the last model, even if the one it owns is working perfectly. Maybe even new features available in the new model are not needed or used, but the hedonistic desire, propelled by sophisticated marketing techniques, will most probably win. So, we must not neglect or even minimize the obstacles and difficulties for implementing CE. How to counterbalance the strength of corporate advertising and marketing with the continued launch of new products and services, and the obsolescence and limited programmed durability?

Effectiveness of communication and marketing by companies is by far more powerful than CE relevance is understood by most people. The majority of individuals would like to be the first to have the most advanced and sophisticated cell phone. A typical posture read in newspapers is: "I know I don't need it, but I want it". Would society's change of stance and reverse logistics be effective enough to balance the search for new and status by consumers? To mitigate this behavior, distributors could for instance offer discounts if for the return of old equipment. This will allow recycling of components and material for other applications.

In order to provide a more circular economy, there is a need to change the way individuals consume. To change the economy model, there is a need of new business models, and for that we need to facilitate a new relationship between producers and buyers, who need to become users rather than owners. Of course, consumption habits change along time: youngsters in many countries do not have a car as their top priority object of desire anymore, as Prof. Carlos Fernández, sociologist at Universidad Complutense, Madrid, emphasizes [7]. Interesting point is the fact that behaviors are changing quickly: a survey carried out in Quebec during 2005 was still showing youngsters willing to have a car for hedonistic reasons [8]. Figure 1 shows what was top priority in brazil 20007.

Figure 1 - Brazilian magazine ad, 2007: "We passed the entrance exam. Where is our car?"

People should be stimulated, before buying a home appliance such as the many times quoted drilling machines, to ask questions such as:

- do I actually need it? How often will it be actually used? (you can even try to remember how many pictures you hanged in the walls in the last years, for instance)
- is there any neighbor, family member, friend, work colleague or club associate who can borrow it?
- can I find somebody selling a used one?
- could I convince residents of my apartment building or neighborhood to buy one machine for shared use?
- is there any shop offering it for rental?

This mindset could apply to buying or not a car, new or used, or winter clothes to go to a trip to a mountain resort or getting used to use laundry utilities installed in the basement of the apartment building. It will be a change of economic arrangement from pay per product to pay per use.

It should also be emphasized that an extraordinary communication effort for all audiences, encompassing governments, companies and society, is indispensable for everyone to get acquainted with the benefits of CE and to practice it; in the case of companies, convincing them that it generates economic benefits should be the focus of the publicity campaign; to use real cases in this conviction should be the point. Such campaigns should be tailored to the target audience, since the awareness level about the importance of CE varies from country to country, age, income level etc.

An interesting case somewhat unexpected is a survey on to what extent can society eat different to practice CE. The paper shows also the different perception between countries of the subject: in The Netherlands 12% of interviewees recognized the importance of eating less meat, whereas in the US only 6% recognized this relationship [9].

In summary: the only way the supply chains can answer to the challenge represented by society's appeal for the introduction of CE practices is to balance sales strategies based on innovation, with clear demonstration of actual initiatives aligned with the adoption of CE principles.

Government

How governments can influence positively the introduction of CE and practices at national, regional and local level, and what challenges official initiatives bring to the supply chain?

The first step is to believe firmly that CE is a sound concept to avoid the depletion of limited Earth resources, reducing as far as possible the carbon footprint of human activities. This will shall be transformed in acts, such as:

- Clear statements by high level authorities of a country, state, province, county or municipality emphasizing the importance of CE
- Promulgation of legislation introducing incentives to companies practicing CE
- Adopting in government offices daily administrative routines and activities CE principles, Internet sites thus showing very clearly that they are actually adopted by public offices
- Sponsoring conferences, exhibitions, books, websites, ads, campaigns, social networks material, awards for people and companies, etc. to foster the adoption of CE countrywide and locally.

As a relevant aspect of sustainability, CE is considered to be a priority by the European Commission (EC). With the issue of circular purchases being given special attention, in 2015 a Plan of Action with detailed guidelines on the subject, including the important document published by the European Union - "Buying Green! A handbook on green public procurement" was published [10].

Governments have a responsibility in policy-making and need to develop initiatives to stimulate CE, foster innovation and creativity; in particular, governments play a very important role in the development of circular purchases, since they acquire a large volume of products and services, estimated at 50% in Sweden, 35% in France, 20% of GDP in Mexico [11] (the estimate in Brazil is between 15 and 20%).

Local governments also must play a relevant role in CE practices adopting:

- procurement procedures considering CE principles
- design thinking in the development of new public services, or when updating or rethinking new ones
- smart cities approach
- service sharing with cities in the neighborhood
- subcontracting transportations services instead of having its own fleet.

A relevant example of the support given by universities to develop CE policies is the contribution the Aalto University in Finland provides through the Design for Government course students [12].

In summary: when selling to government offices, suppliers will be subjected with requirements to provide products and services, that will become progressively more stringent. On the other hand, suppliers should direct efforts towards the issuance of legislation that stimulates the practice of CE.

Suppliers

Suppliers and their sub-suppliers shall be prepared to the irreversible trend towards CE. If you own or manage a company and wish to prepare it to implement CE and is not sure on how to do it, you can attend a course, tutorial or workshop to learn how to [13].

Practices rooted over time by companies need to change; on their part, is the ambition to engage in the movement and be different, defining strategies and policies that result in actions aimed at achieving sustainability goals; the adoption of alternative practices after analysis of those more sustainable involves innovation and creativity. Companies like Philips Lighting are changing their business model from being no longer just sole supplier of lamps to selling services related to lighting, including design, installation and maintenance services, such as provided together with Cofely to Schiphol Airport in Amsterdam [14].

The investment needed to shift to CE is not a problem for big corporations, a major challenge is the way SMEs will cope with this trend, as they have several limitations, as shown in Figure 2 [15].

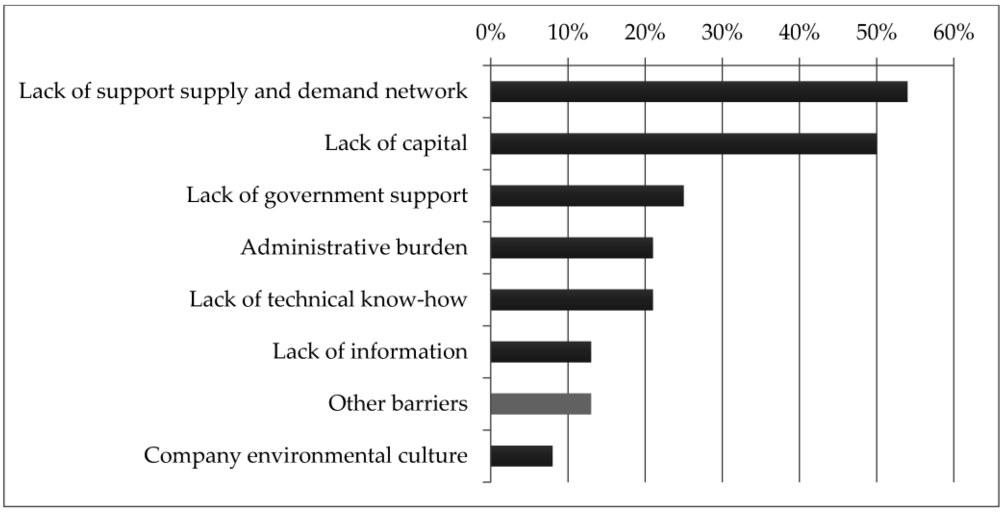

Figure 2 – Barriers to the implementation of CE by SMEs

Changes to the supply chain will become progressively more challenging due to:

- pressure of legislation and public policies: the introduction of tax reductions or exemptions is an example of incentives that can influence private companies to adopt CE practices.

- increased society awareness: the recognition that earth resources are limited is increasing, especially in the more developed countries, but is also progressively encompassing the whole world. This would mean that customers will be more aware of benefits generated by companies that practice CE, thus preferring them.

- economic reasons: governments, corporations and people are understanding that it is less expensive to adopt CE practices rather than continuing abiding to linear economy. Buying used equipments still in good shape is of course cheaper than buying a new one, sharing a boring machine or a car ride means cost reduction. Renting houses or rooms through AirBNB or providing transportation driving your car through Uber generates an additional income. Of course there is a danger of *green washing*: a company advertising energy and water consumption reduction is, of course, reducing its costs, and not necessarily adopting CE as a business policy. For some industries certain specific practices should apply: for instance, buildings must have an inventory of the material used in the construction, so that their eventual demolition considers the material used for balance purposes (observing the dismantling of the immense amount of materials used in Rio's Olympic Games 2016, a reflection on the concept arises: will all those pieces of wood, steel, plastics etc. be reused, or at least recycled? In some cases sports facilities will be transformed into schools, but what will be the effective reuse rate?); however, corporations do not adhere to CE practices unanimously, since they are afraid that they will sell less, thus reducing their income.

- introduction of new business models: a Danish firm is renting baby clothes instead of selling them; electronic banking will mean less personnel in the payroll and less branch space required for customers. Brazilian Government has started to replace official cars to provide transportation services for public servants by a subcontracted service called TáxiGov, similar to Uber [16]. Manufacturers are often also providing services, meaning that the difference between products and services is disappearing in many areas, as the Philips example.

- trends toward sharing of installations, systems, equipments and appliances, either internally or externally

- more stringent CE requirements from purchasers to suppliers: during the Brazilian mirror committee meetings on ISO 20400 - Sustainable procurement, long discussions raised a relevant question: should we concentrate to cover just sustainable products and services, or sustainable suppliers? It seems that a compromise solution was achieved: in general the text concentrates on products and services, but some paragraphs raise the question of sustainable suppliers; one way of the other, purchasers press their supply chain to complying at first with sustainability, especially regarding environmental issues. This means that there is a long way towards CE practices actual implementation throughout the supply chain.

- increasing importance of design, in order to develop products considering life expectancy, maintainability, recycling, reuse and optimization of resources: if we require products to make easier disassembly, repair and destination for other uses, long life and economic use of resources, everything starts with product design. This means that engineering areas shall prioritize, from the very beginning, product life from cradle to cradle. This applies also to services, where usually some products are needed to provide them. For instance, even a small company providing office cleaning services, besides chemical products, will need some kind of equipment which could be either purchased or, even better, rented.

- maintenance, repair, repurposing and recycling market increase: if customers adhere to CE practices, firms providing services to increase usable life of machines, equipments and appliances will need to increase their provision of services and be prepared to return them in a "as new" condition. This will imply the offering of guarantees to be mutually agreed, availability of spare parts, personnel technical and administrative qualification, test equipment acquisition etc.

- environmental issues: suppliers will need to introduce reverse logistic practices, both due to enforced legislation [17] or consumers pressure.

The following questions, among others, should be answered by leadership and employees, before a supplier embarks in the CE implementation:

- does governance developed and middle management know and practice CE's policies and strategies?

- are employees connected with the concept and design of new products or services aware of CE principles?

- do they consider their full life cycle when developing them?

- is the use of recycled material, or a minimum amount of materials considered?

- maintainability, reparability, availability of spare parts were analyzed?

- are employees of the procurement area well trained and conscious of their role to apply CE concepts when selecting low tier suppliers and buying equipments, components, raw materials, services etc.?

- will production be made in the company with the need of new machinery, or instead some processes could be subcontracted?

- marketing and sales thought about offering a discount if customers give back their old appliance or equipment?

- is a reverse logistic structure in place to receive back used items and forward them to recycling or remanufacturing firms?

Regarding the supply chains, this will mean a change from the linear model where responsibility ends at the point of sale to shared responsibility throughout the chain, and including users.

SUBSIDIES FOR CE IMPLEMENTATION AND ACTUAL CASES FOR INSPIRATION

There are many tools available for organizations wishing to implement CE. For instance, the EC offers different levels of support documentation [18]. Danish Government also published a very useful booklet, Best Practice Examples of Circular Business Models [19]. CEPS, the Centre for European Policy Studies, has published the report The Circular Economy - A review of definitions, processes and impacts, an interesting text for an overall view of CE [20].

Benchmarking can offer many actual cases for inspiration towards CE. For an industrial park, for instance, a holistic design approach can result in a very interesting arrangement such as the one shown in Figure 3 for Kalundborg industrial park in Denmark. There CE in action can be seen as a good example of integration, with inputs and outputs flowing in an optimized way between suppliers, producers, customers and users [21].

The "zero waste" concept can also be applied in a limited way, for instance in mining operations. Since gold ore comes from the mine with an enormous quantity of sulfur as waste, a Brazilian company, AngloGold Ashanti, operates two huge sulfuric acid plants, which in turn is sold to chemical industries. The same happens to a Brazilian zinc mining unit from Votorantim, where limestone waste is purified to reach agricultural requirements accepted level and sold to farmers for correcting soil acidity. Steel industry is another example of a punctual operation process adopting CE: it uses a relevant percentage of recycled iron, but ArcelorMittal Tubarão, Brazil, made much better: the plant at is now able to sell and reuse internally around 90% of what was previously categorized as waste. This last case and many other success stories are published by the Ellen Macarthur Foundation [22].

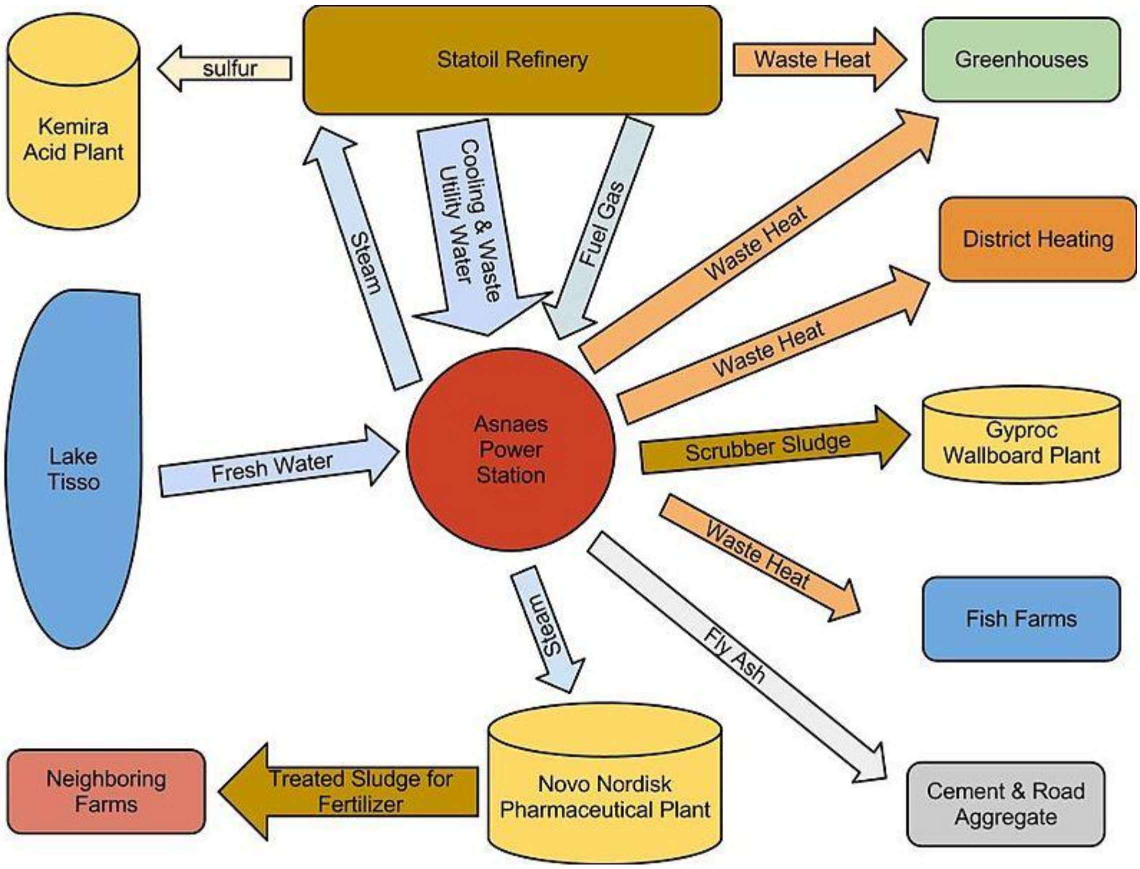

Figure 3 – Kalundborg Industrial Park, in Denmark, a good CE example

Radjou words about India could be true to many other countries [23]: “In the 70s, when I grew up in India, we practiced circular economy principles without even knowing it: we wasted no resources and reused everything. With rapid modernization of its economy, however, India is loosing touch with its frugal roots. This report convincingly shows how India can rekindle its frugal consciousness and implement circular value networks that would set new global benchmarks for efficiency and sustainability". It is a typical example of people adopting CE practices without knowing it, and on the other hand how modernization can impair the use of traditional habits.

It is relevant to highlight as an important CE objective that Japanese recycling rates are extraordinary [24]: the country recycles 98% of its metals[6] and, in 2007, just 5% of Japan’s waste ended up in the ground, compared to 48% for the UK in 2008. Japan's appliance recycling laws ensure that the great majority of electrical and electronic products are recycled, compared with 30–40% in Europe. Of these appliances, 74–89% of the materials they contain are recovered. Perhaps more significantly, many of these materials go back into the manufacture of the same type of product. This is the 'closed-loop' holy grail of recycling, essential for a truly circular economy.

IMPLEMENTING CE AT NATIONAL LEVEL

How to foster CE implementation countrywide, starting from scratch, in order to help a national supply chain to overcome the challenges suppliers will face? Central and local governments have a relevant role to support it. The same applies to universities, sponsoring or providing actions together with other players and thus helping congressmen, high ranking officials, companies and news media to help achieving CE objectives.

Chinese circular economy strategy is deployed at three levels [25]: the enterprise-wide promotion of clean production; in industrial zones to implement industrial ecology; and at the region level to develop eco-cities. A case study is the Eco-City of Guiyang, in which industrial systems have been optimized to achieve a more effective use of materials and energy. It is interesting to notice that the Chinese approach is top-down (government initiative), whereas in Europe and Japan it is bottom-up, as a result of the awareness level of the society.

To support the implementation of CE in Brazilian companies, the Federal University of Rio de Janeiro (UFRJ) has created a CE Nucleus. Based on the observations made in many sources, the following proposals of activities were presented by the Author for the implementation of CE at national or regional level are presented below [26], as a subsidy, considering for instance Brazil but applicable to any country still in the early stages of its usage:

- Identification of areas where it will be easier to start with, in order to demonstrating feasibility and attracting new actors through publicity of success stories; this could be industrial districts, clusters of companies with related activities, for instance:

- Extension of environment or sustainability programs already sponsored by industrial associations, to include CE

- A major communication effort, integrating into a formal plan with the support of professionals in the field several different activities for different target audiences is a priority; it is necessary to sell the idea of CE to the government, so that there is an official policy of circular purchases by the public agencies, for the companies to change the approach of selling products for service, and also for society to become aware of its importance

- Creation of short and long-term courses on CE at different levels

- Encouragement of the introduction of subjects related to sustainability, in particular on CE, in technical and university courses

- Publication of informative notes on the subject, both nationally and internationally, including case reports and successful practices

- Easily accessible database structuring on the subject, including national and international bibliography, success worldwide stories, as an indispensable repository of knowledge on the subject.

- Exchange of specialists with the arrival of European and other countries professionals for short and medium stay, as well as the sending of nationals to European and other countries for internships, technical visits and undergraduate and postgraduate courses, propitiating an exchange and acquisition of knowledge important to give greater speed to CE implementation

- Creation of some kind of recognition (prize?) to organizations and professionals that excel in the area of CE

- Programming of an annual international seminar on the theme with the participation of worldwide recognized experts

- Identification of sources of funding available to public and private organizations interested in implementing CE projects and practices, as well as promoting new initiatives

- Proposition to the Government, at federal level, of legislation that defines a policy and promotes the development of CE; this legislation could be followed by related actions at regional and local government level

- Creation of a set of qualitative indicators for self-evaluation of companies regarding their level of CE practice, in accordance with Annex B of ISO 18091 (tricolor status matrix of qualitative indicators)

- Creation of sets of key performance indicators (quantitative) to evaluate the performance of companies

- Identification of multinational corporations that practice CE, seeking to encourage subsidiaries to implement it using real cases to sell the idea.

Of course there is a long way for these ideas to becoming reality, but to start this process there are some promising initiatives underway.

CONCLUSION

To embark in Circular Economy, a company must think holistically considering its market and supply chain as a whole:

- is the market (customers and final users) able to recognize the company's effort to introduce CE? (this is not mandatory, since this can be an internal decision based on self-motivation, not necessarily focused on image and reputation, or considering marketing strategy)
- is it technically and economically feasible to change design, manufacturing (or delivery if it is a service) and logistics processes [27] in order to have them complying with CE principles?
- has the company the necessary human, technical, physical, managerial and economic resources to introduce CE?
- are its low tier suppliers conscious of their role, namely understanding CE practices and concepts, and ready to introduce them as partners?
- a thorough risk analysis was carried out, to assess the consequences of the decision, before it is implemented?

Collaboration within organizations and with the market is also important in identifying priority categories where supply and material supply chains can move from open or linear to circular or closed, reducing life cycle costs and impacts.

The cultural question, therefore, requires specific treatment, since the practice of CE forces a paradigm shift, thus practices rooted over time by companies must change; on their part, is the ambition to engage in the movement and be different, defining strategies and policies that result in actions aimed at achieving sustainability goals; the adoption of alternative practices after analysis of those more sustainable involves innovation and creativity.

The adoption of CE rather than linear economy is a matter of attitude change of all stakeholders: society, companies, development institutions, governments, etc.; all need to be informed, or better informed and motivated, that CE is an imperative for the preservation of humanity's future, not simply a fad. The implementation of Circular Economy is a subject for deep reflection, given its consequences for the preservation of quality of life on Planet Earth. And supply chain players shall be ready to review in advance trends to avoid being surprised by its speedy evolution.

In 2013 the European Monetary Fund suggested over US$1 trillion a year could be generated by 2025 for the global economy and 100,000 new jobs created during the next five years if companies focused on encouraging the build-up of circular supply chains to increase the rate of recycling, reuse and remanufacture [28]. So, the adoption of CE is of utmost importance economically speaking, especially regarding the maintenance of employment levels. The expected transition to a balanced interplay of environmental and economic systems is, of course, very relevant [29].

However, the evolution from the green consumer (both as individuals and business) to the ethical consumer and then to the citizen consumer, and finally to the circular consumer, will need time. But this does not mean that this objective shall not be pursued. Supply chains must answer as soon as possible to this challenge, acting together with all stakeholders to achieve this goal. Of course innovation and creativity will play a significant role in its successful implementation

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Assessing the financial effects of adopting multiple certifications

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ABSTRACT

Purpose – The aim of this article is to research into the effects of multiple certifications on firms' financial performance by considering the dynamics involved in this process.

Design/methodology/approach – 243 Portuguese companies that had adopted multiple certifications by 2015 among ISO 9001, ISO 14001 and OHSAS 18001 were analyzed with their historical records from 2007 to 2015. The research into the causal effects of the certifications on firms' return on assets (ROA) was based on a panel dynamic approach, namely the system generalized method of moments.

Findings – Firms holding ISO 9001, ISO 9001 + ISO 14001, ISO 9001 + OHSAS 18001 and ISO 9001 + ISO 14001 + OHSAS 18001 significantly improved their ROA in the studied period due to the certifications.

Practical implications – Investors and top-managers shall consider certifications as a potential source of firms' improvement. To this end, ISO 9001 could be the reference for incorporating the other standards into a more efficient and integrated management system.

Originality/value – To the best of the authors' knowledge, this is one of the first studies simultaneously considering the dynamics involved in the adoption of multiple certifications and firm performance.

Keywords: ISO 9001, ISO 14001, OHSAS 18001, financial performance

Paper type: Research paper

INTRODUCTION

In a competitive and continuously-changing business environment, companies are challenged to efficiently achieve their objectives, managing the inter-related parts of their business. According to the International Standard Organization (ISO), management systems (MSs) are defined by the previously mentioned goal (ISO, 2017a), and their certification guarantees the accomplishment of such procedures through external auditing (Power, 1997; ISO, 2017b).

With a wide recognition worldwide, ISO 9001, ISO 14001 and OHSAS 18001 are amongst the mostly adopted certifications of quality (QMS), environmental (EMS) and occupational health & safety (OHSMS) MSs, respectively (ISO, 2017c; Lo et al., 2014). Thus, academics and practitioners had put great efforts to understand their benefits. Nonetheless, the lack of agreement is generalized, especially in regards of their financial performance (FP) improvements (Nunhes et al., 2016; Heras-Saizarbitoria & Boiral, 2013; Bernardo et al., 2015; Sampaio et al., 2009; Robson et al., 2007).

Despite this latent debate, most research has limited to function-specific MS standards (i.e., QMSs or EMSs or OHSMSs) based on both: self-reported and existing data, being the latter recognized as more reliable since they avoid the possible biases of the former (Heras-Saizarbitoria & Boiral, 2013; Corbett et al., 2005; Häversjö, 2000; Sharma, 2005). To complement this debate, researchers have identified the growing trend of implementing multiple certifications according to the market dynamic requirements (Karapetrovic & Casadesús, 2009; Karapetrovic, 2002; Bernardo et al., 2012). However, the literature focused on analyzing whether this dynamic behavior affects FP is almost anecdotal.

Hence, the aim of this article is to analyze empirically, and based on existing data, whether implementing dynamically multiple certifications affects FP.

THEORETICAL FRAMEWORK

In this section, firstly the existing literature relating the function-specific MS certifications and FP is analyzed, followed by the relationship between the adoption of multiple certifications and FP.

Function-specific management systems certifications and financial performance

Almost two decades ago, Simmons & White (1999) developed on of the first studies relying on existing data and relating the effects of ISO 9001 on FP. Although the authors based only on one-year observations, the debate was just beginning as they concluded that certifying might not cause positive FP effects. Later, Häversjö (2000) discussed that some methodological approaches seem not to be clear towards researching into the causal effects of certifications, pattern that seems not be yet solved. Although the author found a positive relationship, the author concluded that this might be due to the innovative management rather than the certification. Heras et al. (2002) used the same methodological approach and concluded that it was not possible to claim for a causal relationship, but that more profitable companies adopted this certification. However, Sharma (2005) was critical about the previous methods and questioned the validity of their results. Although Sharma (2005) improved the econometrical models by accurately controlling for the pre-certification performance, the author did not control the certification dynamics, and concluded that ISO 9001 is associated with FP improvements.

Sharma (2005) also warned that relying on self-reported data might implicate biases in the responses. Nonetheless, even using this approach the relationship has not always being positive. For instance, Singels et al. (2001) found no evidence of a direct effect of the certification itself, concluding that the motivations to adopt it were the leading factor towards an enhanced FP. Later, Dora et al. (2013) also based on surveys, but could only conclude the existence of a positive relationship based on limited statistical methods (mainly descriptive statistics), similarly to Naveh and Marcus (2007).

The scenario is similar in studies focused on ISO 14001 and based on surveys. Darnall et al. (2008) concluded that applying the framework of this certification –regardless of being certified or not– improved FP. Later, Agan et al. (2013) applied a more robust statistical technique for testing causality, namely, structural equation modelling (SEM). Nonetheless, the authors found a complex interdependence between the size of the firms, their performance and the ISO 14001 certification rather than a direct relationship. Using the same technique, Amores-Salvadó et al. (2015) created a construct that integrated the dimensions of ISO 14001 and the certification itself, and found that this factor positively increased FP through the creation of environmental innovations. Nonetheless, such results are not in line with He et al. (2015) or Lisi (2015), who conclude that there is not a causal relationship. Thus, irrespective of using self-reported data, results remain inconclusive.

Another important trend of analysis is based on event-studies. In this line, Corbett et al. (2005) found evidence of an ‘abnormal’ FP until three years after adopting the ISO 9001 certification; however, they could not determine whether the causal effect actually exists, similarly to others applying similar approaches focused on both, ISO 9001 (McGuire & Dilts, 2008; Cândido et al., 2016) and ISO 14001 (Heras-Saizarbitoria et al., 2011; de Jong et al., 2014).

Using other methodologies, scholars have also arrived to different outcomes. Based on the ISO 9001 certification, Sampaio et al. (2012) analyzed six Portuguese case studies. They concluded that, although in most cases there was an increased FP after certifying, such improvement could not be explicitly attributed to this certification.

Focusing on the ISO 14001 certification, Wagner et al. (2002) based on a longitudinal study of 37 firms from different countries and found a negative relationship with FP but a positive relationship with environmental performance. Later, Teng et al. (2014) applied a similar model but with a bigger sample (975 firms) and concluded that even if in the short-term the high maintenance costs would affect FP negatively, firms would be compensated in the long-term and end-up with beneficial results.

In an attempt to understand the lack of agreement about the effects on FP, Horváthová (2010) did a meta-analysis based on EMSs. The author highlights the importance of using dynamic approaches, as well as considering appropriate time coverage as it takes time for the certification to materialize in FP. However, such approach is still scarcely adopted in this field.

Most studies using dynamic models are aligned in their conclusions, generally finding a positive causality related to the adoption of ISO 9001 (Goedhuys & Sleuwaegen, 2013), ISO 14001 (Su et al., 2015) and OHSAS 18001 (Abad et al., 2013). He et al. (2015) is one of the few exceptions. The authors found that firms adopted ISO 14001 for other market-oriented reasons rather than to gain FP.

Studies assessing empirically the effects of OHSAS 18001 on FP are still limited (Robson et al., 2007). However, recent research has related it to a higher productivity (Abad et al., 2013), efficiency for using the assets and increase of sales (Lo et al., 2014).

Although the empirical evidence analyzing the dynamics is limited, less disagreement of the positive causality is found with this approach. Thus, in a dynamic environment of adopting multiple certifications, ISO 9001, ISO 14001 and OHSAS 18001 are expected to increase FP as hypothesized next:

H1: ISO 9001 positively affects FP.

H2: ISO 14001 positively affects FP.

H3: OHSAS 18001 positively affects FP.

The effects of multiple certifications on financial performance

Su et al. (2015) performed one of the few studies that considered simultaneously the dynamics of FP and one of the strategies of multiple certifications, namely the role of the previous experience of ISO 9001. They concluded that implementing ISO 14001 without this previous experience could be detrimental to FP, especially in more competitive environments. Similar findings are reported in Ferrón-Vílchez and Darnall (2016).

Regarding ISO 14001, Melnyk et al. (2002) discussed that its adoption could contribute to the reduction resources. This could be better achieved if firms integrate both quality and environmental perspectives by viewing pollution as a quality defect to be continuously reduced (Deltas et al., 2014; Khanna et al., 2009). In this sense, ISO 9001 seems to act as a support to ISO 14001 (Siva et al., 2016). Thus, H4 is stated as follows:

H4: Being simultaneously certified by ISO 9001 and ISO 14001 positively affects FP.

Regarding OHSMSs, Robson et al. (2007) identified that its implementation increase workplace productivity and, when done voluntarily (which is mostly the case of OHSAS 18001), firms experience decreases in disability-related costs (e.g., workers' compensation costs, short- and long-term disability costs). The authors also discussed that, typically, the firms' commitment to QMSs is higher compared to that of OHSMSs, so firms would prefer to integrate them and prioritize both MSs equally (Zeng et al., 2007).

Empirically, Naveh and Marcus (2007) found that ISO 9001 is positively related to the levels of safety performance and FP. These are attributed to the innovative management practices and the awareness of the customers' requirements. Besides complementing each other with compatible objectives, combining both the QMS and OHSMS visions promotes continuous improvement and motivates employees (Pun & Hui, 2002). Thus, it could be expected that implementing both ISO 9001 and OHSAS 18001 is positively related to FP as stated in H5:

H5: Being simultaneously certified by ISO 9001 and OHSAS 18001 positively affects FP.

Implementing ISO 14001 and OHSAS 18001 standards is not a common path (Bernardo et al., 2012; Karapetrovic & Casadesús, 2009; Domingues et al., 2017). However, their implementation is compatible and might implicate saving resources (Labodová, 2004), especially if firms report and analyze their performance in a coordinated manner (Silva et al., 2017). Therefore, due to the optimization of resources, firms could obtain financial benefits, as hypothesized in H6:

> H6: Being simultaneously certified by ISO 14001 and OHSAS 18001 positively affects FP.

Regarding triple certification, Ionașcu et al. (2017) concluded that, the more certifications, the better FP results. However, the authors did not consider the dynamics of multiple certifications. Wang et al. (2016) adopted a more rigorous statistical approach and, based on their financial, environmental and social results, they concluded that firms holding the triple certification had the best performance while those with non-certification had the lowest. Another important outcome was related to the short- and long-term results, since the high costs associated to the certification in the first years were compensated with greater benefits in the long-term, similarly to Teng et al. (2014). Although the empirical evidence is still limited, it seems that triple certifications have beneficial FP effects, as they can complement each other from different perspectives. Thus, H6 is stated as follows:

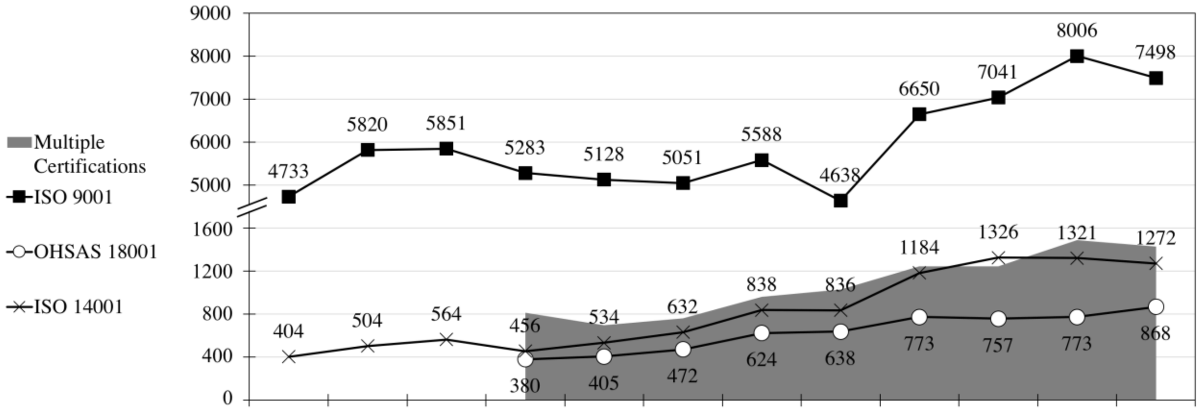
> H7: Being simultaneously certified by ISO 9001, ISO 14001 and OHSAS 18001 positively affects FP

Methodology

In this section, first the population and sample selection is described, followed by the measurement of variables and, subsequently, the model specification.

Population and sample selection

Portugal is the main focus of analysis for this paper due to two main reasons. Firstly, because it has been ranked in the top ten European countries in terms of the number of international academy for quality members, environmental wellbeing results, ecological footprint and ISO 9001 certified organizations (Saraiva et al., 2017). Secondly, because it has undergone different growth stages as shown in Figure 1, and seems to be moving towards a decertification period (To & Lee, 2014; Sampaio et al., 2011). Thus, this country offers an interesting background to analyze the effects on FP of adopting multiple certifications dynamically.



Multiple certifications	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
ISO9001+ISO14001	-	-	-	436	309	312	366	402	483	508	539	586
ISO9001+OHSAS18001	-	-	-	88	93	150	127	120	137	118	120	123
ISO14001+OHSAS18001	-	-	-	6	27	27	39	41	49	29	42	41
Triple certification	-	-	-	281	268	271	429	468	577	589	789	679
Total (2 or 3 MSs)	**-**	**-**	**-**	**811**	**697**	**760**	**961**	**1,031**	**1,246**	**1,244**	**1,490**	**1,429**

Source: Data extracted from i) ISO Survey (2017c) and ii) yearly registers obtained from the Portuguese Certification Institute (Instituto Português de Acreditação – IPAC) (IPAC, 2017) since December 2007.

Figure 1 – Portuguese certifications' dynamics in the period 2004-2015

This study is thus targeted to research into the effects on the FP of Portuguese companies that had adopted two or more certifications among ISO 9001, ISO 14001 and OHSAS 18001 in 2015.

The sampling procedure consisted of four stages. Firstly, 745 unique firms with multiple certifications in 2015 were identified based on the Portuguese Certification Institute (IPAC, 2017). Moreover, the Amadeus database published by the Bureau Van Dijk (2017) contains financial information of Portuguese active companies with complete records from 2007 to 2015. Thus, secondly, the IPAC and Amadeus datasets were matched in Stata/SE 14.0 using a fuzzy-logic approach since both datasets did not have perfect key fields for matching. The former procedure resulted in a gross match of 370 companies. Thirdly, a manual verification of the match was done and their certifications' history was doubled-checked using the official certificates published in the companies' websites. Hence, the final sample consisted of 243 companies with financial information from 2007 until 2015.

Measurement of variables

Following the aim of this article, the dependent variable is a financial indicator, which is related to the certifications' dynamics at the firm level. Control variables are also considered.

Dependent variable

The FP is measured in terms of the return on assets (ROA). This measure indicates the efficiency in exploiting the firms' assets for creating profits and is measured as the ratio of the net profits and the total assets (Reid & Myddelton, 2005). It has been commonly used in papers adopting dynamic approaches such as He et al. (2015) and Su et al. (2015). Its descriptive statistics are shown in Table 1, panel A.

Independent and control variables

The certifications adopted by a firm is the main variable of interest for this study. The selected sample had two or three certifications by 2015: 'ISO9001+ISO14001'. 'ISO9001+ISO14001', 'ISO14001+OHSAS18001' or 'ISO9001+ISO14001+OHSAS18001'. In get to this final state, firms could have adopted different paths, so the seven different combinations identified in this sample are considered in the 'Certifications' variable. The 'None' certification level, that accounts for 26.39% of the observations, is considered as the control category.

Moreover, control variables are contemplated in this study. Industry dummies are included to control potential differences in the levels of FP (see e.g., Heras-Saizarbitoria et al., 2011), as well as firms' size (see e.g., Corbett et al., 2005). The latter is provided directly by Amadeus (Bureu Van Dijk, 2017), and it is based on the employees, revenues and assets. Finally, the year is included to control the effects of time. The descriptive statistics of the categorical variables of this study are summarized in Table 1, panel B.

Table 1 – Dependent and control categorical variables (N=243)

Panel A.					
Dependent variable	**Obs.**	**Mean**	**Median**	**Standard Deviation**	**Standard Error of the mean**
ROA	2,028	3.3183	2.6005	8.9149	0. 1980

Panel B.			
Explanatory Variables	**Value**	**Percentage**	**Frequency**
Certifications	*CERT*		
None	0	13.27%	268
ISO9001	1	16.24%	342
ISO14001	2	1.49%	30
OHSAS18001	3	0.54%	11
ISO9001+ISO14001	4	27.98%	565
ISO9001+OHSAS18001	5	4.80%	97
ISO14001+OHSAS18001	6	0.64%	13
Triple certification	7	34.32%	693
Industry	*IND*		
Mining and quarrying	1	0.79%	16
Manufacturing	2	46.75%	948
Electr., gas, steam & air cond. supply	3	1.23%	25
Water supply	4	6.26%	127
Construction	5	13.31%	270
Wholesale and retail trade	6	5.13%	104
Transportation and storage	7	9.02%	183
Accommodation and food service	8	1.78%	36
Information and communication	9	2.61%	53
Finances and insurance	10	1.97%	40
Real estate	11	0.35%	7
Professional, scientific and technic.	12	3.40%	69
Administrative and support service	13	5.37%	109
Human health and social work	14	0.69%	14
Arts. entertainment and recreation	15	0.89%	18
Other service activities	16	0.44%	9
Size	*Size*		
Large	0	76.87%	1,559
Very Large	1	23.13%	469
Year	*Year*		
2007	2007	9.91%	201
2008	2008	10.21%	207
2009	2009	10.26%	208
2010	2010	11.39%	231
2011	2011	11.59%	235
2012	2012	11.64%	236
2013	2013	11.69%	237
2014	2014	11.88%	241
2015	2015	11.44%	232

Finally, Table 2 contains the Spearman (ρ) correlation coefficients between all the included variables. Certifications are significantly and positively correlated to the industry, size and year; being the latter due to the adoption of multiple certifications among the period of study. Regarding the lagged variables, the previous year's ROA is significantly correlated with the current's, and the 'Certifications' variable is highly correlated with its previous three years, mainly because they must be renewed with this periodicity.

Table 2 – ρ correlation coefficients

	Variable	1	2	3	4	5	6	7	8	9
Variables	1.ROA	1								
	2.Certification	0.0085	1							
	3.Industry	0.0215	0.1113	1						
	4.Size	-0.0925	0.0841	0.1866	1					
	5.Year	0.0152	0.4138	0.0004	0.0136	1				
Lagged variables	6.ROS_{t-1}	0.7137	0.0163	0.0334	-0.0819	-0.049	1			
	7.$Certification_{t-1}$	0.0257	0.8621	0.0829	0.0657	0.4325	0.0175	1		
	8.$Certification_{t-2}$	0.0124	0.7164	0.0435	0.0528	0.4626	0.0168	0.8353	1	
	9.$Certification_{t-3}$	0.0189	0.6048	0.0017	0.0447	0.4813	0.0123	0.7022	0.8397	1

Correlations higher than |0.060|, |0.0489| and |0.0430| are significant at 0.01, 0.05 and 0.10, respectively

Model specification

This study focuses on the effects of the certifications on FP, considering a dynamic environment. To estimate the real effects of the certifications of firm *i*, the lagged ROA_i (i.e., $ROA_{i,t-1}$) captures the effects of the omitted variables, such as the interdependencies with other financial ratios, instead of adding such effect to the variables of interest. Moreover, the studied certifications are renewed every three years, so the effect of $CERT_i$ on ROA_i is analyzed for $t - 1$ and controlled for $t - 2$ and $t - 3$. Thus, the two-step system Generalized-Method-of-Moments (system-GMM) dynamic approach is well suited for this study, as discussed next.

A detailed description of this method is provided by Arellano and Bover (1995) and Blundell and Bond (1998), so this technique was used due the four main reasons. Firstly, because ROA_i and $CERT_i$ are not strictly exogenous but depend on their own past observations, like the three year certification renewal periodicity (see e.g., Corbett et al., 2005; Su et al., 2015). Secondly, because it allows to estimate the fixed individual effects of the certifications even when using lagged variables. Thirdly, this method allows controlling both, the unobserved firm-specific effects correlated with the regressors, and the heteroskedasticity and autocorrelation within firms. Finally, this technique is well suited for a large sample compared with the size of the panel, so no specific distribution is assumed for its estimation (see e.g., Greene, 2003, pp. 201, 525–527, 555). Thus, the studied dynamic model is represented in Equation (1).

$$ROA_{i,t} = \alpha_0 + \alpha_1 ROA_{i,t-1} + \beta_1 CERT_{i,t-1} + \beta_2 CERT_{i,t-2} + \beta_3 CERT_{i,t-3} + \beta_4 IND_{i,t} + \beta_5 Size_{i,t} + \beta_6 Year_{i,t} + \mu_t + \nu_{i,t}$$

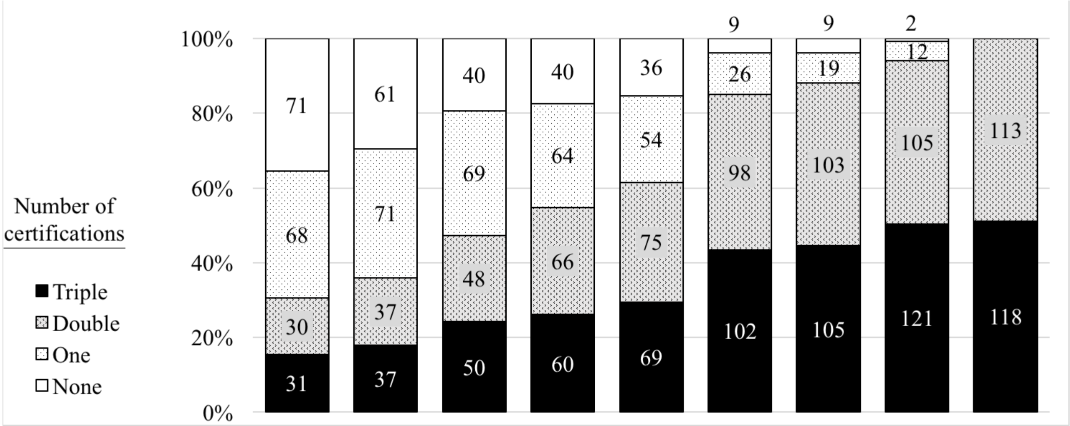
$$\nu_{i,t} = \varepsilon_i + \sigma_{i,t} \quad (1)$$

Where $ROA_{i,t}$ represents the FP for firm i=1,…,243 in year t=2007,…,2015; μ_t is the time-specific effect and $\nu_{i,t}$ stands for the time-invariant error term. The latter depends on the firm-specific effect and controls unobservable heterogeneity (ε_i); $\nu_{i,t}$ also depends on the stochastic error term varying cross-time and cross-section ($\sigma_{i,t}$).

The two-step system-GMM represented in (1) was solved using Stata/SE 14.0 with the xtabond2 command (Roodman, 2006). Thus, the downward bias produced in two-step results was controlled as well as the instrument count (Roodman, 2006; Windmeijer, 2005).

RESULTS

As summarized in Figure 2, 36% of the sample did not have any certification by 2007. Across the dynamic panel study, such firms were increasingly certifying by one, two or three MSs. By 2015, 51% were certified with the three MSs, followed by 40% that adopted ‘ISO9001+ISO14001’. The tendencies of the sample are similar as the country-level reality, which had a growing trend of multiple certifications in the same period.



	2007	2008	2009	2010	2011	2012	2013	2014	2015	
ISO 9001	64	67	62	56	46	21	16	10	0	One certification
ISO 14001	3	3	4	5	5	5	3	2	0	
OHSAS18001	1	1	3	3	3	0	0	0	0	
ISO9001+ISO14001	28	35	43	58	62	80	83	84	92	Double certification
ISO9001+OHSAS18001	1	2	5	8	13	16	17	18	17	
ISO14001+OHSAS18001	1	0	0	0	0	2	3	3	4	

Figure 2 – Evolution of firms certified per year (N=243)

The results of the two-step system-GMM estimators are summarized in Table 3. The Hansen (1982) *J* statistic for overidentifying restrictions is non-significant, which confirms the validity of the instruments exogeneity assumption. To test for autocorrelation aside from the fixed effects, the Arellano-Bond test applied to the second-order correlation, AR(2), shows there is no evidence of serial first-order correlation. The AR(1) is significant by construction. Finally, there are no major concerns regarding the instruments count, which is considerably smaller compared to the sample size.

Regarding the certifications, results suggest that not all of them have a positive impact on ROA. Indeed, only the ‘ISO9001’, ‘ISO9001+ISO14001’, ‘ISO9001+OHSAS18001’ and the triple certification significantly improve ROA. The effects are due to the previous year certifications, so no significant effects are evidenced of the two- and three-year lags.

Regarding control variables, a significant persistence and inertia effect is detected by the significance of ROA_{t-1}. This captures the effect of other variables that might not be included in this research and that consistently affect ROA over time. Moreover, the firms size is not significant.

Table 3 – Two-step system-GMM results

Variables	ROA
FP_{t-1}	0.4181*** [0.0791]
Certifications	
$ISO9001_{t-1}$	**12.4869* [7.2807]**
$ISO9001_{t-2}$	-6.0328 [13.0275]
$ISO9001_{t-3}$	-2.8776 [8.7992]
$ISO14001_{t-1}$	0.4679 [21.5734]
$ISO14001_{t-2}$	-5.5734 [16.3057]
$ISO14001_{t-3}$	1.4188 [22.3848]
$OHSAS18001_{t-1}$	12.0411 [23.033]
$OHSAS18001_{t-2}$	-7.8222 [28.8987]
$OHSAS18001_{t-3}$	1.019 [14.8785]
$ISO9001+ISO14001_{t-1}$	**13.7824* [7.3234]**
$ISO9001+ISO14001_{t-2}$	-7.7057 [10.0256]
$ISO9001+ISO14001_{t-3}$	-2.6094 [8.2428]
$ISO9001+OHSAS18001_{t-1}$	**26.2746** [13.1962]**
$ISO9001+OHSAS18001_{t-2}$	-12.6112 [22.4807]
$ISO9001+OHSAS18001_{t-3}$	-8.0065 [13.0439]
$ISO14001+OHSAS18001_{t-1}$	6.3076 [19.9511]
$ISO14001+OHSAS18001_{t-2}$	-4.3751 [18.0665]
$ISO14001+OHSAS18001_{t-3}$	10.1164 [21.6099]
Triple certificiation$_{t-1}$	**16.0009** [7.4378]**
Triple certificiation$_{t-2}$	-9.627 [10.1678]
Triple certificiation$_{t-3}$	-1.6805 [7.9176]
Size	-0.336 [0.8392]
Year dummies	Yes
Industry dummies	Yes
Constant	23.1919 [37.3628]
Observations	1,762
N	243
Instruments	93
Wald (df)LL	210.03***
AR(1)	-2.51**
AR(2)	0.04
Hansen *J* test (p-value)	40.15 (0.596)

Robust standard errors are in brackets
Significances *** p<0.01; ** p<0.05; * p<0.10

DISCUSSION AND CONCLUSIONS

In this study, a dynamic panel analysis was employed to determine whether certifications have an impact on firm performance. This approach allows a better estimation of the fixed effects of the certifications, while considering the inertia of the lagged FP, as well as the path to achieve multiple certifications.

It is found that ISO 9001 significantly improves FP, thus H1 is supported. This is in line with Häversjö (2000) and Corbett et al. (2005), so the positive effect might be attributed to the cumulative improvements achieved over time (Corbett et al., 2005), and that seem to be transferred to the environmental and operational fields when implemented with ISO 14001 and OHSAS 18001.

Regarding ISO 14001, H2 is rejected as its only adoption does not affect FP; however, its effect is positive when combined with ISO 9001, in accordance with H4. This is in good agreement with Su et al. (2015), and could be attributed to the optimization of resources promoted by ISO 14001 (Llach et al., 2013; Melnyk et al., 2002), and the quality support of ISO 9001 (Siva et al., 2016), which improves ROA compared to adopting only ISO 14001 (Ferrón-Vílchez & Darnall, 2016).

Moreover, OHSAS 18001 has a positive effect on ROA, but only if it coexists with ISO 9001, thus H3 and H6 are rejected, while H5 is supported. This would complement similar results such as Lo et al. (2014) who only controlled the existence of ISO 9001/14001 but did not focus on the dynamics involved in the multiple certification.

Results also show that the triple certification improves ROA, supporting H7. This suggests that it is possible to achieve a better performance even with a more complex certification structure. Thus, firms seem to successfully deal with the complexity holding several certification, as discussed by Wiengarten et al. (2017). They also seem to find the right balance and synergy between MSs in pursuit of FP, for which ISO 9001 might have a major role, in agreement with Siva et al. (2016).

Since the three analyzed MSs follow the PDCA (Plan-Do-Check-Act) cycle, firms can integrate them (Bernardo et al., 2009; Zeng et al., 2007). Ribeiro et al. (2017) recently reported that 95% of Portuguese integrate, at least partially, their MSs. Among other benefits, this boosts FP (Martí-Ballester & Simon, 2017). Thus, the multiple-certifications effects on FP might be attributed at least partly to their integration.

There are two main academic implications of this research. Firstly, this study highlights the need of considering dynamic models. This is because firms are continuously challenged to be competitive in a changing environment, so they can decide to adopt new certifications dynamically. This analysis permits a better comprehension of the effects; for instance, in this study certifications were not directly correlated to the ROA; however, after implementing the dynamic model, results unveiled the fixed effects of the certifications. Secondly, being ISO

9001 the common factor in the leverage of FP suggests it has a major role. Thus, the literature related to multiple certifications, including the integration of MSs, could consider this finding as a potential path for further research.

This article has two main managerial implications. Firstly, managers should not see certifications as the only way to improve FP. Instead, firms should pursue excellence and practice the continuous improvement practices implicated in the standards, so it might be a suitable to adopt a certification if demanded by stakeholders. Secondly, managers could use ISO 9001 as the driving tool to improve FP as the reference to integrate of standards.

The main limitation is the focus on Portuguese companies whose ROA was included in the secondary dataset. Thus, results should be interpreted with caution, especially in populations with less certifications trajectory.

Further investigation will focus on identifying the main attributes of multiple certifications that leverage FP and the role of their integration. Moreover, future research will consider other factors to confirm a causal relationship, including market structure (perfect competition, oligopolies and monopolies), competitiveness measures, and exploring moderators of the relationship between multiple certifications and financial performance, such as the integration strategy.

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Amine Foaming Modelling and Reduction Using Binary Logistic Regression

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ABSTRACT

Purpose - Foaming is one of the main causes of operational shutdowns in natural gas processing plants in general and sweetening processes in specific. This study is carried out to investigate the main factors impacting foaming at natural gas processing plant and provide proposals for foaming reduction

Design/methodology/approach - Historical data of foaming events in a chemical plant will be analyzed using binary logistic regression to determine critical factors affecting foaming and propose ways to control such undesired phenomenon

Findings - Focusing on potential causes, a more proactive and less expensive approach is considered instead of antifoam injection reactive approach. Inlet gas pressure, heat stable salts, total suspended solids, and iron impurities are the most significant contributing factors to foaming. Maintaining inlet pressure below 1045 psi, heat stable salts below 2.7%, suspended solids below 10 g/l, and iron concentrate below 9 ppm will substantially reduce amine foaming.

Research limitations/implications- Findings and analysis is applicable to the chemical plant under study, different processes require repeating same analysis

Practical implications- Based on plant under study historical records, the minimum time required to bring the plant back on during the shutdown is around 20 minutes and foaming incidents occurred 121 times during the period of February 2009 to December 2013. As a result, the total income loss during this period can be estimated as more than $700,000. Optimal settings of factors under study according to recommendations above is expected to result in 85% reduction of foaming events which represent a significant improvement over the current performance.

Keywords: Foaming, Binary Logistic regression, Sweetening, Sour gas.

Paper type: Case study

INTRODUCTION

Natural gas (NG) is one of the critical resources used in various energy and industrial applications (Kidnay, et al., 2011, pp.574). It is often obtained from reservoirs as sour gas containing hydrogen sulfide (H2S) or carbon dioxide (CO2). In order to utilize this sour gas and make use of it, it must be sweetened and freed from acid gas using solutions such as Methyl di-ethanol amine solution (MDEA). However, undesired phenomenon called amine foaming may occur during sweetening process and negatively affect natural gas production and plant overall performance. Such phenomenon may result in millions of dollars losses due to plant shutdown and amine solvent losses.

In this article, one of the major NG producers' plants in UAE with a production capacity of more than 90 Million standard cubic feet per day (MMSQF/Day) will be used to demonstrative the proposed methodology. The main composition of gas processed in this plant is Methane (88.4%) and Ethane (2%) along with impurities such as carbon dioxide CO2 (7.1%), hydrogen sulfide H2S (600 ppm), suspended solids (SS), and water. Such impurities will not only cause acidity in gas, but will also decrease the gas heat capacity measured in British thermal units (BTU) and disturb gas extraction process. The amine process passes through three main vessels in which the inlet gas will be treated from H2S and CO2. Major investments were made to remove impurities such as water, CO2, H2S, SS, degradation products, soap-based valve greases, and organic acids before and during gas extraction. During gas extraction process, the rich amine (saturated with H2S and CO2) will be flashed in the flash tank where, with the effect of pressure drop, the entrapped gas will be separated. Amine from downstream of the flash tank will be filtered in the amine carbon filter from any dust or suspended particles before entering the amine exchanger to be heated before entering the amine stripper. The heated rich amine flows to the amine stripper where the acid gas (H2S and CO2) is sent to the acid gas incinerator and lean amine (free from H2S and CO2) is sent back to the amine contactor. The amine booster pumps provide pre-boost pressure to the amine contactor charge pump. The filters are designed to filter out particulates, degradation by-products, heavy hydrocarbons, and antifoam. The treated gas is dried with tri-ethylene glycol (TEG) in the dehydration unit before flowing to the liquid recovery unit to reduce operation costs. The rich amine will be regenerated in the amine flash tank and amine stripper. The amine contactor unit is called the "sweetening unit", and the amine flash tank and amine stripper are called the "amine regeneration units".

Frequent foaming at the plant under study happened mainly in three areas: amine contactor, amine flash tank, and Glycol contactor. During the sweetening process, foaming of the amine solution in the amine flash tank may occur and cause revenue and operational losses. Foaming will cause many problems that directly or indirectly affect the gas treatment process such as: process instability, plant shutdown, and lower BTU values. Several researchers and practitioners reported losses due to foaming. For example, Al Dhafeeri (Al Dhafeeri, 2007) reported that millions of dollars are spent each year on capital equipment, operations, and maintenance to address foaming problems in addition to fuel sales production losses. Thitakamol and Veawab (Thitakamol & Veawab, 2009) also reported that foaming impacts the integrity of plant operation and may cause several issues such as: excessive loss of absorption solvents, premature flooding, off-specification of products, energy losses, and plant shutdown in some severe foaming cases.

Continuous anti-foam injection has been the most common method used by facilities to suppress foaming (Al Dhafeeri, 2007) (Punnett, 2003). Although antifoam agents are used to break up the bubbles, it is recommended to be used only as a last resort since extra doses of antifoam can reduce the CO2 absorption capacity and result in extra cost and lower gas supply flow rate.

In order to quantify losses for the UAE NG plant under investigation, plant shutdown cost will be considered first since it is the most undesirable outcome of foaming. The plant under investigation daily production income is summarized in Table 1.

Table 1 - Plant total production revenue per day

Product	Production (unit/day)	Selling price ($/unit)[1]	Revenue ($/day)
Light oil/condensate (barrel)	400	$80.6	$32,236
Natural gas (MCF/D)	70,000	$4.1	$287,700
Liquefied Natural (barrel)	541	$75.3	$40,716
Total revenue			$360,652

[1] Average unit selling price used is based on Birchcliff Energy Limited proposed estimates (Tonken, 2014).

Based on plant historical records, the minimum time required to bring the plant back on during the shutdown is around 20 minutes and foaming incidents occurred 121 times during the period of February 2009 to December 2013. As a result, the total income loss during this period can be estimated as shown below:

$$Total\ loss = \frac{360{,}652}{24 * 60} * 121 * 20 = \$606{,}096$$

Additionally, the following losses can be attributed to foaming:

1. Around \$100,000 loss due to solvent losses. This is based on the assumption of incurring a Di ethanol amine (DEA) solution loss of 0.9918 kg/MMSCF and AMDEA loss of 91.245 kg/MMSCF per Sehgal (Sehgal, 2009, pp.1-112).
2. A minimum of \$22,239 every day due to 5% BTU loss resulted from acid gas' lower treatment efficiency (Pauley, et al., 1991) (Al Dhafeeri, 2007).

Moreover, Phul (Phul, 2001) reported other negative soft implications of foaming as gas off-specification due to H2S presence in treated gas, environmental pollution prevention due to contaminant backwash liquids, neutralization chemicals, solids and carbon filter disposal, and energy loss prevention due to the increase in amine circulation rate.

It is evident that foaming has major financial implications among other issues and is therefore worth investigating. The main objective of this article is to identify the potential causes of foaming and provide suggestions to reduce its frequency and cost for the UAE NG plant under investigation.

LITERATURE REVIEW

Foaming Potential Causes

Many researchers investigated the potential causes of foaming (Al Dhafeeri, 2007) (Ratman, et al., 2010) (Shaban, 1995) (Stewart & Lanning, 1994) (Richert & Philip, 1999) (Verma & Verma, 2009)**.** The majority of studies concluded that foaming is caused mainly due to impurities such as HC liquids, iron sulfide, sodium chloride, acetic acid, methanol, and polyethylene glycol. Others focused on both impurities and process parameters such as surface tension, input stream temperature and pressure, excessive anti-foam agents, carboxylic acid and makeup water. For example, Ratman et al. (Ratman, et al., 2010) focused mainly on the effect of impurities such as hydrocarbon liquids, iron sulfide, sodium chloride, acetic acid, methanol, and polyethylene glycol on MDEA foaming behavior. His study concluded that a natural gas stream free of acid gas is very important in order to increase the heating value of the natural gas, decrease the volume of gas transported in pipelines, and reduce corrosion during transportation. Shaban (Shaban, 1995) has also related the major cause of foaming to the impurities present in the crude along with the liquid carry-over with the gas phase and the size of the impurity particles. Moreover, Thitakamol et al., (Thitakamol, et al., (2009)) showed that foaming increases with superficial gas velocity, solution volume, CO2 loading, MEA concentration, gas density, liquid density, liquid viscosity, degradation products and corrosion inhibitors and decreases with solution temperature, surface tension, degradation products or corrosion inhibitors

Thitakamol and Veawabe (Thitakamol & Veawab, 2009) developed a steady-state model to predict the foam height for the CO2 absorption process using MEA solutions as shown in equation 1 below:

$$H_o = 4394 \times \frac{\gamma}{{r_o}^{1.6}} \left(\frac{(\mu_L)^{0.30}}{(\Delta\rho g)^{1.3}} \right) \qquad (1)$$

where γ is the surface tension of liquid, r_o is the bubble radius, $\Delta\rho g$ is the difference in density between the gas and the liquide, and μ_L is liquid viscosity. The study concluded that solution volume and liquid viscosity are the most critical factors affecting the height of foaming, followed by solution temperature, liquid density, and surface tension.

Gracia-Fadrique et al., (Gracia-Fadriqueb, et al., 2001) studied the surface tension of aqueous solutions of di-ethanolamine (DEA) or methyl-di-ethanolamine as a function of concentration using the differential capillary-rise and the pendant-drop methods and defined foaming to be a surface phenomenon. The experimental observation showed that the surface tension of these systems decreases as the concentration of the alkanolamine increases at a given temperature. It also decreases as the temperature increases for a given concentration of the amine.

Al-Dhafeeri (Al Dhafeeri, 2007) studied two cases in two different gas processing plants and found high liquid hydrocarbon entrainment in the sour feed gas and low surface tension leads to more solution susceptibility to foam. Stephanie et al., (Stephanie A & Rochelle, 2011) contributed foaming to condensed liquid hydrocarbon, fine particulates (iron sulfide), additives containing surface active chemicals, and amine degradation products. Similarly, Verma and Verma (Verma & Verma, 2009) also found that HC liquid, Heat Stable Salts (HSS), degradations, condensed hydrocarbons, organic acids, water contaminants and well treating chemicals (antifoam agents), iron sulfide, and high gas velocity contribute to the formation of foaming. Stephanie et al., (Stephanie A & Rochelle, 2011) attributed foaming of aqueous piperazine and monoethanolamine to HC liquid, iron sulfide, additives containing surface active chemicals (antifoam). They also indicated that Amine degradation products and corrosion inhibitors increased the foaming tendency by up to 23%. Emam et al., (Emam, et al., September, 2014) analyzed water used in natural gas operations and concluded that iron precipitations and HSAS causes foaming and should not exceed 0.5%. They also concluded that PH level influences corrosion tendency which is directly proportional to foaming.

Pauley et al., (Pauley, et al., 1991) attributed contaminants as the main reason for amine fouling and foaming. Finally, Agrawal (Agrawal, 1981) reported that liquid hydrocarbons and iron sulphides are the main reasons for foaming. Foaming of amine was due to several factors: suspended solids, condensed hydrocarbons, amine degradation products, and foreign materials such as corrosion inhibitors, valve grease, and impurities in make-up water.

Amine foaming potential solutions

Several researchers discussed the effects of foaming on the gas production process, and proposed potential solutions for foaming reduction. According to Stewart and Lanning (Stewart & Lanning, 1994), remedies can be obtained by preventing solution contamination and mechanical filtration. This can be achieved using wash systems on inlet gas streams to remove organic acids formed in cracker units and use of porous-media filters for iron sulfide removal.

Verma and Verma (Verma & Verma, 2009) applied their own site experience to amine system and recommended a H2S concentration of less than 10 ppm and considered MDEA, TEA (tri-ethanol amine) and DIPA (di-iso-propylalcohol) to be the best for selective removal of H2S. On the other hand, the most selective solutions for CO2 are MEA (mono-ethanol amine) and DEA (di-ethanol amine). They also recommended the removal of HSS which requires costly maintenance, frequent filter changing, amine solvent loss, and gases which are off-specification.

Mesgarian (Mesgarian, 2014, p196) investigated equipment and production lines corrosion rates and amine degradation due to foaming. He recommended limiting HSS to 10% of amine concentration since HSS is non-generable with the solvent.

Anabel et al., (Anabel, et al., 2010) recommended controlling filtration and particulate removal in the amine processing unit to insure the reliability of the sweetening process. They recommended a solid particle size of less than 1 ppm and a liquid hydrocarbon size closer to zero using suspended solid separation technology. Okimoto (Okimoto, 1993) also reported that MDEA surface tension can be reduced by using sulfolane which results in foaming reduction.

RESEARCH METHODOLGY

It is evident from the above literature review that many factors involved in foaming occurrence where some of them exist in the system, while others are introduced to the system. However, the contribution of each factor relative to others is not well quantified yet. In order to do so, the following method will be used to pinpoint the significant contributing factors to foaming at the processing plant with main focus being on the amine flash tank unit:

1. Collect data on foaming occurrences along with potential causes/process parameters for foaming.
2. Develop a logistic regression model that explains probability of foaming as a function of process parameters. Discussion of logistic regression is provided in the next section.
3. Based on statistical analysis of model, determine process parameters significance.
4. Study the effect of each significant parameter on foaming probability and set process parameter to an optimal value that minimizes foaming.

Regression in general, and logistic regression in specific is one of the methods found by many researchers to be an ideal method to identify significant factors impacting phenomena such as foaming (Sehgal, 2009, pp.1-112) (Kleinbaum & Klein, 1994, pp.115-119). The logistic regression (LR) method was proposed as an alternative to the ordinary regression in the foaming case since foaming is a binary variable. One major drawback of using standard regression is that standard regression may result in probability predictions that are negative or larger than 100%. Logistic regression fits a logistic curve to the relationship between *x* and *y* when *y* is binary and *x* is numerical. The simple logistic model form is as follows:

$$ln\left(\frac{\pi}{1-\pi}\right) = log(odds) = logit = \alpha + \beta X \qquad (2)$$

where π is the probability of the outcome of the interested variable such as probability of foaming. α is the intercept of *Y*, and β is the slope parameter. *X* can be categorical or continuous while *Y* is always categorical. The logic of the simple logistic regression has been extended to multiple predictors to be as follows (Peng & So, 2002):

$$ln\left(\frac{\pi}{1-\pi}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_K X_K \qquad (3)$$

Unlike multivariate normal distribution, logistic regression does not require data with equal variances and covariance for all variables. Hence, it is less restrictive and suitable for studying the relation between the categorical variable (*Y*) and one or more predictor variables.

However, the variance for binary data is not necessarily constant. When the average proportion is close to 0 or 1, the variability tends to get smaller, since binary data are truncated due to the upper (1) or lower (0) limit. Therefore, effects that may seem to be larger for factor-specific settings might be due not to interactions with other factors, but to non-constant variance. The use of binary logistic regression will minimize such an effect since data is transferred into logit function instead of linear regression function.

The maximum likelihood (ML) method is used in logistic regression analysis to obtain coefficients but requires a high number of observations to increase the reliability of the model. The least squares method (LSM) can be calculated by finding the best fitting for the regression line and the data set, whereas the ML method estimates the parameter values for which the observed data have the biggest probability (Pagano, 1996). In this study, both methods (ML and LSM) were used and similar results were obtained due to large sample size on hand.

The methodology proposed above is demonstrated using the UAE NG processing plant discussed in the introduction. The identity of this plant will not be declared for confidentiality reasons. The current practice for solving the foaming problem at this plant is reactive in nature where 1.5 liters of antifoam (methanol) is injected daily to handle plant fluctuation due to foaming. When foaming occurs, process operation is disturbed and fluctuation is observed in the control room. If any foaming symptoms are observed, amine flash tank upstream pressure will be manually decreased to control foaming. If this action did not control foaming, the total inlet gas pressure to the plant will be reduced to control the amine flash tank level and may cause a plant shutdown.

Foaming occurrence data were collected for this plant for the period of February 2009 to December 2013 and analyzed. Based on the literature surveyed and discussions with subject matter experts from the UAE NG plant, data for the following nine process parameters were collected to describe the foaming phenomenon at the flash tank unit:

1. Inlet gas pressure (P) taken at the inlet gas pressure vessel unit.
2. Amine concentration analysis (AC) using metric titration method
3. Amine temperature (AT) of the flash tank unit
4. PH of the medium (PH)
5. Dew point (DP) of the flash tank unit
6. Total dissolved solids (TDS) concentration measured by gas chromatograph testing

7. Iron concentration (Fe) measured using ion chromatography testing in the gas stream
8. Total suspended solids (TSS) measured by a side gauge device connected to the gas stream via a sensor.
9. Heat stable salts (HSS) measured by ion chromatographic method using Acetate and Oxalate in alkanolamine solution.

The first four parameters were recorded every two hours resulting into 12 measurements per day. The MDEA concentration was tested once per day since amine concentration takes more than one day to change. TSS, Fe, HSS and TDS were tested every two weeks since these parameters need some time to change significantly. A total of 600 data entries were recorded for each variable covering the period of 2009 to 2013 and 121 events of foaming. Table 2 shows an example of data collected where foaming response is shown in the last column as a binary variable with a value of 1 for foaming and 0 for normal operation, i.e. no foaming.

DATA ANALYSIS

Before conducting logistic regression, a correlation analysis was done to check for any dependency between process parameters under investigation and reduce the dimensionality in case of correlation. Analysis was conducted and indicated a weak correlation between all parameters except for the following pairs: *AC* and *AT*, *Fe* and *TSS*, *DP* and *TSS*, and *HSS* and *TSS* where a medium correlation with a correlation coefficient around 0.5 was present. Keep in mind that the correlation coefficient range from -1 to 1 where -1 indicates a perfect negative correlation and 1 indicates a perfect positive correlation.

A standard practice used in regression analysis is to start with the full model which includes all of the potentially significant factors for which we have collected data (El Naggara et al., 2015). Then eliminate the least significant process parameters from the model by testing the null hypothesis that the coefficient is equal to zero, i.e. parameter has no effect. If the p-value is equal to or smaller than the significance level which is assumed to be 0.1, then the observed data are inconsistent with the assumption that the null hypothesis is true and can be rejected. The p-value is a function of the observed sample results that are used for testing a statistical hypothesis. A Significance level (p-value) of 0.1 will be used to control the maximum Type I error allowed in deciding whether a coefficient is significant or not. Type I error is the probability of accepting the hypothesis that a parameter is significant contributor to foaming when it is not. If the p-value of the predictor is equal to or smaller than 0.1 the value changes in the predictor meaningfully and is associated directly with foaming.

Table 2 - Foaming data collection sample

P psi	**AC %**	**AT, ^{0}F**	**TSS g/L**	**Fe PPM**	**DP ^{0}F**	**HSS, %**	**TDS g/L**	**PH**	**Foam**
995	45	145	8	9	134	2.5	208	7.4	0
1020	45	146	10	15	135	2.7	200	7.8	1
960	43	140	9	10	134	2.7	352	7.3	0
990	43	140	10	9	135	2.5	170	7.5	0
1000	45	138	9	7	135	2.5	180	7.5	0
1000	44	140	8	8	134	2.3	200	7.5	0
1200	43	140	7	9	134	2.4	220	7.3	0
1040	43	140	12	7	135	2.1	190	7.3	0
1000	43	140	8	8	135	2.5	220	7.3	0
950	43	138	10	9	135	2.3	250	7.5	0
950	41	135	9	7	134	2.4	230	7.6	0
965	42	140	8	9	134	2.1	260	7.4	0
1250	43	165	12	15	135	2.3	175	7.5	1
970	43	140	10	9	134	2.3	365	7.5	0
1260	42	165	11	13	133	2.6	205	7.4	1
950	43	139	8	9	135	2.4	270	7.7	0
960	42	140	10	8	135	2.3	215	7.5	0
1300	45	160	10	12	133	2.4	240	7.5	1
980	42	140	10	9	134	2.7	280	6.8	0
1000	42	140	9	8	135	2.5	205	6.6	0
1000	44	165	9	12	133	3.0	255	7.3	1
1000	44	140	8	9	134	2.6	236	7.5	0

Minitab® software was used to conduct regression analysis and results are shown in Table 3. The accuracy of the model can be assessed using coefficient of determination R^2 value which represents percentage of variance/variability of data explained by the proposed model. The full model is summarized below in equation (4) which resulted in a coefficient of determination of 90% indicating a very good prediction model.

$$Logit(foaming) = Ln\left[\frac{p(foaming)}{1-p(foaming)}\right] = -18.45 + 7.63P + 4.56AC$$

$$+6.3AT + 7.43TSS + 6.76Fe + 5.10DP + 7.08HSS + 1.33TD - 1.3PH \qquad (4)$$

Table 3 summarizes results of the estimated coefficients of regression model, standard error of the coefficients, and p-values. The estimated coefficient represents the rate of change of response with respect to change in parameter. For example, the estimated coefficient of 4.56 for amine concentration is the change in the log of P (foaming)/P (no foaming) with a 1 unit (1 pound) increase in amine concentration, with the other factors held constant and so on. From the above explanation, we can conclude that inlet gas pressure, total suspended solids, heat stable salts and iron are the highest foaming effecting factor. Similarly, total dissolved solids and PH of water are the least factors affecting foaming.

Table 3 - Normalized logistic regression coefficient

Term	Coef	SE Coef	P-Value
Constant	-18.50	3.93	0.000
P	7.63	1.91	0.000
AC	4.56	2.51	0.069
AT	6.30	1.80	0.000
TSS	7.43	1.95	0.000
Fe	6.76	1.69	0.000
DP	5.10	1.47	0.001
HSS	7.08	2.16	0.001
TDS	1.33	2.51	0.596
PH	-1.30	3.24	0.688

The standard error of the estimated coefficients of a regression model measures how precisely the model estimates the coefficients' unknown value. The smaller the standard error is the more precise the coefficient estimate. For example, the standard error of pressure coefficient is smaller than that of amine concentration. Therefore, our model is able to estimate the coefficient for pressure with greater precision. Upon a closer look at the table, we observe that the standard error of the total dissolved solids coefficient along with the PH of water value is higher than the value of the coefficient itself, making it a genuine reason to be removed from our model. From the above illustrated *p-value* analysis for all variables to satisfy the significant requirement of *p-value* <0.1, *TDS* and *PH* are rejected and should be removed since they have a value of 0.68 and 0.59 respectively. Therefore, the new mathematical model obtained can be written as:

$$Logit(foaming) = -18.45 + 7.63P + 4.56AC + 6.3AT$$

$$+7.43TSS + 6.76Fe + 5.10DP + 7.08HSS \qquad (R^2 = 88.7) \qquad (5)$$

PROCESS IMPROVEMENT

In order to control foaming phenomenon, the main effect of each significant parameter in the prediction model is investigated through the main effect plot shown in Figure 2.

Based on the main effect plots, the following remarks can be made:

- The higher the pressure, the higher the probability of foaming. Hence, the pressure has to be set to a low value of no more than 1045 psi. Based on the slope of the main effect plot, pressure is the most significant contributor to foaming.
- The higher the amine concentration, the higher the probability of foaming. However, the impact of pressure is much higher than *AC*.
- The higher the amine temperature, the higher the probability of foaming. Hence, the amine temperature has to be set at a maximum value of 143 F°.
- The higher the total suspended solids, the higher the probability of foaming. A *TSS* of <10 g/L is ideal to minimize foaming probability.
- The higher the iron, the higher the probability of foaming. Hence, iron concentration in gas has to be controlled to a value ≤ 9 ppm.
- The higher the dew point, the higher the probability of foaming. Hence, the water absorption process has to be controlled and monitored to have a minimum dew point ≤ - 134 F°.
- The higher the heat stable salts, the higher the probability of foaming. Hence, *HSS* has to be controlled to a percentage value ≤ 2.7.

From the above results, we noticed that none of the above given recommendations involve additional implementation cost except the reduction of total suspended solids, heat stable salts, and iron. These three factors require filtration process operation. Since *TSS* and *Fe* were found to be critical factors, rich-side liquid/liquid coalesces, which costs around $80,000 (Ziemer, 2011) can be utilized to filter the dual variables. Moreover, a vacuum distillation technology which costs around $500,000 (Hajilary et al., 2011) (Mesgarian, 2014, p196) can also be utilized to remove these contaminants. Based on cost of foaming discussed in the problem statement above, the payback period will be less than one year. Inlet gas pressure is the most significant contributor and should be monitored closely for any fluctuation in the stream to be able to control foaming.

Optimal settings of factors under study according to recommendations above is expected to result in 85% reduction of foaming events which represent a significant improvement over the current performance.

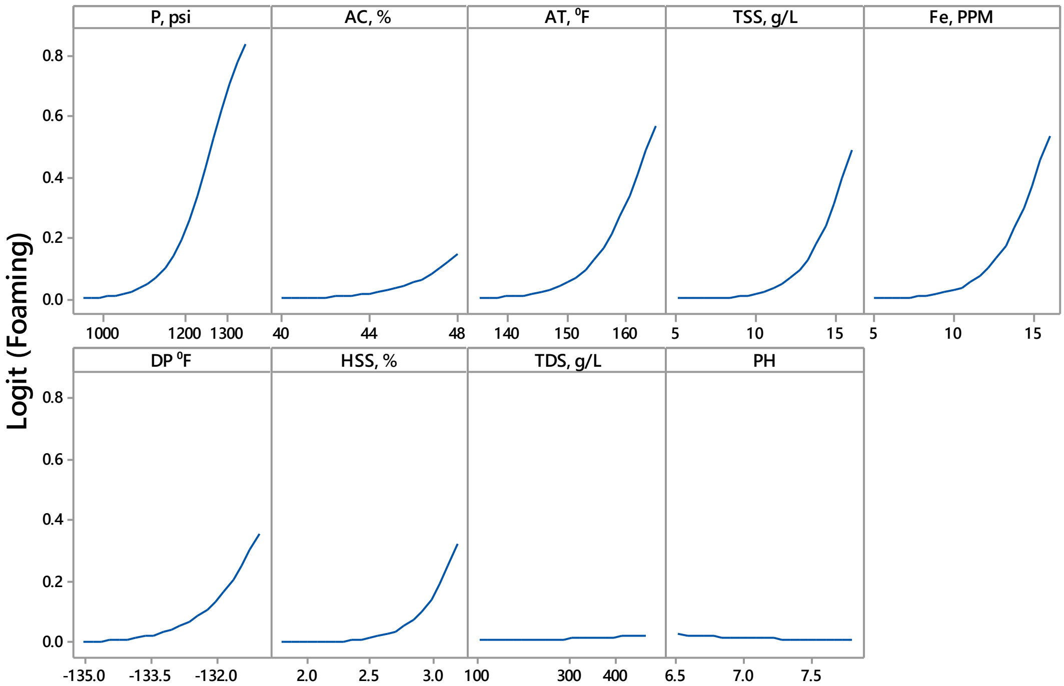

Figure 2 - Main effect plot chart

CONCLUSION

Foaming in amine flash tanks is a major concern at the natural gas sweetening facilities. As a result, antifoam injection has been used traditionally to resolve the problem which is costly, have negative side effects, and reactive approach. In this research, a more proactive investigation of amine foaming has been conducted and main significant contributors for foaming factors were identified using a logistic regression model. The model has indicated that inlet gas pressure, heat stable salts, total suspended solids, and iron are the most significant contributors to foaming that need to be controlled. Heat stable salts, total suspended solids, and iron are also found to be critical factors by many researchers as per literature review surveyed. Analysis indicated that foaming phenomenon is more likely to happen if inlet pressure is above 1045 psi, suspended solids above 10 g/l, heat stable salts above 2.7%, and iron above 9 ppm.

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Delight in excellent tourism experiences: The role of the exceptional value and the appraisal

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ABSTRACT

Purpose - The aim of this study is to determine effects thought positive affect and excellence to elicit a general appraisal in delighted touristic experiences. The goal is to understand the event-chain according to the appraisal options. The cognitive appraisal theory is used to explain why the emotion has a distinct set of appraisals for each person and why one experience can affect future consumptions.

Design/methodology/approach - A survey is administered to tourist have visited Girona. To the statistical analyses were used nonparametric test and for the mediation, analyses have adopted the methodology suggested by (Zhao *et al.*, 2010).

Findings - Research findings suggest that the appraisal it can be evaluated differently according to with the service sector. The appraisal in delighted experience's it is mediated by the excellence and positive affect. There is not a significant direct relationship between exceptional value and the appraisal bat in such a setting, mediation variables may be are more important for customers influenced by previous experiences.

Research limitations/implications- Appraisal was measure with one descriptive factor and the variables in this study correspond to a major construct. Future research may explore other dimensions of the appraisal and compare customers' groups manipulating stimulus.

Originality/value - The results allow linking the exceptional value and appraisal thought mediator variables. Even when the article does not trade to prove the appraisal theory, might introduce considerations that have not yet been addressed in regarding delight.

Keywords: Delight, appraisal, exceptional value, positive affect.

Paper type: Research paper

INTRODUCTION

In recent years' consumer behavior research, involve emotion as a distinctive factor in customer experiences to explain some behaviors like Customer Delight (CD). For some authors it is clear that each client makes a personal appreciation of the consumer experiences (Watson and Spence, 2007). However, it is not clear under what specific circumstances emotions play such a significant role that can modify post-consumption behaviors.

Let us illustrate the whole idea with an example. Imagine a family, mom, dad and two kids visiting a theme park that recreates the world and characters of their favorite console game in Las Vegas for the first time. Every member of the family received the seam stimulus (theater, games, excellent restaurants, cartoon characters coming to life) a complete magic experience emotionally charged. Besides, the park has an online community where members can create and share their experiences and avatars and submit their own designs. Fans can vote for each design on submissions and give feedback. Kids feel pride, excitement, surprise, and joy. While parents are happy and very proud of the decision, that they made. At the end, they agree with the next idea: ¨the experience was delighted for the family¨ in spite of the long lines to eat or the number of people together in small's locations. The parents start to think in return the next year because they felt part of the happiness of their children and they have a very nice memory that they want to relive as a family. All people, including the young people, would appreciate different the value and service even receiving the same stimulus. The underlining variables in this short story suggest studying how the customers come to evaluate the service as a unique and delighted experience, emotionally charged, considering their own mining.

In October at the present year, the authors development and applied a survey for measurement delight in experiences like these with 400 respondents majorly from Europe. In this study was observed that two factors (exceptional value and appraisal) were associated. Therefore, the article aim is to analyze what general appraisal can be elicited in a service context if appears the exceptional value and how the evoked positive affect and excellence mediates between this two factors as an events-chain description on delighted experiences. The study set the next research question: What circumstances favor the appreciation of delight in clients with excellent tourist experiences?

LITERATURE REVIEW

Authors like Plutchik (1980) and others based on their work show a particular focus on the categories of emotions grouped by their similarity to explain the antecedents and consequences related to CD. The delighted consumption can be positive emotionally charged (Watson and Spence, 2007) and identify the cause(s) of emotions it is very imported issue to understand this behavior. According to (Mano, 1991), the emotions are placed in dimensions using valence and arousal to combine affectivity dimensions (positive/negative) with activation (high/low) and then describe the qualities of feeling states (Watson and Spence, 2007). The issues with the categories and dimensions approaches are in empirical studies because they do not identify when the consumers feel one specific emotion. (Laros and Steenkamp, 2005, p. 1437). Besides, the content of emotions ate limited even in the same affective dimension.

Applying emotions, researchers showed a growing interest in measurement behaviors like CD. (Liu and Keh, 2015) e.g. proposed a scale combining the two-dimensional character of emotions in delight/outrage state. However, Laros and Steenkamp (2005, p.1438) disagree with the idea because each emotion has a distinct set of appraisals and if you get memories of both it will be more difficult evaluate the experience and probably you do not measure any of them. The researchers know about the influences of emotions bat still cannot explain why the consumers reach a delighted state.

In this sense, Watson and Spence (2007) explain the growing appraisal theory and how each person has an individual emotional response with the same stimulus and how they can evaluate the experience through a different and opposing appraisals group. The authors support a framework where appraisals can explain an extensive range of emotions. The proposal includes emotions with a similar level of valence and arousal, and how they lead to different behavioral responses trough six dimensions as also refer (Ma *et al.*, 2013).

The consumers made evaluations about the service’s performance continually creating memories that get back when the consumer enjoy another service with similar characteristics. What is important in the first place are not the role of emotions because CD researchers accept emotions as antecedents like an important factor in the so-called Transcendent Customer Experiences (TCE) (Ball and Barnes, 2017), but rather those specific combinations of factors can explain the appraisal to elicit CD. For example, (Laros and Steenkamp, 2005) have shown how two positive emotions (contentment and happiness) in a hierarchical model of consumer emotions have significantly different impacts on consumer behavior. Considering the most abstract level at which emotions can be experienced it is possible to think in a relation between this positive state and the appraisals to improve the meaning of the valance as underline Watson and Spence (2007).

On the other hand, CD as a positive emotional state have some consequences studies in the literature. According to Ludwig *et al.* (2017), the most important consequence in the TCE is to create an exceptional value based on an excellent service. That means high-quality levels considering value and value co-creation, without distinction between consumer and producer. The consumer is an active participant in the value process and not just a receptor. However, what does it mean? To distinguish services according to with the co-created value between customers and enterprise, it is necessary to understand the Service-Dominant Logic (SDL) (Lusch and Vargo, 2006) applied to delight. According to SDL, delight it is a middle state related to the exceptional value creation involve personalization and participatory with the consumer in the business model core. Therefore, delight in an expression of excellent service.

Johnston (2012) e.g. using 400 statements with an iterative process collected a set of characteristics about excellent and poor service concludes that both services have a strong emotional impact bat the enterprises and consumers described a very different picture to deliver an excellent service. The consumers described an excellent service simply as “a pleasure” into four categories: (1) delivering the promise, (2) providing a personal touch, referenced by others authors like personalization (Hasan *et al.*, 2011), (3) going the extra mile and (4) dealing well with problems and queries (Johnston, 2012).

In a touristic setting Bonnefoy-Claudet and Ghantous (2014) summarize some contributions related with the mediated role of emotions on customer satisfaction. The findings underline the significant of three main emotions (joy, excitement and peacefulness) as well as a strong mediating role of overall perceived value between consumption emotions and satisfaction Bonnefoy-Claudet and Ghantous (2014). Others authors before validated some similar hypothesis, e.g. Duman and Mattilla (2005) considering the hedonic consumption translates in excellence services or the novelty with the general evaluation of the service. These antecedents allow considering that in delighted experiences, the consumers feel positive emotions and wish to participate in their self-delighted where positive emotions and excellence appear as mediator factors.

RESEARCH METHODOLOGY

Data collection and measures

The data collection was made by a survey with 5 items to measurement delighted experiences applied to tourist using two ways (1) self-administered online survey in a website designed with Google sites and Survey Monkey Tool and (2) administrated survey by the authors in the Girona Tourism Office. The face-to-face survey was applied in Girona city town (Spain) but the sample scope includes tourist from several regions around the world mostly from Europe. In both cases at the beginning, the consumer has to think in a very good experience enjoined in the last two years and evoking that experience answer the questions. Based on previous delight studies the survey suggests some options like the visit to a hotel (Torres and Kline, 2006) or a restaurant (Barnes *et al.*, 2016). The survey has three sections (1) Demographic dates, (2) How did you evaluate the experience in service? (3) Described your visit. Considering an infinite population based on Catalonia tourism's dates (available at https://www.idescat.cat/pub/?id=aec&n=569&lang=es) the sample scope includes all the tourist locals or estrangers ≥ 18 years old, that arrive at the office during the morning shift. The next table includes the variables in the study, the code for each variable; measurement scale and reference in the literature were other authors used a similar variable.

Table 1 –Variables in the study.

Variable	**Item**	**Scale**	**Reference**
DEX: Excellence in service	This service is an excellent example	Five-point Likert scale from 1- Strongly disagree to 5- Strongly agree	(Vanhamme, 2008) adapted from (Oliver *et al.*, 1996), (Loureiro and Kastenholz, 2011)
DPA: Positive affect	In this experience, I felt positive emotions that made me feel special		The authors based on the literature review
DEV: Exceptional value	This experience has an exceptional value according to my criteria		(Berman, 2005), (Vanhamme, 2008) adapted from (Oliver *et al.*, 1996), (Chena and Lin, 2015), (Loureiro and Kastenholz, 2011)

DAPP: Appraisal	Select one option to describes your experience: A: A good service that did not cause special interest in me B: A very good service that has made me feels comfortable and happy C: An excellent service where I felt positive emotions and I felt an important customer	Select one option from these three	The authors based on the dimensions and general characteristics described by (Watson and Spence, 2007)

Four hundred and five tourists agreed to respond the survey, 400 of them completed the survey and the 24% responded to the self-administrated survey online. The high response rates could be reached because the online survey was designed under rules to respond mandatorily every question and because the Tourism Office has well ambiance and conditions for the responders.

Description of the mediation model and statistical analysis

To development, the mediation effect among the variables in the study has adopted the methodology suggested by (Zhao *et al.,* 2010) who reconsidering the Baron and Kenny's (1986) methodology. Using a relative new SPSS and SAS syntax, developed by (Preacher and Hayes, 2004) Zhao *et al.* (2010) explained how an alternative bootstrap test of the indirect effect is usually more powerful than Sobel's test (Zhao *et al.*, 2010). The main characteristic of this methodology it is to replace the four test in Baron and Kenny's by one test (bootstrap test of the indirect effect). Figure 1 shows the research model where the effect of the exceptional value (DEV) on the appraisal (DAPP) it is mediated through two variables: the excellence in services (a*d in Figure 1) and the positive affect (e*f in Figure 1). Besides, it is considered a second-order mediation through excellence and positive affect (a*b*f in Figure 1). To achieve the research objective the first step was to make a descriptive statistics analysis in order to describe the sample. According to the variables, DEX, DPA, DEV and DAPP's distribution (skewed) were used nonparametric test.

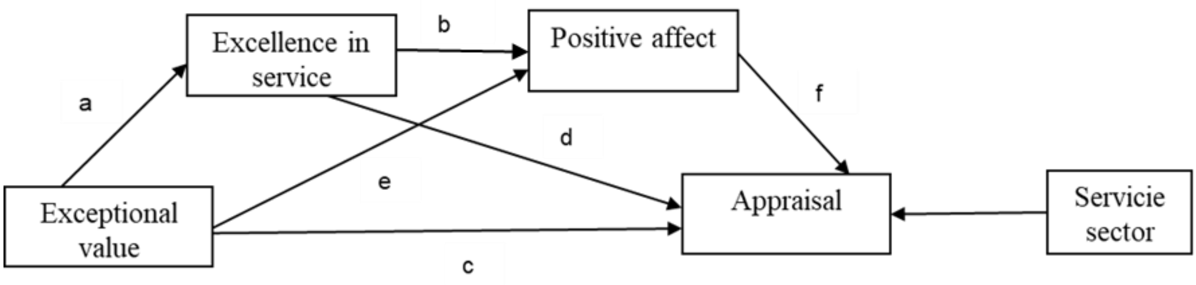

Figure 1 – Mediation model linking exceptional value and appraisal.

To assess a bivariate correlation among variables DEX, DPA and DEV with DAPP it was applied the Rho coefficient in the Spearman's test. As it indicates in the survey, customers could select the experience among the alternatives (Restaurant, Hotel, Spa, Natural Park, Mall/Store and other). Therefore, the Mann-Whitney test was used to achieve differences between the appraisal states and sector services and between the gender and the mean scores with the variables in the study. The use of the test supposes the comparison of two independent samples, therefore, the options were grouped into two main sectors: hospitality (hotels + restaurants) and touristic services (other options). Besides, the Kruskal-Wallis was used to find mean differences between the appraisal states and variables in the study.

RESULTS

Sample characteristics and descriptive statistics

Four thousand respondents (n=400) integrate the study, demographic variables and describe characteristics of the sample are explained in Table 1. The sample includes more than 92.50% of respondents from Europe and America and more than the 56.50% are less than 39 years old. Table 2 list the mean scores by mean and woman for each variable in the study. The table also includes the scores for the Mann-Whitney test regarding the measures and respondent's gender. The Mann-Whitney test (See Table 3) indicated nonsignificant differences ($p > 0.05$) between woman and men in each of the study variables. That can mean a similar way to evaluate the variables; in fact, the mean and standard deviation are very similar to each group.

Table 2 – Description of the demographic variables

Variable	Description	%
Age	Between 18 and 29 years old	37.00
	Between 30 and 49 years old	27.25
	50 or more	35.75
Gender	Male	45.50
	Female	54.50
Nationality	Europe	72.50
	America	20.00
	Asia	5.00
	Ocenia	1.00
	Africa	0.80

Table 3 – Means, SDs, and ranges for the measures. Mann-Whitney U and significance among measures and gender.

Measures	Men (n=182) Mean ± SD	Woman (n=218) Mean ± SD	Range	Mann-Whitney U	Significance
DEX	3.96±0.83	3.98±0.79	0-4	-0.170	*n.s*
DPA	3.98±0.87	4.05±0.89	0-4	-0.907	*n.s*
DEV	3.87±0.90	3.87±0.97	0-4	-0.187	*n.s*
DAPP	2.33±0.61	2.32±0.61	0-2	-0.012	*n.s*

DEX= Excellence in service; DPA= Positive affect; DEV= Exceptional value; DAPP= Appraisal; *n.s*= nonsignificant

The Spearman's coefficients between the variables were calculated. The coefficients are shown four variables related significantly ($p < 0.01$). The exceptional value and the positive affect e.g. (r=0.637) had the highest coefficient. Besides the indicators appraisal and exceptional value are much related too (r=495). Significant and positive correlation ($p < 0.01$) were likewise obtained between the others variables. Table 4 shows the mean, standard deviation, and the Spearman's coefficients.

Table 4 – Descriptive statistics: Means, SDs, Range and correlations coefficients.

Measures	Mean	Std. Deviation	1	2	3	4
DEX	3.97	0.81	1			
DPA	3.87	0.94	.493***	1		
DEV	4.02	0.88	.478***	.637***	1	
DAPP	2.00	0.615	.463***	.495***	.430***	1

Note: n = 400. (***$p < 0.01$; **$p< 0.05$; *$p < 0.1$). The correlations are all Spearman's coefficients.

The variable appraisal allows discriminating among three groups of respondents according to the appraisal categories. The Mann-Whitney test shows a significant difference ($p < 0.05$) between the respondents in the hospitability sector (n=183, include respondents who selected an experience in a restaurant or hotel) and the respondents in another touristic service (n= 217, include natural parks, mall, etc.). The distribution of the sample by sector corresponds to the Figure 2.

Table 5 list the mean appraisal score and SD for the category of respondents creating according to the selected experience in services. The Mann-Whitney test indicated statically significance differences between the mean scores in each group ($p < 0.05$).

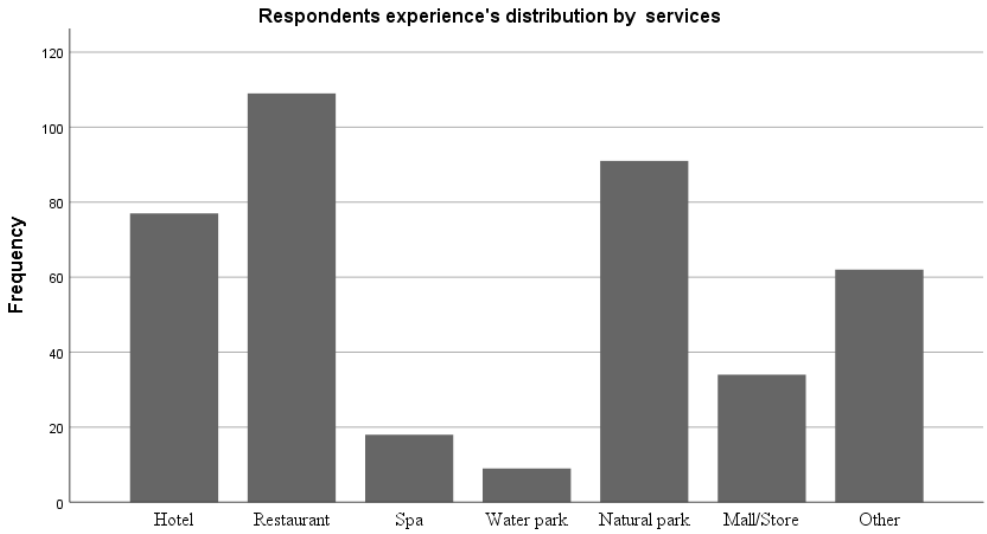

Figure 2 – Respondents experience's by services.

Table 5 – Mann-Whitney Test for Mean Scores (± SD) on the services sector in relation to DAPP Subgroups

Measures	Group A	Group B	Group C
Mean DAPP score (± SD) to Hospitality services	n=9 1.00±0.00	n=91 2.00±0.00	n=84 3.00±0.00
Mean DAPP score (± SD) to Touristic services	n=22 1.00±0.00	n=113 2.00±0.00	n=79 3.00±0.00
Mann-Whitney U: -2,167; Significance $p < 0.05$			

Taking into account the significant differences between the service classification and appraisal categories' in the variable the Kruskal-Wallis test was also used to validate differences in mean scores regarding the excellence in service, positive affect, and exceptional value on the appraisal categories. Table 6 list the mean, SD, x^2 in Chi-Square test and p-value corresponding to the Kruskal-Wallis Test by category. Although the difference among mean scores it is not very important, the contingency coefficient (C_{DEX}=0.505, C_{DPA}=0.506, and C_{DEV}=0.438) in all the cases are higher considering the maximum value C_{Max}= 0.87 and the association is statically significate p <0.01 and proportional.

Table 6 – Kruskal-Wallis Test for Mean Scores (± SD) on DEX, DPA, DEV in relation to DAPP Subgroups

Measures	DAPP Variant A Mean ± SD	DAPP Variant B± SD	DAPP Variant C± SD	Chi-square	P-Value
DEX	n=31 3.27±1.09	n=204 3.75±0.66	n=163 4.40±0.68	133.76	p <0.01
DPA	3.13±1.21	3.77±0.78	4.51±0.63	133.90	p <0.01
DEV	3.26±1.20	3.59±0.85	4.33±0.77	91.65	p <0.01

DEX= Excellence in service; DPA= Positive affect; DEV= Exceptional value; DAPP= Appraisal

Mediation model hypothesis

The model mediation was tested using the Preacher and Hayes's (2004) script and generating the Bootstrap results for indirect effects explained by Zhao *et al.* (2010). The model includes three indirect effects and six direct effects among variables. Applying these steps to the model, it is found the mean indirect effect from the bootstrap analysis is positive and significant (a*e= 0.166), with 95% confidence interval excluding zero (0.402 to 0.661). The indirect effect (d*f= 0.271) it's also significant and positive with 95% confidence interval excluding zero (0.165 to 0.348) and finally the third indirect effect with both mediators working parallel it's significant and positive (a*b*f= 0.129) with 95% confidence interval excluding zero (0.066 to 0.191).

The application of contrast test allows finding the main indirect effects of the tree possibilities. In the proposed model the only statically significant indirect effect it's (a*b*f=0.087) with 95% confidence interval excluding zero (0.010 to 0.159). The others two indirect effects according to the contrast include the zero in the confidence interval: (a*e= -0.064; -0.147 to 0.016) and (d*f=0.022; -0.051 to 0.086).

Table 7 list the indirect and direct effects among variables in the model with the significance level. The direct effect c=0.29 it's not significant (p > 0.05) therefore the exceptional value was not found to be correlated directly with the appraisal. However, the others direct effects are all positive and significant (p < 0.01).

Table 7 – Parameters in the Bootstrapping test.

Linked variables	**Total effect**	**Significance**	**Partial indirect effect**	**Total indirect effect**	**Direct effect**
Exceptional value→ appraisal (c)	0.0268 (8.756)	p > 0.05	a*e= 0.166 d*f=0.271 a*b*f=0.129	0.530 (0.299)	0.268 (8.756) (c)
Exceptional value→ excellent service (a)	0.427 (11,310)	p < 0.01	-		0.427 (11,310) (a)
Excellent service→ positive affect (b)	0.255 (5.281)	p < 0.01	-		0.255 (5.281) (b)
Positive affect → appraisal (f)	0.213 (5.243)	p < 0.01	-		0.213 (5.243) (f)
Excellence service→ appraisal (e)	0.201 (5.080)	p < 0.01	-		0.201 (5.080) (e)
Exceptional value→ positive affect (d)	0.496 (12,041)	p < 0.01	-		0.496 (12,041) (d)

Standardized parameters (t-value). The letters correspond to the Figure 1.

Note: n = 400

Figure 3 shows the variables in the model and the direct effects coefficients to illustrate the impact among them. Besides, it is marked with red color the significant indirect effect according to the results and with a different line the effect c. The methodology proposed by Zhao *et al.* (2010) suggest the classification of the mediation model into four categories according to with the significance and value of the direct and indirect impacts. According to with the classifications, the current mediation corresponds to an indirect-only mediation (a*e=significant and c=nonsignificant).

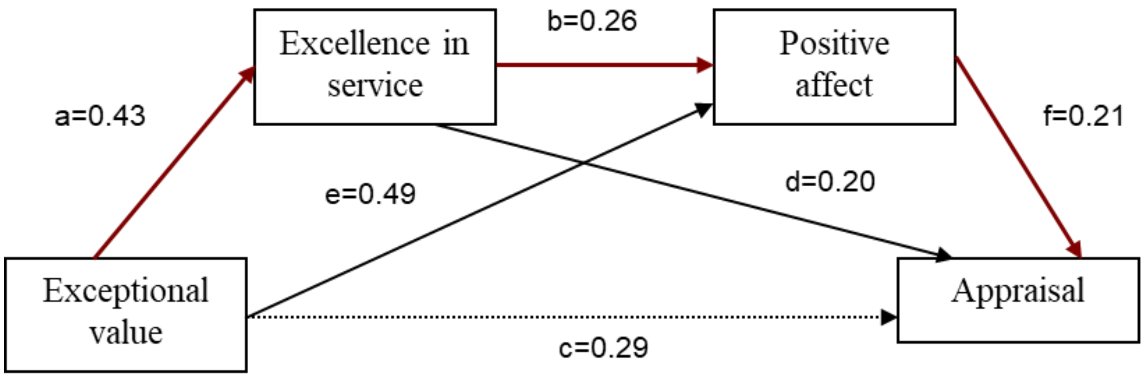

Figure 3 – Mediation model linking exceptional value and appraisal with coefficients.

DISCUSSION

This is the first study to link the exceptional value in delighted service's experience with the appraisal in customers groups. The model supports the mediation hypothesis of the excellence in service and positive affect between the exceptional value and appraisal. More specifically the mediation analyses showed how to get a general evaluation of the experience it has is through the excellence and the positive affect.

The indirect effect of each mediator variable by them self it is not significant, therefore the order and performance regarding with this variable in the customer experience are a key factor to appreciate the service as a delighted experience. However, it is not found a positive relationship between the customer gender and the appraisal, that means what mean and woman receiving a similar stimulus perform a similar evaluation of the experience.

The Mann-Whitney test for mean scores on the services sector in relation to appraisal by subgroups shows a significant ($U= -2,167$; $p <0.05$) difference regarding how the customers appreciate the experience according to the sector. The hypothesis is related to the variables that the customers evaluate in each experience. For example, in a theme park like as in the initial example, could be necessary to consider others factors like the access, the schedules or other variables to get an excellent evaluation of the service. But, in a restaurant, for example, the same family may be can consider more important, others variables as the staff attitude.

There are another two significant ($p <0.01$) and positive correlations between the exceptional value and positive affect through the excellence and positive emotion's mediation and between the appraisal and positive affect ($p <0.01$). The contingency coefficient who described the association level between the variables was high in both cases that can mean a significant correlation among how the customers evaluate the experience and the level of agreement/disagreement with the exceptional value and the attitude facing the positive emotions. The path coefficients in Figure 3 show a strong effect of exceptional value on excellence and exceptional value on appraisal with path coefficient score of 0.43 and 0.49 respectively.

The findings explains the well-suited fact that when an emotional instigator is presented, surprise for example, the organism shows more and more frequently habitual affective reactions. Therefore, in the next experience, the consumer will need an equal or high-intensity stimulus to preserve or to achieve the delight state. There are several authors who suppose the affective reaction in a non-static way, related with the presence or absence of a stimulus and the time in which it is initiated, Solomon and Corbit (1974) enacted this fact on the motivational theory of the opposite process.

The results suggest that the customers who chose the variant C in the appraisal evaluation (An excellent service where I felt positive emotions and I felt an important customer) are affected by more factors than the positive affect or the emotional stimulus and these results. Emotions mediate in the evaluation of the client but can be handled through other factors. It is also necessary to consider the role played by the others factor especially the excellence and exceptional value with the higher coefficients on the model.

The classification of the mediation according to Zhao *et al.,* (2010) corresponds to an indirect-only mediation (a*e=significant and c=nonsignificant). The authors suggest explaining this mediation as a consistent mediation with the hypothesized theoretical framework. This interpretation of the direct and indirect effects suggests those others mediators were not omitted in the model and consequently the mediation it is establishment.

This study does have certain limitations. One of the most important is to use just one item in the survey to measure the appraisal. Another limitation concerns to the testing of various models because the variables in this study correspond to a major construct, which included the measurement of the eight positive emotions individually, and it is evident that the respondents experienced significantly greater levels of positive emotions during their experiences. Besides, if we considered the differences between the appraisal evaluations by sector we need a more broad research design to find the causes in this difference. Therefore, another limitation is related to the study scope. In summary, the result of the study support the proposed model and allow achieving the main objective of the article. The model describes the events-chain to elicit a general appraisal in a service context started with the exceptional value and using two mediator variables: the excellence in service and the positive emotions. In the future, in order to prove the relations established by the model and in general the appraisal theory to explain a delighted state in groups of customers, it is necessary to consider all the dimensions in the appraisal definition and more than one item. Besides, will be positive design an experiment with groups and compare the results.

FINAL CONSIDERATIONS AND CONCLUSIONS

The model tested in the study suggest that the indirect effect of each mediator variable by them self it is not significant for the appraisal. Therefore, the order and performance regarding with this variable in the customer experience are a key factor to appreciate the service as a delighted experience. To date just a few empirical studies validate the appraisal approach to explain customer delight. Watson and Spence (2007) underline with the cognitive appraisal approach how a stimulus characterized by the outcome desirability, agency, fairness and certainty as antecedents evokes an emotion. At time, this emotion influences on the customer behavior. The real issue are in the circumstances were their effects represents a real influence to the customers.

This study validates the positive influence of excellence and emotions to build favorable circumstances for delighted appraised, they act in parallel. Let us back to the example at the beginning of the paper and remember the family who knew the excellent nature of the theme park experience and clarify this last point. The family in the history can participate in the value co-creation with the park through the online platform and live their own fantasy with their kids. Eventually, this new and exceptional value in addition to excellent restaurants and other services around the experience is related to a more high level of positive emotions. Then, the evaluation that the family made, the appraisal, about the whole experience it is higher and represents a delighted customer.

The goal or implications for the service industry are in to understand the customers' subjective experience, to gain insights into their motivations and find the factors that influence their attitudes. Going back again to the family example, in a moment of sudden enjoy, participate in the co-creation of value and share the happiness with others families and people in the social network affect their positive attitude with the service. That exceptional and particular value influenced the evaluation of the excellence, and the positive emotion it is activated thought the stimulus (games, theater, dinners, and excursions). The link between the excellence evaluations on the appraisal is a connection between the rational and emotional brain size. The results suggest the possibility expose by Ma *et al.* (2013) about the process of the cognitive information-processing mechanism; the perception of a situation is influenced by pre-existing knowledge and experience and personally relevant information. The situation is appraised using dimensions relevant to that particular situation and finally, the discrete emotional reaction is distilled and an emotion is elicited. What really means is if the couple goes alone or even if the couple did not have children, it is possible to obtain a different appreciation of the same experience.

How we feel about a certain situation is determined by our own appraisal or experience evaluation because each consumer can be an active agent in the experience construction (Watson and Spence, 2007). The model did not consider all the dimensions recommended by authors like Watson and Spence (2007) to demonstrate the appraisal theory bat a first step to considering differences appraisals evaluation in customers groups regarding with experiences in service.

The proposed model is consistent with the results of Arora (2012) who test a relation between positive effect→ delight and conclude that the emotions are a primary key in services. However, the nature of the service and the cultural perspective of customers represents different kinds of implications to the service. During the research others analysis were conducted. The results of others Mann-Whitney suggests that customers appreciate differently the cognitive variables according with their culture. The difference it is most significant between European and Asiatic tourists.

The results are also consistent with Ma *et al.* (2013) who studied 645 customers in the touristic industry too. Ma *et al.* (2013) understood delight like an emotion related to hedonic consumption and characterized as aroused positive affect. This author explains: “delight can be elicited when tourists appraise their experience either as unexpected, or as important to their personal well-being or special needs, or as in their interests, or as highly goal congruent. The empirical evidence showed how positive affect is not in itself an antecedent of the appraisal. To achieve the broad appraisal in the experience it is also necessary the mediation of the excellence in service, that means a hedonic consumption in quality terms. Bonnefoy-Claudet and Ghantous (2014) e.g. start their research testing the mediate relationship of the satisfaction in the emotional positive experiences into tourists. However, the final model proves a significant mediation of emotion between the behavioral intentions and the satisfaction contrary to the initial research hypothesis. In the present case the positive affect is a mediation variable too considering satisfaction, over satisfaction and delight explained as conditional appraisals.

The results are also in correspondence with authors like Johnston (2012) who suggest that essentially an excellent service it is not necessarily exceeding expectations, in fact, the customers interviewed in the study explained the excellent service as “essay” and “a pleasure”. The analyze of the four categories describes by Johnston (2012) can help to argue the relations presented in the model about customization in offers and value co-creation, also agree with Lusch and Vargo (2006).

The model tested in this article is based on the evaluation of the very good experiences were the emotion had a strong role. For authors, it is not necessary to validate this role, the real issue it is understood what location they have in the event-chain for delighted customers. The model also suggests that behaviors like delight respond to a personal evaluation of the experience in response to the positive affect and the creation of value. This value can change, and not affect directly to the appraisal because the relationship it is conditioned by the excellence and positive emotions. The model suggests groups of clients with different experience’s evaluations influenced by the same mediation variables. It can say excellent appraisals variation influenced by an emotional response (Bagozzi, 1992; Watson and Spence, 2007).

A previous knowledge and personally key indicators influence customers’ appraisal of an experience using dimensions relevant to that particular situation (Lazarus, 1991) if that situation change, the emotional reaction and therefore the appraised can change too. As the model suggests, on delighted experiences it is important the extra-value for the customer and maybe for the organization. In future works will be interesting find a connection between the co-creation of value for both actors and how they can obtain the maximum feedback. The current findings show the emotions as a distinctive factor in client’s behavior, although other variables as excellence in service demonstrate how the client needs and desires to influence the outcome emotions and therefore the appraised experience.

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Human error prevention in manufacturing

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ABSTRACT

Purpose – The purpose of this paper is to provide an answer to a very common problem of discrepancies in Quality of Products due to Human Errors in operations. Human errors often have great effects on quality, safety, and efficiency in manufacturing and service industry: e.g., assembly of wrong component, incomplete operation, loose assembly, scratches and damages on the product while performing operations, wrong data entry or filling wrong fluids. To prevent these errors and their undesired effects, "error proofing" solutions are effective. Successful examples include distinguishing the places of similar looking parts, simplifying the sequence of operation, using color-coded parts to avoid wrong part assembly, using a checklist in hand, and providing facilities for the ease of job. The basic idea of error proofing is very simple. Although human beings are flexible and creative, they also often make errors. This characteristic cannot be changed. Therefore, improving the other element of the work system, i.e., "work operations" including materials, methods and machines is an effective way for tackling errors. Error proofing has many different names such as fool proofing, poka-yoke, mistake proofing, and so on. All can be explained by this simple concept, "changing work operations to fit human beings". Although error proofing solutions are successfully applied in manufacturing and service industry, most of them are generated individually as needed to suit each occasion without the benefit of the knowledge of the wider body of error proofing solutions. This paper explains the error proofing principles and solution directions existing behind these proven solutions and provides a simple methodology for systematically generating workable solutions to reduce human errors in manufacturing industry.

Design/methodology/approach – Study of quality and safety concerns in manufacturing operations

Findings – Rather than focusing only on the human being, the new concept of Human error prevention focuses on the improvement of the work station including method, machine and material which can be used for quality and safety improvements in manufacturing operations

Keywords: Human Error Prevention in automobile Industry, Error Proofing Principles, Error Prevention, Human Error Control

Paper type: Technical paper

INTRODUCTION ON HUMAN ERROR PREVENTION

***Definition*:**

Human Error Prevention is the disciplined and systematic approach for understanding of interactions among humans and other elements of a system, and the profession that applies theory, Principles, Data and Methods to prevent or minimize the human errors in manufacturing operations to optimize human wellbeing and overall system performance.

***Objective*:**

To eliminate the defects arising due to human errors.

Goal:

- To adapt workstations and work conditions to workers
- To increase performance of workers
- To preserve health of workers
- To Overcome technological constraints
- To reduce level of work constraints
- To meet quality requirement of customer

Applicability of Human Error Prevention Concept

1. All Vehicle Manufacturing Plants
2. All Aggregate Manufacturing Plants.
3. All Supply modules
4. Wherever human operations are involved.

HUMAN ERROR PREVENTION FUNDAMENTALS

Three Common Misunderstandings

A. **Attentiveness can prevent errors**: Following is the table mentioning the error occurrence rates in different Physiological states of a Human being. (Reference taken from: Kunie Hashimoto: Safety Human Engineering, Japanese Industrial Safety and Healthcare Association).

Phase	Mode of Consciousness	Physiological State	Error Occurrence Rate
O	Unconsciousness	Sleep	1
1	Week consciousness	Tired	More than 0.1
II	Normal and relaxed	Rest or routine work	0.01～0.00001
III	Normal and clear	Active	Less than 0.000001
IV	Excited	Panicked	More than 0.1

Figure 1 – Misunderstanding No 1

In an Eight hour shift it is very difficult for a person to remain in Phase III (Normal & Clear) for 100 percent time. Due to many factors like fatigue, tiredness, anxiety, personal reasons, day dreaming etc. a person shifts from one phase to other many times in a day. So, it is a misunderstanding that Attentiveness can prevent errors as a human being does not stay attentive (Normal and Clear Mode) for 100% time.

Learning from above description is, while working and performing any task, Human being cannot be 100 % attentive all the time.

B. Education/training can prevent errors. Education and training are only first two steps to reduce Human errors. The flow chart below tells that if there is a deviation from Standard then the question to be asked is “Did operator understand Standard Operating Procedure?” The answer can be YES or NO. If the answer is NO, then efforts must be taken to educate him on Standard Operating Procedure. But if the answer is YES then one must ask another

Question "Did the operator have the skill to follow SOP?" If the answer is NO then efforts must be taken to train him on that SOP, but many times even after education and training deviations from standards are observed. The next question to be asked is "Did operator intend to follow SOP? If the answer is NO then efforts must be taken to motivate operator by making him understand the importance of SOP but if the answer is YES then Human errors are happening not because of problems in Education, Training and Motivation. A deeper understanding of why human errors is happening is required in this case, which comes from applying principles of Human error prevention.

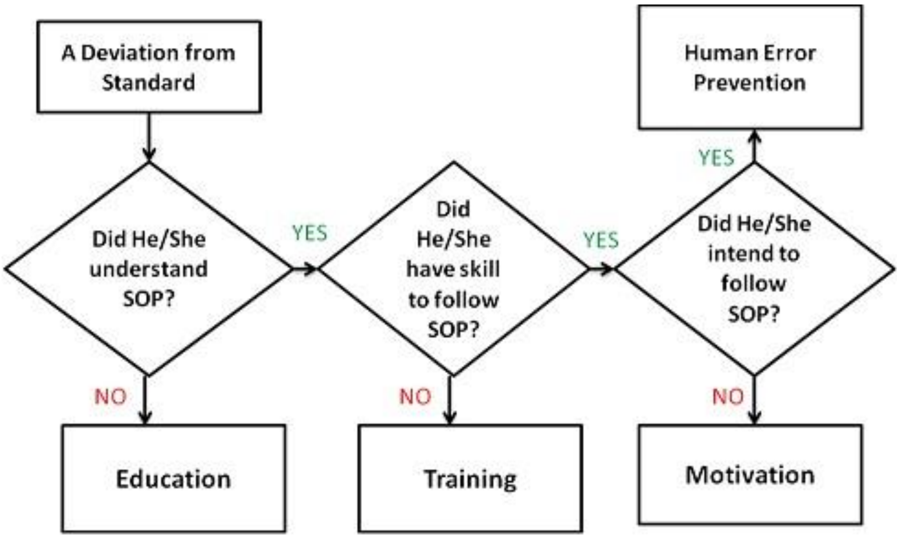

Figure 2 – Misunderstanding No 2

Learning from above description is though education and training is the basic requirements in manufacturing but only education and training cannot prevent 100% of the manual mistakes

B. **Multi-fold inspection can prevent errors:** Another misunderstanding is Multifold Inspection can prevent errors. The graph shown below illustrates the gap between the desired level of error detection rate (blue line in graph below) and actual level of error detection rate (red line in graph below). (Reference taken from: Daisuke Shimakura and Kenji Tanaka: The Validity of Human Defense-in Depths, Quality, Vol. 33). This happens because operators become lenient in checking if they know that the defects are going to get checked once again or have been checked already before.

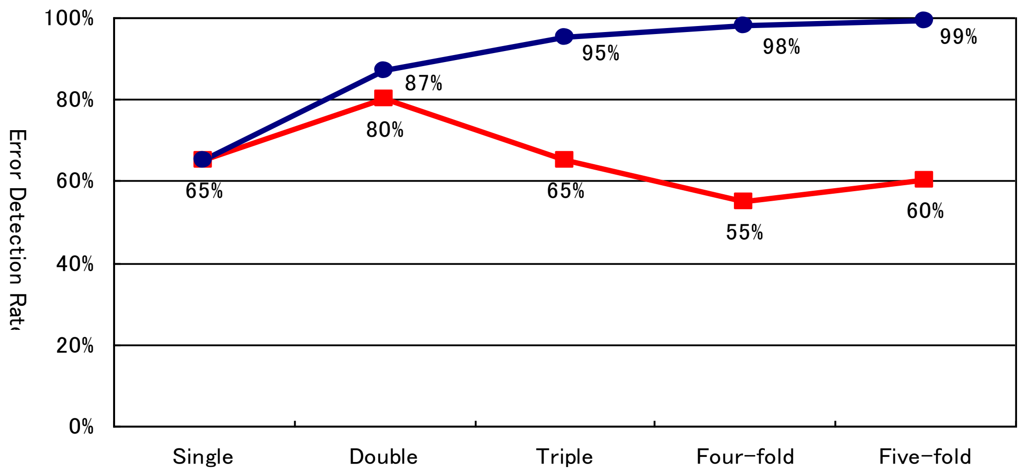

Figure 3 – Misunderstanding No 3

Learning from above description is, to arrest the concerns because of human errors, adding multiple checkpoints in the value stream is of no use.

ERROR PROOFING PRINCIPLES

Despite the simplicity of the basic idea of error proofing, there are various types of solutions. Error proofing is often taught by having people learn many examples. There, however, exist only a few basic principles to be known. Figure 1 illustrates the five principles of error proofing that have been extracted based on the investigation of more than 5000 error proofing solutions implemented in manufacturing and service industry. The top part of the following figure shows a process where human errors occur and cause incidents/accidents. Every operation has its own tasks and risks. Operators must perform the required functions to accomplish these tasks, creating the potential for human error. These errors cause abnormalities, and if necessary actions are not taken, finally cause undesirable results such as quality defects and accidents. The five principles correspond to the process.

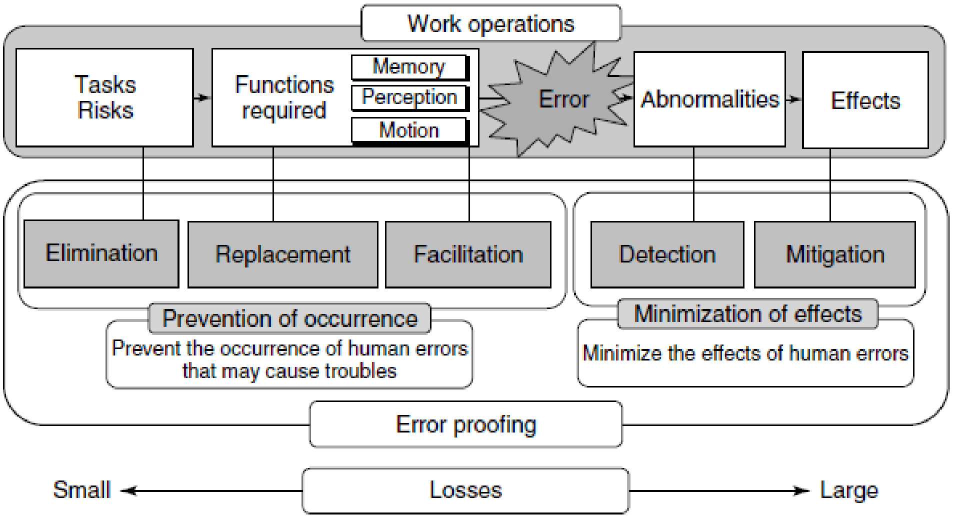

Figure 4 – Understanding Human Errors

The first three principles aim to prevent the occurrence of human errors. The most effective method of preventing errors is to eliminate operations susceptible to error from the process. The next most effective method, if the first cannot be applied, is to replace the human operations with more reliable machines/methods. The third most effective is to make the operations easier for operators to perform. These three principles belong to the first group: “prevention of occurrence”, and are called elimination, replacement, and facilitation, respectively.

On the other hand, the other two principles aim to suppress the development of errors into incidents/accidents. One method for attaining this is to detect abnormalities caused by human error and enable caregivers to take suitable corrective action.

Another method is to mitigate the effects of human error. These two principles belong to the second group: “minimization of effects”, and are called detection and mitigation, respectively.

Elimination - Remove work susceptible to human error from the process. Make the error prone operations unnecessary.

a. Example of error: Forgetting to put stickers or wrong fitment of stickers at certain places on vehicle body
b. Error Proofing: Putting single batch instead of stickers

Figure 5 – Example of sub principle - Task Elimination

The previous example corresponds to "**task elimination**". On the other hand, to avoid burn injury, providing the insulation on the pipe containing the hot fluid is the example of **risk elimination**.

The solutions based on the principle "elimination" can perfectly eliminate the possibility of human errors. In many cases, however, process/equipment design must be changed drastically, and it can have great side effects on cost, productivity, and performance

Replacement - Replace the human operations with more reliable machines.

a. Example of error: Wrong assembly of wire loom in the vehicle.

b. Error Proofing: Use of bar code reader and pick to light system for correct wire loom selection and assembly

Figure 6 – Example of sub principle- Automation

The principle "replacement" can further be classified into two sub principles:

1. **Automation**: completely replace a human operation with machines.

2. **Support system**: Give support tools such as checklists, reminders, guides, or samples to help caregivers to perform the operations more reliably.

The previous example corresponds to "support system".

On the other hand, using a display of parts according to the model mix of the product is an example of the support system which operators can use for selection of the correct part according to the model of the product

Various "replacement" solutions can be considered depending on how many functions are replaced. To replace all functions leads to large-scale and unrealistic solutions. Therefore, it is essential to focus on highly error-prone functions in the operations and replace them.

***Facilitation* -** Make the operations easier for workers to perform.

a. **Example:** Assembling wrong fuse or missing one or two fuses.

b. **Error Proofing:** Providing storage of fuses in the same shape as of part in the sequence of assembly.

Figure 7 – Example of sub principle - simplification

The principle "facilitation" can further be classified into three sub principles:

1. **Simplification**: Decrease the number of changes or differences.

2. **Distinction**: Distinguish changes or differences from each other.

3. **Adjustment**: Adjust objects or operations to suit the individual's capabilities.

The previous example corresponds to "simplification".

On the other hand, differentiating the places of similar looking parts to avoid wrong assembly of parts is an example of the sub principle “distinction”.

Making the size/form of the letters used in prescriptions easy to read also reduces the chance of misreading. This is an example of “adjustment”.

Individual “facilitation” solutions are not so effective, but their cost and side effects to operations are minimal. Therefore, it is possible and practical to use multiple solutions to increase overall effectiveness.

The above 3 principles namely; ‘Elimination’, ‘Replacement’ and ‘Facilitation’ are the principles one can use on the proactive side i.e. before error happens.

The following 2 principles ‘Detection’ and ‘Mitigation’ are to be use on the reactive side of an error i.e. for detection and minimization of the effect.

Detection **-**Ensure that abnormalities caused by human error are detected and suitable corrective action is taken.

a. Example: ABS Block to Pipe one joint loose

b. Error Proofing: Detection Poka yoke for detecting loose joint on ABS Block to Pipe.

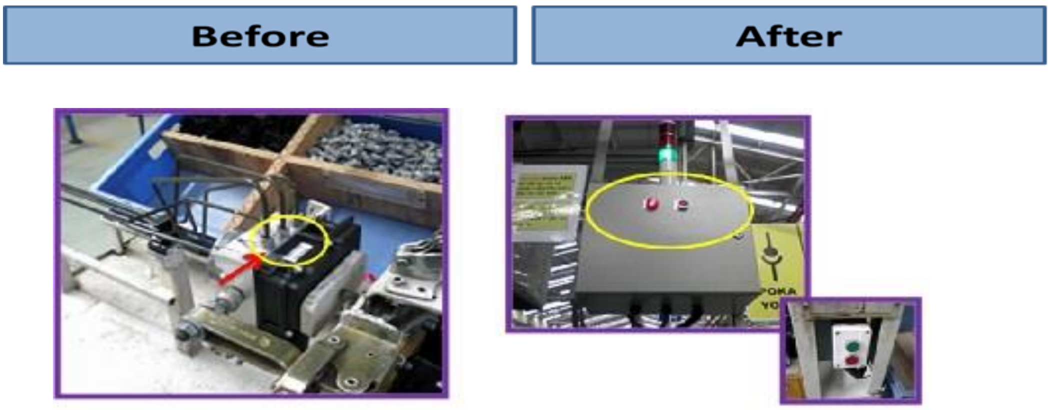

Figure 8 – Example of Sub Principle - Verify results and indicate abnormality

The principle “detection” can further be classified into three sub principles:

1. **Record, verify results and indicate abnormality**: Record precedent motions and verify them at a subsequent point in time.

2. **Restrict motion**: Restrict motions to allow operators to notice abnormalities.

3. **Verify results and indicate abnormality**: Sense the shape/quality/state of work objects at a certain point in the operation

The previous example corresponds to “Verify results and indicate abnormality”.

To avoid the assembly of the wrong part, change the physical shape of the part in such a way that the further assembly will not be possible is an example of the “Restrict motion”.

To overcome the concern of the torque not given to a particular joint, a system to verify the torque and indicate the abnormality if it is more or less is an example of “Verify results and indicate abnormality”.

Because late detection leads to large correction costs, it is essential to develop techniques for detecting abnormal motions or their results as soon as possible.

Moreover, it is also essential to apply “facilitation” solutions at the same time because human beings sometimes ignore obvious abnormalities and continue procedures according to their understanding.

Mitigation **-** Mitigate the effects of error by incorporating functional redundancies or using shock-absorbing materials

a. Example: Scratches and damages on vehicle due to contact of tool bit to vehicle body

b. Error Proofing: Spring loaded nylon bit provision on the battery tool bit to avoid scratches and damages on vehicle

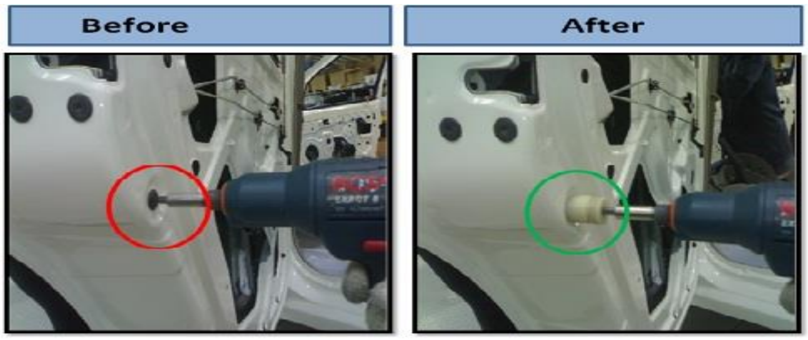

Figure 9 – Example of sub principle - Protector

The principle of “mitigation” can further be classified into three sub principles:

1. **Redundancy**: Make same functions parallel.

2. **Fail-safe**: Incorporate material/equipment to mitigate harmful conditions.

3. **Protector**: Make harmful conditions not produce losses.

The previous example corresponds to “protector”.

On the other hand, a fuse in an electric circuit to avoid the burning of a motor at high current and temperature is an example of “Fail Safe”.

And covering the sharp edges of the tools to avoid the scratches and damages is an example of the sub principle “Protector”.

To make a better use of the “Mitigation” principle it is important to understand the chain of the effects which leads to undesirable effects. It is also important to apply the detection solutions at the same time.

SYSTEMATIC GENERATION OF ERROR PROOFING SOLUTIONS:

Although the five error proofing principles described in the previous section are useful for understanding various error proofing solutions, we need some tools for systematically generating error proofing solutions that can attain the change required by each principle for the individual case.

After understanding the above fundamentals of the Human Error prevention, the following check list to be used for generating different solutions for a human error. (Refer attachments for better view)

After generating different solutions each solution is to be judged according to the solution priority number.

Depending on the feasibility and the SPN the actionable points to be derived and accordingly improvements to be done to avoid the human errors.

Solution Priority Number
=Effectiveness X Cost X Implementation

- Effectiveness: 1(Ineffective) to 3 (Very Effective)
- Cost: 1(High) to 3(Low)
- Implementation: 1(Difficult) to 3(Easy)

HUMAN ERROR PREVENTION CHECK LIST

BWT -		Defect Rate:
Sr.No/Year -		Severity(V1+,V1,V2) :
Date -		Defect rate after 3 weeks of solution :-
CFT -		
Defect -		

Why Why Why Why Why

Principles	Question to be asked to the process	Solution	SPN			
			Effectiveness	Cost	Implementation	SPN
Elimination	Can we eliminate the error-prone process?					
	Can we eliminate harmful objects?					
Replacement	Can we automate the process?					
	Can we provide supporting tools like checklists/gages/samples?					
Facilitation	Can we simplify changes/differences in the operations? (standardization, code matching, etc)					
	Can we distinguish changes/differences in the operations? (color coding, unique shape, etc.)					
	Can We adjust the properties of the operations which suits human beings?					
Detection	Can we record the motion of the earlier operation and verify it before starting the next operation					
	Can we restrict the motion in such way that it will notice the abnormality?					
	Can we verify the results before starting the next operation ? (sensing shape/state/quality of work)					
Mitigation	Can we make function parallel(Redundant)?(Additional Control)					
	Can we incorporate some shock absorbing material/equipment?(Like Fuse)					
	Can we make unsafe conditions more safer so as to not to produce the defects?(Protection)					

Solution Implementation

Sr.No	Actions	Resp	Date	Status

Figure 10 – Human Error Prevention Check list

CHALLENGES IN IMPLEMENTING HUMAN ERROR PREVENTION CONCEPT

1. **Knowledge Gap:** Many people in Indian Industry are not aware of the principles and concept of Human error prevention. Reduction of human errors requires a very deep understanding of Five Human Error Prevention Principles and application of these principles in day to day shop floor operations. Many companies do not have trained managers on this concept.
2. **Conventional Thinking:** Many people in Indian industry assume that Human errors are natural, and it cannot be avoided. In a way they accept human errors as a way of life and learn to live with it instead of eliminating these errors.
3. **Mindset that generic training of the process will overcome Human errors:** Most of the companies follow a practice of providing generic training to operators based on their skill development matrix and sometimes without that too. These trainings include different aspects related to what is the job and how it has to be done. That is what work instructions are and what Standard operating procedures for doing these jobs are. These training also include aspects of how to develop multitasking skills, how to do a job faster etc. but they do not cover a systematic approach to eliminate errors which are due to Human beings.
4. **Resistance to change:** Starting a systematic Human Error Prevention drive in a company faces a typical challenge of resistance to change. Many times, problems related to human errors are very minute in nature and the conventional thinking says that it can be controlled by inspection or multifold inspection. However, we have seen that it is a misunderstanding. Companies prefer this method over application of human error prevention because it is easier to do, and it is a very common practice. To convince companies to go for a systematic drive by applying Human Error Prevention principles becomes a big challenge if this resistance is big.

CASE STUDY OF HUMAN ERROR PREVENTION IMPLEMENTATION AT AUTOMOBILE COMPANY

The Mahindra Group is essentially many companies united by a common purpose – to enable people to ***Rise***. Enjoying a position of leadership in key industries that drive economic growth, such as utility vehicles, information technology, farm equipment, and vacation ownership – the Mahindra Group resonates with quality in every sphere of its activities.

Human error prevention project was started by Mahindra and Mahindra Ltd. Auto Sector in Nashik, Maharashtra, India as a part of implementation strategy for the learning of the Human Error prevention methodology which was imparted by Mahindra Institute of Quality during its flagship program "Post Graduate Diploma in Quality Management".

Why Human Error Prevention at Automobile Industry?

- 100% manual operation
- Contract Labor
- Complexity of operations
- Attention to inspection rather than prevention

Situation before HEP implementation:

In downstream quality checks the percentage of the defects because of manual mistakes was more. When any defects were being reported and if it is because of human error the normal practice was

1. Give DRF (DRF – Defect Reporting Format for communication of the defect and countermeasure to the concerns persons)

2. Re- train the operator for the concerned process.

3. If the operator is doing the mistakes repetitively then send the operator for Dexterity Training (Dexterity – School for imparting the basic skills to the operators)

4. There was no systematic and dedicated analysis for manual mistakes.

HEP implementation stages:

The total implementation plan followed the PDCA approach.

Plan –Plan was made for customizing a single page check sheet with the use of 5 main principles and 13 sub principles. Plan was also made for implementation strategy and training methodology.

Do – According to the training methodology decided step by step training was implemented to supervisors and operators. Training contents in depth understanding of the 5 main principles, 13 sub principles and the use of customized check sheet. Supervisors and operators were asked to take and implement improvement projects on Human errors based on the training imparted.

Check – After completion of several improvement projects, effectiveness was monitored in terms of reduction in the number of the process defects in the downstream checking. Also, numbers of improvements done were monitored.

Act – Finding out the improvement opportunity and implementation was also carried out for internal defects. Horizontal deployment of the improvements and the use for check sheet was done for other plants.

FINDING IMPROVEMENT OPPORTUNITIES FOR IMPLEMENTATION OF HUMAN ERROR PREVENTION

In Mahindra & Mahindra Automotive Division assembly line there are various quality checks carried out by the manufacturing quality assurance and Central quality assurance.

The main indicators are –

1. RFI (Ready for Inspection) – 10% of the vehicles are checked for high severity defects. This is a batch and hold checking process.

2. ANOVA C (Advanced New Overall Vehicle Audit) – One Vehicle /shift is selected randomly and audited thoroughly for aesthetic and functional defects followed by 50 KM test drive.

3. Internal Quality Concerns – Defects found by operators, check men and other quality checks.

For finding out the improvement opportunities rather than focusing on the supplier's or design defects the efforts are taken on the defects which are attributed to process as these concerns are because of some or other manual mistakes in the assembly and body shop processes.

The process defects are then prioritized on defect severity and frequency. Then Human Error prevention methodology is applied on top concerns with the use of customized checklist.

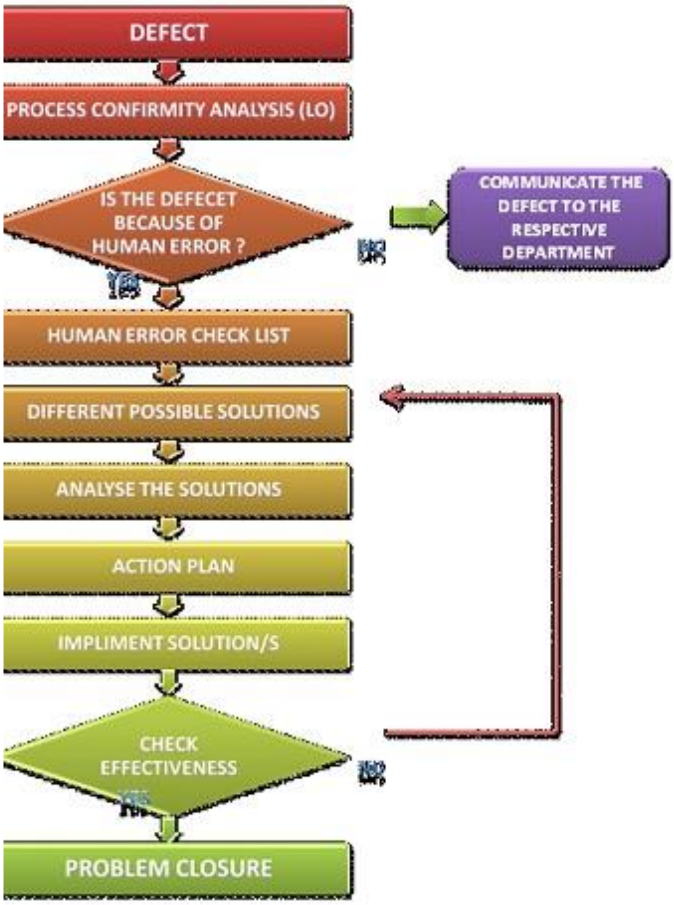

Figure 11 – Flow chart of HEP application

ACHIEVEMENTS

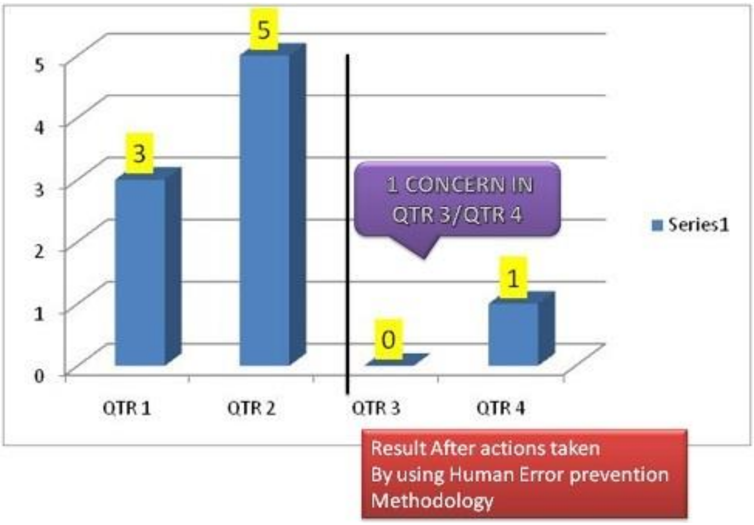

Figure 12 - Improvement In the process defects in downstream Quality checking (Sample report from one of the department)

Post implementation of Human Error Prevention methodology in a systematic manner, there is @ 70 % reduction in nos of high severity concern from manufacturing operations

NASHIK PLANT	
F12	103
F13	195
F14	209
F15	283
F16	195
F17	173
TOTAL	**1158**

Figure 13 - Year wise no of HEP improvements

Manufacturing operators are taking active participation in suggesting and completing improvements to overcome human errors in operations which can be seen as increased no's of improvements year on year

CONCLUSION

With the commitment towards customer satisfaction by improving quality and extensive support of the top management, the initiative of Human Error Prevention is well accepted in the automobile industry. Rather than focusing on the human being the new concept of Human error prevention focuses on the improvement of the work station including method, machine and material. The customized check list is very user friendly for concern resolution arising out of the manual mistakes. Improvements done with the use of this methodology has drastically reduced the process concerns in the quality and has come up with many improvements in the processes which has boosted the morale of the operators.

ACKNOWLEDGEMENTS

We thank Dr. Takeshi Nakajo from Chuo University Japan for teaching us Human Error Prevention concept, all MIQ members for involving in Human Error Prevention implementation and supporting for this paper write up. We also thank management of Mahindra and Mahindra Ltd. - Auto Sector for taking serious efforts on implementation of Human Error Prevention Concept.

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QM and innovation in the Greek agri-food sector

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ABSTRACT

Purpose – The purpose of this paper is to examine the extent to which three enablers of the EFQM Excellence Model, as a single factor, are associated with innovation performance in the Greek agri-food sector (focusing on the North Aegean region). Moreover, it offers insights into the nature of quality management and innovation activities of the responded companies.

Design/methodology/approach – The analysis followed in order to investigate the relations among the various constructs of the proposed model, includes an initial exploratory factor analysis (EFA), followed by confirmatory factor analysis (CFA) and finally structural equation modelling (SEM).

Findings – According to the study findings, the three EFQM model enablers directly contribute positive and significant to innovation performance of the Greek agri-food companies. The level of innovation performance of these firms is medium.

Research limitations/implications –The sample of the responding agri-food companies is limited to small and medium-sized agri-food firms from one country (Greece). Moreover, this study focused mainly to one region (North Aegean) of Greece. In addition, firms from different sectors have different resources, capabilities and performance.

Practical implications – The study offers clear implications for agri-food firms managers who should put additional emphasis on QM and the four dimensions of innovation in order to achieve improved overall firm performance.

Originality/value – Based on the multi-dimensional structure of quality, this empirical study determines the contribution of QM to specific innovation performance dimensions of the regional agri-food companies.

Keywords: Quality management, EFQM model enablers, innovation performance

Paper type: Research paper

INTRODUCTION

The agri-food sector is the largest processing sector within the European Union (EU). It is considered one of the main drivers of the EU economy in terms of the high economic output and plays a major role in employment (Menrad, 2004). In Greece, the agri-food sector contributes 25% of the Greek Gross Domestic Product (GDP) and employs 36% of national labor in 2015, making a disproportionately high contribution to the Greek economy. The Greek agri-food chain can be a key element in the innovation ecosystem, helping Greece to turn to an innovative agri-food member of the EU (Sakali and Skalkos, 2016). Thus, the Greek agri-food sector and especially the small regional companies need to be restructured, and their food products to gain identity in order to compete in a more globalized market (Skalkos, 2014). Kafetzopoulos et al. (2015) suggest that agri-food companies oriented to quality and innovation can perceive their comparative advantage.

The findings of previous research point out that it is still very important to rethink the value of Quality Management (QM) and its role in offering competitive advantages in the future business operation of agri-food firms. However, quality alone is not enough for the competitiveness and survival of organizations. Nowadays, the basis of competitive advantage is swiftly shifted from quality to innovation since it is the other element that plays a key role in providing unique products and services (Silva et al., 2014). According to Zeng et al. (2015) a practical management issue emerges: Does QM foster or hinder innovation? Literature fails to provide a clear answer to this question (Prajogo and Sohal, 2006). There are conflicting arguments pertaining to the relationship between various Total Quality Management (TQM) practices and innovation (Zeng et al., 2015; Prajogo and Sohal, 2006). The aim of the TQM is to support organisations to achieve business excellence, but the extent to which it can also promote innovation is not still clear (Gómez et al., 2017), since the related studies are scarce, partial, and limited to only a few empirical studies (Santos-Vijande and Álvarez-González, 2007). Thus, Palm et al. (2016) recommend further research about how QM can be developed in order to stimulate and improve innovation. Understandably, researchers need to specify the type of QM practices and how they impact innovation. Moreover, many authors conclude that more research into the innovation practices on agri-food sector is required (Baregheh et al., 2014; Capitanio et al., 2009; Avermaete et al., 2004).

Thus, the Greek agri-food sector has to take into consideration both quality and innovation as the key drivers of its economic growth (Sakali and Skalkos, 2016; Skalkos, 2012). Small agri-food companies need to focus on quality practices, moreover, to know how can become innovative and what innovation strategies need to adopt in order to achieve growth and development. Thus, the purpose of this paper is, first, to examine the implementation level of QM and innovation activities in the Greek agri-food sector. Second, to examine the extent to which three criterions of the European Foundation for Quality Management (EFQM) excellence model enablers, as a QM single factor, are associated with innovation performance of the Greek agri-food companies. This study takes into consideration the EFQM model criterions of policy & strategy, processes and partnerships & resources as innovation drivers. Third, to study in depth the development of product, process, organizational and marketing innovations, as the innovation performance dimensions of agri-food companies. This study contributes to the extent of current knowledge on QM and innovation as it reveals the relationship between QM - through the three EFQM model enablers - and innovation performance. This paper focuses on the QM and innovation performance of agri-food companies in one Greek region, the North Aegean. The North Aegean region is an island region consisting of three Prefectures and ten inhabited islands (Lesvos, Chios, Samos, Limnos, Ikaria, Agios Efstratios, Psara, Oinousses, Fournoi, and Thimaina).

The rest of the paper is organized as follows. In the next section, a review of previous literature is presented, followed by the research hypothesis and the related research model. Section 3 describes the methodology used in this study, including data collection, measurement scales, measurement analysis, and hypothesis testing, and section 4 presents the results of the empirical study. Finally, the paper concludes with a discussion of the main findings, conclusions and implications from this study, providing suggestions for future research.

LITERATURE REVIEW AND RESEARCH HYPOTHESIS

The EFQM model enablers

Researchers have classified the TQM's principles and practices into two large groups: the social aspects or soft factors and the technical aspects or hard factors (Lewis et al., 2006; Rahman and Bullock, 2005). Soft factors of TQM are related to behavioural aspects and generally deal with human resource aspects (Lewis et al., 2006). Hard factors of TQM are concerned with strategy, systems, management tools and processes that are necessary to support the implementation of soft factors (Gadenne and Sharma, 2009). Bou-Llusar et al. (2009), Brown (2002), Reiner (2002) and Black and Porter (1995) suggest that the social dimension of TQM is represented in the EFQM model through “people” and “leadership” enablers, while “processes” and “partnerships & resources” comprise technical aspects. On the other hand, “policy & strategy” contains items that relate to both soft and hard issues. This study brings a new idea, it introduces a multidimensional structural model taking into account, as a single QM factor, only the technical dimensions and “partnerships & resources”, without the soft factors of the EFQM enablers in order to enhance innovation results of Greek agri-food companies.

As far as the criterion of *policy & strategy*, Winn and Cameron (1998) maintain that once it has been designed, the policy and strategy must be put into practice through the deployment of key processes, the right human resource management, and the establishment of alliances and other types of cooperation agreements. The organizational policy and strategy is based on the current and future needs and expectations of the stakeholders considering the particularities of the market the organization is working in and the internal organizational environment (EFQM 2003). According to the criterion of *partnerships and resources*, the importance of suppliers’ relationships and the management of tangible and intangible resources are aspects frequently addressed in the literature on QM (Eskildsen and Dahlgaard, 2000). One of the most rapidly emerging theories about the competitiveness of small- and medium-sized enterprises (SMEs) in the agri-food sector is that it can be accelerated through inter-firm partnership. Firms must cooperate with their suppliers, working closely in specific processes and operations, in order to increase the value chain of all organizations (Wrong 2002). Excellent organisations are linked through alliances with agents that optimize the value chain. Collaboration and cooperation relations should be based on confidence, honesty and transparency. Moreover, the key *processes* are considered to be those that have a significant effect on the critical results for a given organization. According to the EFQM model, processes are the connecting link between all the rest critical QM factors (enablers) and the results (Suarez et al., 2016). The nature of these core processes in organisations may vary greatly, from relatively abstract activities, such as support for policy development, or regulation of economic activities, to very concrete activities of service provision. The needs to generate increasing value for its customers and other stakeholders and to raise efficiency are two of the main drivers in process development and innovation.

Innovation performance dimensions

Various types of innovation have been described in literature and researchers have explored its classification in different ways. In the Organization for Economic Co-operation and Development (OECD) Oslo Manual, innovation is distinguished between four main types, namely: product, process, organizational and marketing innovation (OECD, 2005). The current study is based on the above classification of innovation. The same classification has also been adopted from the studies of Tavassoli and Karlsson (2015), Kafetzopoulos and Psomas (2015) and Avermaete et al. (2004). In this study, *product innovation* emerges when a new product or a new variety of an existing product is introduced to satisfy a specific customer demand. Product innovation (new or improved products) must be new to the enterprise, but not necessarily new to the market (Tavassoli and Karlsson, 2015). Moreover, the adoption of *process innovations* in a firm means the introduction of new methods of production or new ways of handling a product or a service commercially. *Organizational innovation* involves changes to administrative processes and/or organizational structures relating to the basic work activities of an organization and its management. *Marketing innovation* it is consider the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing (Kafetzopoulos and Psomas, 2015).

Relationship between quality management and innovation performance

A review of the literature reveals that few articles define the question and systematize an argument on quality as a forerunner of innovation (Hoang et al., 2006). Some scholars argue the positive link between QM and innovation performance while others emphasize the negative link between them. The main reason for this complexity is that both innovation and QM are multidimensional in nature (Mielgo et al., 2009). QM and innovation have traditionally been seen as competing rather than complementary goals with various tradeoffs implied to achieve one goal versus the other (Samaha, 1997). McAdam et al. (1998) stated that, '*Quality is doing things better; innovation is doing things differently'*. Therefore, a key challenge that organizations might confront is to determine how to integrate the two factors, that is, to determine how to manage both quality practices and innovation capability (Leavengood et al., 2014). Most previous research supports the view that QM could be one of the prerequisites for innovation. Understandably, researchers need to specify the type of QM practice and how it impacts innovation. Positive viewpoint contends that companies embracing QM in their system and culture can provide a fertile environment for innovation (Zeng et al., 2015). It could be said that the seminal article that poses the question of the quality–innovation relationship is that of Zairi (1994), in which QM has *"given organizations the impetus and commitment required for establishing climates of never ending innovation or innovativeness"*. Prajogo and Sohal (2006) reached to the conclusion that the relationship between QM and innovation is positive and significant. Process management practices basically aiming at eliminating waste and improving efficiency, but it could be detrimental to innovation since have reduced slack resources that are necessary for fertilizing innovation (Sadikoglu and Zehir, 2010). According to Kanji (1996) introducing QM creates an organizational system and culture that promotes innovation. Moreover, the empirical findings by Kim et al. (2012) highlight the critical role of process management through which the asset of interlocked QM practices positively relates to each type of innovation (e.g. radical product innovation, incremental product innovation). Matias and Coelho (2011) state that QM strategically supports the management of innovation, while Sadıkoglu and Zehir (2010) found that all elements of QM are significantly and positively associated with innovation performance. Furthermore, Hung et al. (2011) conclude that QM practice can significantly enhance innovation performance. This analytical result is consistent with those obtained by Juran (1988). Based on the above research, the following research hypothesis was developed:

H1. Quality management has a positive influence on innovation performance.

A structural research model, as illustrated in Figure 1, was developed in order to analyze the impact of QM, constituting by the three EFQM model enablers, on four dimensions of innovation performance as a single factor. The relationship is double checked using the prior empirical findings based on the QM and innovation literature. The empirical validation of the proposed structural model will provide insights into how excellence in the three enablers explains the achievement of excellent results in the main types of a company's innovation performance.

METHODOLOGY

Research population and sample

To test the proposed structural model of this study, a survey questionnaire was used as the data collection instrument. The population of the study was selected from a list consisted of agri-food companies in Greece including both small and medium-sized firms. A total of 800 questionnaires were e-mailed and 261 were finally received. It was requested that the questionnaire be answered by the Chief Executive Officer or another manager designated by him/her because of the latter's familiarity with the issues dealt with in the questionnaire. The respondents chosen had the best knowledge of the QM and innovation issues in their organizations. The research project was conducted in two phases, due to the initially low response rate of the firms. Nine questionnaires were returned as incomplete and were not included in the study. Finally, 252 usable responses were obtained. This resulted in a response rate of about 31.5 % while 60 % of the sample was from the North Aegean islands. Regarding the size of companies, 87% were small firms and 13% medium-sized firms.

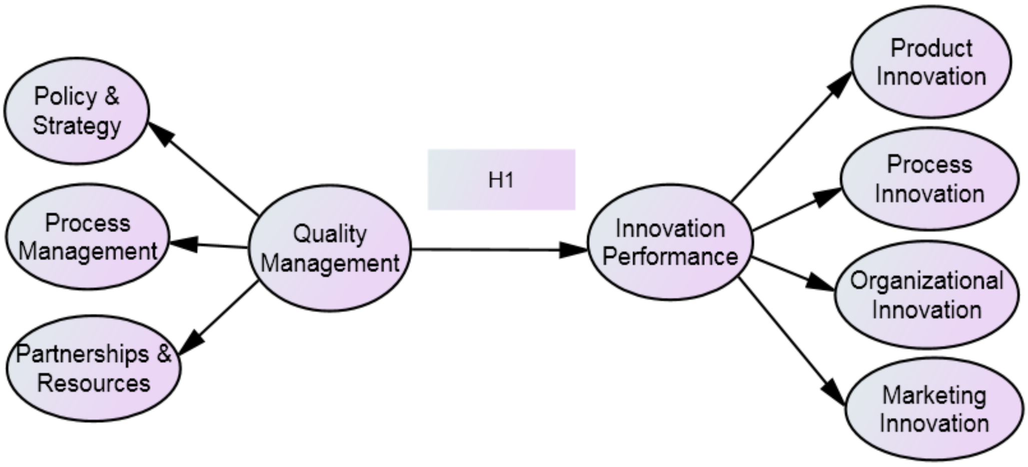

Figure 1 – The conceptual model

Research instrument

To design the research instrument, previous measurement items addressed in the literature were used. The measurement instrument was based on thee EFQM enablers. These criteria were assessed through 14 sub-criteria questions, which enabled the evaluation of the degree to which companies follow QM principles. The present study also adopts a broader concept of innovation, thus, four types were measured (product, process, organizational and marketing innovation) using 19 items. Before conducting the main survey, the draft questionnaire was examined by experts and a pilot-test was carried out in twenty firms. A seven-point Likert scale was used throughout to measure all the items of the research instrument. The respondents were requested to indicate their level of agreement with the items, based on how well they reflected the situation at their work site, ranging from "1 = strongly disagree" to "7 = strongly agree" (Tsai and Yang, 2013). The initial set of items included in the instrument was adapted from the original model which had been validated by many researchers. All respondents completed the survey instrument individually and independently. Each of the variables was examined individually for unique or extreme observations, and no case was defined with a threshold value of a standard score up to 3 (Hair et al., 2006). Consequently, calculating the Mahalanobis d-squared distance, no observations exceed the threshold value of 3 and so, no data points were deleted, leaving 252 observations for the analysis. Regarding the normality of the data, all measured variables in this study exhibited univariate normality and did not suffer from skew and kurtosis ($<\pm1$), indicating, but not guaranteeing, multivariate normality (Hair et al., 2006). The measurement items used in the survey and supporting literature are listed in Table 1.

Response bias

In order to determine whether there are differences between the two successive phases of the research project (early and late respondents) a t-test was performed on the scores of the variables relevant to the research hypotheses. No statistically significant differences ($p > .05$) were found between these groups. Additionally, the One-Way ANOVA test was used in order to detect possible differences (in the mean value of measured variables) among the agri-food companies' based on their demographic profile (small and medium-sized firms). No statistically significant differences were found between these groups indicating that non-response bias was not likely to be an issue in the final sample. Furthermore, the common method bias was checked. This test is run by loading all the items of the dimensions into a principal component analysis and forcing them into one latent factor. The test produced poor results indicating 25 percent of the variance extracted, while many items suffered from poor factor loadings, below 0.4. Thus, common method variance is not a concern in this study.

Method of data analysis

The analysis adopted in this study includes an initial Exploratory Factor Analysis - EFA, to uncover the underlying structure of the variables. Then, Confirmatory Factor Analysis (CFA) is used to refine the resulting scales in EFA and to determine if the number of factors and the loadings of the measured variables (i.e. indicators) on them conform to what is expected on the basis of pre-established theory. Multicollinearity, unidimensionality, scale reliability and construct validity are undertaken for the study as variables as suggested by Hair et al. (2006). According to Hair et al. (2006) if there is a theoretical basis to expect that conceptual layers of a latent construct exist and furthermore if the structural relationships between the latent construct and its sub-dimensions (factors that constitute the layers) are strongly supported by the literature, then a higher order model becomes applicable. The second-order model explains the co-variations among first-order factors in a more parsimonious way. More specifically, in the present study, two different measurement second-order models are constructed using "Quality Management" and "Innovation Performance" as second-order factors that explain the first-order factors. The model and the hypothesis are tested using Structural Equation Modeling (SEM) via path analysis, as it is a multivariate analytic methodology that gives insights into the causal ordering of variables in a system of relationships. The Statistical analysis software SPSS 22 and AMOS 6.0 (Analysis of MOment Structures) were used for the statistical processing of the data.

Table 1 – Constructs, indicators and supporting references

Constructs and indicators	**Supporting references**
Policy & strategy Policy and strategy is based on the current and future needs and expectations of the stakeholders Policy and strategy is based on the information of the indicators of performance, research, learning and external activities Policy and strategy is developed, reviewed and updated Policy and strategy is communicated and deployed via a schematic of key resources	Suarez et al. (2016), Bou-Llusar et al. (2009), Santos-Vijande and Álvarez-González (2007), Calvo-Mora et al. (2005)
Partnerships & resources Management of the external alliances (rejected) Management of the economic resources Management of the buildings, equipment and materials Management of technology Management of information and knowledge	Suarez et al. (2016), Bou-Llusar et al. (2009), Santos-Vijande and Álvarez-González (2007), Calvo-Mora et al. (2005)
Processes, products & services Systemic design and management of the processes Introduction of the necessary improvements via innovation, to fully satisfy the customers and other interest groups, increasingly generating a greater value Design and development of the products based on the needs and expectations of the customers Production, distribution and attention service of the products and services (rejected) Management and improvement of the relationships with customers (rejected)	Suarez et al. (2016), Bou-Llusar et al. (2009), Santos-Vijande and Álvarez-González (2007), Calvo-Mora et al. (2005)

Constructs and indicators	Supporting references
Product Innovation The level of newness (novelty) of the company's products is increased The new products incorporate a large new body of technological knowledge The frequency of developing new products is high Develops new products with technical specifications and functionalities different and superior from the current ones We have an advantage over our competitors in terms of the new products we offer to customers.	Kafetzopoulos et al. (2015), Chang et al. (2015)
Process innovation We strive to keep our production processes ahead of competitors We improve the speed and efficiency of our production processes We use advanced technologies in our production processes The rate of changes in the processes and techniques is high	Prajogo (2016), Kafetzopoulos et al. (2015)
Organizational innovation Actively seeks innovative ideas from R&D, sales, marketing and manufacturing departments Implements new or improved existing computer-based administrative applications Renewing the supply chain management system Renewing the organizational structure to facilitate strategic partnerships and long-term business collaborations Renewing the routines and processes employed to execute firm activities in innovative manner	Yam et al. (2011), Gunday et al. (2011), Forsman and Annala (2011)
Marketing innovation The company has introduced new product pricing techniques for the pricing of the current and/ or new products The company has introduced new product promotion techniques for the promotion of the current and/or new products The company renewing the design of the current and/or new products through changes such as in appearance, packaging and shape without changing their basic functional features The company has introduced new product distribution methods Renewing general marketing management activities	Gunday et al. (2011)

MEASUREMENT ANALYSIS AND RESULTS

Descriptive statistics

Table 2 presents the detailed features of the 3 enablers of the EFQM model and the 4 dimensions of innovation performance of the sample agri-food companies. For each factor, the following descriptors are listed: mean value, standard deviation, minimum and maximum values.

Table 2 – Descriptive statistics

Factors	Mean value	Standard deviation	Minimum value	Maximum value
Policy & strategy	5.27	1.20	2	7
Partnership & resources	5.10	0.90	3	7
Process management	5.20	0.88	3	7
Product innovation	5.09	0.94	2	7
Process innovation	4.88	1.12	2	7
Organisational innovation	4.90	1.18	2	7
Marketing innovation	4.77	1.14	2	7

Reliability and validity

A range of statistical tests was performed on data obtained from the survey to assess the reliability and validity of the model as suggested by Hair et al. (2006). EFA was conducted, to check factor loadings of each item (Gunday et al., 2011; Sadikoglu and Zehir, 2010). Seven latent factors were extracted (Kaiser-Meyer-Olkin = 0.921, Bartlett's test of Sphericity = 5414.874, p = 0.00, eigen-value>1, MSA>0.80, factor loadings >0.636), explaining 72.7 % of the total variance. The examination of factor loadings indicated that 3 items demonstrate cross-loadings >0.50 on more than one latent factor and they rejected from the analysis (see Table 1). Thus, 30 items were used to run CFA and assess the fit of the measurement model and unidimensionality. Following Kim et al. (2012) CFA was conducted to assess the measurement model and the results confirmed the factors revealed by EFA. The fit indexes for the measurement model (see Table 3**)** indicated a good fit of the model to the data based on the recommended criteria: (χ^2/df) value <3.0, CFI, IFI, TLI and NFI > 0.9, RMR <0.08, and RMSEA <0.08 (Hair et al., 2006). Thus, it was concluded that all constructs were unidimensional.

Table 3 – The fit indices of the overall measurement and structural models

Models	$\chi 2$/df value	RMSEA	GFI	CFI	NFI	RMR	TLI	IFI
Measurement model	1.73	0.054	0.824	0.948	0.903	0.072	0.939	0.948
Structural Model	1.76	0.055	0.853	0.944	0.907	0.077	0.936	0.944

Moreover, it was necessary to assess the reliability of the constructs. Cronbach's alpha coefficient is commonly used as a measure of internal. The Cronbach's alpha values for the scales ranged from 0.780 to 0.920, exceeding the recommended 0.70 threshold (Hair et al., 2006). Furthermore, based on the results of CFA, this study calculated the composite reliability (CR) and the average variance extracted (AVE) for each construct of the model. The composite reliabilities ranged from 0.760 to 0.950, while the AVE ranged from 0.537 to 0.750. A value above 0.50 for AVE and 0.6 for CR of any construct is accepted (Hair et al., 2006). The results provided evidence that each construct had an acceptable level of reliability. Table 4 reports the results of the measurement analysis. In the last stage, validity was assessed in terms of content, convergent and discriminant validity (review of literature, AVE>0.50, factor loadings of all items were >0.5, AVE > squared correlation between each pair of constructs). The results provided strong evidence that all of the study constructs were reasonably reliable and valid.

Table 4 – Measurement model: construct reliability and convergent validity.

Constructs	Cronbach's a	CR	AVE	Corr²
Policy & strategy	0.800	0.840	0.537	0.490
Partnerships & resources	0.790	0.770	0.638	0.490
Process management	0.860	0.760	0.562	0.483
Product Innovation	0.810	0.940	0.654	0.494
Process innovation	0.830	0.950	0.750	0.494
Organizational innovation	0.780	0.950	0.660	0.541
Marketing innovation	0.920	0.940	0.623	0.541

Hypotheses testing

After performing the above tests, SEM was applied (maximum likelihood method) to test the hypothesis of the study, using the model illustrated in Fig. 1 as the base model. Table 3 shows the results, indicating that the overall fit statistics for the structural model demonstrated an acceptable fit. Figure 2 shows the SEM analysis results of the structural model regarding the relationship between QM and innovation performance. Figure 2 depicts the path coefficient that indicates the associated hypothesis, as well as the p-value and squares multiple correlations (R^2) for each construct. It can be seen that the hypothesis H1 is supported (table 5).

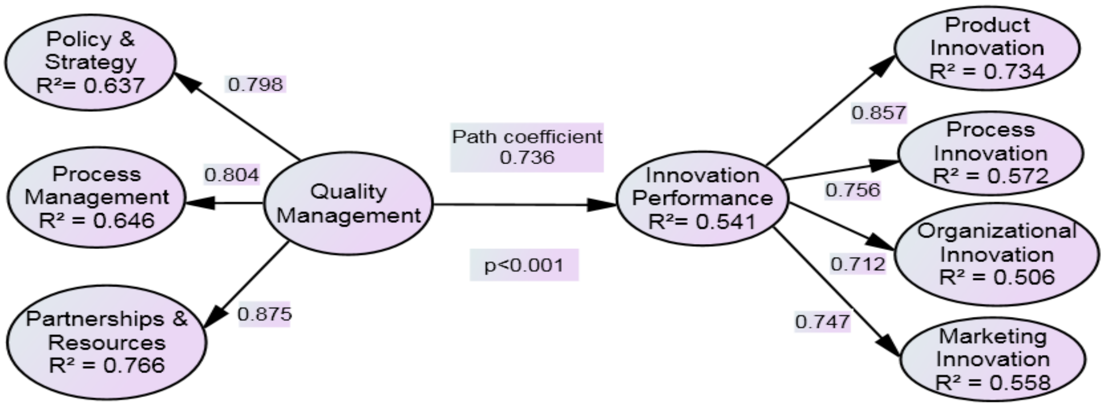

Figure 2 – The structural model

Furthermore, we examined the effect of how QM impacts indirectly the four variables of innovation performance. Looking at the difficulties arising in this kind of analysis, these indirect relationships are not included in a set of hypotheses. Four indirect paths were examined to the proposed structural model; quality management → product innovation; quality management → process innovation; quality management → organizational innovation and quality management → marketing innovation. All four paths were additionally found to be statistically significant. In Table 5 we can see the above total indirect relationships.

Table 5 – Total effects of QM on innovation performance and their dimensions

Effect to / Effect from	Innovation performance	Product innovation	Process innovation	Organizational innovation	Marketing innovation
Quality management	Direct effect	Total indirect effect			
	0.736*	0.630*	0.556*	0.524*	0.549*

*p < 0.001

DISCUSSION

QM and innovation performance has received significant attention from academics all over the world, providing interesting business insights (Palm et al., 2016). Unlike earlier studies which focused on a list of QM practices that directly influence innovation (Kim et al., 2012), the present study introduces a second-order factor called “Quality management”, that can be assessed indirectly through the assessment of its sub-factors (policy & strategy, partnerships & resources, process management), which in turn can be indirectly assessed through the assessment of their indicators that are directly measured. In addition, it introduces another second-order factor called “Innovation performance” with sub-factors the four innovation dimensions. Thus, the current study offers a reliable and valid model which provides empirical evidence to support the significant relationship between the two second order factors.

This study also adds to existing research by introducing organizational and marketing innovation dimensions, providing a much richer and more complex picture of firms’ innovation strategies. According to Kim et al. (2012) the narrow view of innovation may be a barrier that causes a misunderstanding of the contribution of QM to innovation. By using the four dimensions and multiple indicators for innovativeness, it adopts a comprehensive view of innovation, considering the full set of agri-food organizational operations. This approach to the variety of innovation dimensions is sufficient enough to depict the different firms’ innovation strategies within the agri-food sector. Determining the current level of the innovation performance of an agri-food company or the entire sector, may reveal a gap between this level and the excellent level of innovation. Based on this gap, suitable strategies can be selected by a company or the whole sector in order to enhance innovativeness and competitiveness in the global business arena. Appropriate statistical analysis supported the reliability and validity of the proposed model (Tables 3 and 4), and hence the high predictive power of the three EFQM enablers as a framework for innovation performance. The above findings are in line with the results of previous studies regarding the EFQM model, such as Calvo-Mora et al. (2006), Eskildsen and Kanji (1998) or Dijkstra (1997), which show that implementation, development and improvement of the criteria of the EFQM model should not be pursued independently. In addition, our research model contains many potential indirect effects regarding the impact of the “Quality management” construct on the four types of innovation performance. The results show that all indirect relationships are positive and significant while the “Quality management” has the highest indirect effect on product innovation (0.630) followed by process innovation (0.556), while organizational innovation seem to has the least (0.524). Thus, the results of this study provide additional evidence concerning these relationships, shedding light into the effect of Quality management on innovation types. Moreover, it builds on the results of previous studies, such as those of Suarez et al. (2016), Calvo-Mora et al. (2005), Prajogo (2005), or Eskildsen and Dahlgaard (2000) who claim the effective implementation of excellence models, such as EFQM, turn out to be beneficial for organizations fostering a culture of innovation (Calvo-Mora et al., 2014).

The present study also reveals that, the agri-food companies do make remarkable efforts to adopt quality practices and innovation. More specifically, considering the mean values of the EFQM enablers and innovation dimensions revealed (table 2), it is apparent that the sample agri-food companies are familiar with practices concerning quality and product, process, marketing and organisational innovation. It is also obvious that the innovation dimensions revealed do not approach the excellent level, which means that the sample agri-food companies are not, in practice, totally oriented towards innovation. So, there is still room for further increase in the degree to which the innovation practices are implemented. The current crisis may be the reason why these companies cannot afford to fully innovate. In other words, the current economic environment may have a negative influence on the companies' efforts to innovate.

Practical implications

The empirical findings of the present study offer significant managerial implications. First, the study reveals that the EFQM model's excellence enablers are not simply a management tool for promoting and improving quality, but also a significant tool to boost innovation performance and as a result, further increase overall business performance of agri-food firms. Managers should nurture a culture of high quality improvement that encourages, supports, and rewards breakthrough thinking, leading to innovation enhancement. Following the requirements and adopting the principles of the EFQM model, helps managers of agri-food companies to develop clear and effective policy & strategy, encourage employees to develop and implement creative ideas, offer the necessary resources and develop the appropriate partnerships that will enhance process management and support business innovation. Managers should generate a creative synergy among individual processes and focus on developing best practices, eliminating waste, avoiding activities that do not add value and improving efficiency in order to eventually foster innovation. The results indicate that quality strategy is an important major driving force behind agri-food business innovation performance. Thus, it is important for agri-food firms to develop the appropriate quality strategies and allocate the respective resources according to the required type of innovation. Briefly, the results confirm the importance of quality activities and provide support for the encouragement of innovation in agri-food companies in order to lead the sector to restructuring.

The relationship between QM and innovation performance under financial crisis (as it is the case of Greece), may provide a guide as to how agri-food companies should achieve better economic performance by using innovation. Moreover, creating a successful quality - innovation platform may prove to be the most critical catalyst for company's financial success and growth. The message from this study is that focusing an agri-food company on specific quality attributes can lead to higher innovation capabilities, which in turn may act as a catalyst for business improvement and market success. It is also often associated with setting up new enterprises to provide the market with new offerings and create new jobs. This study seems to be especially important for smaller, younger and regional agri-food firms and for those firms operating in highly turbulent environments. It can help an agri-food SME withstand the current downturn and survive in an unstable and financially unhealthy business environment. The fact that the current economic downturn and financial crisis prevail not only in Greece but also in many other European countries too, strengthens this point of view. Moreover, this paper offers clear practical implications for managers who desire to choose strategies and allocate resources in order to improve their company's quality and innovation performance. Moreover, it also adds implications for governments and consultants whose aim is to support the strategic development efforts of agri-food companies (especially SMEs). The research concludes that, in order for firms to achieve excellent business results, the organization's management of suppliers and partners, as well as the management of organization's resources and processes, in combination with enhanced innovation performance activities, are indispensable.

CONCLUSION AND FUTURE WORK

Since the relationship between QM and innovation is rather controversial, this study seeks to fill the literature gap, enhancing the understanding of interdependence among technical aspects of the EFQM model criterions - as a single QM factor - and their relation to innovation performance of agri-food SMEs. The originality of this study in relation to similar previous studies is that it offers a reliable and valid model which presents the notion that hard dimensions of QM provide a foundation to achieve a competitive position in innovation, and suggest the importance of continued efforts with EFQM criterions. By looking at quality from the dimension of hard QM practices, this study further contributes to the understanding of the different role played by different QM dimensions in determining innovation. This is also the first study reflecting Greek agri-food companies' efforts to innovate through QM.

The study presented in this paper suffers from some limitations. A first limitation is caused by the data used to measure the EFQM criteria and innovation types. The study collected data was based on respondents’ perceptual judgment, since there is possibility the respondents did not provide a completely accurate view of reality. Thus, this research should be extended using multiple informants to verify perceptions. A second limitation is related to the model relationships. The study focused on the relationships between QM practices and innovation performance. It might be useful for researchers who study organizational phenomena in complex market environments to assess the same relationships considering the effect of external factors such as environmental uncertainty. Finally, a third limitation is caused by the focus of this research to one region (north Aegean) of Greece. It would be valuable to conduct more studies within agri-food organizations to other counties or to different regions of Greece which would generate more interesting results complementing with ours.

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A maturity model to assess Supply Chain Quality Management integration

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ABSTRACT

Purpose – The purpose of this paper is to present the development of a Supply Chain Quality Management (SCQM) maturity model, a self-evaluation tool with the purpose of assisting and helping organizations in gradually improve the integration of Quality Management (QM) and Supply Chain Management (SCM) practices.

Methodology – A literature research was carried out in order to get understanding about the key concepts of SCQM, and also to identify and study the main existent maturity models on the QM and SCM domains. Then, combining the knowledge acquired, an approach to a SCQM maturity model was developed.

Findings – The main achievements to be accomplished regarding each maturity stage of SCQM integration were identified and then incorporated in a multidimensional structure, which embraces five maturity levels related to five organizational dimensions (Organizational Performance, Quality Management, Information Management, Supply Chain Integration, and Sustainability).

Originality/value – This paper focuses on a subject that has not been broadly explored in the existent literature, since none SCQM maturity model was found in the literature. Thus, this paper contribution lies on providing knowledge to understand which topics must be assessed in order to improve the efficiency of SCQM integration and the performance of the overall Supply Chain.

Paper type: Research paper

Keywords: Supply Chain Quality Management, SCQM, Maturity Model, Integration

INTRODUCTION

With the globalization trend of the market, business competition is passing gradually from the firm level to the supply chain level (Foster Jr, 2008; Fish, 2011), meaning that new challenges are being arising and companies must face it in cooperation with suppliers, customers and the other business partners. In this way, Quality Management (QM) and Supply Chain Management (SCM) are management philosophies from two different domains that share similar goals (e.g., customer satisfaction) (Mahdiraji *et al.*, 2012), which can be integrated in order to improve the overall performance and the competitive power of supply chains (Bastas and Liyanage, 2018).

The integration between QM and SCM can be translated by the concept of Supply Chain Quality Management (SCQM), which is an issue of increasing importance to promote the competitiveness and sustainability of organizations. As shown in the conceptual model developed by Fernandes *et al.* (2017), QM and SCM have several common dimensions influencing firms' performance and, according to Chibba (2017), the synergies between these two management approaches can bring several benefits to organizations. However, this is still a recent matter that needs further investigation to be fully understood (Foster Jr, 2008; Chibba, 2017).

In order to help organizations to implement management practices, assessment tools like maturity models have been developed. Such models provide an evaluative and comparative basis for improvement in order to increase the capability of an organization to operate within a specific area (de Bruin *et al.*, 2005).

In the QM and SCM domains, some maturity models can be identified. However, to the best of our knowledge, no maturity model was found specifically focused on the SCQM integration. The purpose of this paper is to fulfill this gap in the literature, by providing a SCQM maturity model that leads companies to make a self-evaluation about its SCQM practices, enhancing the performance of their supply chain.

To achieve this purpose, a critical literature review was carried out aiming to get information about the state of the art regarding the SCQM subject and to identify the main characteristics of the most relevant existent models, which were used as basis for the development of the SCQM maturity model. The structure of the maturity model is presented in this paper, outlining the organizational dimensions to be evaluated and explaining what must be achieved in each maturity stage.

The remaining part of this paper is organized as follows. Next section presents a literature review regarding the theoretical background that supports the concept of SCQM. It also presents a brief analysis on maturity models, seeking to identify and analyze the most relevant maturity models developed in the QM and SCM domains. Then, the following section presents the SCQM maturity model, describing the approach applied during its development and presenting a description of its architecture and assessment approach. The last section presents the main conclusions of this paper, and also stablishes opportunities for further work.

LITERATURE REVIEW

Supply Chain Quality Management overview

In a world characterized by an increasing globalization and competition, supply chain quality is becoming an issue of concern (Huo *et al.*, 2016). This current paradigm brings new challenges and opportunities to operations managers, leading companies to the necessity of gaining new competitive advantages. In this scenario, an important role is played by two management philosophies: Quality Management (QM) and Supply Chain Management (SCM).

The core task of QM is to assure the fitness of an organization in a growing competition by providing high quality products, i.e., products that fulfill the customers' desires and requirements (Weckenmann *et al.*, 2015). The quality practices have known a great evolution during the twentieth century, from a narrow focus at the final product and standing currently with a holistic view of the organization as a complex system, to be managed and improved considering the mutual relationships between the entities therein (Weckenmann *et al.*, 2015).

Supply Chain (SC) includes all the partners, activities, and flows of material and information, which are interconnected to meet the needs of the customer, going from the extraction of raw material to the end user/customer (Seuring and Müller, 2008; Mahdiraji *et al.*, 2012). Thus, SCM focuses on the integration of all (internal and external) players of the SC, managing the existent relationships and operations in order to get more revenues, reduction of costs and improvement of flexibility along the SC, enhancing quality and ensuring customer satisfaction (Mellat-Parast, 2013). Normally, SCM is based on five main processes (*Plan, Source, Make, Delivery* and *Return*).

Based on the Supply Chain Operations Research (SCOR) model framework (APICS, 2017), *Plan* process describes all planning, coordinating and operating activities of the supply chain.

Source is the process refer to the all necessary activities related to acquiring goods and services that will feed the remaining supply chain. *Make* process is related to all add-value activities (transformation and creation) of products and services. The *Deliver* process encompasses all activities related with the distribution of finish products and services to satisfy final customer needs. The *Return* process comprehends all tasks related to the reserve flow of products from customers to the manufacturer, either by complaints or return of unsold stock.

Although not yet considered on this work, SCOR Model has been updated recently with a sixth process call *Enable* which covers all tasks related to the management of resources, assets, information and performance of all supply chain processes.

The integration of QM and SCM can be seen as a natural evolution process, since both have the main purpose of customer satisfaction (Mahdiraji *et al.*, 2012) and the promotion of practices such as supplier quality management and customer focus (Kaynak and Hartley, 2008). Further, according to Flynn and Flynn (2005), the integration of QM principles contributes to a more embracing approach of SCM, which can lead to improvements on the SC performance (Casadesús and Castro, 2005), enhancing the overall competitiveness of the SC partners (Zhong *et al.*, 2016).

Along with this process of integration, the concept of SCQM comes up. Fernandes *et al.* (2017) developed a conceptual model of SCQM in order to promote the knowledge about these issues. This model explores the key specific and common dimensions that are concerned to QM and SCM in order to promote the organization performance, characterized by the four perspectives of the Balanced Scorecard (BSC) model (*customer, internal process, learning and growth* and *financial*).

In this referred conceptual model, six dimensions can be observed as the common dimensions identified in QM and SCM (*leadership*, *continuous improvement and innovation*, *sustainability*, *management and strategic planning*, *information*, and *stakeholders' involvement and commitment*), which supports the integration concept. Moreover, two dimensions specifically related with QM (*product/service quality* and *quality culture*) and three regarding SCM (*procurement*, *internal logistics* and *distribution*) were identified.

Maturity Models

Being aware of the importance of SCQM to the success of the organization, the necessity of having guidelines to its implementation in a real context arises. For this purpose, a maturity model can be used not only as an example of best practices, but also as a self-evaluation of the current state of a company (Lockamy III and McCormack, 2004; Lahti *et al.*, 2009).

"Maturity" can be defined as the current state of something, as it passes through a gradual evolution process, with several stages of learning. Lockamy III and McCormack (2004) affirmed that the maturity concept is related to the extent to which a process is explicitly defined, managed, measured and controlled. So, one can say that, when the level of maturity of a process increases, the knowledge and the capacity of solving problems about it increase as well (Fraser *et al.*, 2002; Lahti *et al.*, 2009; Domingues, 2013).

The general purpose of maturity models is to provide guidelines to a company to reach a desired level of maturity in a certain field, following an evolutional path, through several maturity levels, gradually. Thus, a maturity model usually describes the typical behaviours and practices that should be considered to reach each maturity level. Further, some authors such as Fraser *et al.* (2002), Lockamy III and McCormack (2004), and Domingues (2013) defended that when a level is reached, some time is required to consolidate that stage.

Maturity models have arisen with the Quality Management Maturity Grid, proposed by Crosby (1979), followed, in 1988, by the Capability Maturity Model integration (CMMi), from the Software Engineering Institute of Carnegie Mellon University, which is applied in the Information Technology (IT) field (Paulk *et al.*, 1993). After that, several maturity models have been developed in other areas such as SCM (Lahti *et al.*, 2009), logistics (Battista and Schiraldi, 2013), or integrated management systems (Domingues, 2013), among others.

SUPPLY CHAIN QUALITY MANAGEMENT MATURITY MODEL

At the moment, and to the best of our knowledge, there is no maturity model specifically dedicated to SCQM. Given the increasing importance of this matter, this paper has the objective of the presentation and discussion of a maturity model to assess the SCQM integration. This model aims to evaluate the maturity and efficiency of the SCQM concept integration, allowing the company to understand the current state of integration of QM and SCM, and providing guidelines about what must be done to reach higher levels of maturity. It also aims at evaluating to what extent some other critical dimensions (e.g., IT, SC integration, Sustainability) are aligned with the efficiency progress towards excellence.

The methodology followed for the development of the maturity model has the background in the SCQM conceptual model designed by Fernandes *et al.* (2017). A literature research was carried out on the SCQM investigation field, aiming the identification of maturity models related either with QM and SCM and assessment frameworks that best fit within the dimensions illustrated by that conceptual model, and which, in that way, could serve as a reference for the development of the SCQM maturity model.

Following this procedure, reference documents were selected regarding the following dimensions: QM (Crosby, 1979), SCM (Lahti *et al.*, 2009; de Oliveira *et al.*, 2011), Sustainability (Cagnin *et al.*, 2005; Carter and Rogers, 2008; Seuring and Müller, 2008; Baumgartner and Ebner, 2010), as well as some related to Information and Technology Management (Lichtblau *et al.*, 2014; Geissbauer *et al.*, 2016).

Then, these maturity models were analyzed in order to obtain guidelines for the development of the SCQM maturity model. In this stage, the structure on which the model would be constructed (number of maturity levels and the organizational dimensions to be considered), and the aspects that should be assessed regarding each level/dimension were defined.

Regarding its structure, Figure 1 shows the proposed model in a schematic way. The model consists in a grid with which the organization is assessed along five dimensions (*Organizational Performance*, *Quality Management*, *Information Management*, *Supply Chain Integration*, and *Sustainability*), being categorized according to five levels of maturity (1 – *Ad-hoc*; 2 – *Basic*; 3 – *Intermediate*; 4 – *Advanced*; 5 – *Mature*).

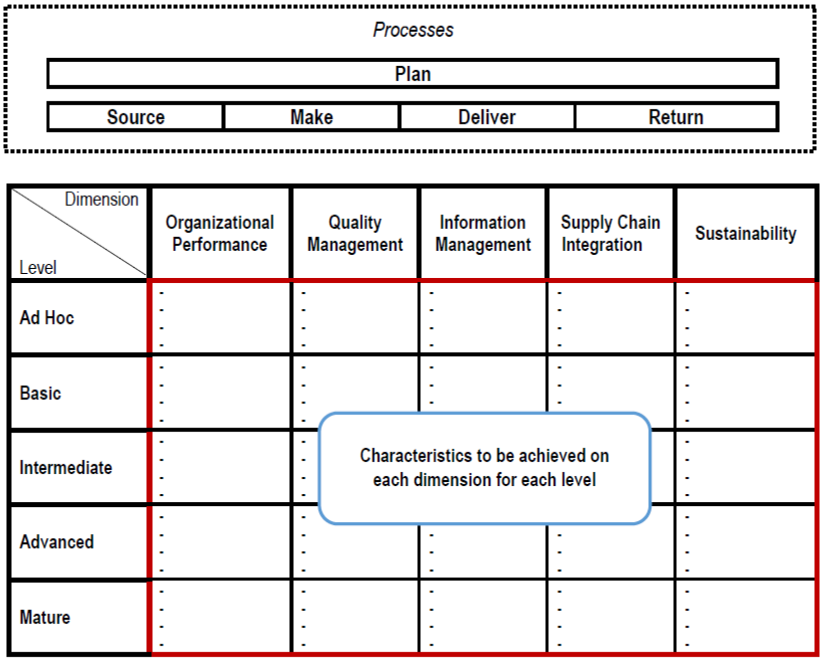

Figure 1 – Proposed SCQM maturity model.

The typical organizational behaviors, practices and characteristics must be defined regarding each maturity level and the different organizational dimensions. In this way, guidelines to follow a progressive and evolutional path to achieve higher levels of maturity regarding SCQM integration can be provided. Thus, incorporating both quantitative and qualitative analysis elements, each maturity stage can be described as the following (Crosby, 1979; Lockamy III and McCormack, 2004; Cagnin *et al.*, 2005; Lahti *et al.*, 2009; Baumgartner and Ebner, 2010; de Oliveira *et al.*, 2011; Lichtblau *et al.*, 2014; Geissbauer *et al.*, 2016):

1. **Ad-hoc** – The processes are not documented neither defined, and the performance measurement is very scarce, as well as the usage of quality tools and practices. A reactive attitude prevails in the company, there are no prevention actions, no knowledge of quality costs and the customer satisfaction remains low. Further, there is low cooperation along the Supply Chain with only basic relationships between the company and stakeholders. Sustainability is not a concern to the company.

2. **Basic** – Main processes are defined, some data collection is done by non-automatic ways and historical data records are gathered and kept in an informal way. Some metrics are used to characterize the main processes but without a regular monitoring. Some cooperation along the Supply Chain can be seen, although there is no share of information, since each process has its own information system. Continuous improvement starts to exist due to some kind of corrective actions. Customer satisfaction shows some increase, but no significant improvements are achieved. Sustainability issues start to be a concern and some practices are implemented.

3. **Intermediate** – The company already shows some significant management and control practices about the processes, although in a non-balanced way, denoting that some business areas/processes are more mature than others. Customer satisfaction shows significant improvements, representing a competitive advantage, although it remains with an inconsistent performance. Sustainability issues are managed in order to promote the company's image towards society and stakeholders.

4. **Advanced** – Processes are already completely defined, measured, and the information system is shared with suppliers and customers. Key Performance Indicators (KPIs) translate the efficiency and effectiveness of the processes. There is a high level of cooperation and involvement of stakeholders in company strategic decisions. Quality tools and continuous improvement practices are used in a regular basis, as well as

preventive actions, which is translated in known costs and improvement of customer satisfaction. Sustainability is a big concern for the organization, although it is not completely integrated with company's goals.

5. **Mature** – The processes are well defined and documented, and there is an integrated information system that allows to manage the overall company's performance. There is a global translation of the efficiency and effectiveness of each main process in terms of evolution and costs. In this level, the continuous improvement is part of the company culture, with regular use of quality practices. A close cooperation between all the different Supply Chain areas can be identified. The stakeholders, including customers, are actively involved in the strategic planning. Sustainability is integrated with company's policy and vision, and translated into goals and practices.

This maturity model is currently in test phase, which is being performed in the real context of a multinational company of the automotive components industry. Having the *Return* process as proof of concept, a selected group of the company's workers (high-level managers and technicians with responsibilities regarding QM and SCM) are using the criteria of the SCQM maturity model in order to assess the company's supply chain processes and to obtain a characterization of the current maturity level of SCQM integration. The purpose of this test is to evaluate if the model criteria and architecture are suitable to the real context, getting a better understanding of its practical use and to detect opportunities for improvement.

FINAL CONSIDERATIONS AND FUTURE WORK

The knowledge about SCQM integration is still in an early development phase. For that reason, although its benefits for organizations, there is, to the best of our knowledge, no model with guidelines to support specifically the implementation and integration of SCQM practices on a company.

This paper intends to fulfill this identified gap in literature. Having as a start point the conceptual model of Fernandes *et al.* (2017), and based on relevant maturity models in the QM and SCM domains, a structure for the SCQM maturity model is proposed here. This self-evaluation tool combines a set of organizational behaviors and best practices, which are related to five maturity stages, embracing five organizational dimensions (*Organizational Performance*, *Quality Management*, *Information Management*, *Supply Chain Integration*, and *Sustainability*).

Future work aims to systematize the model and promote its usability. After the test phase that is being currently carried out in the real context of a company of the automotive components industry, some refinements are expected to be made, more specifically, on clarifying the criteria defined on each dimension, besides the definition of assessment procedures (e.g., required support documentation) and the appraisal and scoring methods. Those refinements are going to be the basis for further work.

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Fusion of partial orderings for decision problems in Quality Management

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ABSTRACT

Purpose – In a rather common problem for the Quality Management field, (i) a set of *judges* express their individual (*subjective*) judgments about a specific *attribute*, which is related to some *objects* of interest, and (ii) these judgments have to be fused into a *collective* one. This paper develops a new technique where individual judgments – which are expressed in the form of *partial* preference orderings, including the more/less preferred objects only – are fused into a collective judgment, which is expressed in the form of a *ratio* scaling of the objects of interest. An application example concerning the design of a civilian aircraft seat is presented.

Design/methodology/approach – The proposed technique borrows the architecture and the underlying postulates from the Thurstone's *Law of Comparative Judgment* (LCJ), adopting a more user-friendly response mode, which is based on (partial) preference orderings instead of paired-comparison relationships. By aggregating and processing these orderings, an overdefined system of equations can be constructed and solved through the *Generalized Least Squares* method. Apart from a ratio scaling of the objects of interest, this approach makes it possible to estimate the relevant uncertainty, by propagating the uncertainty of input data.

Findings – Preliminary results show the effectiveness of the proposed technique, even when preference orderings are rather "incomplete", i.e., they include a relatively limited number of objects, with respect to those available.

Research limitations/implications – Thanks to the relatively simple and practical response mode, the proposed technique is applicable to a variety of practical contexts, such as telephone and street interviews. Although preliminary results are promising, the technique will be tested in a more organic way, considering several factors (e.g., number of judges, number of objects, degree of completeness of preference orderings, degree of agreement of judges, etc.).

Originality/value – Even though the scientific literature includes many techniques that are inspired by the LCJ, the proposed one is characterized by two important novelties: (i) it is based on a more user-friendly response mode and (ii) it allows to obtain a ratio scaling of objects with a relevant uncertainty estimation.

Paper type: Research paper

Keywords: Group decision making, Law of comparative judgment, Partial preference ordering, Generalized least squares

INTRODUCTION

A problem that is rather common to several scientific field is articulated as follows (Keeney and Raiffa, 1993; Franceschini et al., 2007; Coaley, 2014):

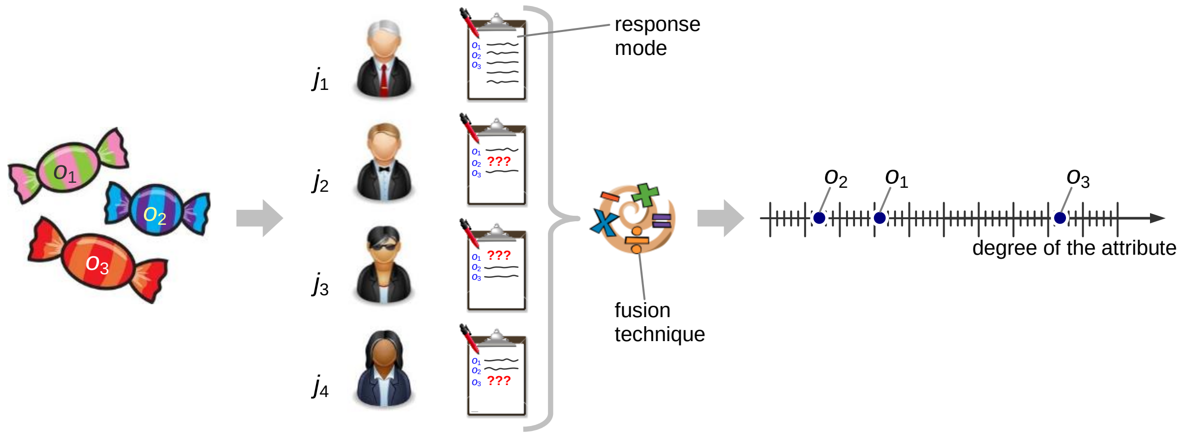
- a set of *objects* (o_1, o_2, …) should be compared on the basis of the degree of a specific *attribute*;
- a set of *judges* (j_1, j_2, …) individually express their *subjective* judgments on these objects;
- these judgments should be fused into a single *collective judgment*, which is usually expressed in the form of a *scaling*, i.e., assignment of numbers to the objects, according to a conventional rule/method (De Vellis, 2016).

With reference to the Quality Management field, possible examples of this problem are: (i) fusing judgments related to the customer satisfaction of set of competing products, or (ii) fusing judgments by reliability/maintenance engineers on the severity of potential process failures, etc..

Figure 1 shows a pedagogical representation of the problem of interest, in which four final consumers (i.e., judges) have to express their judgments on the taste (i.e., attribute) of three types of candies (i.e., objects). It general, judges may refrain from judging part of the objects, when lacking adequate knowledge of them (e.g., see judgments with “???”).

The scientific literature encompasses a plurality of fusion techniques, which differ from each other for at least three features: (i) the *response mode* for collecting subjective judgments; (ii) the underlying *rationale* of the fusion technique, and (iii) the *form* of the resulting collective judgment. For an exhaustive discussion of the existing techniques in various fields (e.g., Quality Management, Multi-Criteria Decision Making, etc.), we refer the reader to the vast literature and reviews (Coaley, 2014; De Vellis, 2016).

Regardless of the peculiarities of the individual fusion techniques, a key element for their success is the simplicity of response mode (Franceschini et al., 2007; Harzing et al., 2009). For example, various studies show that comparative judgments of objects (e.g., "o_i is more/less preferred than o_j") are simpler and more reliable than judgments in absolute terms (e.g., "the degree of the attribute of o_i is low/intermediate/high") (Harzing et al., 2009; Edwards, 1957).



(i) *Objects* of interest (o_1 to o_3), with a certain attribute

(ii) Subjective judgements by several *judges* (j_1 to j_4)

(iii) *Collective judgement* of the objects (e.g., *scaling*)

Figure 1 – Pedagogical representation of the problem of interest.

As to the typology of collective judgments, we note that they are often treated as if they were defined on a *ratio* scale – i.e., a scale with non-arbitrary zero and meaningful distance – even when they actually are not; e.g., rankings or ordinal-scale values of the objects are often improperly "promoted" to ratio-scale values, in the moment in which they are combined with other indicators through weighted sums, geometric averages, or – more in general – statistics that are permissible to ratio-scale values only (Roberts, 1979).

In a recent paper, the authors have developed a technique, denominated "*ZM*-technique", that combines the Thurstone's *Law of Comparative Judgment* (LCJ) (Thurstone, 1927; Edwards, 1957) with a response mode based on preference orderings (Franceschini and Maisano, 2018). The resulting collective judgment is expressed in the form of a *ratio* scaling, which can be constructed without any conceptually prohibited "promotion". An important requirement of the *ZM*-technique is that, apart from "regular" objects (i.e., o_1, o_2, …, o_n), preference orderings also include two "dummy" or "anchor" objects: i.e., o_Z, which corresponds to the *absence* of the attribute of interest, and o_M, which corresponds to the *maximum-imaginable* degree of the attribute (Franceschini and Maisano, 2018).

The *ZM*-technique requires judges to formulate *linear* preference orderings, i.e., orderings including all (regular and dummy) objects, according to a hierarchical sequence with relationships of *strict preference* (">") and/or *indifference* ("~") (Nederpelt and Kamareddine, 2004). This is certainly a limitation, as it makes the response mode unsuitable for some practical contexts where ranking a number of objects can be problematic. It has also been observed that, when formulating preference orderings, judges tend to focus on the more/less preferred objects, providing more reliable judgments about them, to the detriment of the remaining objects (Lagerspetz, 2016; Harzing et al., 2009). Another limitation of the *ZM*-technique – and the traditional LCJ too (Montag, 2006) – is the impossibility to estimate the uncertainty related to the resulting scaling of objects.

The above considerations raise the following research question: "How could the *ZM*-technique be modified so as to (1) make the response more user-friendly and reliable and (2) determine a (statistically sound) estimate of the uncertainty related to the solution?".

The aim of this paper is to address the previous research question, proposing a new technique that overcomes the limitations of the *ZM*-technique while preserving the basic principles. The new technique replaces linear preference orderings with "incomplete" orderings, which are focussed exclusively on the more/less preferred objects. Borrowing the language from Mathematics' Order Theory, these other orderings can be classified as *partial*, i.e., apart from strict preference and indifference relationships, they may also contain *incomparability* relationships among (some of) the objects (Nederpelt and Kamareddine, 2004).

The rest of the paper is organized into five sections. Section "Background information" briefly recalls the LCJ and *ZM*-technique. Section "Methodology" illustrates the new technique, which includes the construction of an overdetermined system of equations and its solution through the *Generalized Least Squares* (GLS) method (Kariya and Kurata, 2004). This technique also allows to estimate the uncertainty related to the solution, "propagating" the uncertainty of input data. Section "Application example" applies the new technique to a real-life example, concerning the design of a civilian aircraft seat. Section "Conclusions" summarizes the original contributions of this paper and its practical implications, limitations and suggestions for future research. Further information on the GLS method is contained in the appendix.

BACKGROUND INFORMATION

This section "prepares the field" to better understand the proposed technique and is organized in two subsections, which respectively recall the LCJ and the *ZM*-technique.

Thurstone's LCJ

Thurstone (1927) postulated the existence of a *psychological continuum*, i.e., an abstract and unknown unidimensional scale, in which objects are positioned depending on the degree of a certain *attribute* – i.e., a specific feature of the objects, which evokes a subjective response in each judge. The position of a generic *i*-th object (o_i) is postulated to be distributed normally, in order to reflect the intrinsic judge-to-judge variability: $o_i \sim N(x_i, \sigma_i^2)$, where x_i and σ_i^2 are the unknown mean value and variance related to the degree of the attribute of that object. Considering two generic objects, o_i and o_j, it can be asserted that:

$$o_i - o_j \sim N(x_i - x_j, \sigma_i^2 + \sigma_j^2 - 2 \cdot \rho_{ij} \cdot \sigma_i \cdot \sigma_j), \tag{1}$$

where ρ_{ij} is the Pearson coefficient, denoting the correlation between the positioning of objects o_i and o_j. The probability that the position of o_i in the psychological continuum is higher than that of o_j can be expressed as:

$$p_{ij} = P(o_i - o_j > 0) = 1 - \Phi\left[\frac{0-(x_i - x_j)}{\sqrt{\sigma_i^2 + \sigma_j^2 - 2 \cdot \rho_{ij} \cdot \sigma_i \cdot \sigma_j}}\right], \tag{2}$$

Φ being the cumulative distribution function of the standard normal distribution $z \sim N(0, 1)$.

The LCJ (*case V*) includes the following additional simplifying assumptions (Thurstone, 1927; Edwards, 1957): $\sigma_i^2 = \sigma^2\ \forall i$, $\rho_{ij} = \rho, \forall i, j$, and $2 \cdot \sigma^2 \cdot (1-\rho) = 1$. Eq. 2 can therefore be expressed as:

$$p_{ij} = P(o_i - o_j > 0) = 1 - \Phi[-(x_i - x_j)]. \tag{3}$$

Although p_{ij} is unknown, it can be estimated using the information contained in a set of (subjective) judgments by a number (m) of judges (Thurstone, 1927). Precisely, each judge expresses his/her judgment for each paired comparison (i.e., $\forall i, j$), through relationships of *strict preference* (e.g., "$o_i > o_j$" or "$o_i < o_j$") or *indifference* (e.g., "$o_1 \sim o_2$"). Then, for each judge who prefers o_i to o_j, a frequency indicator f_{ij} is incremented by one unit. In the case the two objects are considered indifferent, f_{ij} is conventionally incremented by 0.5, so that:

$$f_{ij} = m_{ij} - f_{ji}, \tag{4}$$

m_{ij} being the total number of judges who express their judgment for the *i*,*j*-th paired comparison. In general, $m_{ij} \leq m$ since judges may sometimes refrain from expressing their judgments on some of the possible paired comparisons. We remark that the condition in Eq. 4 is a *sine qua non* for the application of the LCJ (Thurstone, 1927).

The observed proportion of judges that prefer o_i to o_j can be used to estimate the unknown probability p_{ij}:

$$\hat{p}_{ij} = \frac{f_{ij}}{m_{ij}}. \tag{5}$$

Of course, the relationship of complementarity $\hat{p}_{ij} = 1 - \hat{p}_{ji}$ holds.

Returning to Eq. 3, it can be expressed as:

$$\hat{p}_{ij} = 1 - \Phi[-(x_i - x_j)], \tag{6}$$

from which:

$$x_i - x_j = -\Phi^{-1}(1 - \hat{p}_{ij}). \tag{7}$$

In general, objects are judged differently by judges; however, if all judges express the same judgment, the model is no more viable ($\hat{p}_{ij}$ values of 1.00 and 0.00 would correspond to $-\Phi^{-1}(1 - \hat{p}_{ij})$ values of $\pm\infty$). A simplified approach for tackling this problem is associating values of $\hat{p}_{ij} \geq 0.977$ with $-\Phi^{-1}(1 - 0.977) = 1.995$ and values of $\hat{p}_{ij} \leq 0.023$ with $-\Phi^{-1}(1 - 0.023) = -1.995$. More sophisticated solutions to deal with this issue have been proposed (Edwards, 1957).

Extending the reasoning to all possible paired comparisons for which $m_{ij} \geq 1$ (i.e., at least one judge expresses his/her own judgment), the relevant $\hat{p}_{ij}$ values can be determined and the following system of equations can be constructed:

$$\begin{cases} \vdots \\ x_i - x_j + \Phi^{-1}\left(1 - \hat{p}_{ij}\right) = 0 \qquad \forall i, j : m_{ij} \geq 1. \\ \vdots \end{cases} \tag{8}$$

Since, the rank of the system is lower than the number (n) of unknowns of the problem (i.e., x_1, x_2, …, x_n) – and the system itself would be indeterminate (Thurstone, 1927) – the following conventional condition is introduced:

$$\sum_{i=1}^{n} x_i = 0 . \tag{9}$$

Eqs. 8 and 9 are then aggregated into a new system, which is *over-determined* (i.e., it has rank n while the total number of equations (q) is higher than n) and *linear* with respect to the unknowns:

$$\begin{cases} \begin{bmatrix} \vdots \\ x_i - x_j + \Phi^{-1}\left(1 - \hat{p}_{ij}\right) = 0 \qquad \forall i, j : m_{ij} \geq 1 \\ \vdots \end{bmatrix} \\ \sum_{i=1}^{n} x_i = 0 \end{cases} . \tag{10}$$

This system can be expressed in matrix form as:

$$\begin{cases} \vdots \\ \sum_{k=1}^{n} \left(a_{hk} \cdot x_k\right) - b_h = 0 \quad \forall h \in [0, q] \\ \vdots \end{cases} \quad \Rightarrow \quad \boldsymbol{A} \cdot \boldsymbol{X} - \boldsymbol{B} = \boldsymbol{0} , \tag{11}$$

$\boldsymbol{X} = [x_1, x_2, \ldots, x_n]^T \in R^{n \times 1}$ being the column vector containing the unknowns of the problem, a_{hk} being a generic element of matrix $\boldsymbol{A} \in R^{q \times n}$, and b_h being a generic element of vector $\boldsymbol{B} \in R^{n \times 1}$. For details on the construction of $\boldsymbol{A}$ and $\boldsymbol{B}$, see (Gulliksen, 1956).

In the case each judge expresses his/her judgment on the totality of the $C_2^n = n \cdot (n-2)/2$ paired comparisons, the system in Eq. 10 is "complete" – i.e., with $q = C_2^n + 1$ equations – and can be solved in a closed form as (Thurstone, 1927):

$$\hat{x}_j = \sum_{i=1}^{m} \Phi^{-1}\left(1 - \hat{p}_{ij}\right) \qquad \forall j . \tag{12}$$

The LCJ unfortunately has some limitations, including the following ones:

1. The response mode is relatively tedious for judges;
2. The LCJ results into an *interval* scaling, i.e., objects are defined on a scale with meaningful distance but arbitrary zero point (Thurstone, 1927; Roberts, 1979);
3. The solution can be determined only when the system of equations is "complete";
4. No uncertainty estimation is provided.

ZM-method

This technique has been proposed to overcome some of the limitations of the LCJ (Franceschini and Maisano, 2018). A significant drawback of the LCJ response mode is that paired comparisons can be tedious and complex to manage, due to the fact that much repetitious information is required from judges. This problem can be overcome asking each judge to formulate a *preference ordering*, i.e., a sequence of objects in order of preference (more preferred ones in the top positions and less preferred ones in the bottom ones).

Apart from regular objects (o_1, o_2, …, o_n), judges should include two *dummy* objects in their orderings: one (o_Z) corresponding to the *absence* of the attribute of interest and one (o_M) corresponding to the *maximum-imaginable* degree of the attribute, consistently with the current technological and socio-economic context (Franceschini and Maisano, 2018). When dealing with these special objects, two important requirements should be considered by judges:

1. o_Z should be positioned at the bottom of a preference ordering, i.e., there should not be any other object with preference lower than o_Z. In the case the attribute of another object is judged to be absent, that object will be considered indifferent to o_Z and positioned at the same hierarchical level.
2. o_M should be positioned at the top of a preference orderings, i.e., there should not be any other object with preference higher than o_M. In the case the attribute of another object is judged to be the maximum-imaginable, that object will be considered indifferent to o_M and positioned at the same hierarchical level.

Next, the preference orderings of judges can be turned into paired-comparison data (e.g., the four-object ordering $(o_3 \sim o_1) > o_2 > o_4$ is turned into the $C_2^4 = 6$ paired-comparison relationships: "o_1>o_2", "o_1~o_3", "o_1>o_4", "o_2<o_3", "o_2>o_4", and "o_3>o$_4$"; it can be noticed that this response mode forces judges to be *transitive* (e.g., if "o_1>o_2" and "o_2>o_4", then "o_1>o_4").

Next, the traditional LCJ can be applied to the resulting paired-comparison data and a scaling (x) of the objects can be determined (Eq. 12). Through the following transformation, the resulting scaling (x) is transformed into a new one (y), which is defined in the conventional range [0, 100]:

$$\hat{y}_i = \hat{y}_i\left(\hat{\boldsymbol{X}}\right) = 100 \cdot \frac{\hat{x}_i - \hat{x}_Z}{\hat{x}_M - \hat{x}_Z} \quad \forall i \,, \tag{13}$$

where: $\hat{x}_Z$ and $\hat{x}_M$ are the scale values of o_Z and o_M, resulting from the LCJ; $\hat{x}_i$ is the scale value of a generic *i*-th object, resulting from the LCJ; $\hat{y}_i$ is the scale value of a generic *i*-th object in the new scale *y*. This transformation can also be expressed in vector form as:

$$\hat{\boldsymbol{Y}} = \hat{\boldsymbol{Y}}\left(\hat{\boldsymbol{X}}\right) = \left[\hat{y}_1\left(\hat{\boldsymbol{X}}\right), \hat{y}_2\left(\hat{\boldsymbol{X}}\right), \ldots\right]^T, \tag{14}$$

being $\hat{\boldsymbol{Y}}$ a column vector whose components result from a system of *n* decoupled equations. Since scale *y* "inherits" the *interval* property from scale *x* and has a conventional zero point that corresponds to the absence of the attribute (i.e., $\hat{y}_Z$), it can be reasonably considered as a *ratio* scale, without any conceptually prohibited "promotion". We note that the two dummy objects, o_Z and o_M, are used to "anchor" the *x* scale to the *y* scale (Paruolo et al., 2013).

Although the *ZM*-technique simplifies the response mode and allows to obtain a ratio scaling, it still does not solve other relevant limitations of the traditional LCJ:

- The procedure is not applicable to the system in Eq. 10 when it is not "complete" (i.e., there is at least one (*i*, *j*) paired comparison for which $m_{ij} = 0$).
- It does not contemplate neither the variability of $\hat{p}_{ij}$ values, which are actually treated as deterministic parameters (not probabilistic ones), nor the "propagation" of this variability on the $\hat{\boldsymbol{X}}$ solution (and therefore on the "transformed" solution, $\hat{\boldsymbol{Y}}$).

In fact, since f_{ij} is determined considering a sample of m_{ij} paired comparisons (as illustrated in section "Thurstone's LCJ"), it will be distributed binomially; $\hat{p}_{ij}$ is the best estimator of p_{ij}, according to the information available. In formal terms:

$$f_{ij} \sim B[\mu_{f_{ij}} \approx m_{ij} \cdot \hat{p}_{ij}, \sigma^2_{f_{ij}} \approx m_{ij} \cdot \hat{p}_{ij} \cdot (1 - \hat{p}_{ij})], \tag{15}$$

In the hypothesis that $m_{ij} \cdot \hat{p}_{ij} \geq 5$, when $0 \leq \hat{p}_{ij} \leq 0.5$, or $m_{ij} \cdot \left(1 - \hat{p}_{ij}\right) \geq 5$, when $0.5 < \hat{p}_{ij} \leq 1$, the following approximations can be reasonably introduced (Ross, 2014):

$$\begin{aligned} f_{ij} &\sim N[\mu_{f_{ij}} \approx m_{ij} \cdot \hat{p}_{ij}, \sigma^2_{f_{ij}} \approx m_{ij} \cdot \hat{p}_{ij} \cdot (1 - \hat{p}_{ij})] \\ p_{ij} &\sim N\left[\mu_{p_{ij}} \approx \hat{p}_{ij}, \sigma^2_{p_{ij}} \approx \frac{\hat{p}_{ij} \cdot (1 - \hat{p}_{ij})}{m_{ij}}\right] \end{aligned}. \tag{16}$$

It is worth remarking that, even when all judges express their judgments for all the possible paired comparisons (i.e., $m_{ij} = m \ \forall i, j$), the variance of p_{ij} may change from one paired comparison to one other, as it also depends on the relevant $\hat{p}_{ij}$ value.

METHODOLOGY

Response-mode simplification

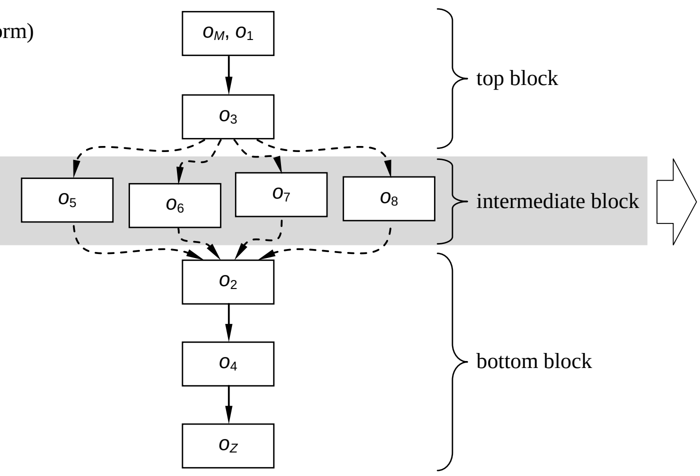
Although the formulation of preference orderings is less tedious and complex to manage than the direct formulation of paired-comparison relationships, it still may be problematic for some practical situations, e.g., asking judges to rank more than a handful of objects during a telephone or street interview may put a very high demand on their cognitive abilities (Harzing et al., 2009; Lenartowicz and Roth, 2001).

To further simplify the response mode, judges could formulate "incomplete" orderings of the more and/or less preferred objects only, neglecting the remaining ones. These orderings can be decomposed into three blocks: (i) a block including the *top* objects (i.e., the more preferred ones, plus o_M), (ii) a block including the *bottom* objects (i.e., the less preferred ones, plus o_Z), and (iii) a block including the *intermediate* objects. Surely the objects in the intermediate block will not be comparable to each other (i.e., it cannot be asserted that one object is more/less/equally preferred to one other), but their hierarchical level will be (1) lower than that of the objects in the top block and (2) higher than that of the objects in the bottom block. The resulting preference orderings can be classified as *partial* since – apart from the relationships of *strict preference* and *indifference* – they may also contain *incomparability* relationships among pairs of objects (Nederpelt and Kamareddine, 2004). Figure 2(a) contains a fictitious partial ordering of n = 10 (regular and dummy) objects, which is divided into the three afore-described blocks.

Any generic partial ordering can be translated into paired-comparison relationships. Among the $C_2^{n=10} = 45$ possible paired-comparison relationships in the example in Figure 2(b), thirty-nine are of *strict preference* (">" or "<") or *indifference* ("~"), while the remaining six are of incomparability ("||") and concern exclusively the elements in the intermediate block (o_5, o_6, o_7, o_8). We note that the objects in the top and bottom blocks are mutually ordered and translated into paired-comparison relationships of strict preference and indifference. An even more simplified response mode could be that one in which each judge merely identifies the more or less preferred objects, without ordering them; this other form of judgment can be translated into a partial ordering too, which also includes mutual relationships of incomparability among the objects in the top and bottom blocks.

(a) Partial preference ordering

(graphic form)



(analytic form) $(o_M \sim o_1) > o_3 > \{o_5 \parallel o_6 \parallel o_7 \parallel o_8\} > o_2 > o_4 > o_Z$

(b) Paired-comparison relationships

	o_Z	o_M	o_1	o_2	o_3	o_4	o_5	o_6	o_7	o_8
o_Z	-	<	<	<	<	<	<	<	<	<
o_M		-	~	>	>	>	>	>	>	>
o_1			-	>	>	>	>	>	>	>
o_2				-	<	>	<	<	<	<
o_3					-	>	>	>	>	>
o_4						-	<	<	<	<
o_5							-	$\parallel$	$\parallel$	$\parallel$
o_6								-	$\parallel$	$\parallel$
o_7									-	$\parallel$
o_8										-

Possible relationships:
">" and "<" → strict preference;
"~" → indifference;
"$\parallel$" → incomparibility.

Figure 2 – (a) Example of partial preference ordering with corresponding *top*, *intermediate* and *bottom* blocks; (b) the partial ordering is turned into paired-comparison relationships.

Returning to the general problem, all the (partial) preference orderings that have been formulated by m judges can be translated into a number of paired-comparison relationships. For each paired comparison, there will therefore be m_{ij} "usable" relationships for determining $\hat{p}_{ij}$. In fact, the (m_{ij}) relationships that contribute to the estimate of p_{ij} values are those of strict preference and indifference, while the remaining (m – m_{ij}) relationships of incomparability do not contribute to this estimate; regarding the example in Figure 2, m_{ij} = 45 – 6 = 39. In the case m_{ij} = 0, p_{ij} cannot be estimated.

GLS solution

In general, the system in Eq. 10 will not necessarily be "complete", as the number of equations (q) could be lower than $C_2^n + 1$ (i.e., for any paired comparison with m_{ij} = 0, no equation can be formulated) and therefore cannot be solved through the LCJ.

The literature dealt with the problem of solving such "incomplete" systems through the *Ordinary Least Squares* (OLS) method. For example, Gulliksen (1956) discusses some approximate numerical methods for the OLS solution formula to Eq. 11 (Kariya and Kurata, 2004; Ross, 2014):

$$\hat{\boldsymbol{X}} = \left(\boldsymbol{A}^T \cdot \boldsymbol{A}\right)^{-1} \cdot \boldsymbol{A}^T \cdot \boldsymbol{B}\,. \tag{17}$$

Also, it can be demonstrated that, in the case in which the equation system is "complete", the LCJ solution coincides with the OLS one – i.e., that one minimizing the sum of the squared residuals related to the equations in Eq. 11 (Gulliksen, 1956):

$$\sum_{h=1}^{q}\left[\sum_{k=1}^{n}\left(a_{hk}\cdot x_k\right)-b_h\right]^2, \tag{18}$$

n being the number of elements in $\hat{\boldsymbol{X}}$, and q being the total number of equations available. In general, the OLS solution is possible even for "incomplete" systems, as long as $q \geq n$; this condition is easily met in practice (Gulliksen, 1956).

Even though the OLS method provides an effective solution to the problem of interest, it does not provide any practical estimate of the uncertainty associated with the elements of $\hat{\boldsymbol{X}}$. In fact, although it is possible to calculate the covariance matrix of $\hat{\boldsymbol{X}}$ as:

$$\Sigma_{\boldsymbol{X}} = \left(\boldsymbol{A}^T \cdot \boldsymbol{A}\right)^{-1}, \tag{19}$$

it is of no practical use for this specific problem, as the uncertainties of the $\hat{\boldsymbol{X}}$ elements are identical and not affected by the real uncertainty of input data (i.e., $\hat{p}_{ij}$ values, see section "*ZM*-method") (Gulliksen, 1956). This limitation can be overcome using the *Generalized Least Squares* (GLS) method, which is more articulated than the OLS method as it includes several additional steps (see the qualitative representation in Figure 3).

The idea of applying the GLS to the problem of interest in the "incomplete" case had already been advanced several decades ago by Arbuckle and Nugent (1973), who contemplated this and other goodness-of-fit criteria, such as *maximum likelihood*. These techniques, however, have not been applied extensively, probably due to some computational constraints that are nowadays overcome. Additionally, the GLS solution proposed by Arbuckle and Nugent (1973) was combined with a "classic" response mode, based on the direct formulation of paired-comparison relationships.

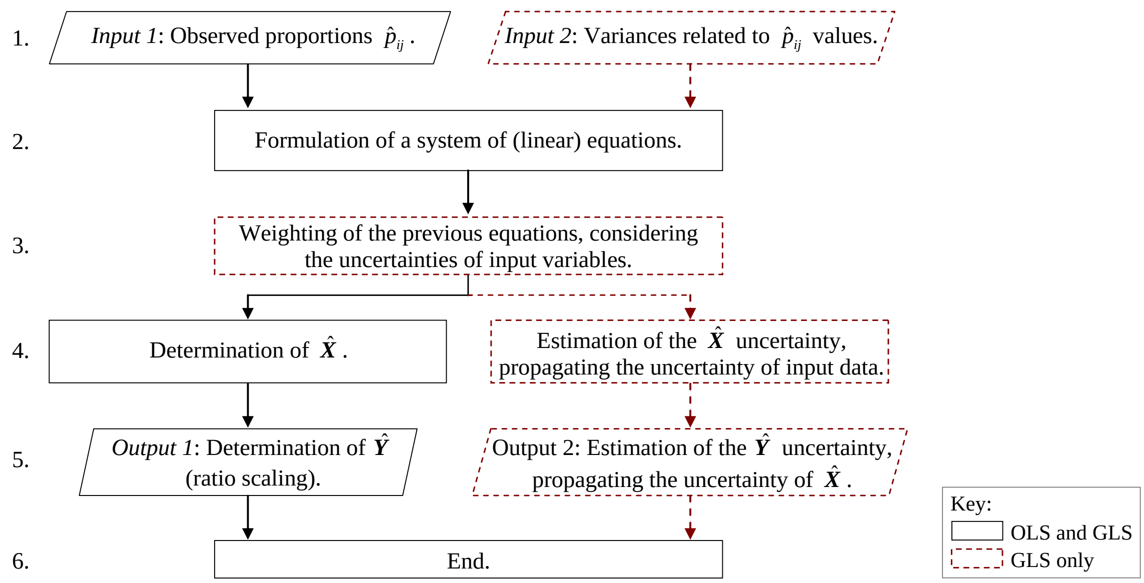


Figure 3 – Flow chart representing the main steps of the OLS and GLS solution to the problem of interest; it can be noticed that the GLS solution includes several additional steps (see dashed blocks) with respect to the OLS one.

From a technical point of view, the GLS method allows obtaining a solution that minimizes the weighted sum of the squared residuals related to the equations in Eq. 11, i.e.:

$$\sum_{h=1}^{q} w_h \cdot \left[\sum_{k=1}^{n} \left(a_{hk} \cdot x_k \right) - b_h \right]^2 , \tag{20}$$

in which weights (w_h) take into account the uncertainty in the $\hat{p}_{ij}$ values. It can be demonstrated that, for a generic equation related to a generic ij-th paired comparison: $w_h = \left[\frac{\partial \Phi^{-1}\left(1-\hat{p}_{ij}\right)}{\partial \hat{p}_{ij}} \right]^2 \Big/ \sigma^2_{\hat{p}_{ij}}$ (Arbuckle and Nugent, 1973).

Next, weights are aggregated into a (squared) matrix $\boldsymbol{W}$, whose construction is illustrated in the “Appendix” section, and $\boldsymbol{X}$ can be estimated as:

$$\hat{\boldsymbol{X}} = \left(\boldsymbol{A}^T \cdot \boldsymbol{W} \cdot \boldsymbol{A} \right)^{-1} \cdot \boldsymbol{A}^T \cdot \boldsymbol{W} \cdot \boldsymbol{B} . \tag{21}$$

Combining Eqs. 21 and 14, the final (ratio) scaling $\hat{\boldsymbol{Y}}$ can be obtained as:

$$\hat{\boldsymbol{Y}} = \hat{\boldsymbol{Y}}[\hat{\boldsymbol{X}}] = \hat{\boldsymbol{Y}}[(\boldsymbol{A}^T \cdot \boldsymbol{W} \cdot \boldsymbol{A})^{-1} \cdot \boldsymbol{A}^T \cdot \boldsymbol{W} \cdot \boldsymbol{B}] . \tag{22}$$

Next, the uncertainty related to the elements in $\hat{\boldsymbol{Y}} = [\hat{y}_1, \hat{y}_2, \cdots]^T \in R^{n \times 1}$ can be determined by applying the relationship:

$$\Sigma_{\boldsymbol{Y}} = \boldsymbol{J}_{\hat{\boldsymbol{X}}} \cdot [(\boldsymbol{A}^T \cdot \boldsymbol{W} \cdot \boldsymbol{A})^{-1}] \cdot \boldsymbol{J}^T_{\hat{\boldsymbol{X}}} . \tag{23}$$

where $\boldsymbol{J}_{\hat{\boldsymbol{X}}} \in R^{(q-1)\times(q-1)}$ is a Jacobian matrix containing the partial derivatives related to the equations of the system in Eq. 14, with respect to the elements of $\hat{\boldsymbol{X}}$. Assuming that the $p_{i,j}$ and $\hat{y}_i$ values are approximately normally distributed, a 95% confidence interval related to each $\hat{y}_i$ value can be computed as:

$$\hat{y}_i \pm U_{\hat{y}_i} = \hat{y}_i \pm 2 \cdot \sigma_{\hat{y}_i} \quad \forall i, \tag{24}$$

$U_{\hat{y}_i}$ being the so-called *expanded uncertainty* of $\hat{y}_i$ with a coverage factor k = 2 and $\sigma_{\hat{y}_i} = \sqrt{\Sigma_{\boldsymbol{Y},(i,i)}}$ (JCGM 100:2008, 2008).

APPLICATION EXAMPLE

The proposed technique is applied to the design of a civilian aircraft seat. The goal is to prioritize the customer requirements (CRs) in Table 1 (i.e., objects), according to their importance (i.e., attribute) for m = 20 regular air passengers (i.e., judges).

Table 2 contains m "complete" linear orderings by judges, assuming that they have no difficulty in managing both the regular and dummy objects. These orderings are then translated into a number of paired-comparison relationships (i.e., $C_2^{12} = 66$ for each preference ordering, resulting in total 66·20 =1320 paired-comparison relationships) and the LCJ is applied, producing the scaling in Table 5(a) (see also the graphical representation in Figure 5). These results are already referred to the conventional scale (y), which is included in the range [0, 100].

Table 1 – List of the major CRs related to an aircraft seat, from the perspective of passengers.

Abbr.	**Description**
o_1	Comfortable (does not give you back ache)
o_2	Enough leg room
o_3	Comfortable when you recline
o_4	Does not hit person behind when you recline
o_5	Comfortable seat belt
o_6	Seat belt feels safe
o_7	Arm rests not too narrow
o_8	Arm rest folds right away
o_9	Does not make you sweat
o_{10}	Does not soak up a spilt drink
o_{11}	Hole in tray for coffee cup
o_{12}	Magazines can be easily removed from rack

Table 2 – Linear (or "complete") preference orderings used in the application example.

Judges	Linear preference orderings
j_1	$o_M > (o_1 \sim o_2) > (o_5 \sim o_6 \sim o_7) > o_3 > o_4 > (o_{10} \sim o_8) > (o_{11} \sim o_9) > (o_Z \sim o_{12})$
j_2	$(o_1 \sim o_5 \sim o_7 \sim o_M) > (o_9 \sim o_6) > (o_2 \sim o_{11} \sim o_8) > (o_4 \sim o_{12} \sim o_{10}) > o_3 > o_Z$
j_3	$(o_1 \sim o_M) > (o_3 \sim o_2) > (o_6 \sim o_5) > o_7 > (o_8 \sim o_9 \sim o_4) > (o_{11} \sim o_{12} \sim o_Z \sim o_{10})$
j_4	$(o_1 \sim o_2 \sim o_7 \sim o_M) > (o_3 \sim o_5) > o_6 > (o_8 \sim o_9 \sim o_{10}) > (o_{11} \sim o_{12}) > o_4 > o_Z$
j_5	$(o_1 \sim o_2 \sim o_5 \sim o_M) > (o_3 \sim o_6 \sim o_9 \sim o_4) > (o_7 \sim o_8) > (o_{11} \sim o_{12} \sim o_Z \sim o_{10})$
j_6	$o_M > (o_1 \sim o_5 \sim o_6) > o_7 > (o_2 \sim o_9 \sim o_3) > (o_{11} \sim o_8) > (o_4 \sim o_{10}) > (o_Z \sim o_{12})$
j_7	$(o_2 \sim o_7 \sim o_M) > o_1 > (o_5 \sim o_8 \sim o_6) > (o_9 \sim o_{10} \sim o_3) > o_4 > (o_{12} \sim o_Z \sim o_{11})$
j_8	$(o_1 \sim o_5 \sim o_M) > (o_6 \sim o_7 \sim o_9 \sim o_{12} \sim o_2) > (o_8 \sim o_{11}) > (o_3 \sim o_4) > (o_Z \sim o_{10})$
j_9	$(o_1 \sim o_4 \sim o_M) > (o_5 \sim o_7 \sim o_9) > o_2 > o_6 > (o_{10} \sim o_8) > (o_{11} \sim o_{12} \sim o_3) > o_Z$
j_{10}	$(o_2 \sim o_5 \sim o_6 \sim o_M) > o_7 > o_1 > o_3 > o_{11} > o_9 > (o_8 \sim o_{10}) > (o_{12} \sim o_Z \sim o_4)$
j_{11}	$(o_1 \sim o_M) > (o_6 \sim o_2) > (o_7 \sim o_5) > o_3 > o_4 > o_9 > o_{11} > o_{12} > (o_{10} \sim o_Z \sim o_8)$
j_{12}	$(o_2 \sim o_7 \sim o_M) > o_1 > (o_9 \sim o_3) > (o_8 \sim o_6 \sim o_4) > o_5 > (o_{11} \sim o_{12} \sim o_Z \sim o_{10})$
j_{13}	$(o_1 \sim o_2 \sim o_5 \sim o_8 \sim o_M) > (o_7 \sim o_3 \sim o_6) > (o_9 \sim o_{11} \sim o_4) > (o_{12} \sim o_Z \sim o_{10})$
j_{14}	$(o_2 \sim o_5 \sim o_6 \sim o_M) > o_1 > o_3 > o_9 > o_7 > o_4 > (o_{10} \sim o_{11}) > (o_{12} \sim o_Z \sim o_8)$
j_{15}	$(o_2 \sim o_6 \sim o_7 \sim o_M) > o_1 > o_9 > o_8 > (o_{11} \sim o_{12} \sim o_5) > o_3 > o_4 > (o_Z \sim o_{10})$
j_{16}	$(o_1 \sim o_M) > (o_2 \sim o_6) > o_7 > o_9 > o_5 > (o_4 \sim o_8) > o_{11} > o_3 > (o_{12} \sim o_Z \sim o_{10})$
j_{17}	$(o_1 \sim o_2 \sim o_M) > (o_7 \sim o_5) > (o_8 \sim o_9 \sim o_{10} \sim o_4) > (o_6 \sim o_{11} \sim o_{12}) > (o_Z \sim o_3)$
j_{18}	$(o_1 \sim o_2 \sim o_3 \sim o_M) > o_9 > (o_7 \sim o_8 \sim o_4 \sim o_5) > o_{10} > (o_{11} \sim o_6) > (o_Z \sim o_{12})$
j_{19}	$(o_1 \sim o_2 \sim o_6 \sim o_9 \sim o_M) > (o_3 \sim o_7 \sim o_4 \sim o_5) > o_8 > o_{11} > (o_{12} \sim o_{10}) > o_Z$
j_{20}	$o_M > (o_1 \sim o_6) > o_7 > (o_5 \sim o_9 \sim o_2) > (o_3 \sim o_{11} \sim o_8) > (o_4 \sim o_{12}) > o_{10} > o_Z$

Total no. of usable paired-comparison relationships: 1320 of 1320;
o_1 to o_{12} are the regular objects, while o_Z to o_M are the dummy objects;
">" and "~" respectively depict the *strict preference* and *indifference* relationships;
$(o_i \sim o_j \sim \ldots)$ is a generic block containing indifferent objects.

Table 5(a) also shows that, consistently with the considerations in section "Methodology", the results of the LCJ are identical to those obtained by applying the OLS method to the same orderings. On the other hand, the application of the GLS method produces a very close – although non-identical – result. The difference stems from the fact that – unlike LCJ and OLS – the GLS takes into account the uncertainties related to $\hat{p}_{ij}$ values. The GLS solution is therefore superior from both a conceptual and practical point of view.

To study the effectiveness of the GLS in the presence of partial orderings, we have intentionally "degraded" the linear orderings in Table 2, replacing some of the relationships of strict preference (">" and "<") and indifference ("~"), with incomparability relationships ("||"). Precisely, two types of partial orderings have been generated according to the following "degradation criteria" (see also the example in Figure 4):

Type-t&b preference orderings, in which the relationships between the *t* more preferred (top) objects – and any other tied object – and those between the *b* less preferred (bottom) objects – and any other tied object – have been preserved ("*t&b*" stands for "top and bottom"). The remaining objects are allocated at an intermediate hierarchical level, which is certainly lower than the top block and higher than the bottom block.

Type-t preference orderings, in which the relationships between the *t* more preferred (top) objects – and any other tied object – have been preserved. The remaining objects are allocated at a lower hierarchical level, with mutual relationships of incomparability. In this case, the bottom block is empty.

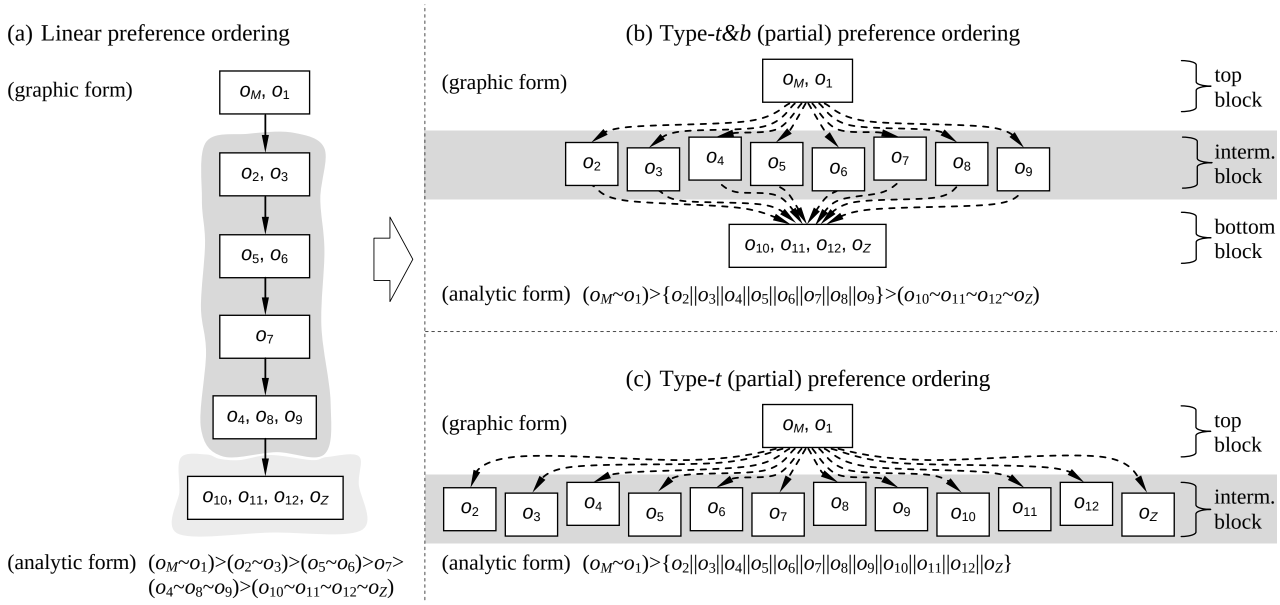


Figure 4 – Example of degradation of the linear preference ordering by j_5 (see Table 5) into a type-*t&b* and type-*t* partial preference ordering. In this case, $t = b = 1$.

Table 3 and Table 4 report the resulting type-*t&b* and type-*t* orderings, which are obtained by degrading the linear orderings in Table 2. In this case, the "level of degradation" is significant since $t = b = 1$; as a rough indicator of this level, we can consider the portion of *usable* paired-comparison relationships that can be obtained from the resulting partial preference orderings: i.e., 1150 out of 1320 for type-*t&b* orderings and 726 out of 1320 for type-*t* orderings.

Table 5 and Figure 5 contain the results of the application of the LCJ, OLS and GLS (where applicable) to the paired-comparison relationships that result from the preference orderings in Table 2, Table 3 and Table 4. In all cases, the resulting (x) scaling has been turned into a (y) scaling, through the transformation in Eq. 13.

The GLS results that are obtained for linear preference orderings (in Table 5(a)) can be used as "gold standard" to evaluate the goodness of the GLS results for degraded (partial) orderings. As for type-*t&b* (partial) orderings, results (in Table 5(b) and Figure 5) are – quite surprisingly – very close to those related to linear orderings, both in terms of accuracy and dispersion. As for type-*t* (partial) orderings, results (in Table 5(c) and Figure 5) worsen considerably, especially for the less preferred objects (see the very wide uncertainty bands). This is probably due by the relatively small amount of usable paired-comparison relationships that concern the less preferred objects.

Table 3 – Type-*t&b* (partial) preference orderings that are obtained by "degrading" the linear orderings in Table 2; both *t* and *b* values have been set to 1.

Judges	Type-*t&b* (partial) preference orderings
j_1	$o_M > \{o_1 \parallel o_2 \parallel o_5 \parallel o_6 \parallel o_7 \parallel o_3 \parallel o_4 \parallel o_{10} \parallel o_8 \parallel o_{11} \parallel o_9\} > (o_Z \sim o_{12})$
j_2	$(o_1 \sim o_5 \sim o_7 \sim o_M) > \{o_9 \parallel o_6 \parallel o_2 \parallel o_{11} \parallel o_8 \parallel o_4 \parallel o_{12} \parallel o_{10} \parallel o_3\} > o_Z$
j_3	$(o_1 \sim o_M) > \{o_3 \parallel o_2 \parallel o_6 \parallel o_5 \parallel o_7 \parallel o_8 \parallel o_9 \parallel o_4\} > (o_{11} \sim o_{12} \sim o_Z \sim o_{10})$
j_4	$(o_1 \sim o_2 \sim o_7 \sim o_M) > \{o_3 \parallel o_5 \parallel o_6 \parallel o_8 \parallel o_9 \parallel o_{10} \parallel o_{11} \parallel o_{12} \parallel o_4\} > o_Z$
j_5	$(o_1 \sim o_2 \sim o_5 \sim o_M) > \{o_3 \parallel o_6 \parallel o_9 \parallel o_4 \parallel o_7 \parallel o_8\} > (o_{11} \sim o_{12} \sim o_Z \sim o_{10})$
j_6	$o_M > \{o_1 \parallel o_5 \parallel o_6 \parallel o_7 \parallel o_2 \parallel o_9 \parallel o_3 \parallel o_{11} \parallel o_8 \parallel o_4 \parallel o_{10}\} > (o_Z \sim o_{12})$
j_7	$(o_2 \sim o_7 \sim o_M) > \{o_1 \parallel o_5 \parallel o_8 \parallel o_6 \parallel o_9 \parallel o_{10} \parallel o_3 \parallel o_4\} > (o_{12} \sim o_Z \sim o_{11})$
j_8	$(o_1 \sim o_5 \sim o_M) > \{o_6 \parallel o_7 \parallel o_9 \parallel o_{12} \parallel o_2 \parallel o_8 \parallel o_{11} \parallel o_3 \parallel o_4\} > (o_Z \sim o_{10})$
j_9	$(o_1 \sim o_4 \sim o_M) > \{o_5 \parallel o_7 \parallel o_9 \parallel o_2 \parallel o_6 \parallel o_{10} \parallel o_8 \parallel o_{11} \parallel o_{12} \parallel o_3\} > o_Z$
j_{10}	$(o_2 \sim o_5 \sim o_6 \sim o_M) > \{o_7 \parallel o_1 \parallel o_3 \parallel o_{11} \parallel o_9 \parallel o_8 \parallel o_{10}\} > (o_{12} \sim o_Z \sim o_4)$
j_{11}	$(o_1 \sim o_M) > \{o_6 \parallel o_2 \parallel o_7 \parallel o_5 \parallel o_3 \parallel o_4 \parallel o_9 \parallel o_{11} \parallel o_{12}\} > (o_{10} \sim o_Z \sim o_8)$
j_{12}	$(o_2 \sim o_7 \sim o_M) > \{o_1 \parallel o_9 \parallel o_3 \parallel o_8 \parallel o_6 \parallel o_4 \parallel o_5\} > (o_{11} \sim o_{12} \sim o_Z \sim o_{10})$
j_{13}	$(o_1 \sim o_2 \sim o_5 \sim o_8 \sim o_M) > \{o_7 \parallel o_3 \parallel o_6 \parallel o_9 \parallel o_{11} \parallel o_4\} > (o_{12} \sim o_Z \sim o_{10})$
j_{14}	$(o_2 \sim o_5 \sim o_6 \sim o_M) > \{o_1 \parallel o_3 \parallel o_9 \parallel o_7 \parallel o_4 \parallel o_{10} \parallel o_{11}\} > (o_{12} \sim o_Z \sim o_8)$
j_{15}	$(o_2 \sim o_6 \sim o_7 \sim o_M) > \{o_1 \parallel o_9 \parallel o_8 \parallel o_{11} \parallel o_{12} \parallel o_5 \parallel o_3 \parallel o_4\} > (o_Z \sim o_{10})$
j_{16}	$(o_1 \sim o_M) > \{o_2 \parallel o_6 \parallel o_7 \parallel o_9 \parallel o_5 \parallel o_4 \parallel o_8 \parallel o_{11} \parallel o_3\} > (o_{12} \sim o_Z \sim o_{10})$
j_{17}	$(o_1 \sim o_2 \sim o_M) > \{o_7 \parallel o_5 \parallel o_8 \parallel o_9 \parallel o_{10} \parallel o_4 \parallel o_6 \parallel o_{11} \parallel o_{12}\} > (o_Z \sim o_3)$
j_{18}	$(o_1 \sim o_2 \sim o_3 \sim o_M) > \{o_9 \parallel o_7 \parallel o_8 \parallel o_4 \parallel o_5 \parallel o_{10} \parallel o_{11} \parallel o_6\} > (o_Z \sim o_{12})$
j_{19}	$(o_1 \sim o_2 \sim o_6 \sim o_9 \sim o_M) > \{o_3 \parallel o_7 \parallel o_4 \parallel o_5 \parallel o_8 \parallel o_{11} \parallel o_{12} \parallel o_{10}\} > o_Z$
j_{20}	$o_M > \{o_1 \parallel o_6 \parallel o_7 \parallel o_5 \parallel o_9 \parallel o_2 \parallel o_3 \parallel o_{11} \parallel o_8 \parallel o_4 \parallel o_{12} \parallel o_{10}\} > o_Z$

Total no. of usable paired-comparison relationships: 1150 of 1320;
o_1 to o_{12} are the regular objects, while o_Z to o_M are the dummy objects;
">", "~" and "||" respectively depict the *strict preference*, *indifference* and *incomparability* relationships;
$\{o_i \parallel o_j \parallel \ldots\}$ is a generic block containing incomparable objects;
$(o_i \sim o_j \sim \ldots)$ is a generic block containing indifferent objects.

Table 4 – Type-*t* (partial) preference orderings that are obtained by "degrading" the linear orderings in Table 2; *t* values have been set to 1.

Judges	Type-*t* (partial) preference orderings
j_1	$o_M > \{o_1 \parallel o_2 \parallel o_5 \parallel o_6 \parallel o_7 \parallel o_3 \parallel o_4 \parallel o_{10} \parallel o_8 \parallel o_{11} \parallel o_9 \parallel o_Z \parallel o_{12}\}$
j_2	$(o_1 \sim o_5 \sim o_7 \sim o_M) > \{o_9 \parallel o_6 \parallel o_2 \parallel o_{11} \parallel o_8 \parallel o_4 \parallel o_{12} \parallel o_{10} \parallel o_3 \parallel o_Z\}$
j_3	$(o_1 \sim o_M) > \{o_3 \parallel o_2 \parallel o_6 \parallel o_5 \parallel o_7 \parallel o_8 \parallel o_9 \parallel o_4 \parallel o_{11} \parallel o_{12} \parallel o_Z \parallel o_{10}\}$
j_4	$(o_1 \sim o_2 \sim o_7 \sim o_M) > \{o_3 \parallel o_5 \parallel o_6 \parallel o_8 \parallel o_9 \parallel o_{10} \parallel o_{11} \parallel o_{12} \parallel o_4 \parallel o_Z\}$
j_5	$(o_1 \sim o_2 \sim o_5 \sim o_M) > \{o_3 \parallel o_6 \parallel o_9 \parallel o_4 \parallel o_7 \parallel o_8 \parallel o_{11} \parallel o_{12} \parallel o_Z \parallel o_{10}\}$
j_6	$o_M > \{o_1 \parallel o_5 \parallel o_6 \parallel o_7 \parallel o_2 \parallel o_9 \parallel o_3 \parallel o_{11} \parallel o_8 \parallel o_4 \parallel o_{10} \parallel o_Z \parallel o_{12}\}$
j_7	$(o_2 \sim o_7 \sim o_M) > \{o_1 \parallel o_5 \parallel o_8 \parallel o_6 \parallel o_9 \parallel o_{10} \parallel o_3 \parallel o_4 \parallel o_{12} \parallel o_Z \parallel o_{11}\}$
j_8	$(o_1 \sim o_5 \sim o_M) > \{o_6 \parallel o_7 \parallel o_9 \parallel o_{12} \parallel o_2 \parallel o_8 \parallel o_{11} \parallel o_3 \parallel o_4 \parallel o_Z \parallel o_{10}\}$
j_9	$(o_1 \sim o_4 \sim o_M) > \{o_5 \parallel o_7 \parallel o_9 \parallel o_2 \parallel o_6 \parallel o_{10} \parallel o_8 \parallel o_{11} \parallel o_{12} \parallel o_3 \parallel o_Z\}$
j_{10}	$(o_2 \sim o_5 \sim o_6 \sim o_M) > \{o_7 \parallel o_1 \parallel o_3 \parallel o_{11} \parallel o_9 \parallel o_8 \parallel o_{10} \parallel o_{12} \parallel o_Z \parallel o_4\}$
j_{11}	$(o_1 \sim o_M) > \{o_6 \parallel o_2 \parallel o_7 \parallel o_5 \parallel o_3 \parallel o_4 \parallel o_9 \parallel o_{11} \parallel o_{12} \parallel o_{10} \parallel o_Z \parallel o_8\}$
j_{12}	$(o_2 \sim o_7 \sim o_M) > \{o_1 \parallel o_9 \parallel o_3 \parallel o_8 \parallel o_6 \parallel o_4 \parallel o_5 \parallel o_{11} \parallel o_{12} \parallel o_Z \parallel o_{10}\}$
j_{13}	$(o_1 \sim o_2 \sim o_5 \sim o_8 \sim o_M) > \{o_7 \parallel o_3 \parallel o_6 \parallel o_9 \parallel o_{11} \parallel o_4 \parallel o_{12} \parallel o_Z \parallel o_{10}\}$
j_{14}	$(o_2 \sim o_5 \sim o_6 \sim o_M) > \{o_1 \parallel o_3 \parallel o_9 \parallel o_7 \parallel o_4 \parallel o_{10} \parallel o_{11} \parallel o_{12} \parallel o_Z \parallel o_8\}$
j_{15}	$(o_2 \sim o_6 \sim o_7 \sim o_M) > \{o_1 \parallel o_9 \parallel o_8 \parallel o_{11} \parallel o_{12} \parallel o_5 \parallel o_3 \parallel o_4 \parallel o_Z \parallel o_{10}\}$
j_{16}	$(o_1 \sim o_M) > \{o_2 \parallel o_6 \parallel o_7 \parallel o_9 \parallel o_5 \parallel o_4 \parallel o_8 \parallel o_{11} \parallel o_3 \parallel o_{12} \parallel o_Z \parallel o_{10}\}$
j_{17}	$(o_1 \sim o_2 \sim o_M) > \{o_7 \parallel o_5 \parallel o_8 \parallel o_9 \parallel o_{10} \parallel o_4 \parallel o_6 \parallel o_{11} \parallel o_{12} \parallel o_Z \parallel o_3\}$
j_{18}	$(o_1 \sim o_2 \sim o_3 \sim o_M) > \{o_9 \parallel o_7 \parallel o_8 \parallel o_4 \parallel o_5 \parallel o_{10} \parallel o_{11} \parallel o_6 \parallel o_Z \parallel o_{12}\}$
j_{19}	$(o_1 \sim o_2 \sim o_6 \sim o_9 \sim o_M) > \{o_3 \parallel o_7 \parallel o_4 \parallel o_5 \parallel o_8 \parallel o_{11} \parallel o_{12} \parallel o_{10} \parallel o_Z\}$
j_{20}	$o_M > \{o_1 \parallel o_6 \parallel o_7 \parallel o_5 \parallel o_9 \parallel o_2 \parallel o_3 \parallel o_{11} \parallel o_8 \parallel o_4 \parallel o_{12} \parallel o_{10} \parallel o_Z\}$

Total no. of usable paired-comparison relationships: 726 of 1320;
o_1 to o_{12} are the regular objects, while o_Z to o_M are the dummy objects;
">", "~" and "||" respectively depict the *strict preference*, *indifference* and *incomparability* relationships;
$\{o_i \parallel o_j \parallel \ldots\}$ is a generic block containing incomparable objects;
$(o_i \sim o_j \sim \ldots)$ is a generic block containing indifferent objects.

Table 5 – Results of the application of several techniques (i.e., LCJ, OLS and GLS) to the orderings in Table 2; GLS solutions are associated with relevant extended uncertainties (according to Eq. 24).

Objects	**(a) Linear/complete orderings**		**(b) type-*t&b* (partial)**	**(b) type-*t* (partial)**
	LCJ=OLS	GLS	GLS	GLS
o_Z	0.0	0.0 ±7.2	0.0 ±7.2	0.0 ±24.1
o_M	100.0	100.0 ±6.7	100.0 ±6.7	100.0 ±8.8
o_1	93.6	90.2 ±8.7	87.8 ±8.9	84.2 ±12.3
o_2	85.1	83.4 ±8.1	86.5 ±9.0	82.6 ±12.6
o_3	46.1	47.2 ±7.6	46.0 ±10.6	21.8 ±26.3
o_4	37.7	37.7 ±7.9	47.4 ±10.6	23.4 ±25.7
o_5	73.7	71.1 ±7.7	73.9 ±9.2	64.5 ±15.0
o_6	68.5	67.7 ±7.5	67.0 ±9.7	54.3 ±17.3
o_7	73.6	70.5 ±7.7	70.9 ±9.3	59.6 ±15.9
o_8	40.3	41.6 ±7.8	40.9 ±10.1	20.6 ±26.8
o_9	55.3	55.1 ±7.8	50.5 ±11.9	20.9 ±26.7
o_{10}	19.3	20.9 ±8.3	17.7 ±9.9	0.0 ±36.2
o_{11}	23.7	26.9 ±8.3	29.0 ±10.6	0.0 ±36.2
o_{12}	13.4	14.8 ±8.7	11.9 ±9.8	0.0 ±36.2

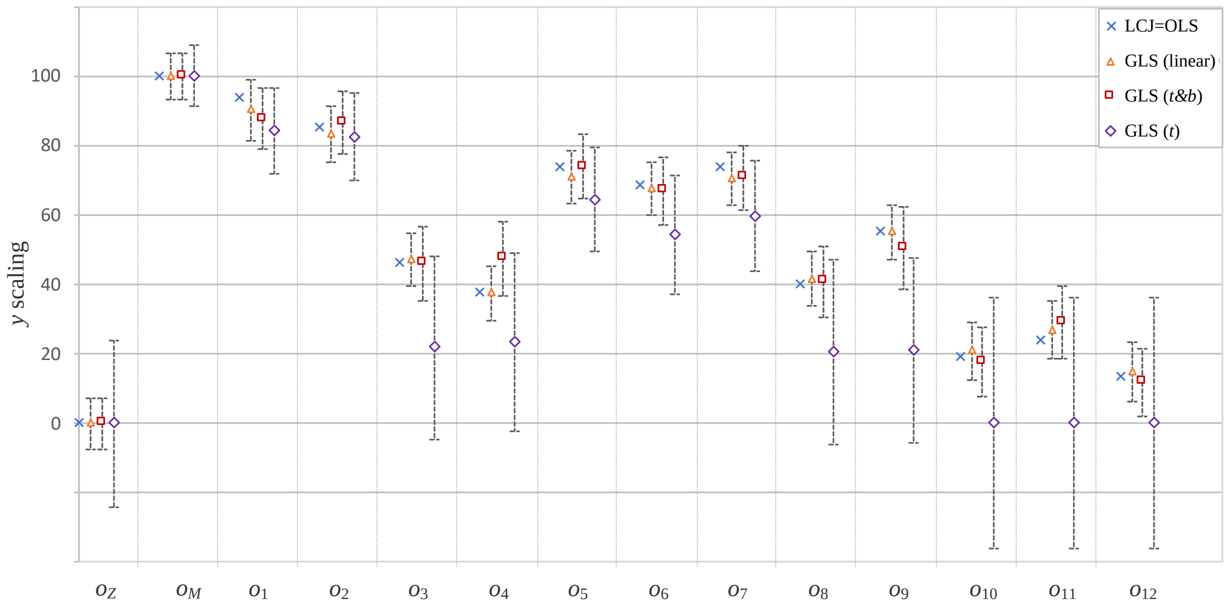


Figure 5 – Graphical representation of the results in Table 5.

These preliminary results have a significant practical implication: even when adopting a simplified response mode like type-*t&b* partial orderings, relatively accurate results can be obtained. On the contrary, the adoption of type-*t* partial orderings produces acceptable results only for the more preferred objects.

CONCLUSIONS

The proposed technique allows to fuse multiple *partial* preference orderings into a ratio scaling with a relevant uncertainty estimation. Apart from regular objects, these orderings will also include two dummy objects, to univocally represent the zero and the maximum-possible degree of the attribute on a conventional ratio scale. This technique represents an important improvement over the technique proposed in (Franceschini and Maisano, 2018), whose application is limited to *linear* orderings exclusively.

From a technical point of view, the proposed technique is based on the formulation of a system of equations – borrowing the underlying postulates/assumptions of the LCJ – and its solution through the GLS method. From a practical point of view, the new response mode makes the technique more versatile and adaptable to a variety of contexts in which the concentration effort of judges cannot realistically be too high (e.g., telephone or street interviews).

Based on the above considerations, the proposed technique reasonably represents an appropriate response to the previously formulated research question: "How could the *ZM*-technique be modified, so as to (1) make the response more user-friendly and reliable and (2) determine a (statistically sound) estimate of the uncertainty related to the solution?".

Preliminary results show that the technique is largely automatable, computationally efficient and provides relatively accurate results, even when preference orderings are significantly "incomplete". Additionally, it seems that much better results can be obtained when partial orderings contain both the more and the less preferred elements (i.e., type-*t&b* orderings).

Regarding the future, we will test the new technique in a more organic way. Precisely, we plan to investigate the accuracy of the solution depending on various factors, such as (i) "level of degradation" of the (partial) preference orderings, (ii) number of judges, (iii) number of objects, (iv) degree of agreement between judges, etc.

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APPENDIX

This section illustrates in more detail the application of the GLS method to the problem of interest. From an operational point of view, the GLS requires the definition of a (squared) weight matrix (***W***), which encapsulates the uncertainty related to the equations of the system. A practical way to define ***W*** is to apply the *Multivariate Law of Propagation of Uncertainty* (MLPU) to the system in Eq. 10, referring to the input variables affected by uncertainty (Kariya and Kurata, 2004); these variables can be collected in the column vector $\boldsymbol{\xi}$. Precisely, ***W*** can be determined propagating the uncertainty of the elements in $\boldsymbol{\xi}$ to the equations of the system:

$$\boldsymbol{W} = \left[\boldsymbol{J}_{\xi} \cdot \Sigma_{\xi} \cdot \boldsymbol{J}_{\xi}^{T}\right]^{-1}, \tag{A1}$$

where $\boldsymbol{J}_{\xi}$ is the Jacobian matrix containing the partial derivatives of the first members of Eq. 10, with respect to the elements in $\boldsymbol{\xi}$, and $\boldsymbol{\Sigma}_{\xi}$ is the covariance matrix of $\boldsymbol{\xi}$.

By applying the GLS method to the system in Eq. 11, a final estimate of ***X*** can be obtained as (Kariya and Kurata, 2004):

$$\hat{\boldsymbol{X}} = \left(\boldsymbol{A}^{T} \cdot \boldsymbol{W} \cdot \boldsymbol{A}\right)^{-1} \cdot \boldsymbol{A}^{T} \cdot \boldsymbol{W} \cdot \boldsymbol{B}. \tag{A2}$$

The uncertainty of the solution can be estimated through a covariance matrix $\Sigma_{\boldsymbol{X}}$, which can be obtained by applying the following relationship:

$$\Sigma_{\boldsymbol{X}} = \left(\boldsymbol{A}^{T} \cdot \boldsymbol{W} \cdot \boldsymbol{A}\right)^{-1}. \tag{A3}$$

$\Sigma_{\boldsymbol{X}}$ – unlike the homologous matrix resulting from the OLS method (in Eq. 19) – is of considerable practical use, since it is obtained by propagating the real uncertainty of input data.

Focussing on the problem of interest, the vector containing the input variables affected by uncertainty is $\boldsymbol{\xi} = [\ldots,\ p_{ij},\ \ldots]^{T} \in R^{(q-1)\times 1}$. On the other hand, the partial derivatives in the

Jacobian matrix $\boldsymbol{J}_{\xi} \in R^{(q-1)\times(q-1)}$ can be determined in a closed form, by approximating terms $\Phi^{-1}(1-\hat{p}_{ij})$ (see Eq. 10) through the following formula (Aludaat and Alodat, 2008):

$$\Phi^{-1}(1-\hat{p}_{i,j}) \approx k\sqrt{\frac{-\ln[1-(1-2\cdot\hat{p}_{i,j})^2]}{\sqrt{\pi/8}}} \qquad \begin{cases} 0 \le \hat{p}_{i,j} \le 0.5 \rightarrow k=1 \\ 0.5 < \hat{p}_{i,j} \le 1 \rightarrow k=-1 \end{cases}, \tag{A4}$$

from which:

$$\begin{aligned} &\frac{\partial\left[\Phi^{-1}(1-\hat{p}_{i,j})\right]}{\partial\hat{p}_{i,j}} \approx \left|\frac{\sqrt{2}\cdot(2\cdot\hat{p}_{i,j}-1)}{\sqrt{-2\cdot\sqrt{2\cdot\pi}}\cdot\ln(-4\cdot\hat{p}_{i,j}^2+4\cdot\hat{p}_{i,j})\cdot\hat{p}_{i,j}\cdot\left(1-\hat{p}_{i,j}\right)}\right| && \text{for } \hat{p}_{i,j} \ne 0.5 \\ &\frac{\partial\left[\Phi^{-1}(1-\hat{p}_{i,j})\right]}{\partial\hat{p}_{i,j}} \approx 2.506628 && \text{for } \hat{p}_{i,j} = 0.5 \end{aligned}. \tag{A5}$$

The matrix $\boldsymbol{\Sigma}_{\xi} \in R^{(q-1)\times(q-1)}$ diagonally contains the variances related to the input variables, i.e., $\hat{p}_{ij}$ terms:

$$\sigma^2_{p_{ij}} = \frac{\hat{p}_{ij}\cdot(1-\hat{p}_{ij})}{m_{ij}}. \tag{A6}$$

The relevant covariances can be neglected, upon the reasonable assumption that the estimates of different p_{ij} values are (statistically) independent from each other.

Next, it is possible to determine the matrix $\boldsymbol{W}$ (Eq. A1) and, subsequently, $\hat{\boldsymbol{X}}$ (Eq. A2) with the relevant uncertainty (Eq. A3); this solution is defined on an interval scale (x), as illustrated in the "Background information" section.

Through the transformation in Eq. 14, the x scaling can be transformed into a new one (y), which is included in the conventional range [0, 100]. The uncertainty related to the elements in $\hat{\boldsymbol{Y}} = \left[\hat{y}_1, \hat{y}_2, \cdots\right]^T \in R^{n\times 1}$ can be determined by applying the relationship:

$$\Sigma_{\boldsymbol{Y}} = \boldsymbol{J}_{\hat{\boldsymbol{X}}}\cdot\Sigma_{\boldsymbol{X}}\cdot\boldsymbol{J}^T_{\hat{\boldsymbol{X}}}, \tag{A7}$$

where $\boldsymbol{J}_{\hat{\boldsymbol{X}}} \in R^{(q-1)\times(q-1)}$ is the Jacobian matrix containing the partial derivatives related to the equations of the system in Eq. 14, with respect to the elements of $\hat{\boldsymbol{X}}$ (demonstration omitted).

Coaching and organizational improvement: A balanced scorecard approach

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ABSTRACT

Purpose – The chief goal of this study is to measure the impact of coaching on organizational improvement using the Balanced Scorecard (BSC) conceptual framework.

Design/Methodology/Approach – Case analysis based on action research, incorporating real management data to track progress in line with the BSC framework.

Findings – The results point to an enhancement of the subject's managerial skills in relation to team management and decision making and to an improvement in the subject's industrial management indicators.

Originality/Value – To the best of our knowledge, this is the first study to specifically examine the relationship between coaching outcomes, management variables and business performance. This study presents a new evaluation methodology, based on the BSC, which can be applied to other processes.

Keywords: Coaching, Balanced Scorecard, Organizational improvement, Business performance

Paper type: Research Paper.

INTRODUCTION

Over the last decade, executive coaching has expanded significantly from being adopted as a one-off solution to becoming the habitual response of organizations (ICF, 2013) as they seek, for example, to develop leadership skills, succession planning and organizational change (Grant, 2014; Trenner, 2013). However, while almost all organizations "know" that coaching has been effective, they lack any actual data or evidence to confirm its efficacy. For this reason, measuring the success of coaching has come to be recognized as representing a significant challenge (ICF, 2013).

Neither has academia been able to reach a consensus on this question. Some studies demonstrate efficacy based on responses to behavioral questionnaires (Orenstein, 2006), but the lack of any conclusive evidence is a problem that has been cited for years (Kampa-Kokesch and Anderson, 2001) and one that has yet to be resolved (Grant et al., 2010). To date, no single academic study has managed to fulfil what might be considered the three key requirements to overcome the most frequently mentioned limitations: 1) the measurement of coaching outcomes using objective indicators; 2) a theoretical framework in which the causal impact of coaching is measured in terms of management variables, and 3) a longitudinal methodology that allows the sustainability of changes to be verified and the causal relationship to be established. This study is, we believe, the first to seek to incorporate all three elements.

In relation to the issues raised above, various research questions can be raised, which should prove to be of equal value to academia and professional practice:

1) How can coaching outcomes actually be evaluated?
2) How can the impact of coaching be demonstrated on business performance?
3) Is it worth investing in executive coaching?

Our goal here is to answer each of these questions by providing empirical evidence. To do so, we adopt a specific methodology, based on the Balanced Scorecard (BSC), which allows us to evaluate the impact of coaching on business performance. Specifically, here, we analyze the case of an Industrial Director who was required to strengthen his team management, decision-making and strategic vision skills.

LITERATURE REVIEW

We first seek to define executive coaching. We review specific contributions examining the possible return on investment (ROI) of coaching and its impact on business performance. In order to relate these processes of personal and internal development with their organizational impact, we use the concept of the managerial role and the contributions of the BSC.

Coaching and business performance

In “coaching”, a professional (coach) offers his or her client (or coachee) a development methodology that can be said to include the following elements (Jones, Woods, and Guillaume, 2016):

(1) Formation and maintenance of a helping relationship between coach and coachee;

(2) A formally defined agreement setting personal development objectives;

(3) The fulfilment of this agreement – that is, the achievement of the objectives – through a development process focusing on intrapersonal and interpersonal issues;

(4) Striving for growth of the coachee by providing the tools, skills, and opportunities they need to develop themselves and become more effective.

Executive coaching includes short-term changes in behavior and learning, promoting the long-term success of the individual, unit and organization (Joo, Sushko and McLean, 2012). As such, we would expect the great acceptance and diffusion enjoyed by executive coaching in recent years (Levenson, 2009; Walker-Fraser, 2011; Parker-Wilkins, 2006) to present clear evidence of a positive correlation with business performance. Yet, there is very little empirical evidence of its impact on business outcomes or of the ROI of coaching, due, in the main, to methodological difficulties (Levenson, 2009; Likierman, 2009). In practice, even companies that invest a considerable amount in services of this type have not introduced any processes to evaluate their return and so continue to base their decisions on perceptions (Walker-Fraser, 2011; Yates, 2015a). However, such a situation can be counterproductive, both for the executives themselves and for coaching professionals. Yates (2015a) points out that almost a third of the companies analyzed in her study are dissatisfied (a score of less than 6.69 out of 10) with the coaching services they receive. The most common reason offered for their dissatisfaction was the lack of a robust evaluation and/or the difficulty of measuring the ROI. Several authors have proposed models (Walker-Fraser, 2011; Levenson, 2009; Lawrence and Whyte, 2014), but they lack empirical support. Other authors have performed ROI calculations based on estimates provided by their respondents that deliver returns ranging from 689% (Parker-Wilkins, 2006) to just 4.86% (Yates, 2015b). The extreme diversity of these figures reflects the limitation of estimations based on personal interviews. Table 1 summarizes studies that have calculated the ROI of coaching. If instead of the ROI, we focus simply on the usual measures of coaching outcomes, no academic study to date provides evidence of this impact using business indicators, as Table 2 shows.

Theeboom et al. (2013) undertake a meta-analysis based on 18 studies with quantitative empirical data, of which only two offer the evaluations of other people (boss, peers), the remaining studies are based on the self-perceptions of the coachees themselves. Jones et al. (2016) propose a classification of studies whose objectives are to generate affective, cognitive, skill-based or results outcomes (in relation to the individual, the team and the organization). As part of this group of outcomes, they consider financial performance, goal accomplishment and productivity. They note that none of the 17 studies that they analyze, and which present empirical results, uses indicators of this type. Blackman, Moscardo, and Gray (2016) perform a critical and systematic review of 111 empirical articles, interpreting this term more broadly than the previous authors, since they also include qualitative studies. The conclusions of these meta-analyses coincide with Grover and Furnham's (2016) findings, who report that the articles analyzed are based, almost in their entirety, on the evaluations provided by the participants themselves after undergoing coaching. Among the main gaps found they highlight the need to evaluate the efficacy of coaching by using objective multisource measures and longitudinal approaches.

Table 1 – Studies related to the ROI of coaching

Author (year)	Sample	Methodology	Key results and contributions
Lawrence & White (2014)	29 Development or HR Managers	Personal and phone interviews.	Specific model proposition
Levenson (2009)	12 pairs coach-coachee.	Qualitative interviews. Semi-structured.	Terms and conditions for the coaching to have a positive impact on the business
Likierman (2009)	N/A	Theoretical exposition.	Enumerate five common errors when measuring business results
Parker-Wilkins (2006)	TOP-10 Managers' Senior from Professional services firm 26 Senior Managers from the same firm	Qualitative interviews. On-line survey. ROI quantification, **using estimations**.	Coaching mainly improves teamwork Holding on to, productivity and quality **ROI: 689% (based on coachee´s estimation)**
Walker-Fraser (2011)	17 HR professionals	Qualitative interview	HR professionals have difficulties when trying to recognise Coaching's impact They are based on perceptions
Yates (2015a)	65 Development or HR Managers	Phone semi-structured interviews.	47.5% don't control coaching's cost 49.3% Involve the Manager at the beginning and during the process 15.3% evaluate ROI
Yates (2015b)	One Company: E.ON UK	Case study ROI quantification, **using estimations**.	Coaching has increased efficiency, productivity, customer service and has improved relationships with key collaborators, pairs and stakeholders **ROI: 4,856 % (based on coachee´s estimation)**

Source: Own elaboration

Table 2 – Meta-analysis on the effectiveness of coaching

Meta-analisys	**K**	**Conclusions**	**Limitations**
Theebom et al. (2014)	18	Coaching's positive impact Hedges' g inbetween 0,43 y 0,74	Results only refer to behaviours and attitudes Mix between different organisational situations
Jones et al. (2016)	17	Impacto positivo del coaching d (de Hunter y Schmitd), entre 0,28 y 1,24	None of the studies uses results with organisational impact Considered outputs come from hability and affectivity ones
Blackman et al. (2016)	111	Coaching's positive impact Recognises success conditions Identifies process' keys	Measure usage based on involved's evaluation Absence of long term and longitudinal approach
Grover & Furnham (2016)	52	Coaching is an effective tool Underlying factors to this effectiveness	Overreliance on self-report measures and retrospective data Incredibly limited use of objective and longitudinal measures

Source: Own elaboration

Note: K is the number of cases in each meta-analysis

Given this situation, two specific questions need to be addressed:

- How can a replicable methodology be applied to individual coaching programs (that is, by definition, unique processes) which would allow us to clearly identify the impact they have?
- How can the bias associated with the self-evaluation of those involved be avoided?

To resolve these questions, we draw on various theoretical contributions provided by business management.

Executive managerial role

Katz (1974) defines the executive manager as someone who provides leadership for the activity of other people and assumes the responsibility of achieving certain results through these efforts. This requires three different types of skill:

- Technical skills: including mastering a specific area of knowledge, as well as associated processes and methodologies.
- Human skills: involving the ability to work as an effective member of a team, directing people, negotiating and reaching agreements, as well as generating commitment.
- Conceptual skills: the ability to see the organization as a whole, to develop a global perspective, relate the different links of the organization with their environment, think about future trends and generate lines of action for the long term.

Katz (1974) adds that their importance is relative and varies with the degree of responsibility the manager attains within the organization: technical skills lose relevance at a higher level; human skills are always complex and require high doses of dedication in terms of time; conceptual skills become more necessary as the degree of responsibility increases, as shown in Figure 1.

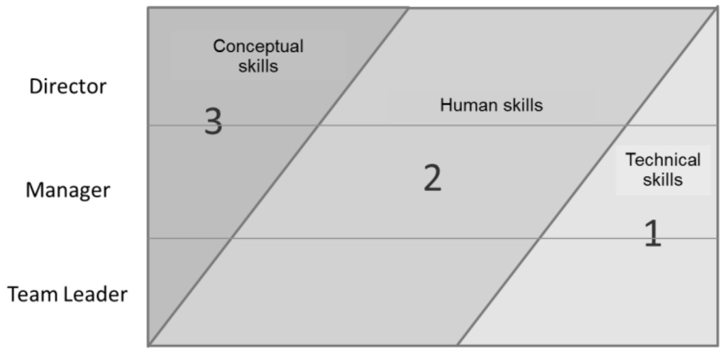


Figure 1 – Managerial skills evolution

Source: Adapted from Katz (1974)

The model serves as a useful tool for observing an executive's actual dedication in terms of time and the extent to which he deviates from the theoretical model, as well as his degree of efficacy or impact in relation to each of the potential indicators associated with each skill area. At the same time, the executive role can be related with the management indicators established by the organization itself and which are largely consistent or similar across different companies.

Balanced Scorecard, causal relationships and their application to coaching

Walker-Fraser (2011) proposes using a Balanced Scorecard (BSC) approach as a method for evaluating the impact of coaching. Her arguments are persuasive, as a rigorous use of the BSC (Kaplan and Norton, 1993; Libby, Salterio, and Webb, 2004; Banker, Chang, and Pizzini, 2011; Kaplan, 2014) has been shown to offer a number of advantages:

- it allows causal relationships to be established between variables drawn from different areas (financial performance, customers, internal processes and learning and development);
- it allows different types of management indicator to be incorporated at each of these levels.

Here, we specify the causal links that are apparent in the coaching process, using plans of action that include objective management indicators and business outcomes, as well as other process indicators that can be considered to be “advanced indicators”. The specification of these links helps raise awareness – which is one of the keys of the coaching process – and, moreover, it has proved useful in management models, even in highly variable environments and in settings where these links may not be entirely accurate (Kasperskaya and Tayles, 2013). Evidence also exists indicating that the orientation toward objectives of greater strategic scope or of a more global perspective have a greater impact on the business and offer greater economic benefits (Anderson, 2004).

Considering the interrelation between different perspectives of the BSC on variables that may be relevant in our case, we can specifically highlight the following:

- Links between *Learning and Growth and Internal Processes*. There are studies that validate the links between human capital and business performance, reporting evidence of a significant impact on internal processes, retention of key staff and productivity (Bontis and Fitz-enz, 2002). Sveiby and Simons (2002) establish that the collaborative climate impacts on the effectiveness of knowledge work. Bourne et al. (2013) identify certain human resource management practices that contribute to performance, which they break down into two categories: “engagement” and “a communication/guiding mechanism”. De Leeuw and Van Den Berg (2011) identified three independent clusters of operator behavior that positively correlate with performance improvement and performance management practices: “Understanding”, “Motivation” and “Focus on Improvement”. Vanichchinchai (2012) shows that employee involvement has a direct impact on a firm’s supply performance, measured in terms of cost, flexibility, relationship and responsiveness. Taesung (2015) assimilates learning and growth with intellectual capital and shows its causal impact on processes and customers. The correct implementation of the BSC enhances the organizational climate and staff commitment (Calderón et al., 2014).

- Links between *Internal Processes, Customers/Market and Economic-Financial Performance*. Ou et al. (2010) show that supply chain management not only improves internal operational performance, but also external customer satisfaction and, as a consequence, a firm's financial performance. Mulero, García-Valderrama, and Rodríguez Cornejo (2016) show the links between R&D activities, market share, customer perceptions and financial performance.
- Links between *Customers/Market and Economic-Financial Performance*. Li et al. (2006) show that the strategic supplier partnership, together with the level and quality of information sharing, and "postponement" suppose a competitive advantage (cost, quality, product innovation and "time to market"), which improves market and financial performance.
- Relating *all perspectives simultaneously*. Wang and Chang (2005) show that human capital indirectly affects performance through innovation capital and process capital. Moreover, innovation capital has an impact on customer capital, which ultimately affects performance. Gómez-Cedeño et al. (2015) establish that HR management indirectly influences customer satisfaction and this, in turn, influences a firm's economic-financial performance. Also, in part, the operational results of the supply chain influence the economic-financial outcomes. Particularly significant contributions include Malbašić, Marimon, & Mas-Machuca (2016), who demonstrate, by drawing on three different information sources and by applying quantitative methods, that certain organizational values impact on organizational effectiveness and, furthermore, that balancing attention between the four perspectives of the BSC moderates this impact. Llach et al. (2017) offer a complete causal map, validated using PLS, that shows the significant mediation of the "internal processes" and "customer" constructs, especially in industrial firms. They also demonstrate the importance of leadership for achieving high performance, which is consistent with studies based on related models such as the EFQM (Heras-Saizarbitoria, Marimon & Casadesús, 2012).

In short, these studies establish empirically causal relationships between all the BSC perspectives. Moreover, this strictly (macro) organizational approach can also be applied at the individual (micro) level (Kaufman, 2017).

METHODOLOGY

Action research (AR) is a science, and while it may not be a science in the way experimental physics or other positivist sciences are, it is genuinely scientific in the emphasis it places on careful observation and on the study of the effects on the behavior of human systems in change management (Coughlan and Coghlan, 2002). Here, the role of the coach is very similar to that proposed by these authors: the coach intervenes as an external support to the customer's system, facilitating reflection and questioning, so that solutions can be created and implemented. This role is, as described by Coughlan and Coghlan (2002), an iterative process, and is summarized in Figure 2.

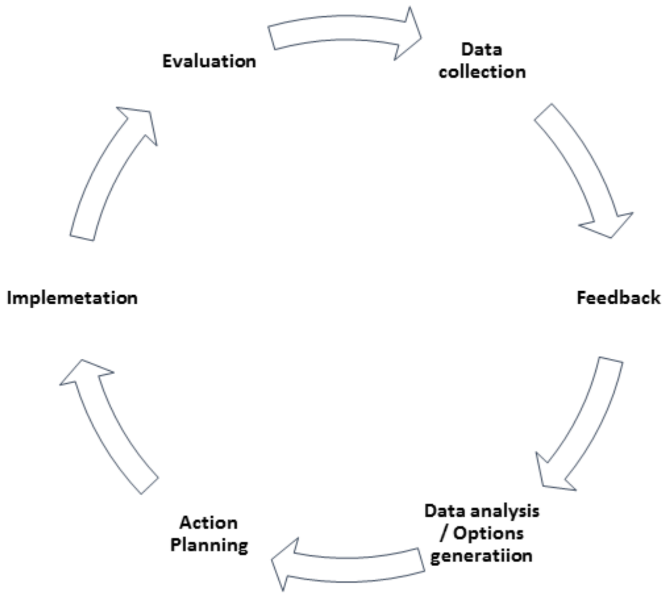


Figure 2 – Iterative process in Action Research

Source: Adapted from Coughlan & Coghlan (2002)

Here, this coaching approach was adopted by the first author and applied to the following case, whose organizational framework is outlined below.

Organization and coachee

The framework is provided by a firm – a subsidiary of a European multinational – operating in the chemical sector. The production process is complex, involving the management of more than 4,000 reference materials and the firm's customers are highly demanding in terms of speed of delivery and quality. The company employs more than 180 workers and its annual sales value exceeds 40 million euros. It implements OHSAS 18001, ISO 14001 and ISO 9001 management systems. At the express request of the company, we shall respect the confidentiality of all names and data that would permit the firm's identification.

The coaching process responded to the need to improve the performance of the firm's industrial area, given that the Industrial Manager was not fulfilling his duties in line with the firm's expectations. On the contrary, he had adopted an overly analytical and technical approach. In the words of the Managing Director:

> "there is a misapprehension concerning his role (which he considers to be more technical than managerial in nature) and there are doubts even about the job profile, given that the manager is highly analytical, rather than taking action and managing his teams … he is coming under a lot of pressure and he appears to be suffering considerable stress as he is overrun by the circumstances".

The Industrial Manager had difficulties in deploying his team, in making rapid decisions and in guaranteeing the rhythm and quality of production needed to ensure good customer service. If this service could not be guaranteed, it would mean a loss of sales, cost overruns, delayed payments, customer complaints and a deterioration in the firm's reputation. Therefore, the situation had to be turned around quickly but there were doubts that, given the manager's personal profile ("very much that of an engineer", "overly analytical", "a perfectionist", "methodical", "extremely self-demanding", in the words of the Managing Director) this could be achieved quickly and effectively as the firm clearly required.

Procedure

Having validated the conditions for initiating the coaching process, a program of six monthly sessions was established, each scheduled to last for approximately 90 to 120 minutes. Coaching took place between November 2015 and April 2016. Each session ended with the drawing up of a specific action plan and the undertaking that this be implemented immediately in the manager's daily work. At the beginning of each session, the progress made was analyzed, as well as possible difficulties encountered, and new objectives were established, in a manner consistent with the principles of action research. The BSC framework was used as a point of reference to integrate and relate the outcomes from the action plans and to design the following steps.

The information sources employed were multiple, and thus ensured maximum objectivity. The approach is summarized in Table 3.

Table 3 – Information sources

Type of information		Coachee	General Manager	HH.RR. Director	Management Systems
Qualitative:					
	Behaviors	X	X	X	
	Management habits	X	X	X	
	Impact on others	X	X	X	
Quantitative:					
	Deadlines and plans	X	X		X
	Management data	X	X		X

Source: Own elaboration

Variables

Drawing on contributions from within management systems analysis: activity-based costing and production practices (Banker et al., 2008); JIT (Kinney and Wempe, 2002) and a meta-analysis of 119 studies of the impact of lean methodologies on performance (Camacho-Miñano, Moyano-Fuentes and Sacristan-Dıáz, 2013), we observe a similar pattern, which can be neatly summed up by referring to the conclusions of Camacho-Miñano et al. (2013):

> "the LM [Lean Management] assessment model should consider jointly financial indicators (such as sales, profits and return on sales (ROS)) and operational indicators (such as inventory level, percentage of on-time deliveries and commitment to JIT)" (p.1110).

Operational variables, more closely related to the process or the return on sales (ROS), facilitate the identification of evidence (Vanichchinchai, 2012, Ou et al., 2010, Li et al., 2006). This is not the case when more aggregate measures are used, such as the ROI (Gómez-Cedeño et al., 2015). For this reason, as aggregate measures of the impact on the industrial area, we use:

- the key customer service rate (due to its direct impact on sales). Specifically, we use the rates for a key external customer and a customer within the firm's same group, due to the high sales value they represent.
- the stock availability rate (a measure of service and flexibility).

Quantitative analysis

Given that we have time series for of different management indicators, we opted to use the Wilcoxon signed-rank test for related samples. This is a nonparametric test recommended for small samples and has been used in similar studies based on action research methodology (see, for example, Wagstaff, Hanton, and Fletcher, 2013), in the analysis of aggregate measures when using the BSC (see, for example, Davis and Albright, 2004),

Below we present the results obtained.

RESULTS

Coaching began in November 2015 and was continued through to April 2016. To obtain an overview that would allow causal relationships to be established, we expanded the data collection at either end so that we covered a full two-year period. We also obtained a series of objective indicators for different management levels, as provided for in the action plans of each session. These included, for example, compliance with launch dates of new products; meeting equipment installation deadlines; maintenance indicators; indicators of accident rates; key customer service rates; and, stock availability rates. These plans were verified with real data from the company's own management systems. The consolidation of new management habits is illustrated in Figure 3.

As a record of these objective achievements, we had access to the company's own internal records on:

- New projects introduced:
    - Change in the plant planning process (MPS)
    - Fulfilment of service-level agreement (SLA) with key customer. Negotiation of a new SLA and redefinition of the internal processes for the management of the customer's specific orders.
    - Review of the production and stock plans. To improve the level of service and build up better stocks of finished product. The approval of an additional three resources and €1,000k of stock had been obtained at year end, to manufacture 2,000 tonnes more than had been budgeted for.
- Stock improvement projects (with direct impact on current assets)
    - Change in the supply management process of commercialized products (products not manufactured in the plant). In this case, with a change in the purchasing process, the value of the stock of commercialized products went from €650k to €514k. With forecasts predicting a fall to around €450k. This drop in stock levels has been achieved without affecting the service level of these products.

  - Change in the supply management process of raw materials. The availability of materials for manufacturing has been enhanced, having improved from three batches/day affected by the lack of raw materials, to one batch/day.
- Plant's strategic plan
  - Flexibility of production. The project involves changing the use of the plant's land management equipment. This project has been scheduled over three years, with a total investment of €240k, and allows the plant to increase production from about 130 to 180 tonnes/day (31,200 t/year -> 43,200 t/year)
  - Improvement of packaging efficiency. A three-year plan, with an investment of about €150k, to improve plant performance.
  - With these two projects, the plant's productive capacity grows from about 35,200t/year to 45,000t/year. More than enough to absorb the future production volume.

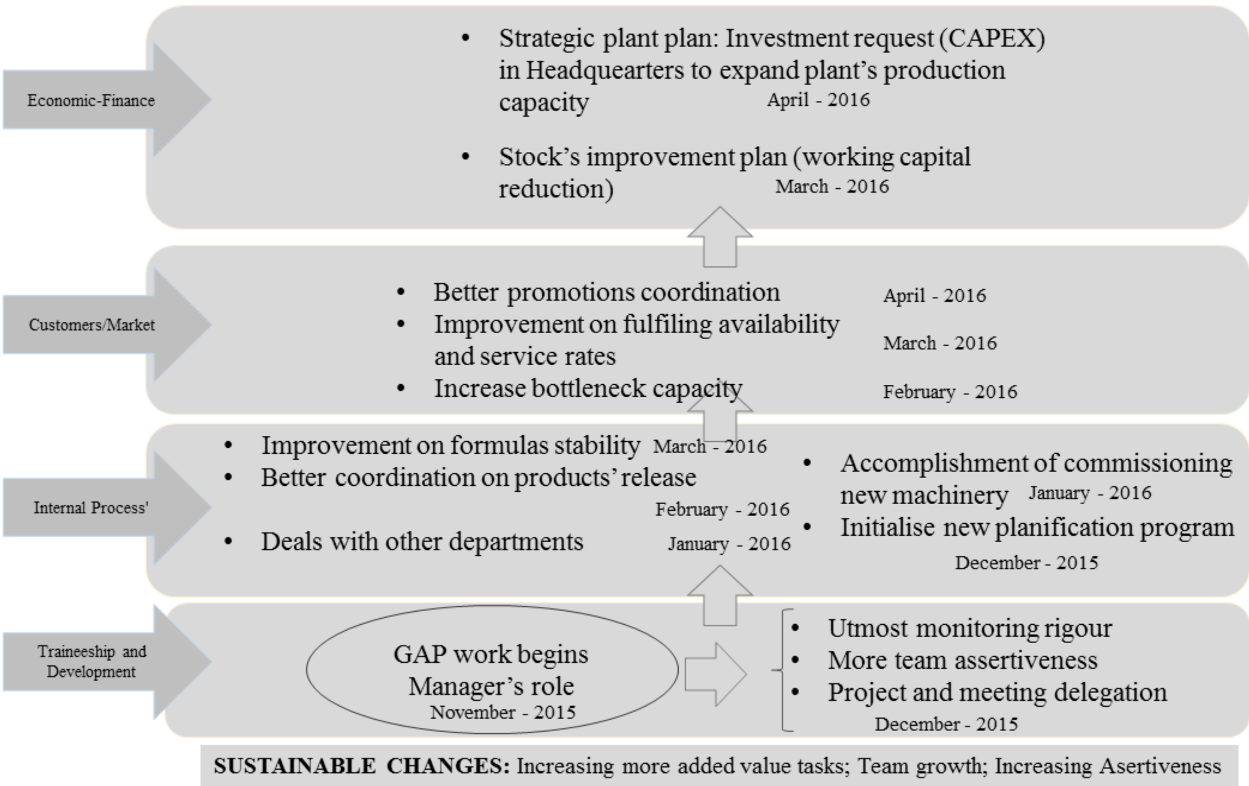


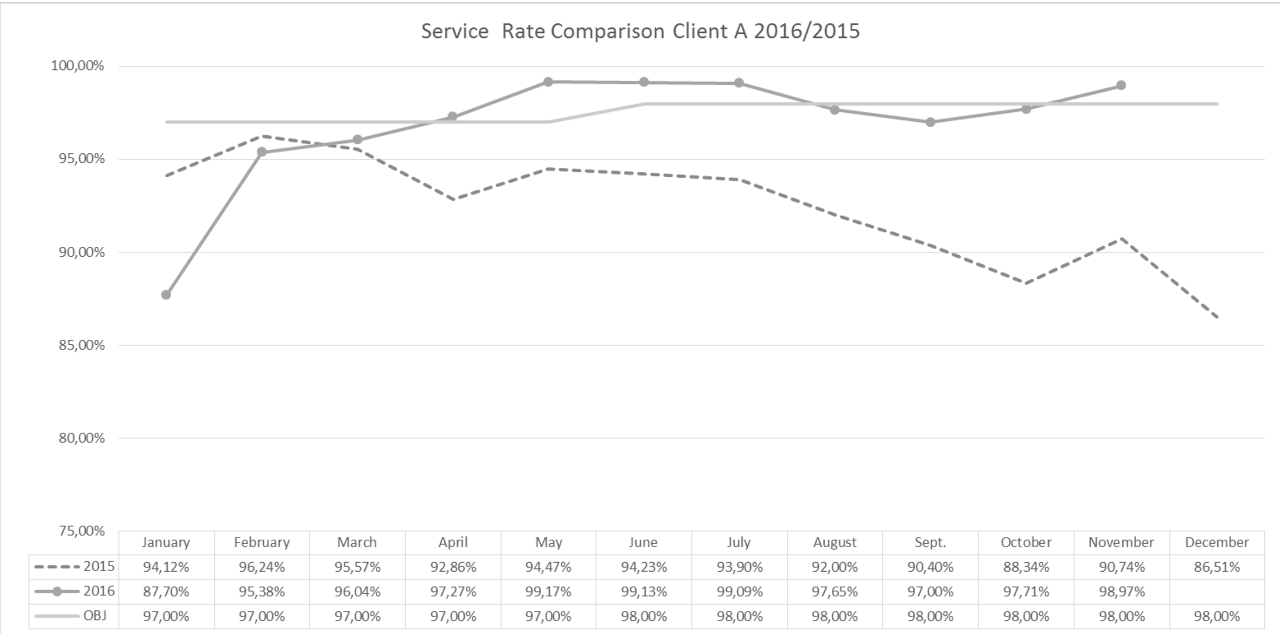
Figure 3 – Synthesis of Coaching Process with BSC structure
Source: Own elaboration

No staff changes were made in the system of direct reporting and there was evidence that the change in management style was valued positively. As for the plant's activity, a 20% increase in volume was reported with respect to financial year 2015, indicating that the context for change was not easier, but just the opposite.

In short, the coachee clearly assumed the managerial role expected of him (Katz, 1974), dedicating greater time to his team, albeit employing different strategies of delegation and supervision. This change was also apparent in his interaction and negotiation with other areas of the company (formula stability with the laboratory; planning of demand with sales; forecasting of launches with marketing) and freeing up time for developing strategic ideas and projects (expansion of the plant's capacity and productivity).

The main values of the Industrial Manager's overall managerial impact can be identified as the service rate applied to the deliveries agreed to with a key external customer, sales that constitute a particularly high volume for the company (see Figure 4). In the words of the Industrial Manager:

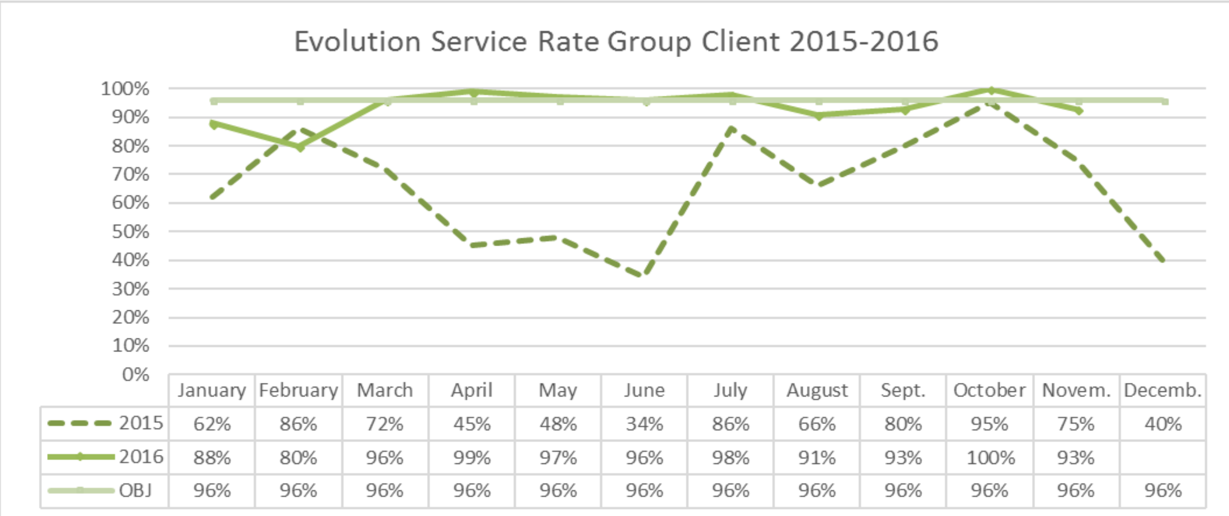
> "Thanks to the MPS project, we've been able to meet this objective – which initially seemed impossible – on a regular basis, and when we have fallen short, we've been able to recover quickly. The financial impact of not complying with this rate is 2% of the amount not serviced. The new planning system was implemented on 01/04/2016, and you can see, that since the system start-up, we've operated above 98%".



	January	February	March	April	May	June	July	August	Sept.	October	November	December
2015	94,12%	96,24%	95,57%	92,86%	94,47%	94,23%	93,90%	92,00%	90,40%	88,34%	90,74%	86,51%
2016	87,70%	95,38%	96,04%	97,27%	99,17%	99,13%	99,09%	97,65%	97,00%	97,71%	98,97%	
OBJ	97,00%	97,00%	97,00%	97,00%	97,00%	98,00%	98,00%	98,00%	98,00%	98,00%	98,00%	98,00%

Figure 4 – Service Rate Client A
Source: Internal management data of the company itself

The second value can be identified as the evolution in the service rate applied to a company within the same group (a key customer also in terms of sales volume). In this case, the improvement was achieved thanks to a renegotiation of the previously agreed SLA, varying the frequency and volume of orders, together with more accurate forecasts and an improvement in internal processes. The SLA came into effect in January 2016. Figure 5 shows the evolution of the service rate, which improves in both stability and compliance.

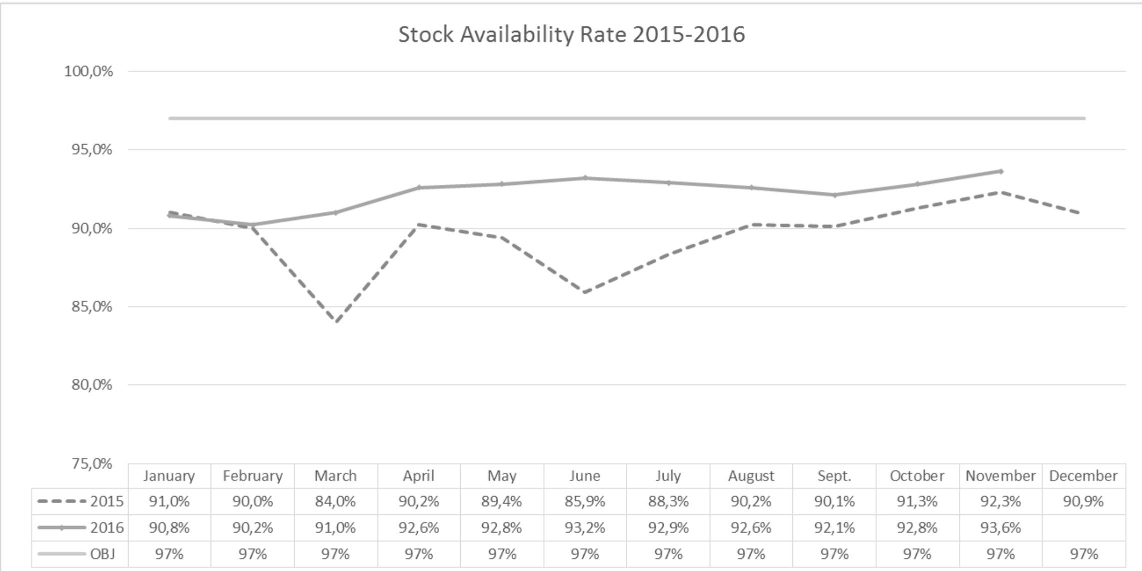


	January	February	March	April	May	June	July	August	Sept.	October	Novem.	Decemb.
2015	62%	86%	72%	45%	48%	34%	86%	66%	80%	95%	75%	40%
2016	88%	80%	96%	99%	97%	96%	98%	91%	93%	100%	93%	
OBJ	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%	96%

Figure 5 – Service Rate Group Client
Source: Internal management data of the company itself

The third value that we identified as being indicative of the coachee's global impact is the stock availability rate (see Figure 6), which represents one of the firm's strategic objectives: an SLA of 97% service in 24 hours, from the time of receipt of the order. This means that if the product is not in stock, it cannot be served in 24 hours. According to our coachee:

> "For this reason, we measure the stock availability rate, on a daily basis, and it is the number of order lines that can be served divided by the total number of lines to be served. This indicator has also improved."



	January	February	March	April	May	June	July	August	Sept.	October	November	December
2015	91,0%	90,0%	84,0%	90,2%	89,4%	85,9%	88,3%	90,2%	90,1%	91,3%	92,3%	90,9%
2016	90,8%	90,2%	91,0%	92,6%	92,8%	93,2%	92,9%	92,6%	92,1%	92,8%	93,6%	
OBJ	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%	97%

Figure 6 – Stock Availability Rate
Source: Internal management data of the company itself

To check whether there really is a significant difference between the values of the two years under comparison, we used the Wilcoxon test. The result of the test allows us to reject the null hypothesis (p> 0.05). The negative sign indicates significantly lower data in 2015, as shown in Table 4. Therefore, there have been significant changes in the management conducted by the Industrial Director.

Table 4 – Wilcoxon test of signed ranges for related samples

	N	Mean	Sd	Z	P
Service Rate Client A					
2015	12	92,45%	2,95%		
2016	11	96,83%	3,29%	-2,045 *	0,041
Service Rate Group Client					
2015	12	65,75%	20,08%		
2016	11	93,73%	5,80%	-2,756 *	0,006
Stock Availability Rate					
2015	12	89,47%	2,37%		
2016	11	92,24%	1,09%	-2,803 *	0,005

* p<.05.   ** p<.01.

Figure 7 uses the structure of the Balanced Scorecard, and based on the contributions discussed in the literature review (Kaplan, 2014; Kaplan and Norton, 2004; Madi et al., 2008; Argilés-Bosch et al., 2014; Malbašić et al., 2016; Llach et al., 2017), we can summarize the key points of the coaching process, highlighting the different management areas, as well as the objective indicators associated with each level.

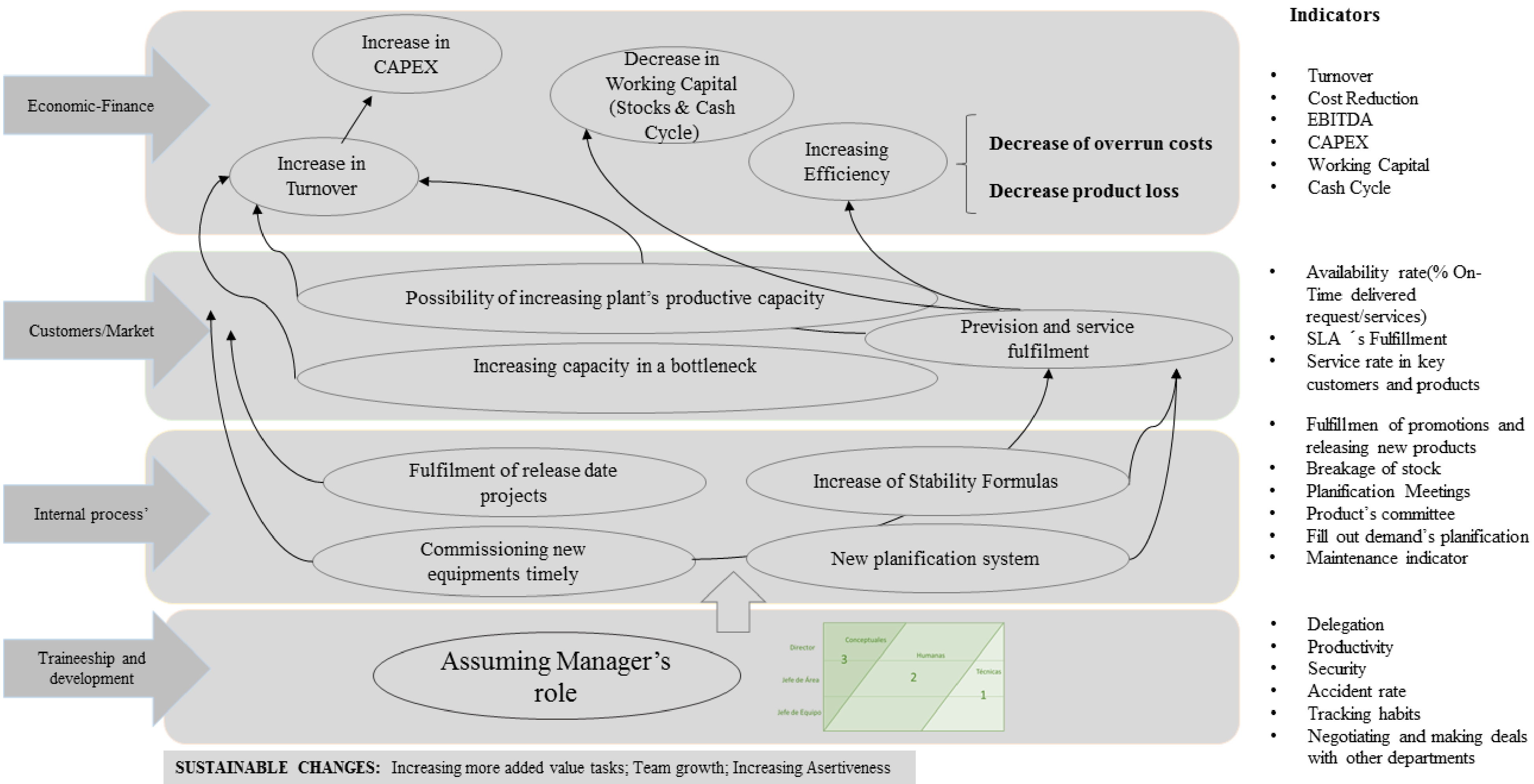


Figure 7 – Key points in the process, causal relationships and indicators

Source: Own elaboration and validation of the company itself

ORIGINALITY AND VALUE

The main objective has been to evaluate the impact of coaching on organizational improvement by applying the BSC conceptual framework. We have reported the analysis of a case employing an action-research methodology, applying action plans focused not only on observable behavior but also on objective indicators of management, and implementing a longitudinal approach.

We provide evidence that the executive manager has improved his managerial skills in terms of team management and decision making and that he has also enhanced his industrial management indicators. Our study makes a number of important contributions:

1. It is one of very few studies that provides evidence of the efficacy of coaching in relation to organizational improvement, using objective management variables.
2. It is also one of few studies that uses longitudinal data, showing that the impact is sustainable over time while highlighting the causal relationship.
3. This causal relationship is also supported at a conceptual level by management research derived from the BSC, with which we are able to integrate interdisciplinary contributions, that are of great use to the academic world and professional practice, both in the field of business management and in that of coaching.
4. The evaluation methodology used, incorporating the concept of the executive managerial role (Katz, 1974) and the Balanced Scorecard framework (Kaplan, 2014; Kaplan and Norton, 2004), is a significant contribution in its own right, since it is replicable and can be used to demonstrate the impact of coaching on business performance with empirical data. It also allows causal relationships to be established between the issues worked on with the coachee and their subsequent impact at different levels of management (Malbašić et al., 2016; Llach et al., 2017). These different types of indicator allow the impact of coaching to be tracked and are also useful as “advanced indicators of success”.

These contributions should serve as the basis for applying a systematized methodology to coaching processes. This would be of great benefit for the following professionals, both in the academic world and in management: coaches, HR managers, managers of growth and development, as well as general managers. The study helps demonstrate the utility and efficacy of a professional service dedicated to organizational change, in which coaches and executive managers can promote its dissemination and careful management. Finally, the study also points the way for further interdisciplinary research in this academic field.

Limitations and future research

The study has examined but one individual case within one industrial company, which means we must consider its application to other formats of coaching (for example, group processes) or to other organizational contexts or sectors with some caution.

As future lines of research, it would be interesting to test the applicability of the proposed model in other sectors, in small and medium-sized companies, and in other countries, in order to corroborate whether cultural factors or size have any limitations or require that modifications be made to the model. It would also be interesting to see how a similar approach might be applied to measuring the impact of coaching on teams.

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Capability index analysis in Short-terms production at the machine supplier and initial manufacturing facility

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ABSTRACT

Purpose – The objective of this paper is to provide a statistical method to approve capability index of new machines that are in the supplier or in the startup of production.

Design/methodology/approach – The approach methodologic involved the development of a mathematical model and the use of simulation to find critical value of Cp and Cpk index to approve machine in the supplier or in the startup of production.

Findings – A statistical probability density function was built to give support in testing short-term capability index. Using numerical analysis, critical values for Cpk and Cp was found. An illustrative case showed the application of proposed method.

Research limitations/implications – The proposed method concerning a short-term sampling for variables that follow a normal distribution. Asymmetric probability distribution is not considered.

Practical implications – In testing machine supplier or pre-production, normally practitioners have used the Cp/Cpk index. However, in general, the practitioners have not been considered the Cp and Cpk as random variables. This paper provides a supportive statistical method to approve machine' capability.

Originality/value – There are not many works that give a supportive method to approve machine capability index.

Paper type: Research paper

Keywords: capability index, Cp/Cpk index, statistical testing, supplier machine, short-terms production

INTRODUCTION

According to Kane (1986), Pearn and Chen (1999), Pearn and Lin (2004); Chen et al. (2001) and Kureková (2001), there are three capability indexes commonly used in manufacturing industries: Cp, Cpk and Cpm. Cp and Cpk have been proposed in the manufacturing industry to provide numerical measures of whether a process is capable of producing items within the specification limits.

Usually, small sample is used in short-time production run to determine machine capabability, when the machine istill is in the supplier, whose analyses are done before the installation of the equipment in the buyer industrial plant. To test machine in the supplier or pre-production testing, normally the companies use the Cp/Cpk indexes, with sampling size between 30 and 100 (Kane, 1986). Traditionally, in the manufacturing industries, several calculation methods of the process capability indexes are used to pre-procdution testing. The calculation methods differ because of the properties as well as by intended use, but their design principle is approximately the same. The ratio between prescribed (required) accuracy and the real process accuracy is always observed (Kureková, 2001; Castillo and Montgomery, 1994; Mhatre et al., 1981).

The objective of this paper is to develop and test a statistical method to approve capability index using short time production run of new machines that are in the supplier or in are in the preproduction testing. The approach methodologic involved the development of a mathematical model and the use of simulation to find critical value of Cpk index to approve machine in the supplier or in the pre-production testing (Arif et al., 2017; Aslam et al, 2017; Ahmad; Aslan; Jun; 2015; Ahmad et al., 2014; Montgomery, 2009; Garcia-Diaz and Parisi, 2005; Pearn; Lin, 2004; Kane, 1986).

The remainder of this work is organized as follows. Section 2 describes the literature review showing the criteria used for approve machine using capability indexes. Section 3 presents the proposed mathematical model. Computational simulations are depicted in Section 4, followed by conclusions and next steps of this research in Section 5.

BACKGROUND

Process capability indices, such as Cp and Cpk, have been proposed in the manufacturing industry to provide numerical measures of whether a process is capable of producing items within the preset specification limits (Ahmad et al., 2015; Pearn and Lin, 2004). Drive by practical approach, there are authors that have been studying statistical tests for the approval of machine capability indices.

Kane (1986) used statistical test to approve machine in the supplier and facilities at the start of production using Qui-Square distribution probability. Before, according to Garcia-Diaz and Aparisi (2005), Kane made use of acceptance sampling plan considering capability indices as control plan by process. He considered critical values of Cp and Cpk considering hypotheses testing to approve machine using short time analyses. For this, he used AQL (Acceptable Quality Level), and RQL (Rejectable Quality Level). AQL is a reference value for Cp, where values above it is acceptable, and RQL is a reference value that below it is not acceptable.

Leiva et al. (2014) proposed a new way of calculating the indices of the process, following the nonparametric distribution Birnbaum-Saunders. The non-parametric statistic must change some elements of the equation of calculation of the capacity indices (previously considered a normal distribution): the standard deviation (σ) is replaced by the amplitude (R), while the average is replaced by the central value of the distribution X (0,5).

There are other works that have used non-normality methods for the calculation of capacity indices (Cp, Cpk). In Pearn and Lin (2004), for example, the indices are calculated assuming that the data follow a combined distribution between chi-square and normal. Another point verified in some studies is the performance of statistical tests, this is important to confirm, with a certain statistical level, if the process is able to meet the requirements of the product. An example of a statistical test is: H_0: Cpk $\leq$ c (Incapable Process) and H_1: Cpk > c (Capable Process).

Kane (1986) argues that the value of 1.33 for the critical value of the capacity index and a sample size of 30 are not sufficient to guarantee that the process is capable. Therefore, the author recommends values higher than those found in the literature (sample size and capacity index) to ensure that the process is capable. Vännman (1997) concludes that it is necessary to verify the expected behavior and the results obtained to decide which estimator and calculation basis should be used.

From of the contribution by Kane (1986), Vännman (1995), Vännman (1997) and Leiva et al. (2014), this paper will propose a new approach to support the decision if a machine is capable to meet the product requirements.

CAPABILITY INDEX TESTING TO APPROVE MACHINE: PROPOSED METHOD

A typical baseline of the potential capability of a process is the relation between the natural tolerance (6σ) of a process and the tolerance limits. The potential capability index, Cp, is showed in equation 1

$$C_p = \frac{USL - LSL}{6\sigma} \qquad (1)$$

where USL=upper specification limits, LSL=lower specification limits, and σ is standard deviation. The primary use of Cp to the machine or startup of production evaluation is to make comparison. In general, to qualify a machine, the minimum acceptable value presented in the literature is Cp=1.33, however the studies that uses this value do not consider if machine is in statistical control. According to Kane (1986), a short time production sampling often is used for the analysis of machinery potential process capability, and typically, a process is evaluated using the estimated Cp using a sample size between 30 to 100. The estimated Cp is showed in equation 2

$$\hat{C}_p = \frac{USL - LSL}{6s} \qquad (2)$$

where s is the estimation of standard deviation, σ.

The hypotheses tests to analyses the sample and consequently, the process, are described as following:

H_0: $C_p \geq c_0$, the process is capable

H_1: $C_p < c_0$, the process is not capable

As s is the estimation of standard deviation, there is a sampling variation. The chi-square distribution can be used to analyses the sampling variation of $\hat{C}_p$. Using chi-square distribution, we have the probability of error type I, α, and o error type II, β, for a critical value c, as following:

$$\Pr\left(\hat{C}_p \geq c \middle| Cp\right) = \Pr(X_{n-1}^2 \leq X_0^2 | Cp) \quad (3)$$

where X_{n-1}^2=chi-square distribution as n-1 degrees freedom, $X_0^2 = \frac{(n-1)s^2}{\sigma^2}$.

As $C_p = \frac{USL-LSL}{6\sigma}$, $\hat{C}_p = \frac{USL-LSL}{6s}$, we can represent σ and s in function of C_p:

$$\sigma^2 = \frac{T^2}{36C_p^2} \quad (4)$$

$$s^2 = \frac{T^2}{36\hat{C}_p^2} \quad (5)$$

where $T = USL - LSL$. Therefore, we have following X_0^2 value:

$$X_0^2 = \frac{(n-1)C_p^2}{\hat{C}_p^2} \quad (6)$$

The probability formula can be used in the operating characteristic curve, and find the sample size for an error α and β specifics:

$$\Pr(accept\ H_0\ |Cp_0) = \Pr\left(\hat{C}_p \geq c_0 \middle| Cp_0\right) = \Pr\left(X_{n-1}^2 \leq \frac{(n-1)\,C_{p0}^2}{{c_0}^2}\middle| Cp0\right) \quad (7)$$

For example, take following hypotheses testing

H_0: $C_p \geq 1.33$

H_1: $C_p < 1.33$

and $\hat{C}_p = 1.33$; as $\Pr\left(\hat{C}_p \geq 1.33 \middle| 1.33\right) = 0.54$, the probability of incorrect judgment of H_0 is of 0.46. This mean that there is a 46% chance of incorrect rejection of H_0.

Using the equation 7 to build the operating characteristic curve. The Figure 1 shows that error type I reduces when the critical value c increase. Therefore, to ensure a higher probability that Cp=1.33, the critical value recommended has to be bigger than 1.5 to approve the startup or testing machine supplier. Figure 2 shows similar information, but the analysis considers the effect of sample size in the discriminate power test. When the sample size increase there is an improve in the correct decision of the hypotheses test.

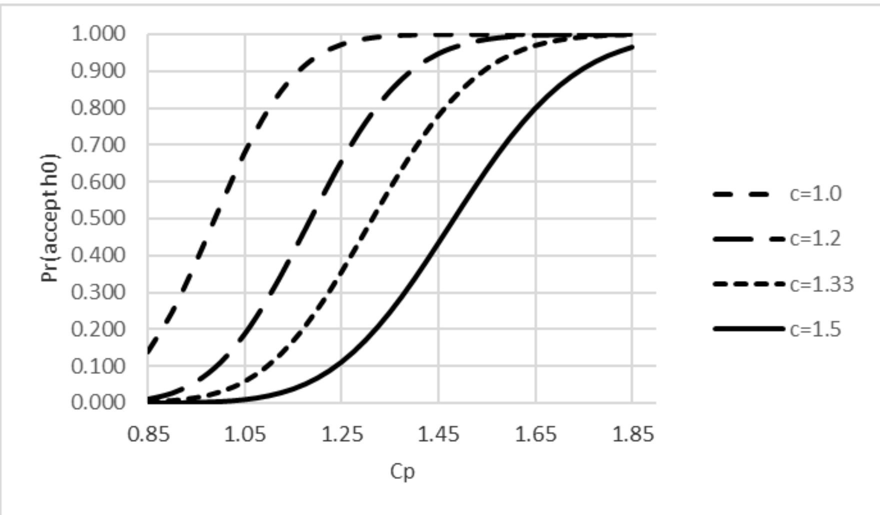

Figure 1 – Operating characteristics curve of the probability of accepting the potential capability for different critical values (c) for sample size n=30.

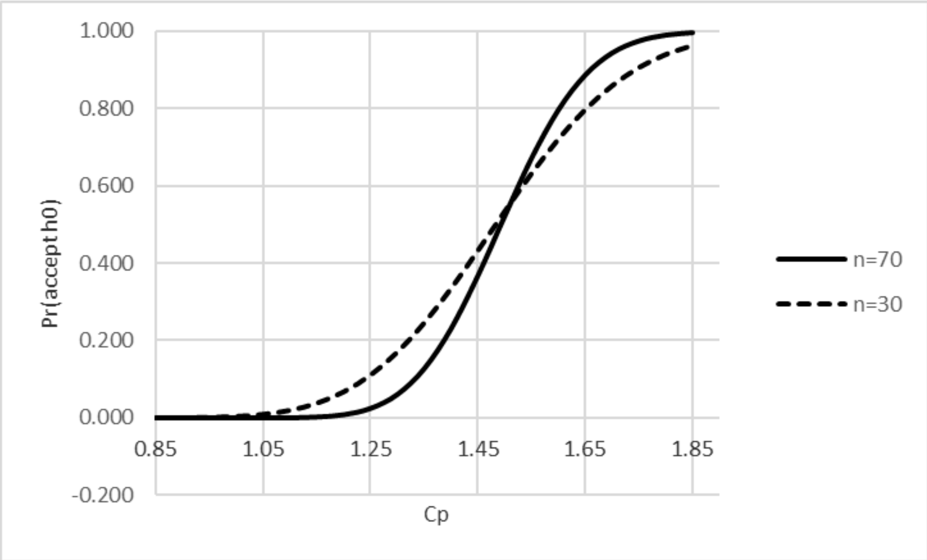

Figure 2 – Operating characteristics curve of the probability of accepting the potential capability for different sample sizes (n=30 and n=70) for c=1.5.

Cp index measures potential process performance and the location of the process mean is not considered. The Cpk index utilizes the process mean and can be considered as a measure of process performance. The most common formula of Cpk index is

$$Cpk = min\left[\frac{\mu-LSL}{3\sigma}, \frac{USL-\mu}{3\sigma}\right] \quad (8)$$

Let us suppose that $(X_{i,1}, \ldots, X_{i,n})$, $i = 1,2,..m$, are independent samples taken from a normal distribution, with μ_0 and σ_0, and i is the subgroup number, Δ represents some specified admissible changes in the μ_0, which the practitioner may allow without seriously affecting the product quality. Therefore, considering that Δ is the permissible mean variation, because the process meets the product requirements even with mean variation, so we have: $\Delta = \frac{\mu-\mu_0}{\sigma_0}$, we can write $Cpk_{max} = \frac{USL-N}{3\sigma_0} = \frac{N-LSL}{3\sigma_0}$.

If $\mu = N = LSL + 3Cp\sigma_0$, and $\mu_0 = LSL + 3Cpk_{min}\sigma_0$ $\left(for\ Cpk_{min} = \frac{\mu_0-LSL}{3\sigma_0}\right)$; thus, $\Delta = \frac{LSL+3Cp\sigma_0-LSL-3Cpk_{min}\sigma_0}{\sigma_0} = 3(Cp - Cpk_{min}) = 3\Delta_{Cpk}$, where Cpk_{min} is minimum acceptable Cpk.

As for the case in which $\mu_0 = N$, the maximum Cpk is obtained, therefore, $Cpk_{max} = Cp = \frac{USL-LSL}{6\sigma_0} = \frac{USL-\mu_0}{3\sigma_0} = \frac{\mu_0-LSL}{3\sigma_0}$.

Considering that δ represents the number of standard deviation in the mean shift, we can write a relationship between Cpk in a state of unacceptable capability (UC), that is, the capacity is less than the minimum admissible Cpk - for example, Cpk=1.00, when $\mu = \mu_0 + \delta\sigma_{0,}$ and in state of acceptable capability (AC) when $\mu = \mu_0 = N$. In the state of acceptable capability, $Cp = Cpk_{max} = Cpk + \frac{\delta}{3}$. If Cpk_u is an unacceptable capacity, we can write that $\delta = 3(Cpk_{max} - Cpk_u)$. Assuming Cpk_u as the minimum capability admissible in industrial process (for example, $Cpk = 1.00$), we can write a new relationship between δ and Cpk as $\delta = 3(\mathrm{Cp} - \mathrm{Cpk_u})$.

An alternative to estimate the Cpk index is (Pearn and Lin, 2004): $\hat{C}_{pk} = \frac{d-|\bar{X}-M|}{3S}$, wherein $d = \frac{USL-LSL}{2}$ and $M = \frac{USL+LSL}{2}$. Pearn and Lin (2004) have rewritten this estimate as: $\hat{C}_{pk} = \frac{\sqrt{n-1}\,(3C_p\sqrt{n})-Y}{3\sqrt{nK}}$, wherein $K = \frac{(n-1)S^2}{\sigma^2}$ has chi-square distribution, and $Y = |Z|$ $(Z = \frac{\bar{X}-M}{\sigma}\sqrt{n})$ has normal distribution. Using these results and the probability density function of Y, the cumulative probability function of $\hat{C}_{pk}$ is:

$$F_{\hat{C}_{pk}}(x) = \int_0^{3C_p\sqrt{n}} P\left(K < \frac{(n-1)\left(3C_p\sqrt{n}-y\right)^2}{9nx^2}\right) f_y(y)dy \quad (9)$$

wherein K has chi-square distribution and $f_y(y) = \emptyset\left(y + 3(C_p - C_{pk})\sqrt{n}\right) + \emptyset\left(y - 3(C_p - C_{pk})\sqrt{n}\right)$, and $\emptyset(.)$ probability density function (pdf) of the normal distribution with mean and standard deviation $(0,1)$. The probability of $\hat{C}_{pk} \geq c$ can be found as follows:

$$P\left(\hat{C}_{pk} \geq c \middle| C_{pk} = C_{pk_0}\right) = \int_0^{3C_p\sqrt{n}} G\left(\frac{(n-1)\left(3C_p\sqrt{n}-y\right)^2}{9nc^2}\right) f_y(y)dy \quad (10)$$

wherein $G(.)$ is the cumulative chi-square distribution and C_{pk_0} is a theoretical value. By including the previous developments, we can have the new pdf of Y: $f_y(y) = \emptyset\left(y + 3(\Delta_{Cpk})\sqrt{n}\right) + \emptyset\left(y - 3(\Delta_{Cpk})\sqrt{n}\right)$. Since, $C_p = Cpk + \frac{\delta}{3}$; therefore, $C_p = Cpk + 0.33$. Therefore, we have the probability of a particular value $\hat{C}_{pk}$ as function of Δ and δ:

$$P\left(\hat{C}_{pk} \geq c \middle| C_{pk} = C_{pk_0}\right) = \int_0^{3C_p\sqrt{n}} G\left(\frac{(n-1)\left(3C_p\sqrt{n}-y\right)^2}{9nc^2}\right) \emptyset\left(y + 3(\Delta_{Cpk})\sqrt{n}\right) + \emptyset\left(y - 3(\Delta_{Cpk})\sqrt{n}\right) dy$$

(11)

To consider that the process is not capable when, in fact, it is can be of great impact in the manufacture. The following hypothesis test was taken into consideration:

$$H_0: C_{pk} \geq C_{pk0}$$

$$H_1: C_{pk} < C_{pk0}$$

As for the present hypothesis test, we have:

$H_0: C_{pk} \geq 1.33$ (process is capable)

$H_1: C_{pk} < 1.33$ (process is not capable)

By equation 11, it was build the Table 1 that shows type I error for different values of δ $[0, 0.25, 0.50, 0.75, 1.00]$, n $[10, 20,]$, $C_{pk0} = [\ 1.33\ ]$ that is the limit value of acceptance or rejection of the hypothesis testing and the estimated value of $\hat{C}_{pk}$ $[1.00]$. Wherein if H_0 is rejected, the process has unacceptable capacity and it is below the Cpk_u. Table 1 shows that, for example, when $n = 20$, δ=0.25, $C_{pk0} = 1.33$, Cp=1.41 and $\hat{C}_{pk} = 1.00$, H_0 is rejected with error type I α=0.0370.

Table 2 – Comparative type I error for the C_{pk} hypotheses testing.

n	δ	C_{pk0}	Cp (Cpk_{max})	$\hat{C}_{pk}$	Type I error α (p-level)
10	0.0	1.33	1.33	1.00	0.1310
10	0.25	1.33	1.41	1.00	0.0924
10	0.50	1.33	1.50	1.00	0.0875
10	0.75	1.33	1.58	1.00	0.0850
10	1.00	1.33	1.66	1.00	0.0832
20	0.0	1.33	1.33	1.00	0.0521
20	0.25	1.33	1.41	1.00	0.0370
20	0.50	1.33	1.50	1.00	0.0320
20	0.75	1.33	1.58	1.00	0.0309
20	1.00	1.33	1.66	1.00	0.0301

With the results of Table 1, obtained by the probability function density developed, the practitioners can use it in hypothesis testing to approve machine in the supplier.

AN ILLUSTRATIVE EXAMPLE

In the previous section, we shown the development of theories for capability analysis of short terms production to evaluate the machine's ability to meet product requirements. In this section, we will show an application of the presented analysis. There are two strategies to use the proposed method. The first, given the sample size, the practitioner will determine the critical value for $\hat{C}_{pk}$ estimated, in function of error type I (supplier error) and of error type II (consumer error). Second, given critical value for $\hat{C}_{pk}$, we will determine the sample size. This example adopts the first strategy because the sample size was fixed in maximum twenty-six pieces.

A sample of 26 pieces were taken from a manufacturing process that produces parts used as car assembly components in short terms production. The products are rings of rubber, manufactured by a hydraulic press. Were evaluated three linear dimensions of quality characteristics of the product. The vendor and consumer errors were fixed in 5% and 10% percent, respectively error type I and II. The buyer does not want to buy the machine with C_{pk_0} minor 1.0 and he wants to C_{pk_0} larger than 1.5. The Table 2 shows that the recommended critical value for hypothesis testing is 1.226, with α=0.053 and β=0.105. The Figure 3 shows Operations Characteristic Curve (OCC) for example. The Table 2 and Figure 3, were build using the equation 11, where probability of acceptance $H_0: C_{pk} \geq 1.33$ is $P\left(\hat{C}_{pk} \geq c \middle| C_{pk} = C_{pk_0}\right)$.

Table 2 – Critical value to hypotheses testing of potential capability.

Sample Size	Critical $\hat{C}_{pk}$	C_{pk_0}	Pr(Accept H0)	Pr(Rejection H0)
26	1,226	0,85	0,014	0,986
26	1,226	0,90	0,030	0,970
26	1,226	0,95	0,059	0,941
26	1,226	1,00	**0,105**	0,895
26	1,226	1,05	0,172	0,828
26	1,226	1,10	0,260	0,740
26	1,226	1,15	0,364	0,636
26	1,226	1,20	0,478	0,522
26	1,226	1,25	0,592	0,408
26	1,226	1,30	0,697	0,303
26	1,226	1,35	0,787	0,213
26	1,226	1,40	0,859	0,141
26	1,226	1,45	0,911	0,089

Sample Size	Critical $\widehat{C}_{pk}$	${C_{pk}}_0$	Pr(Accept H0)	Pr(Rejection H0)
26	1,226	1,50	0,947	**0,053**
26	1,226	1,55	0,971	0,029
26	1,226	1,60	0,984	0,016
26	1,226	1,65	0,992	0,008
26	1,226	1,70	0,996	0,004
26	1,226	1,75	0,998	0,002
26	1,226	1,80	0,999	0,001
26	1,226	1,85	1,000	0,000

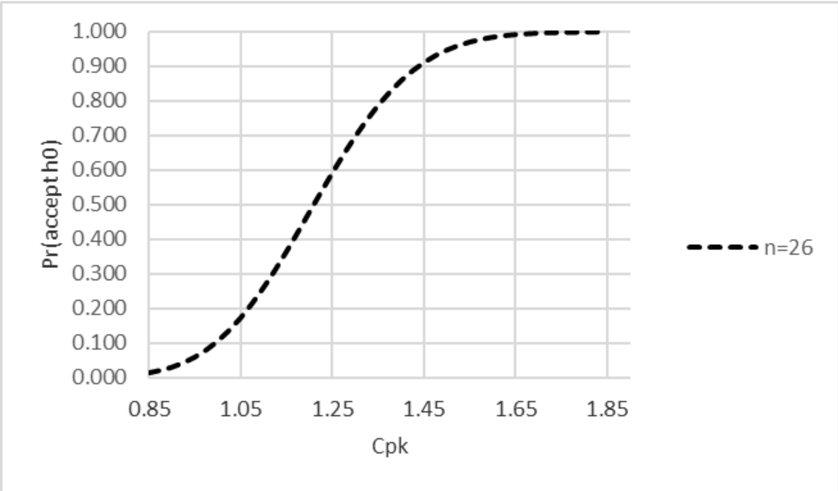

Figure 3 – OC curve with the probability of acceptance of the potential capability process.

For the characteristic thickness the process performance index calculated were $\widehat{\boldsymbol{Cpk}} = \mathbf{1.241}$. For economic reasons, Cpk ≥ 1.33 is considered an acceptable performance capability, and an unacceptable is a Cpk < 1.00. The practitioner will test the following statistical hypotheses:

$$H_0: C_{pk} \geq C_{pk0} = 1.00$$

$$H_1: C_{pk} < C_{pk0} = 1.00$$

How the Cpk<1.00 is unacceptable, then the buyer does not want to accept the machine with a capability index lower than 1.0. Figure 4 shows the OCC for a range of critical value of the Cpk, with the assumption of Cpk_0=1.00. Using Figure 4, and observing that Cpk estimated was 1.241, it was recommended approved the machine (accepted null hypothesis).

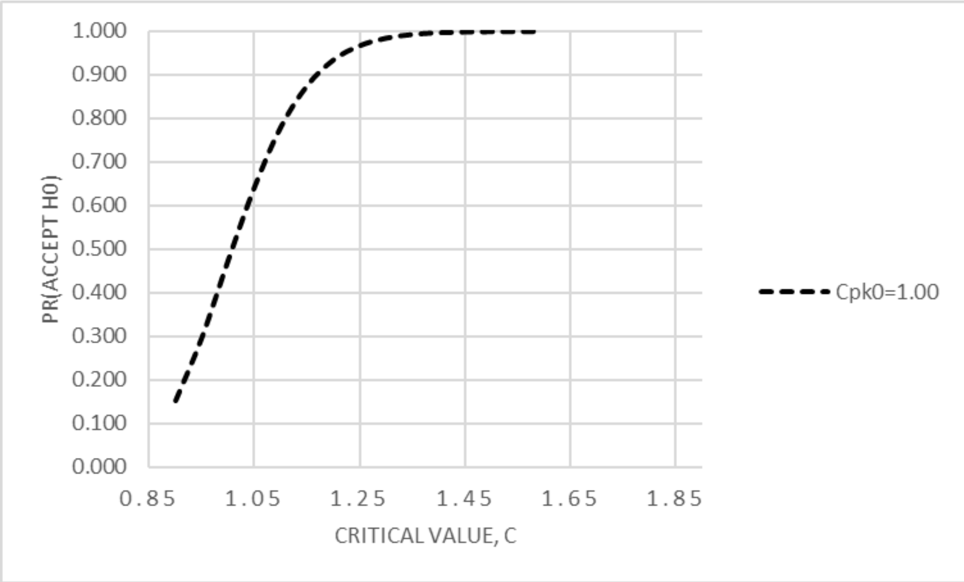

Figure 4 – OC curve for sample size of 26 with the probability of accept H_0, for Cpk_0=1.00.

CONCLUSION

The capability indexes are used for short-terms production analysis in testing at the machine supplier, initial manufacturing and pre-production. By this reason, and considering that these indexes have been widely used in industries, the proposed methods are presented to assist in a more assertive decision about the machine's ability to meet product requirements even when there are not a large number of products for evaluation, ie small lots (or small sample sizes) have to assist in decision making.

The technical literature has not paid attention about short-time capability analysis process, especially in supplier machine, whose analyses are done before the installation of the equipment in the buyer industrial plant. In this case, the sample size to analyse the capability is small, and the technician who designed these studies generally do not have tools and methods based on statistics to decide whether the equipment can produce to meet the product requirements.

The proposed method uses statistical hypothesis testing and building a schema for practical use. With this propose, it was derived an equation for the probability distribution of Cp/Cpk with estimated parameters. Using hypothesis testing, the method provide a operating characteristic curve for the acceptance probability of process capability index.

AKNOWLEDGEMENTS

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Control Chart and Capability Indices:
Systematic Literature Review

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ABSTRACT

Purpose – The objective is to identify how the literature is evolving on acceptance control charts and on control charts that combine process capability indices for decision making.

Design/methodology/approach – The paper proposes the accomplishment of a systematic literature review (SLR) for the identification of the main papers in the subject.

Findings – The SLR identified the period with publications on the subject, which allowed to affirm that the subject is currently relevant and there is a concentration of publication in the last years. It was also possible to identify the main authors and journals that can be references in the treated subject.

Research limitations/implications **–** A limitation was the use of only one database for the search, despite being an internationally recognized base, may not include important papers for the subject. Future studies can expand the search and deal more in depth with the papers found.

Practical implications – The main contribution was the identification of the main themes in which it is possible to put together the papers found. These themes are the use of acceptance control chart, control charts for capability indices, control charts with capability indices (jointly treat control charts and capability indices for greater process control efficiency) and other related issues.

Originality/value – The paper contributes with the identification of studies that correlate control charts and capability, allowing a general idea of the literature in the subject. It was possible to identify the trend of study within each of these themes and to perceive variations of the application of the different charts of control.

Paper type: Literature review

Keywords: Capability index, Acceptance control chart, Systematic Literature Review

INTRODUCTION

Statistical Process Control (SPC) is an essential element of the process control system, and it comprises a set of statistical techniques that are used to monitor and improve production processes and are applied to many industries (Baker and Brobst, 1996; Graves et al., 1999; Chakraborti, 2006; Jensen et al., 2006; Elg et al., 2008; Yu and Liu, 2011; Yang et al., 2012; Castagliola and Wu, 2012; Castagliola et al., 2009). SPC, including control charts, has been used to improve the quality of manufacturing products and processes worldwide (Castillo and Montgomery, 1994; Woodall and Montgomery, 1999).

In 1957 Freund introduced the modified acceptance control chart, which combines the traditional control chart with acceptance sampling in addition to the usual ability to signal special causes. Mohammadian and Amiri (2013) affirm that the acceptance control charts are used to monitor capable processes in which the nonconforming fraction of the produced items is low. The acceptance control charts are intended to monitor the fraction of nonconforming items that exceed specifications (Montgomery, 2009).

The acceptance control chart has a different concept from the control chart that is based on control limits. The acceptance control charts limits are based on the specification limits and this acceptance control chart are recommended for very capable processes, where the natural dispersion of the process is much less than the dispersion permitted by the specification limits of the product characteristics (Woodall, 1985; Wesolowsky, 1992; Steiner and Wesolowsky, 1994; Wu, 1998; Castagliola et al., 2009; Ahmad et al., 2016). As the process capacity is high, some changes in the process mean, caused by some explainable factor, are allowed, and in this chart a production of a small number of nonconforming items is accepted (Steiner and Wesolowsky, 1994; Mohammadian and Amiri, 2013). The process average may change but since the process is very capable, the process mean has sufficient displacement to move before an unacceptable number of defective items is produced (Steiner and Wesolowsky, 1994; Mohammadian and Amiri, 2013).

The classical concept of control charts recommends stopping the process when there is an indication of special causes, in order to keep the production process at a stable variation level. However, there are cases in which it is not financially viable to intervene, even in the presence of special causes and specially with high capability indexes. A process control system must consider making economic decisions, about the quality of the process outcomes (Montgomery, 2009; AIAG, 1991). Small changes in the statistical parameter over time, for example in the mean, may have little or no practical importance (Woodall, 1985).

The control chart should perform in a way that there is small probability of stopping the process when it meets acceptable customers and project requirements; on the other hand, should be high detection probability when the process does not meet the acceptable customers and project requirements. This proposition allows defining practical significance as when the process meets the customers' requirements, but it is not in-control. In other words, it means that a small deviation from the stable process condition may be acceptable. These situations occur when the process has high capability to meet the project requirements.

Process capability indices, such as Cp and Cpk, have been proposed in the manufacturing industry to provide numerical measures of whether a process is capable of producing items within the specification limits (Ahmad et al., 2016; Pearn and Lin, 2004). Garcia-Diaz and Aparisi (2005) argue that it is common to find industries that have process capability indices, Cp and Cpk, greater than two. According to these authors, the process capability indices may be used to create in-control and out-of-control regions in the control chart and this control chart design can assist in deciding whether or not to stop the process for corrective actions.

Control charts may be developed using the process capability indices (Cp and Cpk) in order to establish and monitor the process through control charts based on the combination of two control mechanisms, namely: the control limits and the capability indices (Subramani and Balamurali, 2012). The modified control chart limits are used in situations where the natural variability is considerably smaller than the dispersion of the specification limits, i.e. the Cp, Cpk indices are much larger than 1.0.

For all of the above, it is important to identify how the literature is evolving on acceptance control charts and on control charts that combine process capability indices for decision making. The article proposes the accomplishment of a systematic literature review for the identification of the main papers in the subject.

METHOD

The literature review is the process of identifying, collecting, evaluating, analyzing and synthesizing a set of scientific publications, with the purpose of creating a theoretical-scientific basis on a particular subject researched (Levy and Ellis, 2006).

The review can be carried out through a process approach, containing inputs, processing and outputs, where the processing encompasses the knowledge and understanding of the literature, application of the review, analysis, synthesis and evaluation of the information obtained from the literature (Levy and Ellis, 2006). The Systematic Literature Review (SLR) is distinguished by implying scientific rigor in the way the review is conducted, so that there are no gaps or trends of the researcher and that the research is based on evidence (Tranfield et al., 2003).

According to Biolchini et al. (2007), the SLR must have planning, execution and analysis. Travassos and Biolchini (2007) emphasize the importance of planning, which consists in the elaboration and validation of a protocol in which the following items should be defined: the SLR problem, the question that must be answered with the review, the databases that will be explored, the languages of the publications, selection of which terms are most appropriate for the search, and criteria for inclusion and exclusion of publications for SLR (Travassos and Biolchini., 2007).

After performing the SLR protocol, the protocol steps must be performed, which involves the search and selection of publications (Travassos and Biolchini, 2007). After approval of the execution of the research, the last step, which includes the extraction and synthesis of the data for analysis (Travassos and Biolchini,2007).

The research protocol was elaborated so that the question to be answered was: in what way is there relationship between control charts and process capability for process control and improvement? For the search we chose the Web of Science base, for gathering important journals in the area and for being a recognized base worldwide. We also decided on the ((“control chart*”)AND((“capability”)))OR(“acceptance control chart*”)OR(“modified control chart*”) search string. No delimitation of language or search period was made.

The acceptance criteria for publications were: journal paper and present some kind of relationship between capability and control chart in the abstract or title. The search returned 427 publication results, when only journals papers were selected, the number found was 310. The search period was the maximum allowed by the base, from 1945 - current (january of 2018). The 310 articles had their titles and abstracts read, of these 34 were selected for further analysis and are discussed in this study.

As two broad terms were used for the search “control chart” and “capability”, several papers about control charts applications and capability analysis were returned, these were not considered for the study, so the exclusion criteria were papers that applied control charts and capability but did not connect the two themes.

RESULTS

The temporal analysis of the publications can be seen in Figure 1, there was an evolution of the number of publications in time, and the year 2017 was the one that presented the largest number of publications. The first publication is from the year 1981 with the theme Acceptance Control Chart. Specifically, on the subject of Access Control Chart, there are publications in the years 2013, 2005, 1998, 1994, 1992, 1190 and 1981, one publication each year.

The sources of the articles were analyzed, and five journals present more than one article about the subject. We identified 27 journals, which can foster research in the area and be sources of searches related to the topic (Table 1).

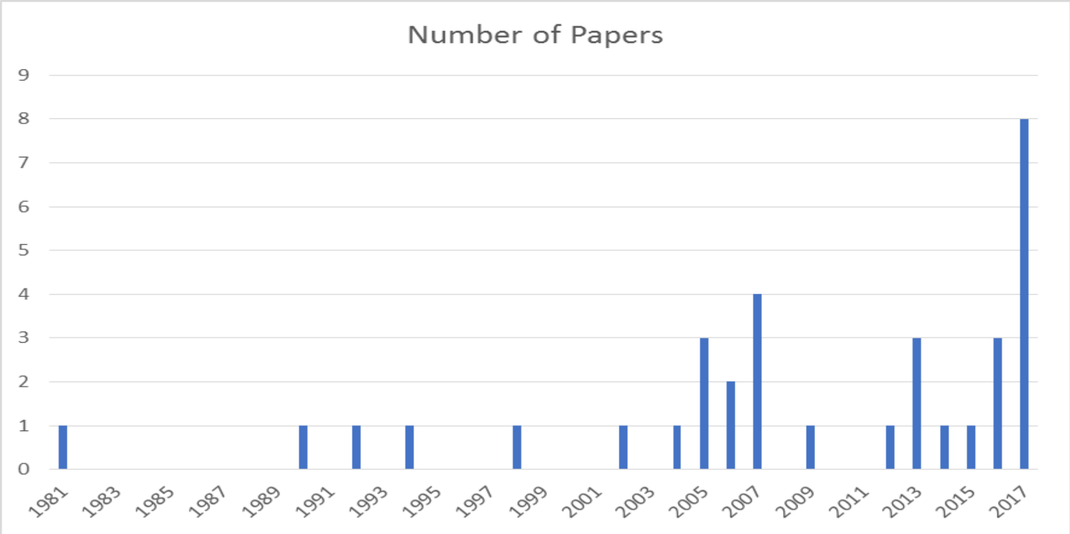

Figure 1 – Number of papers found in the Systematic Literature Review.

Table 3 – Sources of the Systematic Literature Review.

Journal	Number of Papers
International Journal of Production Research	4
Quality and Reliability Engineering International	3
International Journal of Advanced Manufacturing Technology	2
Quality Technology and Quantitative Management	2
Transactions of the Institute of Measurement and Control	2
Journal of Separation Science	1
Communications in Statistics-Simulation and Computation	1
South African Journal of Industrial Engineering	1
Sequential Analysis-Design Methods and Applications	1
Journal of Statistical Computation and Simulation	1
International Journal of Quality & Reliability Management	1
Journal of Advanced Mechanical Design Systems and Manufacturing	1
Journal of Reliability and Statistical Studies	1
Communications in Statistics-Theory and Methods	1
Physics in Medicine and Biology	1
Iranian Journal of Fuzzy Systems	1
Australian & New Zealand Journal of Statistics	1
Quality & Quantity	1
International Journal of Production Economics	1
European Journal of Operational Research	1
IIE Transactions	1
Journal of Applied Statistics	1
Journal of Manufacturing Systems	1
Journal of the Royal Statistical Society Series C-Applied Statistics	1
Technometrics	1
Journal of Quality Technology	1

The main authors were also identified, in total 71 authors were found, however only 12 (Table 2) have more than one publication in the subject. Four main subjects were identified in the search: creation of control charts for the capability indices, control charts with limits that use the capabilities indices, pre-control charts and acceptance control charts.

Table 2 - Authors identified in the Systematic Literature Review.

Authors	Number of papers
Aslam, M.	5
Jun, C.-H.	4
Ahmad, L.	3
Chatterjee, M.	3
Pearn, W. L.;	3
Wesolowsky, G. O.	3
Amiri, A.	2
Chakraborty, A. K.	2
Chen, K. S.	2
Chen, H. T.	2
Riaz, M.	2
Wu, Z.	2

Acceptance control chart

Acceptance control charts propose a relation between capable process and low number of nonconformities items, that is, the capability of the process influences the analysis; it establish control limits based on specification limits for capable processes and it is permissible the mean to vary (Wesolowsky, 1992; Steiner and Wesolowsky, 1994). The acceptance control chart is applied in situations that a X-bar chart is used to control the fraction of nonconforming items produced by the process and where the dispersion of the process is much less than the specification limits (Wu, 1998; Chou, Chen and Liu, 2005).

The first papers found in the Web of Science that are related with the subject date from 1981 and 1990. Wesolowsky (1990) worked with acceptance control charts for correlated processes and Mhatre et al. (1981) studied acceptance control charts based on normal approximations to the poisson-distribution.

Wesolowsky (1992) studied acceptance control charts where two or more independent processes are responsible for a product, or multi characteristics of a product need to be controlled for simultaneous conformity to specification. Steiner and Wesolowsky (1994) designed acceptance control charts when a product has multi correlated characteristics that must be conform to specification limits for the product to be acceptable. The authors find the control limits and sample sizes for each of the multiple characteristic that minimize sampling costs.

Wu (1998) proposed an adaptive acceptance control chart in which the sample size can be adjusted during the process control and the average number of measurements may be significantly reduced. Chou et al. (2005) studied the appropriate control limits or sample size for the acceptance control chart under non-normality. Mohammadian and Amiri (2013) discuss the economic issue of this type of control chart, controlled changes in the process mean are allowed since it does not generate a high number of non-conformities. The acceptance control chart can consider the cost of sampling, detecting, investigating out-of-control signals and the correction of special causes, which can result in economic advantages (Mohammadian and Amiri, 2013).

Control charts for capability indices

Aslam et al. (2017) and Aslan et al. (2017) emphasize the importance of control charts to control the quality characteristic and to enhance the efficiency of the manufacturing process and the quality of the products. The process capability indices and analysis are well known and widely used as a measure of the process to assess the ability to produce items within specification limits of a product (Chatterjee and Chakraborty, 2015). Process capability control charts were developed because they allow continuous assessments provide managers with information enabling process improvements and meeting customer needs and product specifications (Montgomery, 2009).

A type of control chart that considers the process capability indexes is the pre-control chart. Pre-control charts has the objective to evaluate the process capability during the set-up stage or for the initial evaluations and to detect process changes in production stage (Pan, 2007; Matias et al., 2004). The information of pre-control should be used to adjust the process generating feedback and actions (Matias et al., 2004). Jarrett and Pan (2007) focus on multivariate pre-control charts and compared it with Hotelling T2 control charts. Matias et al. (2004) proposed new alternatives to the pre-control, particularly in its initial phase when try to certify if the process is capable.

Traditional control charts fail to analyze situations where the process is capable but not stable (Ganji and Gildeh, 2016; Gildeh and Angoshtari, 2013; Castagliola and Vännman, 2007). Capability indices can be monitored instead of the the traditional statistics such as the mean, median, standard deviation, or range (Castagliola and Vännman, 2007). The limits used for the monitoring of capability indices are based on the capability level assumed for the process and the approach is efficiently to monitor capable processes and in detecting changes in the capability level (Castagliola and Vännman, 2007).

Chen et al. (2007) raise the issue of unilateral limits of capability especially C(pl) and C (pu) limits. The authors state that process capability index control chart can be used to monitor the stability of process and to monitor the quality of a process, they construct the control chart of unilateral specification index C (pl) and C (pu) with the objective of controlling the stability and the capability. Chatterjee (2017) describes a process capability control charts to enable continuous evaluation of a process, the author proposed a plug-in estimator of Cpk based on the information of the following charts - X-bar/R and X-bar/S considering that each of the samples are drawn independently. In other paper Chatterjee and Chakraborty (2016) studied the expressions of some process capability indices considering unilateral specification limits and the relationship with proportion of nonconformance. The author designed the process capability control charts for these process capability indices. In other paper of the authors they designed the process capability control charts of C(pu) and C(pl) (capability indices for unilateral specification limits) based on the uniformly minimum variance unbiased estimators and in their distributions (Chatterjee and Chakraborty, 2015). The proposed process capability control charts are efficient to identify the changes in process capability (Chatterjee and Chakraborty, 2015).

The capability control charts have the potential to generate an improvement in economic performance (Morita et al., 2009). Cpm capability index includes an economical concept since it is based on Taguchi's quality loss (Morita et al., 2009). The process capability index Cpm is effective in analyzing manufacturing systems, the index is composed of the specification limits of items and the deviation with respect to a specified target value of items (Morita et al., 2009). Cpm has been called the Taguchi index due to the definition of Cpm is identical with that of the Taguchi’s quality loss (Morita et al., 2009). Morita et al. (2009) evaluate an operating cost of Cpm control chart they discuss about an optimal operating plan observing sample size and sampling interval.

Gildeh and Angoshtari (2013) argue that complex processes may not have stability, considering that the process cannot be analyzed when they are unstable, this creates a problem for the process. For this reason, the authors discuss Cpk based on fuzzy data and they proposed control charts that are constructed by the alpha-cut sets of Cpk for the natural instable manufacturing processes with fuzzy normal distributions.

The process capability control charts allow to analyze the process's ability to meet or exceed customer requirement or product specification (Liao, 2016). Liao (2016) developed a process capability control charts for non-normal processes.

Control charts with capability indices

It is possible to find companies with process in which the value of the capability indices is larger than two (Garcia-Diaz and Aparisi, 2005). In this situation the detection of very small shifts may not be of interest considering practical as well economic issues (Garcia-Diaz and Aparisi, 2005). The objective was to design a chart capable of quickly detecting the shift that is important for detection whilst having a low probability of false alarms for the shifts it is not important (Garcia-

Diaz and Aparisi, 2005). Therefore, the authors relate the process capability and control charts for better decision making.

Zhang et al. (2002) presented a new algorithm for designing the X-bar/S control charts and it allocates the detection power in an optimal manner and associates the in-control and out-of-control process conditions with the process capability index, Cpk. That is, when Cpk decreases the control charts will give a signal in a short time period making chart performance more effective (Zhang et al., 2002).

Chen et al., (2007) emphasize the importance of control charts for monitoring process stability, but as others emphasize the issue that a stable process can produce products out of specification. Pearn and Wu (2006) state that capability indexes for processes with multiple characteristics are neglected in the literature. Chen et al., (2007) developed a multi-process performance analysis chart with zones based in capability and in interval estimates of these indices. Pearn and Wu (2006) also developed a chart for analyzing the performance of multi-process product useful in making decisions for capability testing. A similar question was investigated by Pearn et al. (2005), they proposed the Cpmk multi-process performance analysis chart combining the accuracy index Ca to access the performance of multiple manufacturing processes.

Braun and Han (2017) affirm that the improvement in data visualization is critical for the communication of information about a process and proposed the junction of stability and capability in one plot. Adeoti and Olaomi (2017) proposed a control chart for variables based in a process capability index considering the Downton estimator with a specified Cp value and the chart can hand with control and capability simultaneously.

Aslam et al. (2017) proposed a technique to join the merits of the attribute and the variable control charts. The control chart uses the concept of in-control and out-of-control and the authors argue that control chart has a satisfactory performance. Aslam et al. (2017) affirm that the attribute and the variable control charts are unsatisfactory for process monitoring and for this reason they proposed a new technique. Ahmad et al. (2014) proposed a the Shewhart X-bar chart in combination with the process capability index Cp with repetitive sampling and the chart has a better performance than with single sampling in detection of changes in the mean of the process.

Aslam et al. (2017) propose a control chart using the process capability index when the quality characteristic follows the exponential distribution. Ahmad et al. (2016) also proposed a control charts of repetitive group sampling based on the process capability index Cpk, the aim of the chart is monitoring the process average when the quality characteristic follows a normal distribution.

Analyzing and comparing the proposed control chart it was found that it is effective in detecting small shifts in the mean of the process (Ahmad et al., 2016).

Oprime and Mendes (2017) discuss the smallest number and size of the sample that detect the out of control state of a process and ensure a capability index – Cpk – that meets the product specification limits.

Other related issues

Plante and Windfeldt (2012) proposed a method to monitor highly capable process, the method is based in monitoring the probability of the next item is out of the specification limits. The authors affirm that the method help to evaluate risk. Chao and Lin (2006) also relates capability and control charts for automatic gauge and stresses questions about economic performance.

Sanghangthum et al. (2013) proposed an operational procedure to analyze tolerance limits and action limits in combination. The procedure is to first ensure process control using the I-MR control charts and the action limits are determined using the Cpm process capability index, but to use it the process must be in-control.

Related to acceptance sampling plan for products Arif et al. (2017) proposed an acceptance sampling plan in problems with multiple independent manufacturing lines using exponentially weighted moving average (EWMA) statistic of the process capability index. And the authors affirm that the use of the proposed plan can minimizes the cost and time of inspection.

Oliva and Martinez (2017) evaluated the usefulness of control charts in combination with the process capability indices, Cpm and Cpk, to control an analytical method.

Overview of collected data

It was possible to identify that the papers found presented consonance with three main themes. One of them is derived from the very choice of the keywords of the search, "acceptance control charts", the others were identified in the reading of the papers, which would be control charts for the process capability indices and charts that use the indices for better decision. There was also a fourth strand, which contained papers that addressed other issues. The papers are presented in Table 3.

Table 3 – Papers and related themes.

Themes	Papers found
Acceptance Control Chart	Mhatre et al. (1981); Wesolowsky (1990); Wesolowsky (1992); Steiner and Wesolowsky (1994); Wu (1998); Chou et al. (2005); Mohammadian and Amiri (2013)
Control charts for capability indices	Matias et al. (2004); Pan (2007); Castagliola and Vännman (2007); Chen et al. (2007); Morita et al. (2009); Gildeh and Angoshtari (2013); Chatterjee and Chakraborty (2015); Liao (2016); Chatterjee and Chakraborty (2016); Chatterjee (2017)
Control charts with capability indices	Zhang et al. (2002); Garcia-Diaz and Aparisi (2005); Pearn et al. (2005); Pearn and Wu (2006); Chen and Chen (2007); Ahmad et al. (2014); Ahmad et al. (2016); Adeoti and Olaomi (2017); Aslam et al. (2017); Aslam et al. (2017); Braun and Han (2017); Oprime and Mendes (2017)
Other related issues	Shiau et al. (2006); Plante and Windfeldt (2012); Sanghangthum et al. (2013); Arif et al. (2017); Oliva and Martinez (2017)

An important fact was that many authors stress the use of acceptance control charts due to the economic issue and cost reduction (Wesolowsky, 1992; Steiner and Wesolowsky, 1994; Mohammadian and Amiri, 2013), the same occurs when the subject is control chart for capability indices (Garcia-Diaz and Aparisi, 2005; Morita et al., 2009) as well as authors who point out the same issues when they study about the joint use of control charts and capability and other related issues (Zhang et al, 2002; Chao et al., 2006; Arif et al., 2017). This shows that efficiency and better decisions for managers are important issues when considering correlate control charts and capability indices.

CONCLUSION

The Systematic Literature Review allowed the identification of the period with publications on the subject, which allowed affirming that the subject is currently relevant, since and there is a concentration of publication in the last years. It was also possible to identify the main authors and journal that can be reference in the treated subject.

The main contribution was the identification of the main themes in which it is possible to put together the papers found. These themes are the use of acceptance control chart, control charts for capability indices, control charts with capability indices (jointly treat control charts and capability indices for greater process control efficiency) and other related issues.

It was also possible to identify the trend of study within each of these themes and to perceive variations of the application of the different charts of control, considering unilateral limits, other estimators for the indices of capacity, different distributions of the data, correlated data, among others. Therefore, the proposed article aims to contribute with the theme allowing a general idea of the literature in the subject.

Some limitations exist in the present study as the use of only one database for the search of the papers, despite being an internationally recognized basis, may not include important studies for the subject. Future studies can expand the search and also deal more in depth with the papers found.

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Collaborative Networking of Researchers in Quality: A Portuguese Case

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ABSTRACT

Purpose – Experience of a Portuguese network of researchers in quality is presented, and future development is discussed based on literature related to business collaborative network.

Design/methodology/approach – Literature review based on company's networks was used whenever applicable, and it was adapted to individual networks. A critical analysis of the network is carried out, bearing in mind development along its functioning for 9 years.

Findings – The experience shows some positive achievements (ex. a scientific journal), and some difficulties (ex: common projects). However, the most important issues for future sustainability are related to management dimensions like structure, strategy, earnings, relationships and performance.

Research limitations/implications – Higher Education Institutions are increasingly competing for resources and students. Small Research and Development (R&D) teams, such as quality, face relatively more difficulties than large ones. Collaborative networking can be a good solution.

Practical implications – Conclusions and reflection may interest other countries and regions.

Social implications – The weak mutual knowledge among quality researchers, as well as the lack of synergies between groups and individuals, can be a seriously weak point for development and scientific production. Coopetition can be possible and advantageous.

Originality/value – Research on quality issues is often carried out in small R&D teams. Collaborative networking can improve both theoretical and practical development.

Paper type: Conceptual

Keywords: Quality, Network, Collaborative, Research

INTRODUCTION

This paper describes the experience of a Portuguese network of researchers in quality, mainly composes of higher education teachers. It reports the development of the network till now, and reflects on the mains results, learned lessons and future perspectives.

In the year of 2010 a small group of researchers carried out the first meeting, aiming to discuss some issues such as the relevance of a Portuguese conference and the adequacy of networking. It was decided to build the RIQUAL (Network of Researchers in Quality), mainly focused on networking and fostering Research and Development (R&D) in younger generations. So, an annual meeting (not a conference) is carried out, where Msc and Phd students are invited to show ongoing or finished thesis and projects. They receive advices and insights from senior members to develop and or improve.

During the last nine years, some initiatives have been developed, highlighting: a) the scientific journal TMQ-Techniques, Methodologies and Quality, the only magazine in Portuguese language dedicated to quality and related areas (www.publicacoes.apq.pt). The journal accepts articles written in Portuguese, Spanish and English; b) Publications website. This platform was designed to accommodate other technical / scientific journals. c) Annual meetings. In 2018 will be held the 9th meeting, which have been happening without interruption. We estimate that they have already been used by about 500 participants. The proceedings of these meetings are published on the publications website. d) The Integrated Information and Corporate Knowledge Platform (IICKP*)*. This platform is being designed to promote cooperation and collaboration among members, as well as to know the technical and technological capacity of territorial or sectorial areas and to promote the development of studies and the practice of benchmarking. A partnership started in 2013 with the Polytechnic Institute of Setúbal, to which the Technological Center of Ceramics and Glass has joined since 2017. d) SCOPE - Center for Organizational Development Studies. The Study Center was constituted as an internal structure of the Portuguese Association for Quality (APQ) as an instrumental for accessing funds, establishment of partnerships and specific projects. e) Quality and Network Observatory. Since early the network has reflected on the need to play some role in the observation and critical analysis of research practices and results in the quality field. In the context of the annual meetings these subjects were discussed and it is hoped that they will continue to find a solution.

Bearing in mind the period of nine years, the main achievements as well as the found difficulties, we considered appropriate to look for other networks, aiming to define the best framework for future development.

The first difficulty came from the literature review, because this is focused on company's networks and not on professionals. So, we used that literature based on companies, and always possible adequate and applicable it was adapted to networks for individuals. Based on the main models of governance, and in the critical analysis of the authors to their own accumulated experience in the coordination of the RIQUAL a model was identified and proposed (Figure 1).

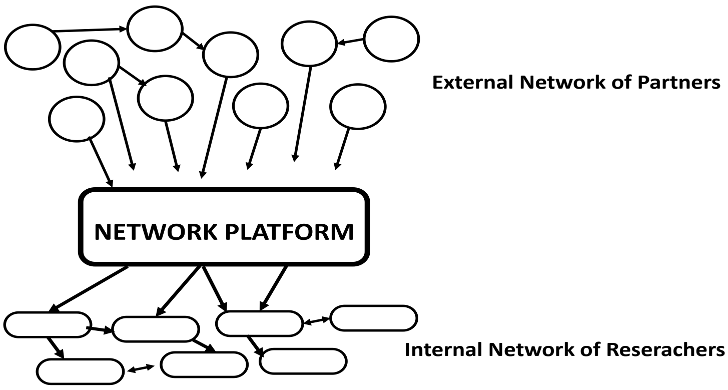

Figure 1 – Future perspective of the network.

Bearing in mind that the members of the RIQUAL are essentially academic researchers, we considered appropriated to characterize the context of higher education institutions and the levels of competitiveness to which they are subject in terms of scientific production, because this type of networking helps.

So, research work and this paper are structured as follow: Firstly, the context of higher education (HE) is characterized as well as the research and development teams in Portugal. The competition between higher education institution (HEI) and also among researchers appears in this context as a new conditioning dimension for research work in quality issues. For small research and development units, such competition becomes even more problematic, and it is compounded if efforts are dispersed and without synergies. In addition, there are other more important issues related to the need for theoretical development of quality, especially in terms of the topics to be researched.

Secondly, some typical purposes are identified for a collaborative network such as some type of observatory-level tasks and carrying out partnership projects. In addition, the network may be in the best position to study the teaching-learning processes in higher education (eg. pedagogical approaches, study cycles conception, success, dropout, employability). It may not be difficult to recognize that quality techniques and methods are taught, but these are not practiced or researched.

Thirdly, the publication of the ISO Standard 44001: 2017, Collaborative business relationship management systems - Requirements and framework proves that collaborative networks can be managed as a management system.

Finally, the issues of cooperation and competition are discussed on the basis of the literature on networking for business, aiming to draw lessons to networks of professionals.

THEORETICAL BACKGROUND

Context of Higher Education Institutions

Higher Education Institutions (HEIs), in particular Portuguese ones, are faced with a new context characterized by: (1) a market logic with a view to an increasingly better strategic and competitive position; (2) a broad market at European and world level where physical borders are no longer limited, and national and international mobility is assumed as one of the pillars of development; (3) new management models, where resource management and quality are particularly relevant; and (4) a new accreditation processes, both at course level and at institutions level.

The Bologna process, which is the European movement for the modernization of higher education, is naturally one of the main responsible for this new context, providing new perspectives for pedagogical methodologies and practices, increasingly focused on students, autonomous study, in the research capacity and in the accompanying study, consubstantiating "the transition from a system of education based on the transmission of knowledge to a system based on the development of students' competences, in which the components of experimental or project work, among others, and the acquisition of transversal competences must play a decisive role "(Decree-Law no. 107/2008 of 25 June). This movement brought new challenges to HEIs, based on three fundamental pillars: (1) the degree system; (2) quality assurance; and (3) degree recognition and mobility (Heitor, 2009).

These new perspectives are generally considered to be difficult to implement, many of which are in support of the statement that "it is always difficult to change people and institutions. Such changes to be profound and meaningful, require financial and human resources, and require time to be internalized in the culture and institutional practice” (University of Minho, 2008). However, it has been widely recommended by institutions such as the European Association for Quality Assurance in Higher Education (ENQA) and the European Association University (EUA) and it is consensual in the academic and political environment, the need for HEIs to adopt systems of quality and improvement to which effective decision-making processes are associated, so that the improvement process has a concrete effect on the administrative, financial, scientific and pedagogical activity of these institutions. According to the EUA, there is a need for HEIs to develop a process for quality, with a proper information strategy in order to promote a culture of internal quality, where quality units are not the only ones responsible for this quality but including responsibility of all the elements of the organization.

The important thing is that each HEI sees itself as a truly autonomous institution, defining its quality parameters as long as it has internal and external performance indicators associated with education and research (EUA, 2009). "Higher Education plays or should play a special role in the global challenge for building the new knowledge-based society. Particular attention should be paid to the consolidation of the pillars on which its evolution should be based, namely the pillar of citizenship, the culture pillar, the pillar of science and the pillar of innovation, the latter integrating quality and competitiveness, which are assumed to have efficient management models and timely evaluation" (Simão et al, 2002).

On the other hand, most HEIs are very concerned about traditional approaches to promoting excellence in education, such as diplomas, work experience, copyrights, patents and research activities. They may also not be receptive to new management approaches, such as quality management systems (QMS), identified as coming from the business world (a sufficient sign that they are not applicable to HEIs). Kells (1995) stresses that the academy has been aggressive to external interference on the institution, and on the introduction of new management techniques. Experience has shown that their resistance has been successful. According to Hackman & Wagerman (1995) "Implementation (of QMS) is easy, but the old organizational structures and systems remain untouched and continue to generate the same dynamic of previous behaviour" (p.336).

Supporters of chaos / complexity theory have a very dissonant view, suggesting that instead of trying to repair the old image of the university, we must be involved in a global initiative to link students to multiple sources of information and local and regional reality (Dervitsiotis, 2003; Snyder et al, 2000). Youth tends to view the world as interconnected networks of relationships, while universities often still see it as segmented fields of knowledge and experience.

The academy performs multiple activities, all of which have significant impacts on the quality of teaching-learning systems. First, it develops knowledge at the level of the scientific areas that shape the educational activities. In addition, they educate the teachers themselves as well as the teachers of the teachers.

At the level of the economic and social environment, it holds and develops the knowledge and the instruments for analysing those realities, which conditions the planning activities of the teaching-learning systems and processes. Particularly important, the academy accumulates experience and knowledge in methods and pedagogical approaches, key tools for planning, operation, monitoring, evaluation and improvement of processes.

In the particular case of quality, it also has an increasingly important role in designing new methods for quality control and management. The field of education is a field with relatively little experience in applying the most characteristic techniques and methodologies of quality, so that the academy can not only apply them to itself but also study applications at other levels of education, and sectors of activity, systematizing practices, consolidating and broadening theories and approaches in general and in particular at the level of their teaching processes. This field can take advantage of greater experience in other sectors, adapting existing techniques and methods, and developing new ones, particularly useful to educational institutions.

In spite of the huge and important changes made in organizations, such as main process integrations, the elimination of activities / tasks that did not add value, many organizations did not essentially change their management. According to Walsh (1995), Deming noted that functional departmentalization of the different bodies of an organization constitutes the greatest obstacle to quality improvement. The objectives of processes that provide "customer and organization value" are often overlooked and deprecated in favour of the goals of the traditional functional areas. But Functional areas and processes have to coexist and cooperate (Hammer and Stanton, 1999).

All these characteristics, in our view, reinforce the need for structured approaches, namely approaches that look at HEIs as "a group of groups that are incompletely connected" (Weick, 2003, p.380) in which the functional areas, such as departments or scientific areas, do not appear as a discrete and isolated set of well-defined boundaries, but instead appear as flexible and interconnected groups of information flows, underpinning the adoption of transparent management models that allow the integration of economics and a humanistic vision and give greater decision-making power (Simão, 2002).

Today, quality has new areas of development and therefore new contributions to competitiveness of business and society. The evolution of products, markets and technologies has created new challenges, such as:

a) The quality of services provided online. In these cases, quality systems must overcome the disadvantages caused by the lack of physical contact with clients / students / stakeholders, in particular through the quality of the site itself and the service delivery platforms.

b) New structural formats (eg. virtual and multidimensional organizations, cooperation networks). The quality function in this type of organization has to be rethought since there is not a single chain of command and action, the relations being more of cooperation and coordination. Eventual solutions will be to hand over the coordination to one of the partners, or to a joint committee.

c) Integration of services. In these cases, the situation is similar to the previous one with the advantage of having a stable structure around which several alternatives can be built.

d) Organization design. This will be an area of activity for some quality professionals.

e) Quality in unstable environments. The solutions to act in these environments should be as much as possible foreseen. However, since it is difficult to predict, several scenarios must be constructed, according to the forms of management that may be adopted.

The context and the dimension of these challenges imply new forms of organization for the researchers in the quality field, reason why the RIQUAL can be a good case study bringing relevant contribution.

Coopetition

The competitive environment allows and makes to challenge limits and achieve higher individual or collective performances wherever we are competing (Porter, 2001; Rolo Alves, 2015). However, competition at the level of Higher Education Institutions (HEIs) cannot be leaded solely or fundamentally by conflicts of interest and opportunistic behavior. In a time of networks, competition and concurrency have been replaced by a new market / social area perspective that highlights the joint opportunities, synergies and mutual benefits, and the advantages of a win-win-win strategy. Therefore, the terms coopetition, co-creation, co-working, are increasingly used. The concept of "network" is a relatively recent paradigm, a new form of co-management or co-operation.

The synergy and performance effects resulting from collaborative strategies represent an asset for all parties that have become more efficient and sustainable (Rolo Alves, 2015). As a consequence of this strategy of collaboration in a competitive environment, the term "coopetition" arises from the combination of the concepts of cooperation and competition and means: cooperate competing (Porter, 1996, Quaresma Dias, 2013). It translates a third approach in the relationship between entities, which simultaneously contemplates rivalry and cooperation, and the two opposing situations can coexist harmoniously (Osarenkhoe, 2010). For the success of cooperative relationships, trust, a key factor in transactions, contributes to important benefits in the cooperative relations between economic actors and other entities, either at upstream (purchase transactions) or at downstream (sales transactions), facilitating the communication process and contributing positively to the process of innovation and knowledge creation (Zhang and Huo, 2013).

Network flexibility, as proposed by Galbraith (1997), requires the organization to create an external capacity network complementary to its own internal network of competencies, which can even be established with competitors from the perspective of coopetition.

According to Sánchez (2003), the complexity of these phenomena leads the entities to cooperate for: (a) reducing and sharing Research and Development (R&D) costs; (b) ensuring the technology complementary to its key competences; (c) capturing the tacit knowledge and technology of partners; (d) shortening the life cycle of processes and products; (e) sharing the costs of product development; and (f) ensuring access to markets, qualified personnel and financial resources.

Some of the most important aspects of globalization are linked to the new Information and Communication Technologies (ICT). These seem to have been one of the main "engines" of acceleration of the globalization process (Aguin, 2003). In many respects, ICT represents the first "global" technological mutation that our societies have faced in their history (OECD, 1996 cited by Soete, 2000).

The selection of new technological paradigms may focus on the linkages between pure science and technological progress, and based on the criteria and means of research used by economic agents, on the constraints and uncertainties faced by innovators or on the clarification between invention and innovation. The empowerment of ICT in all processes of dematerialization of partnerships is nowadays a national design to which organizations must associate (Coates, 2000).

There are projects, activities or objectives that cannot be achieved individually, leading to the union of efforts between individuals and companies. Networks present themselves as the organizational solution best suited to the contemporary challenges that plague companies and current and future productive needs, which must consider efficiency, agility, resilience and sustainability as the critical goals to be achieved.

According to Ballou (2006), the growing interest in cooperation and partnership relationships arises from the fact that it is not possible for a single company to have control on all flows of materials or services, from raw material source to consumption. For example in R&D, it is not always possible for a group to have enough knowledge and technology to achieve project objectives.

The term network has several meanings and applies to several areas. At the computer level you may want to designate computer systems that are geographically separated from each other, interconnected by telecommunications, usually permanent. In social terms it means a set of relationships and exchanges between individuals, groups or organizations that share interests, which work mostly through Internet platforms.

In a business perspective it represents: strategic alliances between companies; economic cooperation agreements between countries; interaction between groups; set of contacts that an individual possesses, among others. At the level of organizational networks, it means a strategic interaction between companies (Lopes and Morais, 2012). By analogy, and at the level of a network of researchers, we can say that these are interactions between individuals and groups, who voluntarily accept common purposes, and wish to increase partnerships and synergies. Similar to business, researchers also tend to be part of one or even several networks.

While cross-industry alliances began to intensify in the high-tech industrial sectors since the 1980s (Baldwin, 2013), it is also expected that some forms of cooperation among researchers will develop in response to extra interests (personnel and professional) behind HEIs interests.

According to Vale et al. (2006), Lambert (2008), Bowersox, Closs and Cooper (2009) and Mattos and Laurindo (2012), competitiveness has ceased to occur between companies to occur between organizational networks. The evaluation methods of HEIs and their teachers (much based on the number of publications) have been encouraging competition also in terms of HEIs networks and to some degree among researchers.

Pires (2009), Cho and Soh (2010) and Christopher (2011) corroborate that the optimization of production and business management was shifted from competition between individual companies to competition between supply networks. If this situation holds true for companies, why not for individuals and knowledge workers? These can cooperate independently and autonomously, jointly developing projects and / or acquiring and sharing resources; or they can form a group of researchers that unit forces (eg. networks, associations, alliances, consortia or formal or informal groups). The establishment of partnership relations leads to the flexibility of the "productive" process of research, technical expertise and economies of scale.

The multidisciplinary of quality advises to bring together researchers from several areas of knowledge, develop methodologies for integrating efforts that can synthesize very specialized (vertical) knowledge of an area with specialized knowledge of other areas, in order to obtain cross-horizontal / horizontal knowledge.

To this end, there is a need for integrators / mobilizers who are neutral, credible, and influential and have specialized knowledge to start this process. This element can be an individual, an institution or a professional association (Carvalho, 2011). In the case under analysis, the Portuguese Association for Quality (APQ) has been playing this role by integrating RIQUAL as an internal structure.

In a virtual collaborative environment each partner contributes with their knowledge and each can reach their individual goal and with it contributes individually to the common goal. It also requires the acceptance of the differences between partners, tolerant attitude, adjustments of part, respect, trust, negotiation and non-hierarchical relations between the parties (Zacharia, Nix and Lusch, 2011; Cao and Zhang, 2011).

Mintzberg and Quinn (2001), Cohen and Roussel (2005), Mariani (2007) and Harrison and Van Hoek (2008) point out that in a hyper-competitive environment, companies should seek to develop relationships that foster sustainable competitive advantages for both parties , in an attempt to overcome their weaknesses or limitations, to the detriment of competition and price war whose impacts are always negative for the whole industry, crushing the profit margins of competitors and their own, translating into losses for both parties .

Similarly, hyper-competition between HEIs and researchers suggests that methodologies be found at individual level. Cooperation is considered to be positive and conducive to networking. At the level of market companies, so-called open innovation is another concept that has been used for activities that transform the needs of markets and society into products and services. At the R&D level it seems easier to call for open research.

The concepts are summarized in Table 1, and forms of cooperation according to the objectives are shown in Table 2.

Table 1 – Concepts

Typology of relationships	Description	Authors
Cooperation	It involves the division of tasks into sub-tasks to be carried out by multidisciplinary or mixed teams, with elements representing the various partners.	RCED (2007); Balestrin e Verschoore (2009); Zacharia, Nix e Lusch (2011); Cao e Zhang (2011)
Collaboration	It involves the division of tasks into independent sub-tasks, performed independently by each partner.	RCED (2007); Zacharia, Nix e Lusch (2011); Cao e Zhang (2011)
Competition	It happens when two or more companies that oppose and compete with each other for the same market, with identical or substitute products or services, strive to maintain leadership and gain market share.	Porter (1999); David (2012); Esteves e Ascensão (2011)
Coopetition	It means to cooperate competing and mirrors the relationship of companies that collaborate in certain projects and compete in others.	Porter (1999); Mariani (2007); Carvalho *et al.* (2010, 2011); Osarenkhoe (2010); Quaresma Dias (2013)

Source: Rolo (2015).

The presented types of cooperation can be grouped into three distinct areas of cooperation: (1) cooperation for research and development of new products; 2) cooperation in production and logistics; 3) cooperation in marketing and distribution.

Table 2 – Types of cooperation according to objectives

	Objectives
C*o-inform*	Identification of members and their competences; sources of information that the company uses to promote its own product or process innovations, as well as in promoting and improving communication between partners.
C*o-learn*	Development of training programs sponsored by the group to meet the interests of the network and employees.
C*o-market*	Organized activities to promote and sell services and products from the cooperation network.
C*o-purchase*	Joint acquisition of equipment and other resources.
C*o-produce*	Alliance to produce a particular product.
C*o-sale*	Alliance to sell a particular product / service.
Co-lobby	Defence of policies, legislation and programs of interest to the network.

Source: Adapted from Molina and Yoong, *apud* Pereira *et al*. 2007.

Technological innovation is increasingly a collective process with the participation of multiple actors (OECD, 1992, 2005). On the other hand, Pereira (2007, p.39) states that "the concepts of "network" and “community "are inserted in the more general context of collaborative networks, that is, a set of independent organizations or individuals interacting, using intensively collaborative processes aimed at achieving collective results through the joint execution of tasks, supported by collaborative IT. "

In the present case, researchers start by collaborating on information and learning, and later can collaborate in technological production and in the defence of group interests.

From another perspective, the network can be seen a set of nodes (companies, groups, individuals), each occupying a certain position in the network, that relate to each other through the flows of goods or information.

Casarotto and Pires (2001) present a typology based on flexibility where they distinguish between flexible networks and top-down networks. Considering the boundaries of the network, Wood Jr. and Zuffo (1998) classify organizations without borders into barrier-free, modular or virtual structures.

Roth et al., (2012), in their study on governance and management of interorganizational networks, had the goal to understand how certain conditions can influence the obtained results, analyzing aspects of the network as a whole and not as individual companies or simply relations between companies. In this study, it is emphasized the model called horizontal network, which presents some particular characteristics that distinguish it from other types of networks: there is no central coordination of a large company; decisions are usually taken by consensus or by the majority; most often they are formed by companies of the same sector; members can often be direct competitors. They present three models of network governance (Figure 2) from which, hybrid combinations and models can emerge: shared governance; governance with leading organization, and governance through a network administrative organization.

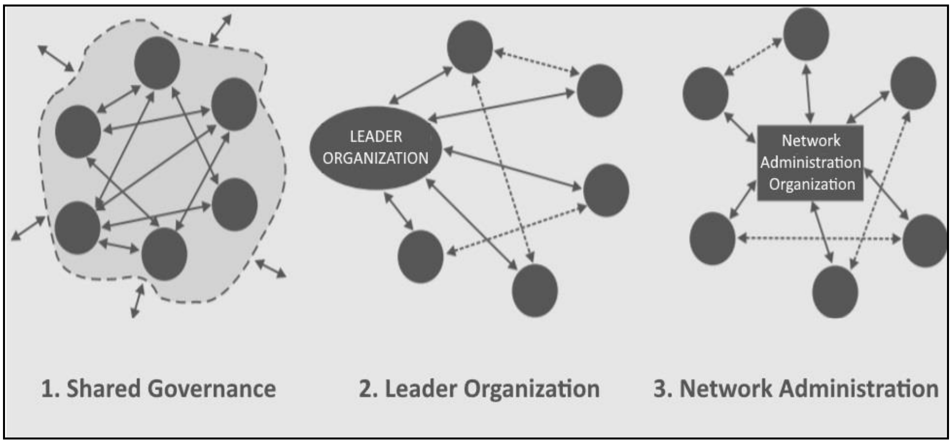

Figure 2 – Network Governance Models.
Source: Provan e Kenis (2008) apud Roth *et al.,* (2012).

CONCLUSIONS

The RIQUAL network can claim some success stories, but also less achieved purposes. In the same case are the annual meetings, where the presentations of Msc final thesis and projects (and also PhD students) has been very positive aspects, in many cases the first public presentation experience of the students. The supervisors found out an extra element for student motivation. The scientific journal is another success story, as well as the electronic platform for publications, although the platform not having the desired level of functionality yet. The publication of proceedings had some success, but it has the potential to integrate other events proceedings.

In the second case are the common projects that were less than expected. Main reasons are the dominance of the relationships of researchers to their home research groups.

From another point of view, the RIQUAL operates as an open platform as desired, but experience shows it seems too open, because, for instance, we do not know how many we are. These issues and other needs for fostering common projects request the creation of a management structure. For example, the connection between RIQUAL and the companies and business projects has not yet been successful, because the functional and management structure still needs development. So, we adopt a management model that shows the future perspective of the network (Figure 2). This model allows that the projects (from business companies, entities from the public and social sectors, or the own projects of the network) can be channeled to the network management platform, which will find the best way to respond to them (eg. teams, technologies, resources).

The major challenges remain on the management of the RIQUAL network itself, implying in particular its several dimensions: structure, internal and external relationships, performance evaluation and earnings and the strategic alignment between the “cooperators” and other partners. There is broad agreement that integration and coordination bring benefits to network members and that coordination should be seen as an administrative mechanism to achieve integration.

The "relationships" dimension contemplates the cooperative relationship between the partners of the network, established by long-term contracts based on trust, which is referred by several authors as essential for a real long-term cooperation relationship [Speakman et al. (1998), Lambert et al. (1998), Parsons (2002) quoted by Cunha and Zwicker (2009: 148) McHugh et al., (2003), McLaren et al. (2004); Cohen and Roussel (2004), Vale et al. (2006), Martin (2007) and Carvalho (2011)].

The "earnings" dimension includes benefits. Regarding strategic alignment, some authors consider that companies can be part of different networks simultaneously, relating to customers in several sectors, which may even be competing with each other, so that strategic alignment is not always easy to achieve. This dimension in RIQUAL has been replaced by common objectives, assuming that distributed benefits underlie cumulative performance and efficiency.

The "Structure" dimension reflects the relationships that are established among the “cooperators”, and emerges from the need to define the role of each partner in the network, considering that not all should be integrated; it will be necessary to choose and rank them according to the skills and knowledge. It is preferable to work with a reduced base of researchers, with which it will be possible to integrate processes and activities, contributing to the increase of the collective efficiency (of the network), resulting from the accumulation of individual efficiencies. The information flow should be bidirectional.

Alves Filho et al. cited in Cerra et al. (2008) also consider the cumulative structure and efficiency dimension. The integration of processes and activity is essential as is the maintenance of a two-way flow of information.

The "Performance" dimension will consist of the key indicators defined to monitor network performance and evaluate the impact of defined strategies, assuming that it cannot be managed without measuring. Possible network scorecards may be necessary, using internal and external indicators to the network, based on project-by-project evaluation.

LIMITATIONS AND FURTHER DEVELOPMENTS

A first limitation is related to the nature of the case study research, and the second comes from the auto analysis, because researchers are reflecting over their own experience. However, we consider that both experience and reflection will be useful for other networks of professional and researchers and can motivate other researches to approach this issue.

A third limitation comes from the literature review, being clear that more research is needed on other experiences with networks of professionals and researchers. As few cases are related in literature (most focused on companies) the research of networks of professionals and researchers is a new and innovative field.

The replication of this experience (in Portugal) in other countries would be a test that collaborative research networks is a relevant issue, but also a way for benchmarking between several networks. Additionally, the integration of researchers from other countries, and cooperation with other similar networks would be another potential area.

As further development, we can state that it is clear that this type of networks needs to move from interaction within the network of individuals to interacting with networks of organizations. This perspective is another field to research.

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Barriers to the development of Continuous Improvement maturity in the manufacturing company

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ABSTRACT

Purpose – The purpose of this study is to identify barriers to the development of Continuous Improvement (CI) by using a five-stage CI Maturity Model.

Design/methodology/approach - This study is based on a case study approach. One manufacturing company producing electronic devices which has been using continuous improvement principle was selected. In the study, a five-stage CI model, presented by Bessant at al., has been applied and used to identify CI maturity barriers. The case study data were primarily collected using an interview, documentary evidence and results of the survey questionnaire.

Findings – The research has led to the collation of factors/barriers that lead to the problems of development of Continuous Improvement initiatives within the manufacturing enterprise.

Research limitations/implications - The results of the research are based on a single case study; therefore, caution is required before making generalizations on the basis of the data.

Originality/value – The research allowed to identify the factors that constitute a barrier in achieving the highest level of CI maturity in the manufacturing company. That is a quite new approach from the point of Polish production enterprise. There is a lack of studies that approach this issue in such a way.

Paper type: Case studies

Keywords: Continuous Improvement (CI), CI Maturity Model, barriers

INTRODUCTION

Continuous Improvement (CI) is one of the basic principles used in modern concepts and operational management models, such as: Total Quality Management, Lean Management, Six Sigma, Lean Six Sigma or process management. Most of these approaches are based on the assumption that CI is the result of using a set of appropriate tools, techniques and systems supported by employees' communication, engagement, training and team work (Fryer and Ogden, 2014). Studies on the evolution of this approach indicate both its Japanese and its western roots, related to the principles of Total Quality Management (Sua'rez-Barraza et al., 2014, Sanchez and Blanco, 2014, Bhuiyan and Baghel, 2005, Dahlgaard-Park et al., 2013). Currently Kaizen is alternatively used with CI as the western variant of not only one of the principles of management, but its independent concept (Aoki, 2008). Many researchers express the view that the modern organization is not able to build a high level of performance without a key component such as CI (Fryer and Ogden, 2014). Continuous improvement is a major driving force for companies. Swinehart et al. (Swinehart et al., 2000) describe CI as the ultimate solution for building an organization belonging to the 'World Class' group, whereas research regarding the application of the continuous improvement concept in countries such as Japan, Australia, Sweden, Great Britain, Spain, Belgium and China confirms that it is implemented in enterprises all over the world (Boer and Gertsen, 2003, Marin-Garcia et al., 2008, Dabhilkar et al., 2007).

Despite the benefits these can bring, Continuous Improvement efforts are consistently reported to have a high failure rate (McLean et al., 2015). CI implementations are not the easiest ones, especially when CI tools and techniques are emphasized, neglecting the use of appropriate behaviour patterns (Dabhilkar et al., 2007). It is often easier to try to introduce a specific technique in a chosen process or at a workplace than to take advanced actions in the area of building a new organizational culture. Then there is a certain dissonance: a set of CI tools and techniques has been introduced, but the effect of their application does not translate into the results of processes and the entire organization. Therefore, the literature proposes a number of tools dedicated to enterprises that want to measure and evaluate, and then develop their own advancement stage in the process of continuous improvement. They enable self-assessment, which aims at identifying areas of activity that require strengthening of improvement behaviours as well as increasing activity in this area. One of such models is the Continuous Improvement Maturity Model, which assumes a five-stage process to develop the ability to improve continuously (Caffyn, 1999, Bessant et al., 2001). The analysis of the literature shows that achieving the highest level of maturity constitutes an ambitious challenge for many organizations, and the current model applications encourage discussion about hindrances and difficulties in the development of improvement activities. Research, however, regularly focuses on success factors rather than directly addressing failures, and as a result, failure factors are currently fragmented (McLean et al., 2015). Reports that most of these organisational change efforts fail or do not meet targets (Axelrod et al., 2006; Stanleigh, 2008) demonstrate the need to identify and address the issues associated with organisational change.

The identification of the subject of this research has become the basis for conducting a study using an in-depth case study in order to answer the question: what are the weaknesses of the CI system operating in a given production company? And what barriers make it difficult to achieve maturity in implementing key CI behaviours? It should be emphasized that the assessment of the level of the enterprise's CI maturity indicates the third level, and the analysis carried out focuses on the difficulties associated with the further development of the concept. The purpose of this study is to identify barriers to the development of Continuous Improvement (CI) by using a five-stage CI Maturity Model. The use of the CI Maturity Model enabled the conduction of this analysis in a holistic and systematic way. Taking up the subject is all the more justified as the use of this model in large manufacturing companies operating in Poland is very rare.

This paper is organised as follows. The next section presents a literature review of the CI and the CI Maturity Model. The next one describes the research methodology. At the next stage, the test results were presented and the last one presents a discussion of the main results, limitations and directions for future research.

LITERATURE REVIEW

Continuous improvement

Continuous improvement can be defined as improvement initiatives that increase successes and reduce failures or progressive amendment involving all company's employees (Sanchez and Blanco, 2014). The newest definitions say, that CI tends to small incremental changes in productive processes or in working practices that permit an improvement in some indicator of performance (Grütter et al., 2002), that do not require big investments in order to implement them, and in which all members of the firm are involved (Terziovski and Sohal, 2000). CI is also referred to as pervasive and continuous efforts, beyond the standard defined participants' roles in order to identify and achieve results, which contribute to the achievement of organizational goals (Brunet and New, 2003). Bhuiyan and Baghel studying the history of CI presented a range of definitions from other leading authors (Bhuiyan and Baghel, 2005). In this article, CI is understood as a planned, organized and systematic process of sustainable, incremental and company-wide changes of existing practices, aimed at the improvement of the company's activities (Boer and Gertsen, 2003; Boer et al., 2017).

The CI Maturity Model

Enterprises using CI obtain different levels of engagement to implement its principles. According to Bessant and Caffyn (Bessant, Caffyn, 1997) the CI Maturity Model assumes the level of CI implementations. The model illustrates how an organization is able to stride towards higher levels of maturity by acquiring, practicing and repeating key behaviours until they become an established practice and an integral part of its organizational culture. It focuses on organizational skills and key behaviours (practices/principles) regarding the adopted values, level of commitment and management principles of the continuous improvement process (Caffyn, 1999).

According to them, CI is not a static concept but rather one that has developed through five levels, in each of which specific behaviour patterns emerge in the successful implementation of CI. They distinguished 5 levels of maturity (Bessant et al., 2001). An explanation of the different level are describes in Table I.

Table 4 – The Five Stages of Maturity in the CI (based on Bessant et al., 2001)

CI Level	Characteristic behaviour
Level 1 Pre-CI/ “background” CI Trying out the ideas	Interest in the concept has been triggered There is no formal CI structure, problem solving is random, and the dominant mode of problem solving is by specialists
Level 2 Structured and systematic CI	There are formal attempts to create and sustain CI, and a formal problem solving process is used, supported by basic CI tools. CI is often parallel to operations.
Level 3 Goal Oriented CI/	All of stage 2, plus formal deployment of strategic goals and monitoring and measurement of CI against these goals.
Level 4 Proactive/empowered CI Autonomous innovation	All of stage 3, plus the responsibility for CI is devolved to the problem solving units.
Level 5 Strategic CI/full CI Capability The learning organization	CI has become a dominant way of life, involving everyone in the organization. Learning is automatically captured and shared.

It is worth emphasizing that it is a certain archetype of attitudes and in each organization they are going to be implemented in an individual way. However, the CI development process is very similar and is linked with the introduction of new practices, learning process about them, linking them with strategic goals, making them a natural part of performance till shaping behaviours, which are characteristic for a learning organization. Navigating between individual levels, represents the process of learning and progress in applying the practice of continuous improvement. The CI maturity model, built on this basis, is a self-assessment tool with a very wide reach. It involves eight aspects of the conduction of the improvement activities to which they belong (Bessant i in., 2001, s. 72):

- the ability to articulate the basic values of CI,
- the ability to generate sustained involvement in CI,
- the ability to link CI activities to strategic goals of the company,
- the ability to lead, direct and suport the creation and sustaining of CI behaviours,
- the ability to create consistency between CI values and behaviour and the organisational context,
- the ability to move CI activity across organisational boundaries,
- the ability to strategically manage the development of CI,
- generating the ability to enable learning to take place and be captured at all levels.

RESEARCH METODOLOGHY

In order to answer the research questions, a case study was carried out, while applying the principle that its application is useful when the knowledge of the studied phenomenon is limited (Eisenhardt and Graebner, 2007). It takes place in terms of the undertaken research issue, which has not been analysed yet in operating in Poland, large manufacturing companies. Therefore, the study was carried out in the mode of targeted selection in a large enterprise producing electronic devices. The company is pursuing its goals, developing subsequently in the field of application of improvement techniques and building an ever stronger organizational culture based on the principles of continuous improvement. This case was chosen because:

- the company's management has recognized the principles of continuous improvement as priorities in the company's strategy, which prepares the basis for assessment of the ability to use key CI practices,
- the company's management in a thoughtful and orderly way implements and applies all key practices included in the Continuous Improvement maturity model, which enables observation and evaluation of their adaptation processes,
- a structured system of activities related to CI was created in the company, which eliminates the randomness in the selection of CI practices,
- employees of the company demonstrate a high level of knowledge regarding the CI concept, which facilitates interviews conduction,
- there is documentation in the company confirming the use of the CI practices, what permits the use of documentation analysis,
- the top management notices difficulties appearing in a pursuit of the continuous development of CI practices and expressed the need to assess the ability to improve and identify the strengths and weaknesses of the implemented practices.

In the analysis, a team consisting of the Chief Operating Manager, 3 managers and 3 members and a facilitator took part. They meet three time. The rating applies to the whole company. Evaluators used the evaluation questionnaire divided into eight sections (according to the CI ability) including 35 statements. They presented their point of view within behaviours included in the subsequent sections. The assessor had ten points to allocate within each section. The participants discussed and used the documentation concerning the implementation of the improvement activities program. Attention was focused on identifying obstacles which make the implementation of particular behaviours difficult, especially those that have not achieved a high level of maturity. An important source of information was also the results of the survey research, carried out in the company a few months before, in which 135 employees participated. This research aimed to identify and analyze factors determining the efficiency of the suggestion system. The use of this data has proved to be very helpful in the evaluation process. It was also a tool enabling the maintenance of the objectivity. It allowed relying on facts and not on feelings and allowed to take into account the insights of line workers.

RESULTS

The ability to articulate the basic values of CI

In interviews conducted among managers, it was emphasized that: articulating and strengthening the core CI values requires a constant work on the consciousness and behaviour of all company's employees. These include (Bessant et al., 2001):

- building faith in the value of small improvements and the feeling that everyone is able to contribute to the creation and implementation of gradual improvements,
- in case of problems, searching for reasons instead of blaming individual behaviours,
- use of formal rules in order to identify the problem and solve it subsequently.

While conducting interviews with employees, it was pointed out that the impediment to the implementation of the above-mentioned rules could be the lack of appropriate behaviour patterns in some corporate teams and too little emphasis on working on changing of thinking patterns and work culture. This applies to employees with a passive attitude or a negative approach to change. It results from the ill-understanding, lack of interest or lack of knowledge about the organization's values, and sometimes it is associated with a sense of uncertainty concerning the situation. In some cases, passive and even cynical attitudes towards changes are passed on to other employees, discouraging them from introducing improvement actions. Factors that hinder operations in line with CI values are also employee fatigue and bad experiences in making improvements.

The problem that has been noticed is also the different level of commitment and understanding of CI's value depending on the employee's position, as well as employees' different perception at various levels of the organizational structure. This is evidenced by the results regarding employee's participation in the suggestion system and different levels of their activity (process leaders - 100% participation, middle managers - 57% participation, linear production workers - 47%, office workers – 67%).

According to the employees, hindrances that make it difficult to focus on identifying the reasons of emerging problems are primarily: lack of time resulting from too many other duties and focusing on eliminating their effects. However, attention was also drawn to the concerns related to the identification of real causes and their link to errors made by the employee. Identification of the emerged reasons of the problems is not supported by the approach of "seeking the guilty ones" and the lack of distinguishing between the error committed by the employee from the evaluation of his person. Employees also point out that there are situations in which they lack knowledge to recognize the causes of problems correctly and thoroughly.

Formal rules of identification and solution of problems are in force and apply in the company. Obstacles that hinder their use are the impression that they are complicated and unclear, and that they are time-consuming and require special skills to apply them. Employees also express concerns that they have not got adequate experience and knowledge to participate in particular activities. During the interviews, it was also pointed out that some employees feel bad when working in a group and lack the basic team work.

The ability to generate sustained involvement in CI

According to CI Maturity Model sustained involvement are implemented when (Bessant et al., 2001):

- people use appropriate tools, techniques and measurement to support the improvement process,
- people initiate and carry through CI activities,
- ideas are responded to in a clearly defined and timely fashion,
- CI activities are connected with employees' operational activity and striving to ensure that these activities are carried out in parallel.

The research which had been carried out in the company showed that employees indicate several reasons that make permanent commitment to continuous improvement difficult. Not everyone demonstrates appropriate easiness to use CI tools and techniques, fearing of inadequate knowledge and experience they possess in this area, which may lead to ineffectiveness of their actions. However, a bigger problem is the use of measurements that should facilitate the diagnosis of the situation and decision making. The results of the survey pinpoint that this aspect belongs to the weaker areas of the CI activity. According to the employees, hindrances that make the use of measurements difficult are: the lack of proper guidelines, shortage of time to carry them out, and fear of making mistakes during measurements. Attention was also paid to situations in which the employee has not got access to appropriate measuring devices or to forms facilitating data gathering.

Eagerness to engage employees in the introduction of improvement activities requires, however, the reduction of hindrances in the form of: prioritizing ideas of people with a stronger position in the team, lambasting employees' proposals or ignoring them. On the other hand, employees are afraid of tasks in which they are set too high goals and are expected to get too quick results.

Employees pointed out following hindrances preventing the carrying out of improvement initiatives till the end: incorrect determination of the improvement purpose, insufficient resources needed to perform the task, lack of support from the management and too many activities in which they are simultaneously involved. In the case of the implementation of team improvement projects, attention was also paid to problems related to the inappropriate selection of team members, too slow pace of work or lack of support in bringing the work to an end.

Sometimes project objectives stop being valid because daily tasks take the overhand or sudden disruptions appear. Tasks are postponed to a different date regardless of the previously set schedule. This sometimes affects the timeliness of implementing ideas and suggestions, which results in their degradation of importance in the eyes of employees, impatience and building passive attitudes.

The ability to link CI activities to strategic goals of the company

The combination of improvement activities with the organization's strategic operation is a task directed primarily at managers who are mainly responsible for the cohesion of strategic and operational activities (Bessant et al., 2001).

Hindrances, which were determined by employees in the area of applying the organization's goals in prioritizing their improvement activities, are: their lack of knowledge in such extend, that would let link them with operational activities. The objectives are presented quite superficially and often seem very distant from the activities carried out at a particular workplace. Employees feel the lack of influence of their daily activities on the implementation of the adopted strategy, as well as the lack of understanding of the relationship that is taking place in this area. They mention an emerging impression of too large a "gap" between small solutions at the level of workstations and a very ambitious corporate strategy. It is also a hindrance preventing an assessment of the proposed improvements. An issue worth paying attention to is also the "simplification" of the organization's goals and reducing them to the level of numerical indicators, such as costs, efficiency or the number of improvements made. In some cases, this creates misunderstanding what is the actual company's purpose. Another problem is the difference in the perception of the importance of individual goals and the focus on the operational, short-term objectives of the given area, not always consistent with the company's strategy.

An obstacle in conducting the score analysis of improvement activities regarding their impact on meeting the company's goals is to focus on numerical indicators, which further demotes the promotion of learning processes inscribed in the organization's strategy.

The problem is also to concentrate on the number of undertaken improvement activities, and not on their effects. Employees also notice, emerging in some cases, difficulties to determine and clarify how to assess the effect of implemented improvements.

Tasks prioritization resulting from the production plan implementation and other current work plans, as well as the treatment of improvement activities as activities that can be carried out at the end, are existing obstacles which prevent to treat CI activities as an integral part of the individual or groups. Another problem pinpointed by employees is also the failure to include time, needed to conduct improvement activities, in the work schedule.

The ability to lead, direct and support the creation and sustaining of CI behaviours

Running, managing and supporting improvement activities requires (Bessant et al., 2001):

- allocating adequate space, time, finances and other resources,
- recognition of the employees' contribution in a formal way, not necessarily financial,
- an example of great commitment on the part of managers,
- support in the area of conducting experiments and accepting risks in the form of errors.

Company's employees draw attention to several reasons that impede the achievement of implementation's maturity concerning these requirements. Despite the management's awareness of the need to provide adequate resources, their deficiency is often felt, especially in terms of time. It is not always that improvement tasks are correctly estimated in terms of their labour intensity, which is especially difficult while conducting experiments. Precisely developed production plans which base on well-developed labour productivity standards, in many cases constitute the opposite of the schedules regarding the improvement actions. In the latter case, they are based on estimation methods, whereas the probability to determine the duration of individual activities correctly is at the medium level. The second factor that constitutes a difficulty is the lack of adequate space which is necessary to make a group of employees, who jointly implement the improvement action, meet. Often a larger area among workstations is needed, along with a worktop or a board. While designing workstations, the space needed for CI activity was not taken into account.

The third resource, that the employees pay attention to, is the knowledge necessary to create ideas and to take improvement actions.

In terms of the formal system, recognising employees' contribution to improvement, which was introduced in the enterprise, both financial and non-financial forms are foreseen. The system is clear and well known to employees, which affects its high assessment of the maturity level as revealed in the research. The area's weakness, which was pointed out by the employees, is the feeling that the reward obtained is not adequate to the effort and work put into the improvement activity. The issue here is an underestimation of the effort required to achieve results.

The principles of continuous improvement put high demands on the managerial staff regarding their impeccable attitude, promoting this approach to management. They should be active and fully involved in the improvement processes. The obstacle which has been identified in this area is primarily a heavy load of the current responsibilities arising from operational activities. This applies especially to the middle management level which is responsible for overall activities in areas subordinated to them. It was also pointed out that not all representatives of the managerial staff have a strong, charismatic personality, which lack is noticed by the team.

Conducting experiments is a very important part of the improvement actions. It sets the managers, however, significant organizational and methodological requirements. A hindrance while conducting experiments, which was particularly mentioned, is the lack of experience in the application of procedures supporting this area of activity as well as the lack of sufficient knowledge, especially in the field of mathematical analyses. Attention was also paid to the time-consuming nature of such activities' conduction. In addition, employees are concerned with the risks associated with the implementation of such experiments and the shortage of positive effects. Not everyone is able to accept the method of learning from mistakes, refraining from criticism or demotivating remarks. On the other hand, the lack of understanding of the idea of experimenting, among some employees, leads to regarding them a source of unnecessary costs.

The ability to create consistency between CI values and behaviour and the organisational context

Coherence creation between the CI values and behaviour and the organisational context requires integrating a continuous improvement system with the company's management system. A system of continuous improvement constituting a set of rules, procedures and techniques must be designed to support each other, and to be 'fit within the current structure and infrastructure'. The management should "hold ongoing reviews to assess" whether these systems are compatible. On the other hand, when a major organizational change is being planned, its impact on the continuous improvement system should be assessed and, if necessary, necessary adjustments should be performed (Bessant et al., 2001).

People responsible for the CI activities and the company's management pay special attention to the difficulties related to the implementation of the adopted rules in this area. The dynamics of the operational activities being carried out, resulting in the lack of an in-depth analysis of the effects of the introduced changes, are becoming a priority. Situations occur when the previously introduced changes require agility in action and it is simultaneously impossible to take into account their consequences they may incur in the CI system at the same time.

Sometimes the problem is to skip the analysis of the effects of organizational changes on the system operation and the conviction that it "will match itself", and that possible difficulties will be eliminated later. In some cases it is a matter of priorities. Mid-level managers, resolving dilemmas related to the introduced changes, focus on those which will improve the efficiency or costs reduction, despite the fact that they are not compatible with the CI system.

The ability to move CI activity across organisational boundaries

Development of the capacity of the CI activity implementation across organisational boundaries requires, from the enterprise, a co-operation across internal divisions, understanding and sharing an holistic view and orientation towards internal and external customers. Equally important are specific CI projects with outside agencies (customer, suppliers, etc.) and relevant activities involve representatives from different organizational levels (Bessant et al., 2001).

The study conducted in the company pointed to the difficulties that arise while developing effective cooperation between versatile company's departments and between different levels. This ability was assessed rather unevenly. Some people (almost 1/3) indicated just level 1, the same number pointed at 3. This means that this practice functions, to a different extent, in different areas of the enterprise. The basic factor hindering its implementation is the focus on the implementation of operational objectives assigned to particular departments. Mid-level managers are focused on the plans which they are responsible for, what constitutes their priority. On the other hand, operational employees aimed at the lack of the possibility to involve themselves independently in inter-departmental initiatives. The hindrances are: their shortage of time, focusing on their own duties and tasks, lack of knowledge concerning the entire process and lack of opportunities to integrate with people working in various areas of the organization.

Another unfavourable factor for the development of CI across organisational boundaries is the shortage of the promotion of a common, coherent vision of the whole enterprise's development and the role of an interdisciplinary approach to problem solving. Another obstacle is the introduction of different internal rules concerning operations in company's particular areas. It is also not favourable to build improvement teams composed of employees working in the same area and create a feeling that they have to deal with a given issue themselves.

Another hindrance indicated in the research is also the lack of awareness raising concerning the importance of the managerial process approach and how important is the role of the internal client in the company. This promotes circumstances in which attention is paid, during improvement activities, to the benefits of a small group of employees without considering their impact on other processes.

It is worth mentioning the obstacles turning up during the accomplishment of the principle of focusing on the external client's needs. Operational staff pay attention to the fact that in the case of the emphasis on tasks aimed at the organization's internal goals, the external client becomes a fairly remote factor. They often have the impression of not being able to meet their expectations. This feeling is not conducive to the development of joint improvement projects with both: customers and suppliers. The weak bond, lack of trust, lack of confidence regarding constant cooperation and high rotation of suppliers and customers are also obstacles to the development of the analysed capacity.

The analysis of difficulties related to the implementation of CI activities at various organizational levels has indicated such hindrances as: mental distance between employees of different operational levels, disparities in the level of training among these groups of employees and clear differences in remuneration. They affect other level of employees' motivation and commitment regarding CI activities. This distance is deepened when employees from higher levels of the organizational structure are involved in the improvement projects, workshops and CIP teams.

The ability to strategically manage the development of CI

The CI system development must be included in the strategic activities of the organization. This depends primarily on the top management's attitude, which should ensure its continuous monitoring and results measurement as well as a cyclical planning process that allows the introduction of necessary modifications in its operation. Besides, periodic review of the system in relations to the organisation as a whole which leads to a major regeneration is recommended. The management should provide adequate resources in order to support sustainable development of the CI system as well (Bessant et al., 2001).

The research, carried out in the company, revealed a high assessment of the maturity regarding the accomplishment of this area of behaviour. Nevertheless, this is not yet the fifth level. The difficulty, pointed out by managers, is the choice of appropriate indicators used to monitor the CI activity effects. However, if the performance measurement system is refined and contains a complex set of indicators, adequate to the processes being carried out, becomes very useful. The problem is too much focus on the financial effects of activities, which in many cases can dominate managerial decisions. A hindrance to strategically managing the CI activity is also considering it as a periodic program, which will be terminated after achieving the determined effects or marginalizing the importance of its cyclical review. Although it seems paradoxical, after all it is an action against its own assumptions, in reality it sometimes becomes a fact. Activities related to the 'continuous improvement of continuous improvement' are set aside due to the implementation of current goals and operational tasks. The weakest point of the discussed area of abilities turned out to be the provision of sufficient resources (time, money, personnel) by senior management. Shortage of adequate resources may become a serious obstacle resulting from other priorities in the scope of investments carried out in the enterprise or temporary personnel or financial problems of the enterprise.

The development of the CI is also not conducive to the belief that CI activities does not require a lot of resources, and should be a natural, cost-free part of employees' activities.

Generating the ability to enable learning to take place and be captured at all levels

Building the 'learning organization' requires the implementation of several important practices related to the acquisition and improvement of the organization's knowledge. Employees should be aware that they learn on the basis of their experiences, both positive and negative and should search for opportunities for learning and personal development. It is also important that they share knowledge and experience. The organisation should articulate and consolidate the knowledge as well as accept the learning activities. The company should also use tools that allow for capturing and sharing of learning (Bessant et al., 2001).

The research carried out in the company revealed that the application of the presented practices encounters some obstacles related, to a large extent, to the management of human resources and the values adopted in this area.

In some cases, there is an insufficient trust to employees, which would permit to accept making mistakes and the inability to draw conclusions from them. It discourages from sharing knowledge about failures that have happened. A certain hindrance is also the fact that some employees do not feel the need to be educated and do not attach much importance to personal development. For them the awareness of being permanently employed and they are doing their job well is sufficient

The lack of incentive for self-improvement, as well as the lack of time and lack of accurate identification of the training needs are also factors that employees pay attention to. However, in the case when employees had the opportunity to raise their qualifications during trainings, they noticed that they are undertaken too rarely, not consistently and insufficiently in relation to their needs. Often employees did not have the opportunity to immediately apply the knowledge of the training in practice. This raises later fears concerning the implementation of theoretical solutions and causes too little experience in the range of their application.

The obstacle making it difficult to share knowledge is also the infrequent use of appropriate tools that facilitate it (meetings, seminars, workshops). A similar problem is the negligence of practices that allow the capture of employees' and teams' knowledge. It happens that well-trained, knowledgeable people are taken over by other organizations what make knowledge retention difficult. The building the "the learning organization"is not facilitated by the employees' rotation and the lack of an adequate knowledge level among newly hired employees as well as a certain type of fatigue, habits or even professional burnout among employees with long-term experience.

CONCLUSIONS

The purpose of this study is to identify barriers to the development of Continuous Improvement (CI) by using a five-stage CI Maturity Model. Conducting research using the case study approach allowed a detailed analysis of the issue and indication of many factors that hinder the development of the CI concept in a manufacturing enterprise. The conclusion of the presented study is that the CI maturity model is a useful tool which allows a systematic analysis of the difficulties in the implementation of the key behaviours included in it. Thanks to its application, the answers to the research questions have been obtained.

The results of the research confirm the views of McLean et al. about errors that appear during the application of the CI concept and about the need to identify them in order to solve problems related to organizational changes. Movement between individual levels of the CI maturity results from the development of the learning and the progress processes in applying the recommended practices. The research carried out in the company confirms that there is a group of behaviours that, naturally or on the basis of informed decisions, develop faster and easier than others

The limitation of the conducted research is to focus only on a single case study. Although it contributes to a better understanding of issues related to the use of the CI maturity model in identifying the obstacles that appear in the implementation of this concept, it does not allow the formulation of generalizations concerning the collectivity. Future research should include a larger group of manufacturing companies operating in Poland, which will allow detailed characterization of the process of implementation of the key CI behaviours and the identification of their usage conditions in domestic companies.

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A QFD-based approach to identify product-service systems functional requirements

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ABSTRACT

Purpose – Product Service Systems (PSSs), i.e. integrated offerings of products, services and supporting infrastructures, represent the output of a growing number of manufacturing companies. This paper extends the Quality Function Deployment (QFD) method to the design of PSS. The proposed approach aims at the elicitation of functional requirements taking into consideration all the different players who interact with the PSS and all the possible interfaces of value exchange.

Design/methodology/approach - The research objectives were achieved by: reviewing current methodologies, analysing the architecture of existing PSSs and selecting a framework to be applied for defining their functional requirements. A practical example contributes to illustrate the proposed approach.

Findings - The paper aims at closing the gap concerning the identification of PSS' players and the definition of their specific functional requirements. It stimulates the opportunity to enable new services, new functionalities and related requirements based on an analysis of the expectations of the players involved in the PSS life cycle.

Research limitations/implications - Although the paper provides a basic approach, it is liable to extensions and improvements. In the current version, the method mainly focuses on the functional requirements generated from services and products.

Originality/value - This work represents a first attempt to provide a practical methodology to identify PSS functional requirements. It is a first step in the development of a comprehensive and useful support for the design of a new PSS.

Paper type: Research paper

Keywords: Product-Service System; Requirements identification; Quality Function Deployment; Servitization

INTRODUCTION

The provision of product support services is becoming a factor of distinction and competition between advanced manufacturing firms (Spring and Araujo, 2009). For this reason, a number of manufacturing companies have recently enriched their portfolio of product offerings with a wide range of services (Neely, 2009).

This paper aims to provide an introductory “design for quality” method able to assist a design team in the definition of the basic requirements of a new Product Service System (PSS), i.e. a complex system composed of products, services, infrastructures and people/organisations that interact each-other (Tietze et al., 2011). Designing a PSS means considering all these elements, without neglecting any possible aspect of interest.

The method stimulates the opportunity to enable new services based on an analysis of the expectations of the players involved in the PSS life cycle.

The remainder of the paper is structured as follows. The literature concerning PSS and the servitization process is analyzed in Section 2. Section 3 describes the gap addressed by the proposed method. Section 4 analyzes the basic elements of a generic PSS. The novel approach is then presented in Section 5 and exemplified in Section 6. Section 7 discusses the output of the method. The concluding section summarizes the original contributions of the paper, focusing on the benefits, limitations and possible future developments.

LITERATURE REVIEW

In 1988 Vandermerwe and Rada introduced the term servitization. According to the original conception, the servitization process can be defined as a set of incremental expansion phases beginning with product-related services such as spare parts and maintenance and moving towards integrated solutions (Gebauer and Fleisch, 2007). This process has been found to provide many advantages, such as: (i) enhancing the customization of the offerings according to customer’s needs; (ii) developing customers’ loyalty, spurring the interaction between customer and manufacturer; (iii) allowing the manufacturer to distinguish from its competitors and to gain potential market share and (iv) generating more profits throughout the entire product life cycle (Baines et al.; 2009).

Over the past 30 years there has been a significant increase in researches related to this topic. These studies focused their attention on different aspects: the definition of the PSS notion (Vandermerwe and Rada, 1988, Baines et al., 2009); the classification of different corporate approaches (Voss, 1992, Mathieu, 2001); the drivers that affects their employment (Malleret, 2006); the methods for the implementation of servitization strategies (Oliva and Kallenberg, 2003, Gebauer et al., 2006) and the challenges that manufacturers have to tackle when moving into services (Martin and Horne, 1992, Martinez et al., 2010), among others.

Relying on the analysis of few case studies, other authors covered a variety of other sub-topics including, for instance, service design and industrialisation (Johansson and Olhager, 2004, Vandermerwe and Rada, 1988, Mastrogiacomo et al., 2016, Barravecchia et al., 2018).

By analyzing the literature it can be observed that "there is a paucity of previous works that provide guidance, tools or techniques, that can be used by companies to servitize", so that "the principal research need is to engineer tools or techniques that practitioners can apply to help in service design, organisational design and organisational transformation" (Baines et al., 2009, Lightfoot et al., 2013).

PROBLEM DESCRIPTION

A PSS is the typical output of a servitized manufacturing company. For this reason, there is an important demand for specific methods to support the design process of new PSSs. A number of studies focused on the examination of design approaches for service systems, mainly emphasising the management and marketing aspects of the problem. Quality aspects are frequently neglected (Williams, 2007). In this context, it is now well established that Quality Function Deployment (QFD) can significantly reduce project modification and time-to-market during new products and service development, linking the customer needs with technical attributes (Xu et al., 2010). The QFD can support designer in the development of product or service systems, taking into account various demands of users (Akao and Mazur, 2003). However, the QFD was adopted for the design of a single product or service in its original formulation. According to several authors, the interpretation of the customer voice and the elicitation of requirements is one of the main difficulties in QFD application (Chan and Wu, 2005, Carnevalli and Miguel, 2008). These limitations are even more amplified in the design of multi-player and multi interface PSS (Shimomura and Arai, 2009).

In this paper we try to address the limitations of the traditional QFD. Throughout a structured analysis of the elements of a generic PSS, we try to fill this gap by proposing a novel approach for identifying all the functional requirements related to the services and functions of a PSS.

The proposed approach supports a design team in the elicitation of the PSS Functional requirements, i.e. "what should be offered to the customer" (Müller et al., 2009).

THE BASIC ELEMENTS OF A PSS

According to the definition of Tietze et al. (2011), a generic PSS can be defined as a system composed of four basic elements:

- *Product*. It is the physical component of a PSS. Its peculiarity is that the production of a product can be achieved without any transaction between provider and customer.
- *Service*. It is the intangible component of a PSS. Services are characterized by activities performed between the provider and the customer.
- *Players*. They are the people or organisations, that contribute to the creation of the PSS value through their mutual interactions.
- *Infrastructure*. It is the underlying base or foundation for a PSS. It may include the basic facilities, networks and installations needed for the proper functioning of the system.

PSS Players

PSS players interact with each other by exchanging services. Players can be:

- *Users*, i.e. the people or organisations that use the PSS. There can be different types of users of a PSS. User is the driver of a car in leasing, but also a mechanical that operates on the same car to carry out the necessary maintenance interventions.
- *Producers,* i.e. the people or organisations that create the PSS. The producer designs and combines all the elements of the PSS with the aim of meeting all users' needs (Tukker and Tischner, 2006).

Both PSS user and producer can act as customer or provider of the service components of a PSS: on the one hand the producer typically provides the product support services, such as warranty, after-sale, software upgrade services; on the other hand, the user can provide services to the producer for instance acting as a "beta" user or survey responder.

PSS interfaces

We define as *PSS interface* the "place" at which customers and providers of a PSS meet, act or communicate with each other. Given the nature of a PSS, the possible interfaces at which the different players may interact by exchanging services can be divided into three categories:

(i) *Product-Embedded Interface*. Provider and customer interact through the product components of a PSS. Using its own resources, the provider offers services to the customer through the use of the product. The product is the physical platform through which services are delivered. As an example of Product-Embedded Interface, consider the telephone service which is offered by the provider through the smartphone that is commonly used by the customer.

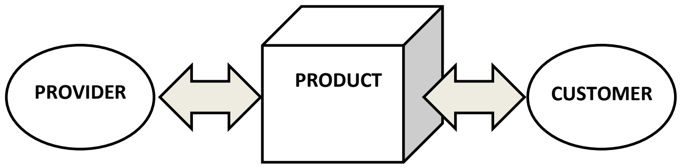

Figure 1 – Product-Embedded Interface: schematic representation of the interaction between customer and provider

(ii) *Product-Related Interface*. Customer and provider interact directly, without the filter of the physical product. However, the interactions between the two players would not take place without the presence of the physical product.

As an example of Product-Related Interface, consider the support service that a manufacturer of a machining centre provides to its customers. Given the complexity that usually characterizes such systems, the manufacturer typically provides the customer with the support of qualified personnel to assist the early stages of use.

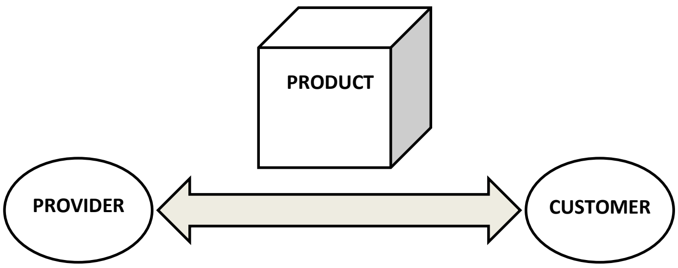

Figure 2 – Product-Related Interface: schematic representation of the interaction between customer and provider

(iii)*Product-Independent Interface*. Provider and customer interact and exchange services regardless of the presence of the product.

Examples of this kind of services are financial, educational, training, legal services, etc.

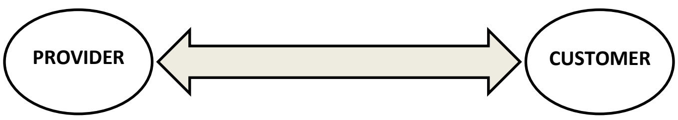

Figure 3 – Product-Independent Interface: schematic representation of the interaction between customer and provider

The design of a PSS should consider all the possible service interfaces. Particularly the first two interface categories may have an impact on the final project of the PSS, being directly or indirectly related to the physical product.

A PROPOSAL FOR IDENTIFING FUNCTIONAL REQUIREMENTS OF A PSS

One of the key phases of the PSS development is the identification of PSS requirements (Maussang et al., 2009). This section describes a structured approach for the definition of customer desires, in the form of a set of requirements related to PSS functions and services. As the input for the subsequent practical development phases, the Quality Function Deployment can convert this set to identify the PSS technical requirements. To design a PSS, a “heterogeneous team, possessing divergent expertise, must collaborate in early development to nourish both a service and a product perspective” (Ericson et al., 2009). The elicitation of PSS customer needs requires the involvement of all the different players that interact with the PSS (Peruzzini et al., 2015). In this view, the authors suggest that the method should be applied by a team consisting of designers and players that will interact in the PSS, including customers.

The proposed method can be applied in different cases: (i) to identify new service components of a PSS when the product and infrastructure components are already defined; (ii) to systematically plan services and product components when the infrastructure is already available, or (iii) to produce a joint and simultaneous design of all the PSS components.

Input of the method

To properly define PSS requirements, the design team should provide few preliminary inputs:

1. A sketch of the PSS to be conceived. Exploring market opportunities and analyzing business skills, the design team must a-priori identify the value proposition of the PSS.
2. The identification of the players. One of the team's preliminary tasks is to identify which are the players that can interact with and through the PSS during its entire lifecycle.
3. A sketch of the necessary PSS infrastructures. If already existing, the design team must define the rules that the product should follow to interact with the infrastructures.

The proposed approach leads the design team to the identification of the services and functions exchanged between the different elements of the PSS (Section 3) depending on the interface type (Section 3.2).

The logic is that the team must consider all combinations of interfaces and elements of a PSS for a correct and complete design. The method is based on the use of a set of different matrices that are meant to be applicable in different contexts: either when all the components of the PSS must be defined or when a part is already existing.

The different matrices guide the design activity of the team by stimulating the analysis of all the possible combinations of elements and interfaces of the PSS in order to consider all the relevant dimensions. According to the three identified PSS interfaces the method can be described through the following four steps: (i) Product-embedded interface analysis; (ii) Product-related interfaces analysis and (iii) Product-independent interfaces analysis and (iv) translation of PSS Services and Functionalities into Functional Requirements.

First step – Product-embedded interface analysis

The first step is aimed at the identification of the intangible elements exchanged between players, products and infrastructures through the product (players deliver and receive services, while products and infrastructure provide functions). It is possible to call this kind of service as product-embedded services. The first question that the design team has to answer is:

> Q1*: which kind of services or functionalities should be delivered through the physical components that will compose the PSS?*

In this phase, the design team fills the first form of the method – shown in Figure 4 – indicating respectively the services and functions that players, products and infrastructure "exchange" through the product, i.e. at the Product-embedded interface. Each field of the form indicates a dimension to be potentially considered for the development of the PSS concept.

For the sake of clarity, it is appropriate to split this first step in two phases:

- Phase 1: identification and definition of the product-embedded services in Matrix A (see Figure 4);
- Phase 2: identification and definition of the functionalities of products and infrastructures, in Matrix B and Matrix C respectively (see Figure 4);

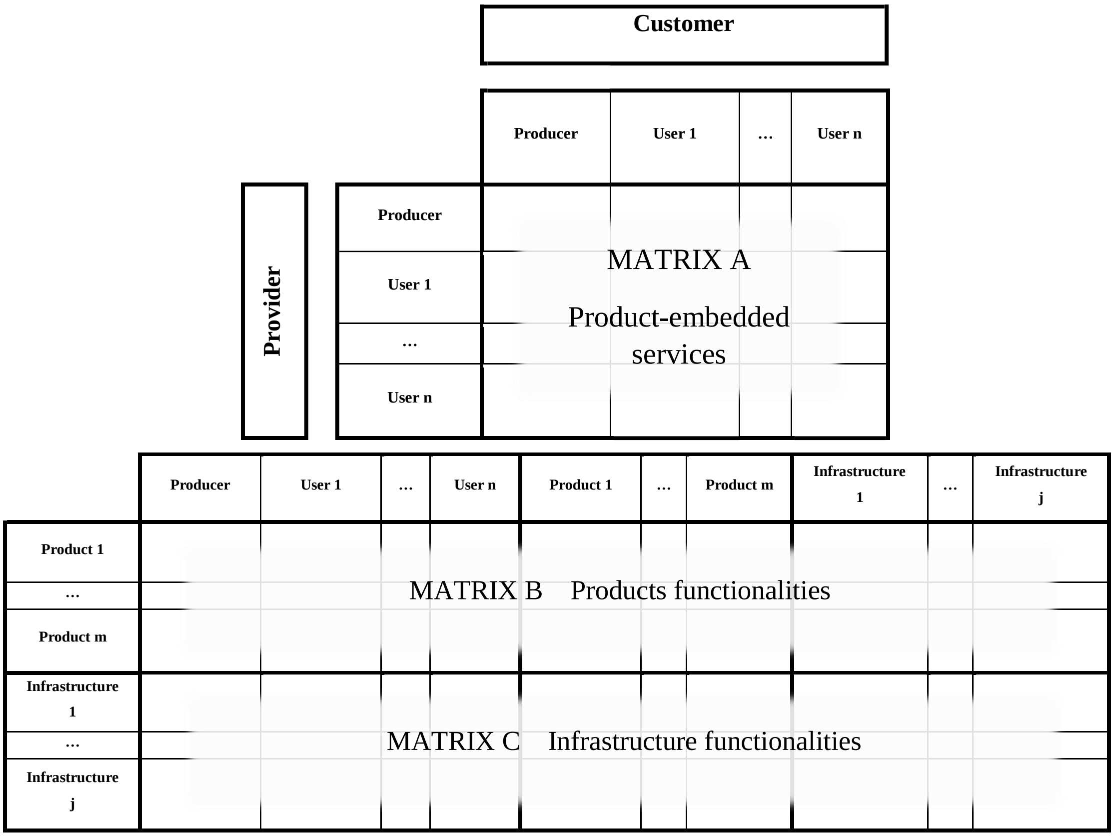

Figure 4 – First form of the method (Product-embedded interface).

The selection of specific services may affect the definition of product and infrastructure features to be included respectively in Matrix B and C which generally contains the functions the products and infrastructures offer to the players. Therefore, the team has to iterate between these two phases.

As an example, consider a heavy-duty lathe. Its main functionality is the turning of heavy duty and large size objects. Matrix B reports this information. A possible product embedded service, to be listed in Matrix A, is the reporting and process efficiency analysis services that the producer can provide to the customer relying on process data the machine sends in real time to the producer. The producer may, for example, alert and communicate with the client via the console on the lathe. The selection of this service potentially involves the enhancement of product functionalities with the addition of sensors and an advanced control console. It also requires an Internet connection.

Second step – Product-related interfaces analysis

The second step is aimed at the identification of the service components of a PSS exchanged by the players at the product-related interface, i.e. when the players directly interact each other. These services – only indirectly affected by the product features – have to be included in the second form of the method (see Figure 5), specifically in Matrix D. It is possible to call this kind of service as product-related services. The filling of Matrix D helps the design team in giving an answer to the questions:

> Q2: *What are the new needs that the PSS will create? And how new services should enhance value exchanges between the players?*

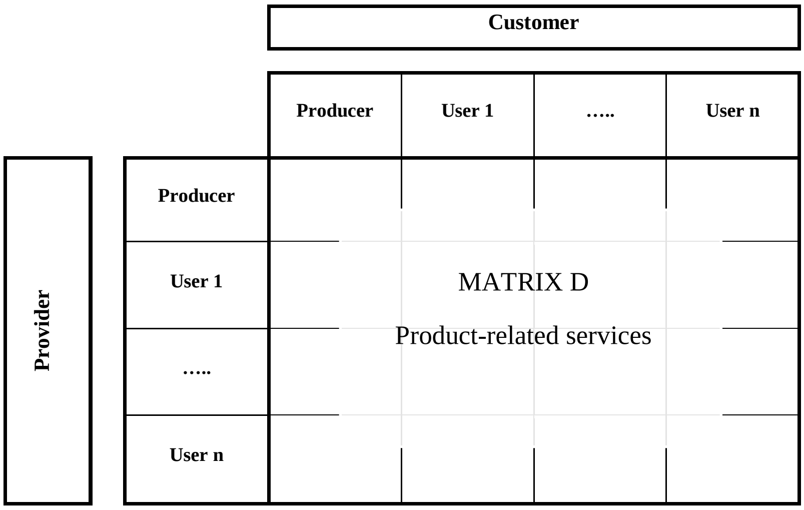

Figure 5 – Second form of the method (Product-related interfaces).

With reference to the heavy-duty lathe exemplified in Section 4.3, examples of product-related services, to be included in Matrix D, are the services of replacement and regeneration of machine tools and equipment. If not present, necessary personnel and skills have to be acquired.

Third step – Product-independent interfaces analysis

The third step of the method aims at considering the services that the players exchange independently from the product components of a PSS, i.e. at the product-independent interface. Typically, product-independent services are only provided by the PSS producer. Since that the PSS will create relational links between the producer and different players, the filling of Matrix E supports the design team in giving an answer to the question:

> Q3: *How we can capitalize these relationships in terms of exchange of new services?*

These services are not affected by the product characteristics and they need not necessarily be conceived together with the aforementioned services and products elements. Such services should be included in Matrix E, the third and last form of the method (see Figure 6).

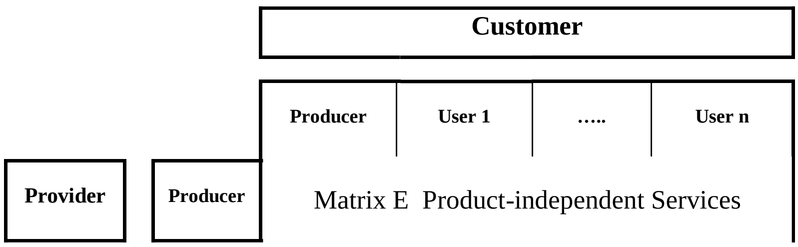

Figure 6 – Third form of the method (Product-independent interfaces).

Considering the case of the heavy-duty lathe, the skills acquired by the producer can be also used for the provision of advisory services on energy efficiency of industrial facilities. These services have to be listed in Matrix E.

We highlight that the described method is intended to be iterative: it can happen that the identification of a product-related service requires specific product functions that, if not previously planned, the design team must indicate in the first form of the method, iterating the procedure.

Fourth step – Translation of PSS Services and Functionalities into Functional Requirements

Finally, in order to obtain the final set of PSS functional requirements the design team has to elaborate services and functionalities identified in the preceding phases. In this final step, the design team is supported to answer to the question:

> Q4*: How we can concretize PSS services and functionalities in terms of PSS functional requirements?*

The use of an overview table can be useful for this purpose. The previously collected and organized information need to be transformed in functional requirements. In this process, the translation of a single service or functions may result in several functional requirements. On the other hand, a functional requirement can be related to different services and functionalities. This last step of the method provides a qualitative outcome which can be used in the following activities of the PSS design.

Figure 7 shows an example of how to define PSS functional requirements starting from on a set of possible PSS product functions and services.

PSS components		Related Functional Requirements
Type	**Definition**	
Product function	Braking	• When the user put down a pedal the vehicle will slows or stops
...	...	...
Product-embedded service	Automatic assistance emergency services	• In case vehicle's sensors detect a collision the GPS position of the vehicle will be formwarded the emergency center of the company that will send a tow truck and an ambulance. • In case the emergency button is pressed, the GPS position of the vehicle will be formwarded the emergency center of the company that will send a tow truck and an ambulance.
...	...	...
Product-related service	3 Years Maintenance Service Plan	• Company technicians will assist in maintaining the vehicle's optimal thecnical condition for three years after the purchasing.
...	...	...

Figure 7 – Example of translation of PSS services and functionalities into the functional requirements

APPLICATION EXAMPLE

This section proposes a pedagogical example of the proposed method for the identification of the PSS functional requirements. Specifically, the PSS product is an airplane seat used for long-haul flights (see Figure 8). Data and information were collected in the academic context between student and researcher under the guidance of an airplane seat designer.

Figure 8 – Representation of the object of the design: an airplane seat for long-haul flights

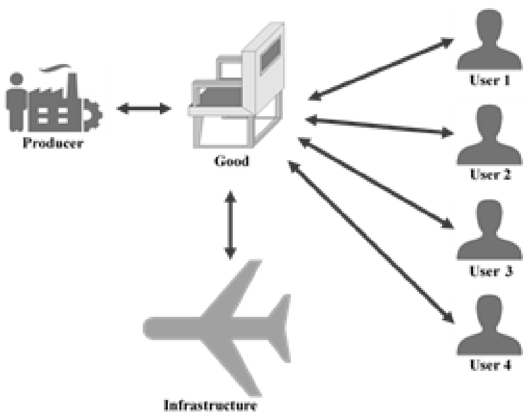

Figure 9 – Airplane seat: PSS architecture

The sketch of the PSS is a seat with a media console to entertain the traveller during the flight.

The players interacting with the PSS are:

(i) The producer, i.e. the organization that is developing and producing the new concept of PSS based on the airplane seat products;
(ii) User 1: the company that assembles the planes on which the seats should be placed;
(iii) User 2: the travellers that uses the PSS during the flight;
(iv) User 3: the airline companies that interacts with the seat, for example for cleaning or small maintenance activities.
(v) User 4: the multimedia service provider, i.e. the organization that manages and updates the offer of multimedia materials available through the multimedia console.

Each of these user categories has specific needs to be considered in the definition of the PSS concept and interact with it during different lifecycle phases. The main infrastructure is the plane on which the seats are mounted and for which there are dimensions and assembly standards to be respected. See Figure 9 for a schematization of the PSS architecture. This information will be useful in subsequent design phases of the PSS design.

First step

The first step of the application of the proposed method identifies Matrix A, Matrix B and Matrix C in which product-embedded services and product and interface functions are listed (see Figure 10 and Figure 11). The recognition of product-embedded services started asking to travellers to indicate the services they would like to receive during the flight in relation to the seat. From the initial list, the design team extracts the most significant and valued services: web browsing, multimedia entertainment and phone call. With the purpose of obtaining important information from travellers, surveys concerning the perceived quality of the flight and multimedia contents were also considered.

The subsequent analysis outcomes in the definition of seat functionalities. In this case too, travellers were firstly considered. Among others, functions for travellers are meal support, reclination, reading light, etc. Other functions of the seat were delineated considering the other PSS players. For instance, the seat should be easily packable for the seat manufacturer, it should be easily fixable on standard supports for the aircraft manufacturer and it should be efficiently cleanable for the airline company.

In this specific example, the functions that the infrastructure offers to players are not considered.

		Customer				
		SEAT MANUFACT.	**AIRCRAFT MANUFACT.**	**TRAVELLERS**	**AIRLINE COMPANY**	**MULTIMEDIA PROVIDER**
Provider	**SEAT MANUFACT.**	-	-	-	-	-
	AIRCRAFT MANUFACT.	-	-	-	-	-
	TRAVELLERS	-	-	-	• Survey on flight quality	• Survey on digital console multimedia content quality
	AIRLINE COMPANY	-	-	• web browsing • Telephone service	-	-
	MULTIMEDIA PROVIDER	-	-	• Entertainment with multimedia content	-	-

Figure 10 – Airplane seat: Matrix A of the first form of the proposed method (Product-embedded interface)

	SEAT MANUFACT.	**AIRCRAFT MANUFACT.**	**TRAVELLERS**	**AIRLINE COMPANY**	**MULTIMEDIA PROVIDER**	**SEATS**	**AIR-PLANE**
SEATS	• Easy to pack • Easy to assemble	• Easy to fix on standard supports • Easy to wire • Easy to set up	• Meals support • Reading support • Glass and drink support • Reclinable • Footstool • Reading light • Arm supports • Head restraints systems • Seat belts • Videogame joystick • Console controller • Wide screen • Telephone software	• Easy to clean • Easy to relocate	• Connection to control unit for multimedia entertainment • Software and hardware problems self-testing	-	-
AIRPLANE	-	-	-	-	-	• Standard seats attachment • Electrical connection • Internet connection	-

Figure 11 – Airplane seat: Matrix B and C of the first form of the proposed method (Product-embedded interface)

Second step

The Matrix D of the method is presented in Figure 12. It contains the product-related services, such as the services that the producer must provide to the aircraft manufacturer. In this step, the initial focus was on the airline company for which a series of services were identified, such as technical assistance updates and training. For the aircraft manufacturer the design team indicates those related to installation and security certification of the seats as possible product-related services. Other services such as advise and surveys for user's feedbacks were also considered.

Provider \ Customer	SEAT MANUFACT.	AIRCRAFT MANUFACT.	TRAVELLERS	AIRLINE COMPANY	MULTIMEDIA PROVIDER
SEAT MANUFACT.	-	• Support for seats installation • Seats safety certification	-	• Technical assistance • Replacement of spare part • Software update • Training for ordinary maintenance and cleaning	• Drivers and user guide release
AIRCRAFT MANUFACT.	• Advice in product design and improvement	-	-	-	-
TRAVELLERS	• Feedback on seats quality	-	-	-	• Feedback on multimedia entertainment quality
AIRLINE COMPANY	-	-	• Flight travels	-	-
MULTIMEDIA PROVIDER	-	-	-	-	-

Figure 12 – Matrix D of the second form of the proposed method (Product-related interface)

Third step

Matrix E, is presented in Figure 13. It contains the product-independent services, such as the service of different products procurement. Notice that these services are not related to the designed tangibles of the PSS.

Provider \ Customer	SEAT MANUFACT.	AIRCRAFT MANUFACT.	TRAVELLERS	AIRLINE COMPANY	MULTIMEDIA PROVIDER
SEAT MANUFACT.	-	• Procurement of cockpit pilots' seat	-	-	-

Figure 13 – Matrix E of the third form of the proposed method (Product-independent interface)

Fourth step

The last step of the method application consists in the translation of PSS's services and functionalities into functional requirements. Table 1 reports this activity. The last column of the table can be the input of the PSS operational design.

In the proposed example it can be noted how two functional requirements may arise from a single service. This is evident for the telephone service enabling both the possibility of making telephone calls and sending text messages (SMS). On the contrary, two (or more) functionalities can result in the same functional requirement: for example, the seat's functions "reclinable" and "sleeping position" both require the ability to change the position from seated to reclined.

THE OUTPUT OF THE METHOD

After having identified the PSS functional requirements, the design team must translate the list of functional requirements into a set of technical requirements of the PSS. Product and infrastructure functions must be converted into technical specifications, while the specifications of the service delivery process should be derived by the list of services.

This brief example evidences the complexity of this activity and the need of further supports for designers. Many different tools can be used to this end (Ericson et al., 2009, Maussang et al., 2009, Franceschini and Mastrogiacomo, 2018, Franceschini et al., 2015, Franceschini and Rossetto, 1995). Shen e Wang (2008) suggest the use of Quality Function Deployment (QFD) to design PSS for different reasons (see Figure 14): (i) the application of QFD requires the involvement of the customers in the development process; (ii) the QFD can be used both for products and services; (iii) it favours and stimulate the interaction in the design team and (iv) although being a structured method, it is suitable for a variety of application.

Table 1 – Translation of the exemplified PSS services and functionalities into functional requirements.

PSS components Type	PSS components Definition	Related Functional Requirements
Product-embedded services	Telephone service	The console on the seat will allow travelers to make telephone call The console on the seat will allow travelers to send SMS
	Web browsing	The multimedia console on the seat will allow travelers to navigate on internet
	Multimedia content	The console on the seat will allow travelers to view films, tv shows, to listen music or to play to videogame
	Survey on flight quality	The console on the seat will allow to compile a survey on flight quality
	Survey on digital console and multimedia quality	The multimedia console on the seat will allow travelers to compile a survey on digital console and multimedia quality

	Reclinable	**The seat should permit to change the position from seated to reclined**
	Sleeping position	The seat should permit to change the position from seated to reclined
	Easy to pack	The seat will be easily packed
	Easy to assemble	The seat will be easily assembled
	Easy to fix on standard supports	The seat will be easily fix on standard supports
	Easy to wire	The seat will be easily wired
	Easy to set up	The seat will be easily set up
	Meal support	The seat will support meal platters
	Reading support	The seat will support a book, a newspaper or a magazine
	Footstool	The seat will permit travelers to put their feet on a specific support
	Reading light	The seat will permit travelers to read when the aircraft cabins is dark
	Arm support	The seat will permit travelers to put their arms on a specific support
	Head restraints system	The seat will have a head restraints system
Product functions	Video game joystick	The multimedia console on the seat will have a joystick to allow travelers to play video game
	Console controller	The multimedia console on the seat will have a controller to allow travelers to select the multimedia contents
	Wide screen	The multimedia console on the seat will have a screen
	Telephone software	The multimedia console on the seat will have a telephone software to allow travelers to make telephone call
	Easy to clean	The seat will be easily cleaned
	Easy to relocate	The seat will be easily relocated
	Replacement of spare parts	Seat’s components with limited lifespan will be easily replaced
	Connection to control unit	The seat will be connected to a to control unit for multimedia entertainment
	Software and hardware self-testing	The multimedia console on the seat will autonomously test
	Standard seat attachment	The seat will be fix to the airplane with Standard attachment
	Electrical connection	The seat will be connected to the electrical system of the airplane
	Internet connection	The seat will be connected to the internet system of the airplane

Product-related services	**Advice in product design and improvements**	**The airplane manufacturer will advise the seat producer for product design and improvements**
	Feedback on seat quality	Seat travelers will give feedback to the seat manufacturer on seat quality
	Support for seat installation	Seat manufacturer will give support in the seat installation
	Seats safety certification	Seat manufacturer will certificate the seats safety
	Technical assistance	Seat manufacturer will provide technical assistance to repair seats
	Provision of replacement components	Seat manufacturer will provide seat replacement components
	Software update	Seat manufacturer will provide software updates of the multimedia console software
	Training for ordinary maintenance and cleaning	Seat manufacturer will train airline company's employees in the maintenance and cleaning activities
	Feedback on multimedia quality	Seat travelers will give feedback on multimedia entertainment quality
Product-independent services	Procurement of cockpit pilots' seat	Seat manufacturer will procure cockpit pilot's seat for the airplane manufacturer

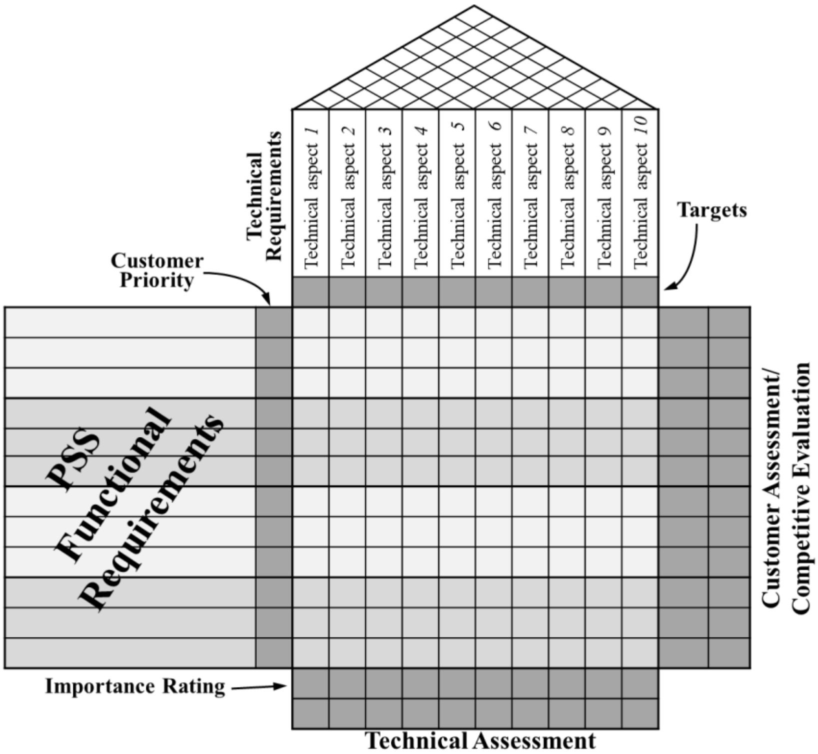

Figure 14 – The PSS functional requirements as the input of the House of Quality in QFD.

CONCLUSION

This paper presents a first proposal for a structured approach to assist the design of a PSS in its early development phases.

The method concurrently considers all design elements in order to stimulate a complete and exhaustive definition of the functional requirements of a PSS. To this end, the method may assist a design team in a structured analysis of all the combinations of players, products, infrastructures and service interfaces. The set of activities defined by the method may support PSS designers to involve the customer already in early stages of development.

The method can be applied to: (i) to identify the service components of a PSS when products and infrastructures already exist, (ii) to systematically design the services and product components when the infrastructure is available or (iii) to produce a concurrent design of all the components of a PSS.

The method represents a first proposal and still lacks a preliminary technical and economic analysis of feasibility of the proposed solution which will be the object of further developments. In the current version, the method mainly focuses on the functional requirements generated from services and products. This purpose can easily be extended to a wider analysis of PSS non-functional requirements.

The findings of this works may have a number of practical implications. Taken together, they suggest the need to closely examine relations between players, products, and interfaces in PSS conceptual design. To this end, greater efforts are needed to develop a more integrative practical design method able to deal with the variety of activities required by the PSS development.

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Robustness analysis of inspection design parameters for assembly of short-run manufacturing processes

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ABSTRACT

Purpose – Defining a method for evaluating the robustness of models for defectiveness prediction and quality cost of inspection procedures in short-run assembly manufacturing processes.

Design/methodology/approach – First, the assembly process is decomposed into several workstations (working phases), each one potentially critical in generating defects. Then, exploiting some models of defect generation, the probabilities of occurrence of defects in each workstation are obtained. At this point, by the law of propagation of variances, the inspection design parameters' uncertainty is derived. Finally, the uncertainty is propagated to two indicators related to the effectiveness and affordability of inspections. The proposed methodology is tested through the uncertainty evaluation of a case study concerning the assembly of hardness testing machines.

Findings – The proposed methodology allows the producers to identify the uncertainty of inspection design parameters for assembly of short-run manufacturing processes.

Research limitations/implications – The proposed methodology relies on the following simplifying assumptions: (i) absence of correlation between the occurrence of defects and inspection errors in the same workstation and (ii) between different workstations.

Practical implications – The methodology may be extended and applied to a variety of different industrial contexts, related to short-run assembly manufacturing processes.

Originality/value – The quantitative approach, including the uncertainty evaluation, represents an important novelty with respect to the classical qualitative approaches in identifying the more suitable inspection procedure for short-run productions.

Keywords: Uncertainty evaluation, Inspection design, Short-run production, Defect generation

Paper type: Research paper

INTRODUCTION

In the manufacturing field, the problem of defects generation can heavily impact on product final quality and cost. The root causes of defects can vary in accordance with the products and the production context. Previous research has deeply focused on defects of the assembly process. In fact, in assembly production, a faster response speed as well as a lower defect rate are required because the product life cycle is increasingly short. In this sense, in the modern manufacturing environment, assembly quality control is becoming one of the most challenging problems (Suzuki et al., 2003). Among all different root causes of defects, human errors have significant influence on assembly system performance (Shibata, 2002; Su at al., 2010), sometimes more than the technological ones (Shin et al., 2006). Different studies were devoted to the problem of defects generation in assembly process with respect to the close relationship between assembly complexity and human mistakes (Hinckley, 1993; Hinckley and Barkan, 1995; Shibata, 2002; Su et al., 2010). In his work, Hinckley found empirically that defects per unit were positively correlated with total assembly time and negatively correlated with the number of assembly operations (Hinckley, 1993; Hinckley and Barkan, 1995). Shibata detailed Hinckley's model by subdividing the product assembly process into a series of workstations (Su et al., 2010), defined through sheets of operation standards (Shibata, 2002; Shibata et al., 2003). In each workstation, a certain number of job elements (Aft, 2000), i.e. elementary operations, was identified. In addition, Shibata introduced a design-based assembly complexity factor because he remarked that the time related measures might not capture all the sources of defects (Shibata, 2002). In line with Hinkley and Shibata's research in the field of semiconductor products, Su et al. developed a new mathematical model of defects generation to match the characteristics of copier assembly (Su et al., 2010).

Furthermore, more recent studies have exploited these models of defects generation for obtaining reliable predictions of the probability of occurrence of defects in manufacturing assembly processes (Franceschini et al., 2016). These probabilities, together with several parameters related to inspection effectiveness and cost are combined into a probabilistic model. Finally, the more effective and economically convenient inspection procedures can be determined using two specific synthetic indicators. The aim of these models is to design quality inspection procedures mainly for small productions (Franceschini et al, 2016; Genta et al. 2018). In fact, in the case of productions of single units, small-sized lots (i.e., the so-called short-runs) or in the start-up of a process, most of the SPC techniques are unsuitable (Montgomery, 2013; Marques at al., 2015).

However, despite the importance of the issues relating to assembly quality control, no previous study has investigated in detail the robustness analysis and the uncertainty evaluation of the models' parameters, both of the defects generation models and of the inspection design procedure.

The aim of this paper is to provide a methodology for evaluating the robustness of the inspection design parameters for assembly of short-run assembly manufacturing processes Specifically, using the law of propagation of variances (Ver Hoef, 2012), it is possible to estimate the uncertainty of the statistical variables of the defect generation models and to propagate the uncertainty to the inspection design parameters. In order to test the proposed methodology, a practical application concerning the assembly of mechanical components in the manufacturing of hardness testing machines is dealt with.

REFERENCE MODELS

Models of defect generation

According to Shibata (2002), the assembly process is subdivided into a series (m) of "workstations" (Su et al., 2010), defined through sheets of operation standards (Shibata, 2002). In each workstation, a certain number of "job elements" (Aft, 2000), i.e. elementary operations, is identified.

Based on Shibata and Su et al. works (Shibata, 2002; Su et al., 2010), the defect generation model used in this paper is that one reported in Eq. (1):

$$DPU_i = k_3 \cdot Cf_{P,i}^{k_1} \cdot Cf_{D,i}^{k_2} \tag{1}$$

where i=1, …, m, i.e. the total number of workstations; $Cf_{P,i}$ is the process-based complexity factor of a generic workstation i (see Eq. (2)); $Cf_{D,i}$ is the design-based complexity factor of a generic workstation i (see Eq. (3)) and k_1, k_2, k_3 are regression coefficients that may be obtained by a power-law nonlinear regression (Genta et al., 2018).

The process-based complexity factor of a generic workstation i, $Cf_{P,i}$, is defined as follows (Shibata, 2002):

$$Cf_{P,i} = \sum_{j=1}^{Na,i} SST_{ij} - t_0 \cdot N_{a,i} = TAT_i - t_0 \cdot N_{a,i} \tag{2}$$

where $N_{a,i}$ is the number of job elements in the workstation i, SST_{ij} is the time spent on job element j in the workstation i, TAT_i is the total assembly time relevant to the workstation i, and t_0 is the threshold assembly time, i.e. the time required for performing the least complex assembly operation. Further information about the Sony Standard Time (*SST*) is provided by Shibata (2002) and Aft (2000).

When dealing with electromechanical products, the design-based complexity factor of a generic workstation i, $Cf_{D,i}$, is expressed as follows (Su et al., 2010; Genta et al., 2018):

$$Cf_{D,i} = \sum_{q=1}^{l}\left(w_q \cdot \frac{1}{e} \cdot \sum_{k=1}^{e} A_{kqi} \right) \tag{3}$$

where q is included between 1 and l, i.e. the total number of parameters selected as criteria for evaluating the design-based assembly complexity; w_q is the weight of the parameter q allocated on a scale between 0 and 1 using the analytic hierarchy process (AHP) approach (Wei et al., 2005); e is the number of evaluators involved in the comparison of the relative importance of each parameter, in order to determine the difficulty of putting a part into a product; the degree of difficulty A_{kqi} is the evaluation of the parameter q in the workstation i estimated by the evaluator k (it is a score between 0 and 10).

At this point, the probability of occurrence of defects in each workstation i (p_i) may be estimated as the fraction of defective outputs in the workstation i (Genta et al., 2018), i.e.:

$$p_i = 1 - \left(1 - \frac{DPU_i}{N_{a,i}} \right)^{N_{a,i}} \tag{4}$$

According to Hinckley's research, Eq. (3) is obtained by making some assumptions (Hinckley, 1993):

- each job element may introduce at most one defect;
- for each workstation i, the probability of occurrence of a defect is the same for each job element.

The concept of inspection effectiveness

In each workstation, different kinds of quality control activities may be performed, according to specific types of defects, thus defining different inspection procedures (Genta et al., 2018).

Subdividing the assembly manufacturing process into a number (m) of workstations (Shibata, 2002; Su et al., 2010) or process steps (Franceschini et al., 2016) and assuming that (i) the occurrence of defects and that of inspection errors are uncorrelated and (ii) the parameters related to different workstations are uncorrelated (Franceschini et al., 2016), the outcome of each i-th workstation can be modelled by a Bernoulli distribution (Montgomery, 2013). Thus, each i-th workstation can be described through three parameters:

- p_i: probability of occurrence of a defective-workstation-output (i.e., the parameter of the Bernoulli distribution);
- α_i: probability of erroneously signaling a defective-workstation-output (i.e., type-I inspection error);
- β_i: probability of erroneously not signaling a defective-workstation-output (i.e., type-II inspection error)

where $i = 1, \ldots, m$, i.e. the total number of workstations.

The parameter p_i may be estimated, as a first approximation, by using Eq. (4). Parameters α_i and β_i are estimated basing on prior experience, i.e. by using empirical values obtained by inspectors in similar processes.

According to the adopted model (Franceschini et al., 2016), the mean total number of defective-workstation-outputs which are erroneously not signaled in the overall inspection procedure can be defined as:

$$D = \sum_{i=1}^{m} E(X_i) = \sum_{i=1}^{m} p_i \cdot \beta_i \tag{5}$$

where X_i is a Bernoulli random variable, equal to zero when (i) a defective-workstation-output is correctly signalled or (ii) no defect is present in the i-th workstation, and equal to one when a defective-workstation-output is erroneously not signalled in the i-th workstation. The steps for obtaining Eq. (5) are detailed in Franceschini et al. (2016) and Genta et al. (2018).

The variable D provides an indication of the overall effectiveness of the inspection procedure.

In addition, to provide a general overview of the inspection design, this indicator may be analyzed together with an inspection cost indicator (Franceschini et al., 2016).

The total cost for inspection and defective-workstation-outputs removal related to the overall production process (m workstations) can be expressed as:

$$C_{tot} = \sum_{i=1}^{m} C_{tot,i} = \sum_{i=1}^{m} \left[c_i + NRC_i \cdot p_i \cdot (1 - \beta_i) + URC_i \cdot (1 - p_i) \cdot \alpha_i + NDC_i \cdot p_i \cdot \beta_i \right] \tag{6}$$

where:

- c_i is the cost of the i-th inspection activity (e.g., manual or automatic inspection activities);

- NRC_i is the necessary-repair cost, i.e., the necessary cost for removing the defective-workstation-outputs;
- URC_i is the unnecessary-repair cost, i.e., the cost incurred when identifying false defective-workstation-outputs; e.g., despite there is no cost required for defective-workstation-outputs removal, the overall process can be slowed down, with a consequent extra cost.
- NDC_i is the cost of undetected defective-workstation-outputs, i.e., the cost related to the missing detection of defective-workstation-outputs.

Apart from the estimate of the probabilities p_i, α_i and β_i, the calculation of the total cost requires the estimate of additional cost parameters. In general, c_i and NRC_i are known costs, URC_i is likely to be relatively easy to estimate, while NDC_i is difficult to estimate since it may depend on difficult-to-quantify factors, such as image loss, after-sales repair cost, etc. (Franceschini et al., 2016).

The indicator C_{tot} provides a preliminary indication of the total cost related to the inspection procedure in use. In this sense, it can be used as a proxy for economic convenience of an inspection procedure.

The block diagram schematizing the proposed methodology is reported in Figure 1.

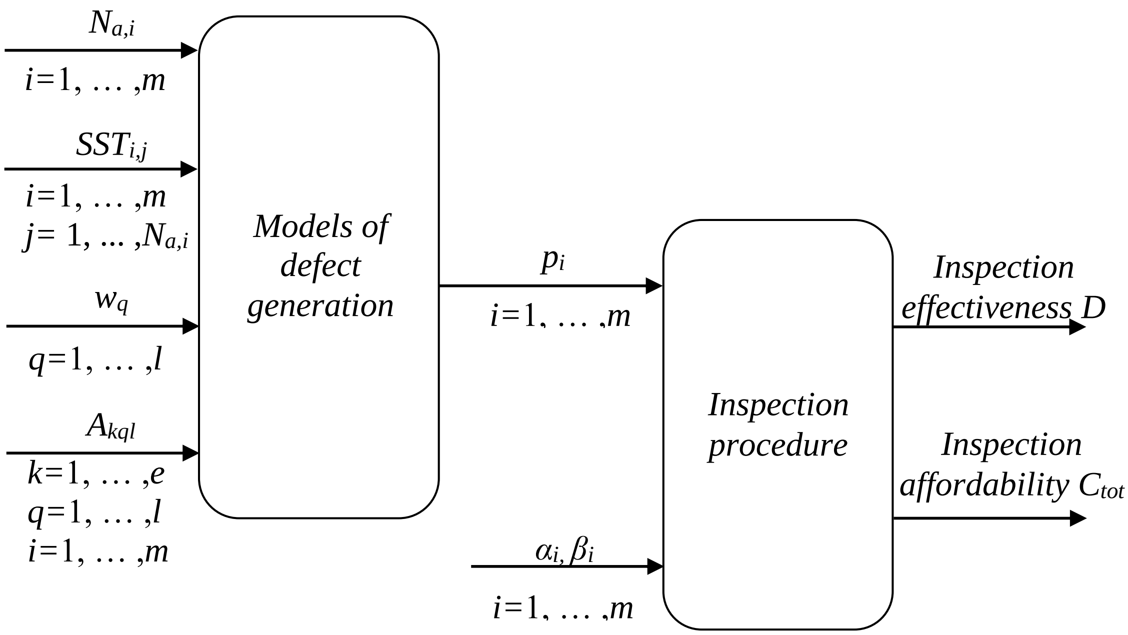

Figure 1 – Scheme of the reference models (see Eq. (2), (3), (4), (5) and (6)). Adapted from Genta et al. (2018).

VARIABILITY ESTIMATION

Variability estimation of the models of defect generation

The Eq. (1) and (4) presented above allow to estimate the measures of central tendency of DPU_i and p_i respectively: namely their mean values can be calculated replacing the input parameters with the corresponding mean values. However, since DPU_i and p_i are two statistical variables, they are affected by variability. In this view, it would be appropriate to estimate the resulting variability of DPU_i and p_i due to the variability of the input parameters.

Specifically, assume to know the variability of the input parameters in terms of variances. The variances of DPU_i and p_i may be obtained by applying the law of propagation of variances (Ver Hoef, 2012).

More precisely, the variance of DPU_i, induced by the variability of the parameters k_1, k_2 and k_3, for predefined values of $Cf_{P,i}$ and $Cf_{D,i}$, may be obtained as:

$$\begin{aligned} VAR(DPU_i) \approx &\left(\frac{\partial DPU_i}{\partial k_3}\right)^2 \cdot VAR(k_3) + \left(\frac{\partial DPU_i}{\partial k_1}\right)^2 \cdot VAR(k_1) + \left(\frac{\partial DPU_i}{\partial k_2}\right)^2 \cdot VAR(k_2) + \\ &+ 2 \cdot \left(\frac{\partial DPU_i}{\partial k_3}\right) \cdot \left(\frac{\partial DPU_i}{\partial k_1}\right) \cdot \operatorname{cov}(k_3, k_1) + 2 \cdot \left(\frac{\partial DPU_i}{\partial k_3}\right) \cdot \left(\frac{\partial DPU_i}{\partial k_2}\right) \cdot \operatorname{cov}(k_3, k_2) + \\ &+ 2 \cdot \left(\frac{\partial DPU_i}{\partial k_1}\right) \cdot \left(\frac{\partial DPU_i}{\partial k_2}\right) \cdot \operatorname{cov}(k_1, k_2) \end{aligned} \tag{7}$$

where the partial derivatives are evaluated at the mean values of the input parameters (i.e. k_1^*, k_2^*, k_3^*). Therefore, it results:

$$\begin{aligned} VAR(DPU_i) \approx &\left(Cf_{P,i}^{k_1^*} \cdot Cf_{D,i}^{k_2^*}\right)^2 \cdot VAR(k_3) + \left(k_3^* \cdot Cf_{D,i}^{k_2^*} \cdot Cf_{P,i}^{k_1^*} \ln(Cf_{P,i})\right)^2 \cdot VAR(k_1) + \\ &+ \left(k_3^* \cdot Cf_{P,i}^{k_1^*} \cdot Cf_{D,i}^{k_2^*} \ln(Cf_{D,i})\right)^2 \cdot VAR(k_2) + \\ &+ 2 \cdot \left(Cf_{P,i}^{k_1^*} \cdot Cf_{D,i}^{k_2^*}\right) \cdot \left(k_3^* \cdot Cf_{D,i}^{k_2^*} \cdot Cf_{P,i}^{k_1^*} \ln(Cf_{P,i})\right) \cdot \sqrt{VAR(k_1)} \cdot \sqrt{VAR(k_3)} \cdot \rho_{k_1,k_3} + \\ &+ 2 \cdot \left(Cf_{P,i}^{k_1^*} \cdot Cf_{D,i}^{k_2^*}\right) \cdot \left(k_3^* \cdot Cf_{P,i}^{k_1^*} \cdot Cf_{D,i}^{k_2^*} \ln(Cf_{D,i})\right) \cdot \sqrt{VAR(k_3)} \cdot \sqrt{VAR(k_2)} \cdot \rho_{k_3,k_2} + \\ &+ 2 \cdot \left(k_3^* \cdot Cf_{D,i}^{k_2^*} \cdot Cf_{P,i}^{k_1^*} \ln(Cf_{P,i})\right) \cdot \left(k_3^* \cdot Cf_{P,i}^{k_1^*} \cdot Cf_{D,i}^{k_2^*} \ln(Cf_{D,i})\right) \sqrt{VAR(k_1)} \cdot \sqrt{VAR(k_2)} \cdot \rho_{k_1,k_2} \end{aligned} \tag{8}$$

where ρ_{k_1,k_3} is the correlation coefficient between k_1 and k_3, ρ_{k_3,k_2} is the correlation coefficient between k_3 and k_2, ρ_{k_1,k_2} is the correlation coefficient between k_1 and k_2.

Extending the reasoning to p_i (see Eq. (4)), the related variance may be expressed as:

$$VAR(p_i) \approx \left(\frac{\partial p_i}{\partial DPU_i} \right)^2 \cdot VAR(DPU_i) \tag{9}$$

where the partial derivative is still evaluated at the mean value of the input parameter (DPU_i^*). As a result, Eq. (10) is obtained:

$$\begin{aligned} VAR(p_i) &\approx \left(N_{a,i} \left(1 - \frac{DPU_i^*}{N_{a,i}} \right)^{N_{a,i}-1} \cdot \left(-\frac{1}{N_{a,i}} \right) \right)^2 \cdot VAR(DPU_i) = \\ &= \left(-1 \left(1 - \frac{DPU_i^*}{N_{a,i}} \right)^{N_{a,i}-1} \right)^2 \cdot VAR(DPU_i) = \left(\left(1 - \frac{DPU_i^*}{N_{a,i}} \right)^{N_{a,i}-1} \right)^2 \cdot VAR(DPU_i) = \\ &= \left(1 - \frac{DPU_i^*}{N_{a,i}} \right)^{2\cdot(N_{a,i}-1)} \cdot VAR(DPU_i) \end{aligned} \tag{10}$$

where the variance of DPU_i may be calculated using Eq. (8).

Variability estimation of the inspection procedure

Now extend the reasoning to the indicators of effectiveness and affordability, D and C_{tot} (see Eq. (5) and (6) respectively).

The variance of D may be expressed as:

$$VAR(D) = VAR\left(\sum_{i=1}^{m} E(X_i) \right) = \sum_{i=1}^{m} VAR[E(X_i)] = \sum_{i=1}^{m} VAR(p_i \cdot \beta_i) \tag{11}$$

in the hypothesis of absence of correlations between defects originated in different workstations and between defects and inspection (see Section 2.2). From Eq. (11), it is possible to obtain:

$$VAR(D) \approx \sum_{i=1}^{m} \left[\left(\frac{\partial E(X_i)}{\partial p_i} \right)^2 \cdot VAR(p_i) + \left(\frac{\partial E(X_i)}{\partial \beta_i} \right)^2 \cdot VAR(\beta_i) \right] \tag{12}$$

where the partial derivatives are evaluated at the mean values of the input parameters. Therefore, it results:

$$VAR(D) \approx \sum_{i=1}^{m} \left[\beta_i^2 \cdot VAR(p_i) + p_i^2 \cdot VAR(\beta_i) \right] \tag{13}$$

where the variance of p_i can be calculated using Eq. (10).

According to Eq. (13), the variance of D is the sum of the variances of the parameters p_i and β_i, weighted respectively by the squares of β_i and p_i. It can be noticed that the effect of relatively higher variances of p_i can be compensated by relatively lower β_i values, and vice versa.

With respect to C_{tot} (see Eq. (6)), the relevant variance may be expressed as:

$$VAR\left(C_{tot}\right) = VAR\left(\sum_{i=1}^{m} C_{tot,i}\right) = \sum_{i=1}^{m} VAR\left(C_{tot,i}\right) \tag{14}$$

again in the hypothesis of absence of correlations. From Eq. (14), it is possible to obtain:

$$\begin{aligned} VAR\left(C_{tot}\right) \approx \sum_{i=1}^{m} \Bigg[& \left(\frac{\partial C_{tot,i}}{\partial p_i}\right)^2 \cdot VAR\left(p_i\right) + \left(\frac{\partial C_{tot,i}}{\partial \alpha_i}\right)^2 \cdot VAR\left(\alpha_i\right) + \left(\frac{\partial C_{tot,i}}{\partial \beta_i}\right)^2 \cdot VAR\left(\beta_i\right) + \left(\frac{\partial C_{tot,i}}{\partial c_i}\right)^2 \cdot VAR\left(c_i\right) + \\ & + \left(\frac{\partial C_{tot,i}}{\partial NRC_i}\right)^2 \cdot VAR\left(NRC_i\right) + \left(\frac{\partial C_{tot,i}}{\partial URC_i}\right)^2 \cdot VAR\left(URC_i\right) + \left(\frac{\partial C_{tot,i}}{\partial NDC_i}\right)^2 \cdot VAR\left(NDC_i\right) \Bigg] \end{aligned} \tag{15}$$

where the derivatives are once more evaluated at the mean values of the parameters. Therefore, it results:

$$\begin{aligned} VAR\left(C_{tot}\right) \approx \sum_{i=1}^{m} \Big[& \left(NRC_i - NRC_i \cdot \beta_i - URC_i \cdot \alpha_i + NDC_i \cdot \beta_i\right)^2 \cdot VAR\left(p_i\right) + \\ & + \left(URC_i - URC_i \cdot p_i\right)^2 \cdot VAR\left(\alpha_i\right) + \left(-NRC_i \cdot p_i + NDC_i \cdot p_i\right)^2 \cdot VAR\left(\beta_i\right) + VAR\left(c_i\right) + \\ & + \left(p_i - p_i \cdot \beta_i\right)^2 \cdot VAR\left(NRC_i\right) + \left(\alpha_i - p_i \cdot \alpha_i\right)^2 \cdot VAR\left(URC_i\right) + \left(p_i \cdot \beta_i\right)^2 \cdot VAR\left(NDC_i\right) \Big] \end{aligned} \tag{16}$$

where the variance of p_i can be once more calculated using Eq. (10).

According to Equation (16), the variance of C_{tot} is a sum of the variances of the input parameters, weighted by polynomial combinations of p_i, α_i, β_i, NRC_i, URC_i and NDC_i. It can be noticed that the weights of the variances of the probability parameters (p_i, α_i and β_i) depend on both probability and cost parameters, while the weights of the variances of the cost parameters (c_i, NRC_i, URC_i and NDC_i) only depend on probability parameters.

A PRACTICAL APPLICATION

Description of hardness testing machines assembly

Consider a manufacturing process aimed at producing hardness testing machines, specifically AFFRI® LD 3000 AF. The production of these machines can be considered a short-run production process (Genta et al., 2018). From the manufacturing point of view, this process may be subdivided into nine assembly phases. They are in the order: 1) threaded shaft, 2) machine working axis, 3) axis movement mechanism, 4) machine head, 5) reference plan movement device, 6) measurement device unit, 7) machine processing unit, 8) machine electrical system, 9) final assembly.

In this paper, for simplicity of representation, only the first four assembly phases, corresponding to the overall assembly of machine head, are dealt with in detail (see Figure 2). In each of this four assembly phases a certain number of workstations is identified, as illustrated in Figure 2 by the rectangular shapes, together with the specific types of performed controls, represented in Figure 2 by the oval shapes.

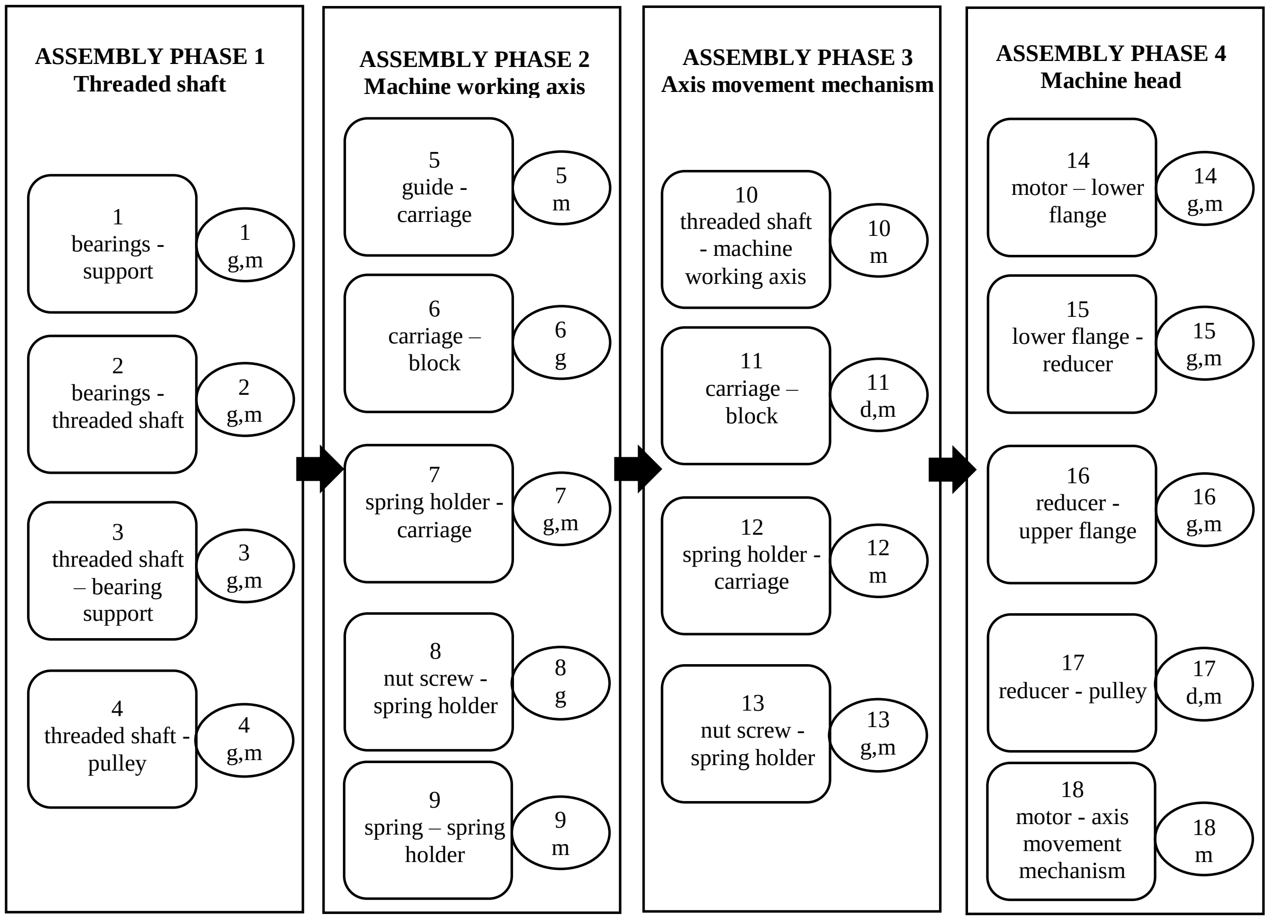

Fig. 2 - Graphical representation of the workstations of the overall assembly of machine head with indication of the specific type of performed controls. Legend of the type of control: g: geometric, m: mechanical, d: dimensional.

Defect generation model with variability estimation

According to Shibata (2002) and Su et al. (2010) models (see Section 2.1), Table 1 provides, for each workstation i, the total assembly time TAT_i, the number of job elements $N_{a,i}$, the process-based complexity factor $Cf_{P,i}$, the design-based complexity factor $Cf_{D,i}$ and the defects per unit DPU_i. The process-based complexity factors are calculated, according to Eq. (2), by exploiting the threshold assembly time t_0, which is equal to 0.5 minutes. This threshold assembly time coincides with the time required to perform the least complex job element. The design-based complexity factors are obtained, according to Eq. (3), by using the parameters shown in Table 2 together with their weights. These eleven parameters were selected according to the characteristics of the assembly of hardness testing machines, slightly modifying the parameters relevant to copiers chosen by Su et al. (2010). Defects per unit are calculated from the corresponding process-based and design-based complexity factors by applying Eq. (1). Specifically, the power-law model used is reported in Eq. (17) and illustrated in Figure 3.

$$DPU_i = 3.04 \cdot 10^{-5} \cdot Cf_{P,i}^{1.27} \cdot Cf_{D,i}^{1.49} \tag{17}$$

The model parameters in Eq. (17) have been estimated, as a first approximation, by applying a nonlinear regression to the data derived from previous works (related to 30 workstations) concerning a similar case study involving the assembly of mechatronic devices (Shibata, 2002; Su et al., 2010).

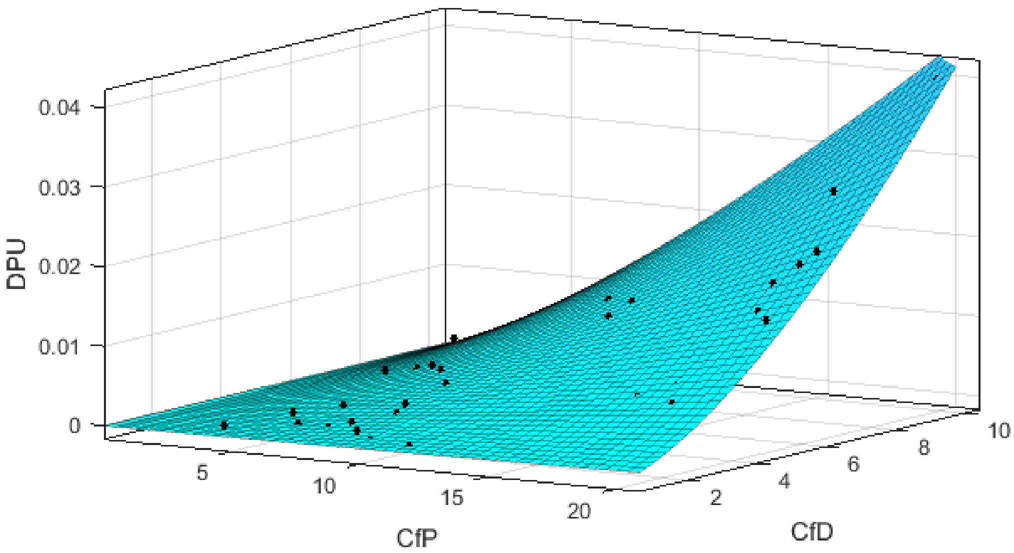

Fig. 3 - 3D surface plot of *DPU* against Cf_P and Cf_D. (experimental points of 30 workstations concerning an analogous assembly process for mechatronic devices, and theoretical model)

Table 1 - Application of Shibata and Su models to the overall assembly of machine head.

Assembly phase no.	**Workstation no.**	TAT_i **[min]**	$N_{a.i}$	$Cf_{P.i}$ **[min]**	$Cf_{D,i}$	DPU_i
1	1	17.0	6	14.0	3.5	0.0055
	2	15.5	7	12.0	3.7	0.0050
	3	9.0	5	6.5	2.4	0.0012
	4	9.5	6	6.5	3.3	0.0019
2	5	6.0	2	5.0	1.7	0.0005
	6	11.0	3	9.5	2.9	0.0026
	7	18.5	6	15.5	2.9	0.0049
	8	5.0	3	3.5	4.8	0.0015
	9	4.5	5	2.0	3.2	0.0004
3	10	13.5	7	10.0	4.0	0.0044
	11	8.5	5	6.0	4.4	0.0026
	12	4.5	3	3.0	3.2	0.0007
	13	7.0	3	5.5	3.3	0.0015
4	14	3.0	2	2.0	3.7	0.0005
	15	7.0	6	4.0	5.9	0.0025
	16	3.0	2	2.0	3.7	0.0005
	17	5.0	3	3.5	3.3	0.0009
	18	12.5	6	9.5	3.4	0.0033

Table 2 - Parameters for evaluating the design-based assembly complexity in case of hardness testing machines with indication of weights.

Parameter no.	**Parameter description**	**Weight**
1	Components shape	0.095
2	Required forces	0.070
3	Coupling directions	0.104
4	Components alignment	0.167
5	Components size	0.118
6	Components geometry	0.119
7	Ratio between components size and geometry	0.081
8	Components play	0.130
9	Worktable stability	0.063
10	Equipment requirements	0.052
11	Electrical disturbances	0.000

Then, according to Eq. (8), the variances of DPU_i, reported in Table 3, are calculated by exploiting the variances of the regression parameters ($VAR(k_1)$=$5.73\cdot10^{-4}$; $VAR(k_2)$=$3.54\cdot10^{-4}$; $VAR(k_3)$=$4.65\cdot10^{-12}$) and the correlation matrix of the model parameters. Specifically, the correlation coefficients in the correlation matrix (ρ_{k_1,k_3} = - 0.85; ρ_{k_3,k_2} = - 0.30; ρ_{k_1,k_2} = - 0.24) are derived from the variance-covariance matrix of the parameters (which is obtained by applying the

QR decomposition) produced by the Gauss-Newton method for the nonlinear regression applied to the model of Eq. (17) (Bates and Watts, 1988; Devore, 2015; Draper and Smith, 2014; Horn and Johnson, 1985).

Once calculated the variance of *DPU*s, it is useful to determine the 95% confidence interval and the 95% prediction interval, for each DPU_i.

The 95% confidence interval of DPU_i may be expressed, in this specific case study, as follows:

$$(DPU_i - 2.052 \cdot \sqrt{VAR(DPU_i)}\,,\; DPU_i + 2.052 \cdot \sqrt{VAR(DPU_i)}) \tag{18}$$

The 95% prediction interval of DPU_i may be expressed as:

$$(DPU_i - 2.052 \cdot \sqrt{VAR(DPU_i) + S^2}\,,\; DPU_i + 2.052 \cdot \sqrt{VAR(DPU_i) + S^2}) \tag{19}$$

where *S*, known both as the standard error of the regression and as the standard error of the estimate, represents the average distance that the observed values fall from the regression line, according to Eq. (20):

$$S = \sqrt{\frac{RSS}{N - P}} \tag{20}$$

where RSS is the sum of the squared residuals, N is the number of observations and P is the number of free parameters. In this case study *S*, equal to $3.49 \cdot 10^{-4}$, is still obtained from the power-law nonlinear regression model of Eq. (17). In Table 3 the lower limits (LL) and upper limits (UL) of the confidence intervals (CI) and the prediction intervals (PI) of defects per unit are reported, separately for each workstation *i*.

At this point, it is worth noting that the standard uncertainty of defects per unit, which will be used to estimate the variability of p_i (see Eq. 10) and that of the inspection procedure indicators (see Eq. 13 and 16), is the standard error used for the calculation of the prediction intervals, i.e. the standard error of the predictions of each singular value of DPU_i, as reported in Eq. (21):

$$u(DPU_i) = \sqrt{VAR(DPU_i) + S^2} \tag{21}$$

In Table 4 the square of the standard error of the prediction of defects per unit ($u^2(DPU_i)$) are reported.

Table 3 – Defects per unit in each workstation i (DPU_i), variance of DPU_i ($VAR(DPU_i)$), square of the standard error of the prediction of DPU_i ($u^2(DPU_i)$), lower limit of the confidence interval of DPU_i (*LL CI*), upper limit of the confidence interval of DPU_i (UL PI), lower limit of the prediction interval of DPU_i (LL PI) and upper limit of the prediction interval of DPU_i (UL PI).

Workstation no.	DPU_i	$VAR(DPU_i)$	$u^2(DPU_i)$	***LL CI***	***UL CI***	***LL PI***	***UL PI***
1	0.0055	$6.77 \cdot 10^{-9}$	$1.28 \cdot 10^{-7}$	0.0054	0.0057	0.0048	0.0063
2	0.0050	$5.70 \cdot 10^{-9}$	$1.27 \cdot 10^{-7}$	0.0048	0.0051	0.0042	0.0057
3	0.0012	$1.15 \cdot 10^{-9}$	$1.23 \cdot 10^{-7}$	0.0011	0.0012	0.0005	0.0019
4	0.0019	$2.53 \cdot 10^{-9}$	$1.24 \cdot 10^{-7}$	0.0018	0.0020	0.0012	0.0026
5	0.0005	$3.32 \cdot 10^{-10}$	$1.22 \cdot 10^{-7}$	0.0005	0.0005	-0.0002	0.0012
6	0.0026	$3.02 \cdot 10^{-9}$	$1.25 \cdot 10^{-7}$	0.0025	0.0027	0.0019	0.0033
7	0.0049	$7.33 \cdot 10^{-9}$	$1.29 \cdot 10^{-7}$	0.0047	0.0050	0.0041	0.0056
8	0.0015	$3.52 \cdot 10^{-9}$	$1.25 \cdot 10^{-7}$	0.0014	0.0017	0.0008	0.0023
9	0.0004	$4.54 \cdot 10^{-10}$	$1.22 \cdot 10^{-7}$	0.0004	0.0005	-0.0003	0.0011
10	0.0044	$5.59 \cdot 10^{-9}$	$1.27 \cdot 10^{-7}$	0.0043	0.0046	0.0037	0.0052
11	0.0026	$4.86 \cdot 10^{-9}$	$1.26 \cdot 10^{-7}$	0.0025	0.0028	0.0019	0.0034
12	0.0007	$8.52 \cdot 10^{-10}$	$1.22 \cdot 10^{-7}$	0.0006	0.0007	0.0000	0.0014
13	0.0015	$2.08 \cdot 10^{-9}$	$1.24 \cdot 10^{-7}$	0.0015	0.0016	0.0008	0.0023
14	0.0005	$6.89 \cdot 10^{-10}$	$1.22 \cdot 10^{-7}$	0.0005	0.0006	-0.0002	0.0012
15	0.0025	$7.74 \cdot 10^{-9}$	$1.29 \cdot 10^{-7}$	0.0023	0.0026	0.0017	0.0032
16	0.0005	$6.89 \cdot 10^{-10}$	$1.22 \cdot 10^{-7}$	0.0005	0.0006	-0.0002	0.0012
17	0.0009	$1.18 \cdot 10^{-9}$	$1.23 \cdot 10^{-7}$	0.0008	0.0009	0.0002	0.0016
18	0.0033	$3.97 \cdot 10^{-9}$	$1.25 \cdot 10^{-7}$	0.0031	0.0034	0.0025	0.0040

Now, for each workstation i, the probability of occurrence of a defective-workstation-output p_i is derived from the defects per unit DPU_i through Eq. (4). For low values of DPU_i, the differences with the relevant values of p_i (shown in Table 4) are negligible, i.e. p_i values may be approximated by the corresponding DPU_i values. This result could be proved by considering the first-order Maclaurin series expansion of p_i with respect to DPU_i obtained from Eq. (4) (Genta et al., 2018). Then, according to Eq. (10), the variances of p_i are calculated and reported in Table 4, by exploiting the DPU_i uncertainty reported in Eq. (21).

It is worth noting that an overall validation of the proposed methodology is a huge issue. Since the assembly of hardness testing machines is a short-run manufacturing process, a real data collection cannot be easily completed in a short term. However, a preliminary validation of the proposed methodology may be provided, for some workstations, by collecting the data relevant to the assembly of different kind of hardness testing machines and comparing the empirical values with those predicted. For example, the empirical values of DPU_i for the first four workstations are consistent with those reported in Table 3. Consequently, the corresponding empirical values of p_i are consistent with those reported in Table 4 (Genta et al., 2018).

The adopted inspection procedure requires the controls represented in Figure 2. Each control is affected by the inspection errors, α_i and β_i. According to Genta et al. (2018), the inspection errors α_i and β_i are estimated by exploiting empirical values of similar assembly processes of mechatronic devices (see Table 4). With reference to the standard deviation of each inspection error, it is assumed to be 5% of the relevant value of the parameter itself.

Table 4 - Estimates of probabilities p_i and relative variances, αi and βi relevant to each workstation, in the overall assembly of machine head (Genta et al., 2018).

Assembly phase no.	Workstation no.	p_i [%]	$VAR(p_i)$	α_i [%]	β_i [%]
1	1	0.55	$1{,}27 \cdot 10^{-7}$	2.0	0.5
	2	0.49	$1{,}26 \cdot 10^{-7}$	1.0	0.1
	3	0.12	$1{,}22 \cdot 10^{-7}$	3.0	1.0
	4	0.19	$1{,}24 \cdot 10^{-7}$	1.5	0.5
2	5	0.05	$1{,}22 \cdot 10^{-7}$	0.5	0.1
	6	0.26	$1{,}24 \cdot 10^{-7}$	3.5	1.0
	7	0.49	$1{,}28 \cdot 10^{-7}$	0.5	0.1
	8	0.15	$1{,}25 \cdot 10^{-7}$	1.0	0.2
	9	0.04	$1{,}22 \cdot 10^{-7}$	0.5	0.1
3	10	0.44	$1{,}26 \cdot 10^{-7}$	4.0	0.7
	11	0.26	$1{,}26 \cdot 10^{-7}$	0.5	0.1
	12	0.07	$1{,}22 \cdot 10^{-7}$	0.5	0.1
	13	0.15	$1{,}23 \cdot 10^{-7}$	1.0	0.2
4	14	0.05	$1{,}22 \cdot 10^{-7}$	0.5	0.1
	15	0.25	$1{,}29 \cdot 10^{-7}$	3.0	1.5
	16	0.05	$1{,}22 \cdot 10^{-7}$	0.5	0.1
	17	0.09	$1{,}23 \cdot 10^{-7}$	1.0	0.3
	18	0.33	$1{,}25 \cdot 10^{-7}$	0.5	0.1

Inspection procedure with uncertainty evaluation

The indicator on inspection effectiveness D may be calculated by using Eq. (5) and the estimates of the probabilities in Table 5. It results that the mean total number of defective-workstation-outputs which are erroneously not signaled in the overall inspection procedure is:

$$D = \sum_{i=1}^{18} p_i \cdot \beta_i = 1.70 \cdot 10^{-4} \tag{22}$$

According to Eq. (13), from the sum of the variances of the parameters p_i and β_i, weighted respectively by the squares of β_i and p_i, it is possible to obtain the variance of D (see Eq. (23)):

$$VAR(D)=\sum_{i=1}^{18}\left[\beta_i^2\cdot VAR(p_i)+p_i^2\cdot VAR(\beta_i)\right]=7.95\cdot 10^{-11} \tag{23}$$

Finally, the 95% confidence interval for D may be expressed as: $(1.52\cdot 10^{-4}\,;\,1.88\cdot 10^{-4})$.

In other words, given a production of 10^4 machine heads, there are, with a confidence level of 95%, about 2 defective-workstation-outputs which are erroneously not signaled. Since the production of the examined type of hardness testers is only of some tens per year, the number of defective-workstation-outputs which are erroneously not signaled is negligible. By extending the analysis to the other five process phases, the indicator D becomes $3.8\cdot 10^{-4}$, and the 95% CI becomes $(3.41\cdot 10^{-4}\,;\,4.24\cdot 10^{-4})$. These results are considered reasonable by the producer of hardness testing machines and they are supported by the experience matured in the field.

Moreover, since D is a sum, it possible to separately analyze and compare its addends $p_i\cdot\beta_i$ in order to identify the most critical workstations. Considering the highest addends (in this case study, those related to workstations no. 10 and 15), more effective inspection procedures may be designed.

Table 5 reports the estimates of the cost parameters for each workstation. These estimates were calculating taking into account the time required for identifying and repairing possible defective-workstation-outputs, and the labor cost of operators/inspectors. However, these values are just indicative because the real ones are confidential.

The information contained in Table 5 may be exploited for calculating the total cost for inspection and defective-workstation-outputs removal related to the overall production process (C_{tot}), according to Eq. (6).

$$C_{tot}=\sum_{i=1}^{m}C_{tot,i}=7.35\ € \tag{24}$$

Considering that the standard deviation of each cost parameter is assumed to be 5% of the relevant value of the parameter itself, the variance of C_{tot} can be obtained, according to Eq. (16):

$$VAR(C_{tot})=0.02\ €^2 \tag{25}$$

Finally, the 95% confidence interval for C_{tot} may be expressed as: (7.05, 7.75) €.

By extending the analysis to the other five process phases, the indicator C_{tot} becomes 16.53 €, and the 95% CI becomes (15.86, 17.20) €. These results, of course considered reasonable by the producer of hardness testing machines, are a preliminary indication of the total cost related to the inspection procedure in use. In this sense, they can be used as a proxy for economic convenience of the inspection procedure and could be useful to compare this kind of inspection procedure with others.

Table 5 – Estimates of cost parameters relevant to each workstation, in the overall assembly of machine head. (Cost values are codified. Real costs values are confidential).

Assembly phase no.	**Workstation no.**	c_i **[€]**	NRC_i **[€]**	URC_i **[€]**	NDC_i **[€]**
1	1	0.17	1.75	1.75	20.94
	2	0.17	1.75	1.75	20.94
	3	0.17	1.75	1.75	20.94
	4	0.35	0.70	0.70	6.98
2	5	0.10	0.78	0.78	23.40
	6	0.20	1.95	1.95	23.40
	7	0.20	1.95	1.95	11.70
	8	0.21	2.09	2.09	50.16
	9	0.10	0.78	0.78	7.80
3	10	2.09	4.18	4.18	50.16
	11	0.10	0.39	0.39	3.90
	12	0.10	0.39	0.39	3.90
	13	0.10	0.39	0.39	3.90
4	14	0.10	0.39	0.39	3.90
	15	0.36	1.82	1.82	10.93
	16	0.09	0.36	0.36	3.64
	17	0.36	0.73	0.73	7.28
	18	1.82	3.64	3.64	10.93

CONCLUSIONS

In literature, many papers have been provided in the field of defects generation models, especially for predicting operator-induced assembly defects. More recently, the attention has been focused on the exploitation of these models for getting reliable predictions of the probability of occurrence of defects in each manufacturing step, with the aim to design quality inspection procedures for short-run productions. However, both the models of defect generation and the inspection design procedure, did not include a robustness analysis, without which reliable results cannot be obtained.

In this work, a methodology for evaluating the uncertainty of the average outgoing defectiveness and quality cost of inspection procedures in short run assembly manufacturing processes is proposed. By applying the law of propagation of variances, it is possible to estimate the uncertainty of the statistical variables of the model of defect generation (p_i and DPU_i) and to propagate the uncertainty to the inspection design parameters (D and C_{tot}). An application example concerning the assembly of mechanical components in the manufacturing of hardness testing machines is dealt with. The results of the proposed method applied to this case study show that the inspection design parameters have small confidence intervals. Therefore, this makes it possible to provide reliable estimates of the inspection design parameters.

The originality of the proposed method is its quantitative connotation in analyzing the inspection performances of short run productions, where traditional SPC tools may not be implemented. The methodology may be extended and applied to a variety of different industrial contexts, related to short run and single unit assembly manufacturing processes.

Even if the mathematical modeling of the method seems very complex and difficult to be implemented by production engineers in the gemba, it can be easily automated and the whole process for data acquisition and defect prediction can be guided by specific software procedures, which draw information by historical databases and on-the-field acquisitions. Currently, a first prototype of such a software is going to be completed and tested on the field in a production of components for automotive industry.

A first limitation of the proposed methodology is that it requires the estimation of various not-so-easily-quantifiable parameters (i.e. α_i, β_i, c_i, NRC_i, URC_i, NDC_i). A thorough understanding of the process of interest and the opinion of experts may contribute to overcome this limitation (at least partially). According to the different nature of the various parameters, diverse approaches may be undertaken. For example, parameters α_i and β_i can be estimated by using historical data collected for the same typology of inspections applied to other similar processes or by conducting specific experiments in order to qualify the used inspection procedures. Concerning in particular these two parameters, future research will be aimed at developing specific models for the prediction of inspection errors using an approach similar to the one adopted for the defect-generation models.

On the other hand, c_i and NRC_i are well known costs for a production line, while URC_i can be easily estimated by considering waste materials and manpower invested for false defective outputs. Instead, NDC_i is more difficult to quantify because it is related to image loss, after-sales repair cost, etc. In any case, it can be (at least, roughly) estimated by analysing historical data obtained for similar products about claims, guarantee services, market researches, etc.

Secondly, the proposed methodology relies on the following simplifying assumptions, which are acceptable for most of the realistic cases, but could be removed in future research: (i) absence of correlation between the occurrence of defects and inspection errors in the same workstation and (ii) between different workstations.

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University absenteeism: Students' and lecturers' point of view

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ABSTRACT

The main aim of this study is to analyse the students' absenteeism reasons in different social science degrees taught at the Universitat de Barcelona. Both the students' perception and lecturers' perception are studied and compared. A survey was used in order to gather data from both students and lecturers. The final samples analysed were 2,673 students from five different degrees and 276 lecturers or staff members. A difference analysis of means using ANOVA and a factorial analysis were done to analyse the data. The findings show that students and lecturers identify the reasons of absenteeism similarly, although the level of importance given is different. From the factorial analysis, students grouped the reasons into five factors, while lecturers do it in four. How students design their profiles and the teaching methodology are similar factors for both. However, students differentiate among different aspects of the subject, while lecturers consider these aspects as a whole. This is one of the first studies, to the best of the authors' knowledge, in comparing the students' and lecturers' perceptions of the absenteeism reasons. The results of this research would help in proposing actions to be taken to increase students' engagement and to reduce the gap in perceptions of both groups. The identification of stakeholders' responsibilities will also help in reducing absenteeism.

Keywords: students' absenteeism, subject characteristics, teaching methodology, students' profile.

Paper type: Research paper

INTRODUCTION

In recent years, the spending on tertiary education in the majority of the countries has decreased (OECD, 2018). This is affecting how the available resources are allocated and used in higher education institutions (see e.g., Ramchander, 2017), which have to find more efficient and effective methodologies to provide a high quality teaching. Thus, a call for a more efficient use of these resources is needed, trying to avoid phenomena that could mean a waste of them, such as students' absenteeism. An absent student is considered as the one not attending the lessons despite being enrolled in the subject (Triadó-Ivern et al., 2013).

The interest to analyse the reasons and effects of absenteeism at the university level has increased (see e.g., Triadó-Ivern et al., 2013; Triadó-Ivern et al., 2014; López-Bonilla and López-Bonilla, 2015; Ramchander, 2017; Sarmento-dos-Santos et al., 2017), although the existing literature is still scarce (Pithers and Holland, 2007; López-Bonilla and López-Bonilla, 2015). For example, Romer (1993) detected, in a study performed in the United States, that a third of students do not attend class, while Barlow and Fleischer (2011) analysed the absenteeism in a British university with a survey of academic staff (33 responses) and 25 interviews with first year students, finding that each stakeholder has its responsibility on reducing the problem.

Absenteeism is not only negative for the sources spent but it also contradicts the European Higher Education Area, in which students should play an active role in the learning process, with a high level of engagement and commitment required and also a high level of attendance and participation in class activities (EU, 1999). However, absenteeism could be voluntary or involuntary. The former refers to absent students who do not attend because they prefer to devote their time on other activities, such as staying at home, doing leisure activities, attending a test preparation service or working with tutor. The latter refers to students that work or have other subjects at the same time and thus, cannot attend because of that.

Regarding the reasons of absenteeism at the university level, the most highlighted are, among others (see e.g., Romer, 1993; Triadó-Ivern et al., 2013; Triadó-Ivern et al., 2014; Ramchander, 2017): health problems, problems in the relationship between teacher-student or student-student, lack of interest in the learning process, difficulty in meeting academic requirements, and scheduled tests. Analysed in detail, Triadó-Ivern et al. (2013) identified 12 different reasons of absenteeism in six different degrees which were grouped into four factors: (1) factor related to course characteristics in which attending was not compulsory, (2) factor referred to lecturers’ and subjects’ characteristics, (3) factor related to structural elements such as schedules, and (4) factor grouping to resources available such as notes or manuals. Triadó-Ivern et al. (2014) found significant differences in absenteeism perception depending on the timetables, i.e., students of morning lessons compared to evening lessons. The former gave more importance to how the lecturer explains the subject and give it as a reason for attending the test preparation services, for example; while the latter gave more importance on how they manage their profile, for example because they work.

López-Bonilla and López-Bonilla (2015) analysed 28 determining factors in a sample of tourism students, which could be grouped into seven factors: (1) efficiency, (2) teaching style (the most important), (3) academic interest, (4) teaching content and format, (5) classmates influence and fears, (6) imponderables and (7) convenience. Ramchander (2017) analysed a sample of 140 management students in South Africa concluding that one important factor of absenteeism is studying for tests or complete assignments, which make students be absent the day before the test and the day of the test. Oldfield et al. (2017) analysed a single UK university with a sample of 618 undergraduate students and found that the most important reasons for non-attending are: lower sense of belongingness, working more hours in paid jobs, more social life commitments, assignments deadlines, and mental health issues. According to Barr (2017), using anonymity (clickers) could increase students' engagement into lectures by an increased participation, influenced cognitive engagement, allowed for normative comparisons and allowed for more processing time.

Another aspect analysed in the literature has been the relationship between attendance and performance (see e.g., Paisey and Paisey, 2004; Woodfield et al., 2006). For example, Cabrera et al. (2006) found that attending class helps in finishing the degree in the established years. Walker et al. (2008) found that although class attendance did not ensure knowledge gaining, there is a direct and positive relationship between attendance and passing the subject.

The point of view analysed is also important. Students' perception on absenteeism has been widely analysed (see e.g., Triadó-Ivern et al., 2013; López-Bonilla and López-Bonilla, 2015) but few studies analyse the comparison between their perception and lecturers' or staff members' perceptions (see e.g., Barlow and Fleischer, 2011; Marchand et al., 2014). As said, the perception of participants is used to measure the absenteeism and it follows the model proposed by Cronin and Taylor (1992) called SERVPERF in which only the perceptions of service users were analysed. This model has been widely used in the quality service studies and also at the university level (see e.g., Oldfield and Baron, 2000; O'Neill and Palmer, 2004; Stodnick and Rogers, 2008; Brochado, 2009; Torres and Araya-Castillo, 2010; Icli and Anil, 2014), at the point of becoming a decision-making factor to choose the institution (Bayraktaroglu and Atrek, 2010).

Thus, considering the abovementioned, the aim of this study is to analyse the students' absenteeism reasons in different social science degrees taught at the Universitat de Barcelona. Both the students' perception and lecturers' perception are studied and compared. The results of this research would help in proposing actions to be taken to increase students' engagement and to make the differences in perceptions of both groups come together. The identification of stakeholders' responsibilities will also help in reducing absenteeism.

The structure of the paper continues with the methods used and the results are presented. The paper is closed with the conclusions.

RESEARCH METODOLOGHY

In order to analyse both the students' perception and lecturers' perceptions on this phenomenon, an existing questionnaire was adapted and used (see Triadó-Ivern et al., 2013). The same questionnaire was submitted to students and lecturers and data gathered was analysed using statistical techniques. The description of these aspects is presented in this section.

Sample

Data were collected during the spring of 2017, with a sample of 2,673 students from the Social Science degrees, i.e., Business, Economics, Sociology, Law and Labour Relations at the Universitat de Barcelona (Spain). Different subjects taught in each faculty were selected and in each of them, different scheduled groups and languages of teaching were studied. Regarding lecturers' sample, 276 valid responses were received. Lecturers teaching in each of these degrees participated in the study. Table 1 shows the respondents' sociodemographic profile.

Table 1 – Students' and lecturers' sociodemographic profile

		Students	Lecturers
By gender	Men	52.5%	54.9%
	Women	47.5%	45.1%
By course	1st year	33.3%	32.0%
	2nd year	26.7%	28.8%
	3rd year	21.6%	25.2%
	4th year	18.4%	14.1%
By schedule	Morning	79.2%	
	Afternoon	20.8%	
By degree	Business	39.2%	42.4%
	Economy	27.0%	18.2%
	Sociology	4.6%	2.2%
	Law	22.7%	27.9%
	Industrial Relation	6.4%	9.1%

Questionnaire and data gathering

Students' absenteeism is a real problem and it is not easy to measure directly. In an attempt to overcome this lack of measurement agreement, a questionnaire supported by the literature (Triadó-Ivern et al., 2013) was used, composed of 18 items and 5 sociodemographic items. A Likert scale ranging from 1 (totally disagree) to 4 (totally agree) was used (see Table 2 for the list of items analysed). The reliability analysis takes a correct value, obtaining a Cronbach's alpha of 0.70, and was statistically significant for the t-square test of Hotelling and the test of Tukey's additivity.

In order to analyse the students' absenteeism, the questionnaire asked to those students attending class for the reasons of their classmates for not attending. Although this measurement is indirect, it was the only way of gathering these data, as the non-attendants were not in class in the moment of submitting the survey. The researchers of the team gathered the data for each group of subjects selected in the different degrees analysed. The survey was paper-based and was completed in class (similar to Aparicio-Chueca et al., 2017). The objective was to know the reasons of students' absenteeism, not to analyse the level of absenteeism of each specific subject. Figure 1 shows the protocol used to gather students' data.

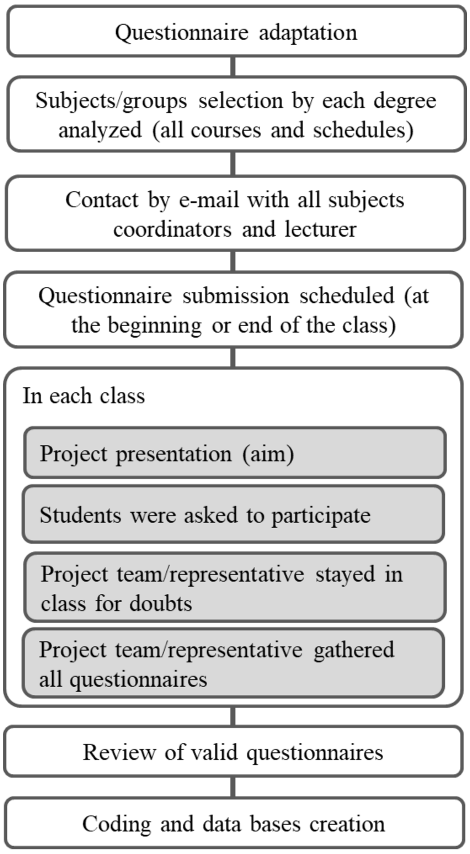

Figure 1 – Students' opinions gathering

Regarding the lecturers' point of view about absenteeism in university lessons (see Table 1 for sociodemographic profile characteristics), the same questionnaire was applied and submitted to all the faculty members of the participant faculties (only the sociodemographic items were different). Their opinion was asked after collecting the data from students and the tools used to collect them were different, as an online survey was used (see Figure 2). With the data collected, both points of view were compared and discussed (see also Marchand et al., 2014).

Data analysis

Data analysis was performed using the SPSS 24 software package. First, a difference analysis of means using ANOVA analysis, with the aim of knowing differences between students' and lecturers' perceptions on the phenomenon was calculated. Then, a factorial analysis for each group, students and lecturers, was carried out with the aim of grouping the reasons why the students are absent.

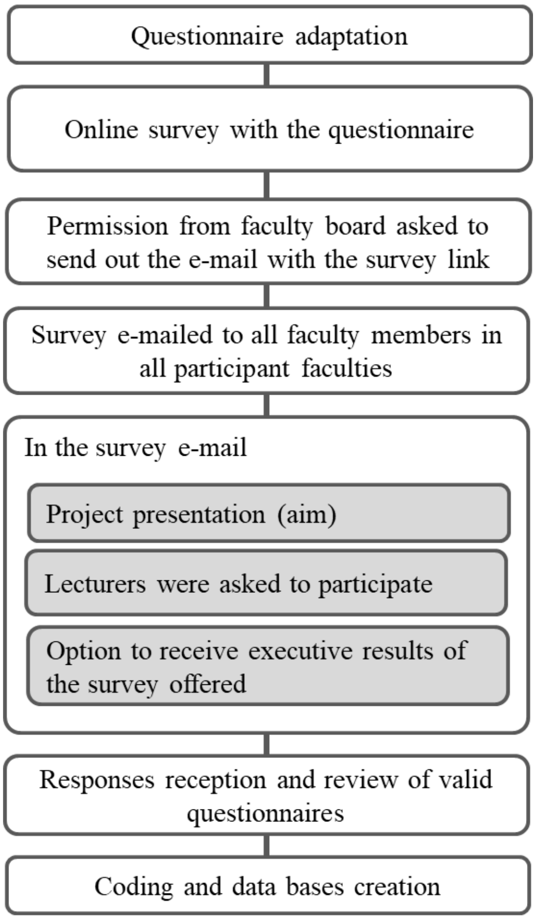

Figure 2 – Lecturers' opinions gathering

The findings of these analyses are presented in the next section.

RESULTS

The data gathered were analysed using two different methods. First, a difference analysis of means using ANOVA was done and then, a factorial analysis. The comparison between students' perceptions and lecturers' perceptions is also presented.

Difference of means

Table 2 presents the different reasons why students and lecturers think the absent students do not attend class, comparing the average valuations and their deviations. These findings show that both students and lecturers have the same opinion only in three out of the 18 items analysed, named 'the teacher does not oblige to attend', 'they study simultaneous degrees' and 'they work and cannot attend lessons'. For the rest of the items the perceptions of both groups are different.

Table 2 – Comparison between the average valuations

	Students	Lecturers		
	Mean *(SD)*	Mean *(SD)*	F	*Sig.*
Because of the subject, lessons become heavy and/or boring	**2.95** (.799)	2.22 (.908)	203.298	.000*
The content is not interesting	**2.36** (.810)	2.12 (.816)	20.244	.000*
The content is simple	2.04 (.860)	**2.48** (1.00)	64.316	.000*
They repeat the subject and do not attend lessons	2.48 (1.189)	**2.64** (1.210)	4.426	.035*
Attending class is not useful to pass the subject	2.16 (1.062)	**2.38** (1.030)	10.942	.001*
Because of the lecturer's explanation, lessons are heavy and/or boring	**3.21** (.807)	2.19 (1.026)	375.711	.000*
The lecturer provides sufficient material and it is not necessary to attend the lessons (book, intranet, etc.)	2.34 (.924)	**2.76** (.929)	50.336	.000*
The lecturer dictates the notes or reads the slides	**2.83** (.984)	2.11 (1.083)	131.063	.000*
The lecturer does not oblige to attend	2.83 (1.050)	2.86 (1.044)	0.162	.687
It is more useful to study in the library or at home than attending lessons	2.38 (.984)	**2.55** (1.173)	7.124	.008*
It is better to attend test preparation service to pass	2.08 (1.258)	**2.53** (1.378)	30.040	.000*
They have access to alumni notes and do not attend class	2.56 (.958)	**2.77** (1.009)	11.142	.001*
They follow the single evaluation	**2.69** (1.137)	2.16 (.927)	56.908	.000*
The schedules match with another subject	2.25 (1.209)	**2.45** (1.153)	6.861	.009*
They study simultaneous degrees	2.32 (1.293)	2.31 (1.157)	.014	.906
They have enrolled many credits	2.21 (1.214	**2.69** (1.179)	38.490	.000*
They work and cannot attend lessons	2.66 (.968)	2.70 (1.110)	0.410	.522
They live far away and do not come to class	2.50 (1.098)	**2.71** (1.224)	8.830	.000*

Regarding the significant differences, students weight higher the following reasons of absenteeism: ‘because of the subject, the lessons become heavy and/or boring’, ‘the lecturer dictates the notes or reads the slides’ and ‘they (absent students) follow the single evaluation’. The lecturers, in turn, weight higher: ‘they have enrolled many credits’, ‘it is better to attend test preparation service to pass’, ‘the content is simple’ and ‘the lecturer provides sufficient material and it is not necessary to attend the lessons (book, intranet, etc.)’. Thus, for both students and lecturers, aspects related to the teaching methodology and support material and resources could explain absenteeism. Also, aspects related to students' decision on their profiles, such as the type of evaluation or in how many credits they are enrolled have been highlighted.

Factorial analysis

In order to group the items into factors to ease the interpretation of the data gathered, a factorial analysis was performed, one for the students' perceptions and another for the lecturers' perceptions.

Regarding the **students' perceptions** factorial analysis, the Kaiser-Meyer-Olkin (KMO) measure is 0.772, the Bartlett's test is significant (p-value=0.000) and the χ^2 is 5901.53, with 153 degrees of freedom. From the analysis, five factors (those with an eigenvalue higher than 1) were extracted which explained the 52.30% of the total variance. Table 3 presents the rotated matrix of the components. Oblique oblimin rotation was applied because the factors were considered as correlated (students affect lecturers and viceversa). Only those factor loadings higher than 0.5 were considered.

According to the analysis, the first factor explains 17.41% of the total variance. It groups the items related to the students' design of their profile, such as 'they study simultaneous degrees', 'the schedules match with another subject', 'they work and cannot attend lessons', 'they have enrolled many credits', 'they live far away and do not come to class' and 'they follow the single evaluation'. The second factor explains 13.90% and refers to the items related to how to pass the subject (evaluation): 'it is more useful to study in the library or at home than attending lessons', 'attending class is not useful to pass the subject', and 'it is better to attend test preparation service to pass'.The third factor has a variance of 8.34% and contains two items related to the subject characteristics, which are 'the lecturer does not oblige to attend' and 'they have access to alumni notes and do not attend class'. The fourth factor explains 7.03% of the variance and also contains two items related to the subject content, such as 'the content is simple' and 'the lecturer provides sufficient material and it is not necessary to attend the lessons (book, intranet, etc.)'. The last factor explains 5.64% of the total variance and grouped items related to the teaching methodology: 'because of the subject and lecturer's explanation, the lessons become heavy and/or boring' and 'the content is not interesting'.

Table 3 – Students' factorial analysis matrix

	F1	F2	F3	F4	F5
They study simultaneous degrees	.797				
The schedules match with another subject	.776				
They work and cannot attend lessons	.765				
They have enrolled many credits	.732				
They live far away and do not come to class	.518				
They follow the single evaluation	.512				
It is more useful to study in the library or at home than attending lessons		.789			
Attending class is not useful to pass the subject		.710			
It is better to attend test preparation service to pass		.607			
The lecturer does not oblige to attend			.710		
They have access to alumni notes and do not attend class			.629		
The content is simple				.753	
The lecturer provides sufficient material and it is not necessary to attend the lessons (book, intranet, etc.)				.664	
Because of the subject, the lessons become heavy and/or boring					.837
The content is not interesting					.751
Because of the lecturer's explanation, lessons are heavy and/or boring					.703
Variance (%)	17.41	13.90	8.34	7.03	5.64

Extraction method: principal components analysis
Rotation method: Oblimin with Kaiser normalization

Regarding the **lecturers' perceptions** factorial analysis, the KMO measure is 0.848, the Bartlett's test is significant (p-value=0.000) and the χ^2 is 1709.915, with 153 degrees of freedom. From the analysis, four factors (those with an eigenvalue higher than 1) were extracted which explained the 58.17% of the total variance. Table 4 presents the rotated matrix of the components. Oblique oblimin rotation was applied because the factors were considered as correlated (students affect lecturers and viceversa). As for the students' factorial analysis, only those factor loadings higher than 0.5 were considered.

The first factor explaining the absenteeism reasons according to lecturers' perceptions explains de 27.76% of the total variance. It consists on content, materials and no obligation to attend, aspects related to the subject, as the 'content is simple', 'attending is not useful to pass', 'more useful to study in the library', 'lecturer provides sufficient material', 'access to alumni notes' and 'lecturer does not oblige to attend' are the items belonging to this construct. The second factor explains 16.32% of the variance and grouped items related to the students' design of their profile, such as 'simultaneous degrees', 'enrolled in many credits, 'schedules match', 'living far away' and 'work'.

The third factor represents the 8.54% of the variance and is related to lecturers' teaching methodology, as the items belonging to this construct are 'lessons are boring because of the lecturers' explanation and subject', 'content is not interesting' and 'lecturer dictates the notes or read slides'. The final factor explains 5.56% of the variance and is related to the evaluation characteristics or how to pass the subject, according to the items grouped: 'single evaluation', 'better to attend test preparation service' and 'repeat the subject'.

Table 4 – Lecturers' factorial analysis matrix

	F1	**F2**	**F3**	**F4**
The lecturer provides sufficient material and it is not necessary to attend the lessons (book, intranet, etc.)	.776			
Attending class is not useful to pass the subject	.733			
The lecturer does not oblige to attend	.715			
The content is simple	.700			
It is more useful to study in the library or at home than attending lessons	.673			
They have access to alumni notes and do not attend class	.670			
They study simultaneous degrees		.856		
They have enrolled many credits		.809		
The schedules match with another subject		.813		
They live far away and do not come to class		.772		
They work and cannot attend lessons		.708		
Because of the lecturer 's explanation, lessons are heavy and/or boring			.839	
Because of the subject, the lessons become heavy and/or boring			.834	
The content is not interesting			.733	
The lecturer dictates the notes or reads the slides			.702	
They follow the single evaluation				.831
They repeat the subject and do not attend lessons				.607
It is better to attend test preparation service to pass				.568
Variance (%)	27.76	16.32	8.54	5.56

Extraction method: principal components analysis
Rotation method: Oblimin with Kaiser normalization
Source: Own elaboration

CONCLUSIONS

The aim of this study is to analyse the students' absenteeism reasons in different social science degrees taught at the Universitat de Barcelona. In order to have a wider vision of the phenomenon, both the students' perception and lecturers' perception are studied and compared. A survey asking for their perception of absenteeism reasons has been used. Based on the results, the following conclusions could be extracted.

First, students and lecturers think that the same absenteeism reasons are significant but give them different weight of importance. Taking this into consideration, both think that the teaching methodology (see also, Triadó-Ivern et al., 2013; López-Bonilla and López-Bonilla, 2015) is an important reason but also how the students design their profile, such as the type of evaluation they choose or if they work or study another degree simultaneously (see also, Triadó-Ivern et al., 2013; Oldfield et al., 2017). Thus, it could be stated that students and lecturers agree on the absenteeism reasons but when responsibilities should be accepted, then the perception is different (Barlow and Fleischer, 2011). In other words, students perceive that lecturers should teach and prepare better the subjects, while lecturers think that students should design and perform better their profiles.

From the factorial analysis, students' perceptions are grouped into five main dimensions related to the students' design of their profile, the subject characteristics (three factors), and the teaching methodology (see also, Triadó-Ivern et al., 2013; López-Bonilla and López-Bonilla, 2015). Regarding the lecturers' perceptions, four main dimension were found which are related to the subject (content, materials and no obligation to attend), to the students' design of their profile, to lecturers' teaching methodology and to the evaluation characteristics or how to pass the subject.

These results show that the reasons of absenteeism related to the subject characteristics are perceived differently between students and lecturers. On the one hand, lecturers considered the materials, content and way of studying it in the same factor and the evaluation or how to pass the subject in another construct. On the other hand, students grouped the same items into four different factors. Thus, it could mean that the perception of a subject characteristic is different depending on the point of view. While lecturers consider subject characteristics as a whole, students consider them to be different. However, students and lecturers identify two factors similarly. The first is related to the students' profile, and the second is related to the teaching methodology. In both cases, almost all the items grouped are the same.

Another aspect of these results is that both groups are aware of their responsibilities on this phenomenon (Barlow and Fleischer, 2011). Students' know that the way they organise and design their profile could contribute to be absent. But at the same time, lecturers know that the content, way of teaching and materials, among other reasons, could also enhance absenteeism. The identification of reasons, responsibilities and awareness are the main contributions of this paper.

Implications

The main implications of this research are for students, lecturers but also for the university government and the state government. For the first, students should mainly try to engage more in their learning process, being more motivated and committed to achieve the learning requirements, and try to improve their profile organization and design. Lecturers should listen to what students propose, at least through the teaching satisfaction surveys (students pose qualitative comments about the subject and the lecturer), in order to improve and adapt their way of teaching (lecturers need to be active and predispose to change), trying to make their subjects more attractive (improved and updated content) and to provide the additional basic information and material that could help students in their learning process. The university should also be involved at all levels trying to improve the design of the degrees in terms of schedules and compatibility with students' labour profile. Finally, the state government should be able to provide the resources needed in order to make these practices be implemented, mainly economic resources to hire more personnel but also to train them in improved and more suitable teaching methodologies and also to renew the technologies used in teaching. Although this is not going to be an easy change, all stakeholders should accept their responsibility to achieve a better use of resources and increase the knowledge and satisfaction of university members.

Limitations and future research

Limitations of this study are mainly the indirect measurement of absenteeism. Also the degrees analysed, in which the type of knowledge could condition the way teaching and learning processes are developed. Also, the type and size of university studied could also conditioning the results. Another important factor to be considered in future research is the type of lecturers, as differences between full- and part-time dedication could also condition the results. A wider study considering more degrees and different types of universities, as well as trying to gather direct data, e.g., using an online survey to try to obtain the absentees' opinions, could enhance the generalisation of results and future research will be focused on achieving them.

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Practices adopted to the execution and quality control of foundations in building construction

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ABSTRACT

The foundations are the elements of a building that have the function of transmitting the loads of the building to a resistant soil. A drawback of foundations is the difficulty of identifying execution failures upon completion, because their elements are buried. Therefore, these failures are often discovered only when pathologies arise in the building, such as cracks. In order to avoid the occurrence of failures in a building, it is essential that the engineer and his team have full control of the execution of foundations and the company has a strict quality control system. Thus, this article aims to conceptualize briefly the execution techniques of foundations applied in building construction and analyse their quality control. In addition, the procedures adopted by construction companies in terms of execution of foundations and quality control are evaluated through the case study of a construction of a multifamily residential project from a large construction company in the city of Rio de Janeiro, Brazil. In this construction were implemented three different types of foundation, namely: spread footings; steel piles; and micropiles. Finally, the main practices to be adopted by construction companies toward making the execution and quality control of foundations more effective are identified.

Keywords: Quality Control, Foundation, Execution Procedure, Case Study.

INTRODUCTION

In order to reduce apartment pricing and making it more attractive to customers, most of the construction companies seek to optimize construction costs and duration. This is a reality especially in constructions sponsored by social programs, which intends to reduce the number of Brazilian families who do not own a house. One consequence of compressing construction schedule is the negligence in performing critical services and its quality control.

Foundations are responsible for supporting and transferring loads from the structure to the ground. Execution errors in foundations are hardly observed during service execution or soon after its completion. This difficulty occurs because once completed and buried, failures are not visible. Generally, the reflexes of the poor execution of the foundation are identified in the end of the construction, in terms of quality, performance and reinforcement expenses (PINTO, 2015).

Construction companies should focus on improving the knowledge of execution techniques of different types of foundation by construction engineers and the staff involved in the service. In addition, the implementation of an effective quality control system, which ensures that the execution of the services follows the technical standards, is fundamental. Therefore, the identification of good practices that make the execution and the quality control of foundations in building constructions more efficient is an important strategy for construction companies.

This article aims to evaluate the execution techniques of different types of foundations applied in building construction and their quality controls. Therefore, it is analyzed the practices adopted by a large construction company, through the study of the construction of a multifamily residential building located in the city of Rio de Janeiro, Brazil.

This work was developed through bibliographical research in scientific articles, academic papers and quality control and foundation execution books. In addition, it is analyzed the technical standard NBR 6122 version 2010 of Design and construction of foundations (ABNT, 2010) and the Manual of foundation and geotechnical execution made by the Brazilian Association of Foundations Engineering and Geotechnics companies (ABMS / ABEF, 2009).

For the case study, it was selected a construction site composed by three different types of foundations: footing, steel piles and micropiles. This study includes the executive techniques used and their respective quality controls, as well as, the main problems due to the negligence in execution and quality control.

FOUNDATIONS IN BUILDING CONSTRUCTION - CONTEXTUALIZATION

Before starting a foundation project and selecting the most appropriate foundation type, it is essential to know the stratigraphy and classification of the soil, the position of the water table and the resistance of the soil. In order to obtain this information, a geotechnical investigation must be performed. The main in-situ test is the Standard Penetration Test.

Once the soil profile of the construction site and its surrounding information is obtained and it is defined the type of foundation to be used, the foundation projects can be designed.

According to NBR 6122 (ABNT, 2010), foundations are often divided into shallow foundations and deep foundations. The foundation is considered shallow when the load is transmitted to the ground by the stresses distributed at the foundation base. In general, the usage of shallow foundation is considered in terrains that have outcropping rocks, rocks near the surface or high resistance soils in their shallower layers. Shallow foundation includes spread footing, mat-slab and slab-on-grade.

Deep foundations transmit the load to the ground by its base, by its lateral surface or by a combination of both. Among the deep foundations are the piles and the caissons (ABNT, 2010).

The usage of deep foundation is considered mainly in terrains that receive high load of the structure on a thick layer of soil of low resistance, such as clays (ABMS / ABEF, 2009).

VELLOSO and LOPES (2010) divide the different types of piles into two groups, driven pile and bored pile, according to their execution process. Among the driven piles are the wooden, steel, precast concrete and Franki pile. Among the bored piles, the most common in buildings are the micropiles and the Augercast pile. They are performed in situ through ground drilling.

Although the diversity of foundation types available is vast, this article analyzes the types of foundation used in the case study, namely: spread footings; steel piles; and micropiles.

THE CONSTRUCTION SITE OBJECT OF STUDY

The project under study is located in the neighborhood of Andaraí, in the city of Rio de Janeiro, Brazil. The enterprise has a total area of 6,804.98 m² and its total constructed area of 7,368.56 m².

The enterprise consists of four residential buildings in structural masonry. The blocks 1 and 2 have four floors and the blocks 3 and 4 have three floors, as shown in Figure 1. The project has 99 apartments with an area ranging from 53 m² to 65 m².

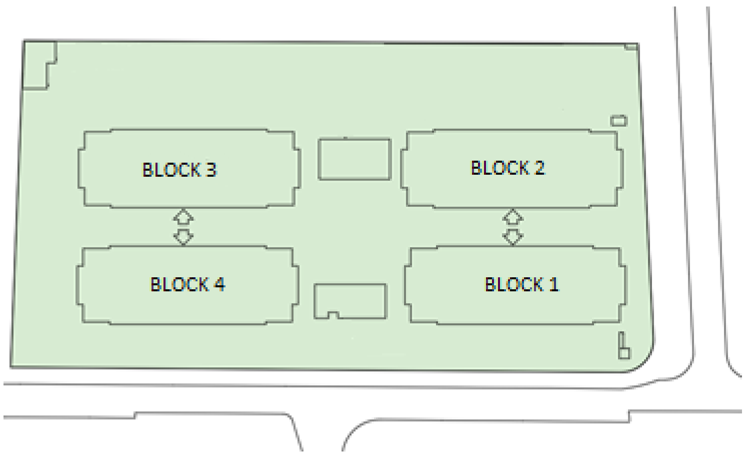


Figure 1 – Simplified floor plan of the enterprise. Source: Construction company (2015)

In order to design the projects of foundation, 24 Standard Penetration Tests were performed. According to the investigation results, it was determined that it should be executed 61 spread footings and 48 steel piles in Block 1 , 81 steel piles and 10 micropiles in Block 2, 81 steel piles in Block 3 and 44 spread footings and 68 steel piles in Block 4.

PRACTICAL ASPECTS IN EXECUTION AND QUALITY CONTROL OF FOOTINGS

In this project, the services of formwork, reinforcement assembly, concrete production and concreting of spread footings were outsourced. The execution stages of the spread footings were: location of the foundations axis to materialize their coordinates in the ground; excavation of the arches to the height of the footings; regularization of the footing base with lean concrete; execution of the formwork and reinforcement steel; concreting of spread footings; and bore backfill.

Execution techniques and quality control

The company hired to elaborate the projects of foundation, also elaborated a project with details and specifications of footings. In this project are presented the execution sequence of the footings, pertinent observations, the quality control and details to facilitate its execution.

In parallel, the quality sector of the construction company prepared an execution procedure regarding the execution of footings in a construction site. This procedure contains a description of the materials and equipment, execution sequence and quality control items.

These documents should be studied by trainees, engineers and foremen prior to the execution of the foundation. However, staff members who claim having sufficient knowledge of the information contained therein often ignore them. Consequently, outdated techniques and unsuitable practices can compromise the quality of the service performed.

The lack of study of the projects by the construction engineer results in the identification of project inconsistencies only during execution of a service. As mentioned by FUKS et al. (2002), the need to find solutions quickly for the project can compromise the quality of the solution adopted.

The location of the footings in the site was marked by a worker of the construction company, through benchmarks located by an outsourced topographer. The location method adopted was the contour method, which spikes are driven in the building contour, where wooden boards are nailed in. The alignments of the foundation elements are marked on the boards and, by stretching lines or wires in both directions, it is possible to locate the foundation elements (VEIGA, 2017).

After the completion of this stage, the construction engineer was responsible for checking the elements on the wooden board. In addition, an engineer of another construction site was invited to recheck it. Upon completion of these conferences, the materialization of the footings on the ground could be started.

The execution plan of the footings was indicated in the geotechnical design of foundations of each block, based on their predicted settlement quotas. Footings that had deeper settlement quotas should be executed first, as recommended in NBR6122 (ABNT, 2010).

The construction company was advised by a consultant specialized in foundations, who recommended that the excavation of the footings were to be done until finding strong residual soil or altered rock.

In the case of footings settled on soil, it was necessary to perform the Manual Dynamic Penetrometer test (ASTM, 2009). The penetration resistance index of the Rehearsal is usually adopted as the number of strokes required for a penetration of 20 cm rods (CUSTÓDIO, 2003). The results obtained were informed to the foundation consultant who analyzed if the settlement quota was adequate.

In addition to the test result, a picture of the surface on which the lean concrete would be executed was sent to the consultant. When approved, the execution of the lean concrete was allowed and could commence. Otherwise, it was necessary to continue the excavation to a new recommended depth. The approval control of footings of the Block 1 is presented in Table 1.

After levelling the settlement quotas, a worker of the construction company and the formwork team placed the bases of the footings. The formwork team should then assemble the footing shapes according to the dimensions specified in the project, guaranteeing the locking, alignment and square of the formwork.

Before completing the footing molds, the enforcements are inserted, following the design of the frame. Then the execution of the mold was completed, using slats and struts for structuring the mold and locking it.

The concreting of the footings was executed after cleaning the mold and wetting it with water. The concrete abatement test was performed, as described in NBR NM 67 (1998), and also the molding of test specimens for the compression test. After these steps, the concreting was started, using a needle vibrator to obtain a well-compacted concrete. During concreting, a trainee fills the concrete mapping to identify the concrete launch site.

Table 5 – Approval control of footings. Source: Construction Company (2016)

BLOCO 01: CONTROLE DE LIBERAÇÃO DAS SAPATAS – R00

Sapata						Ensaio				Parecer		
						Nùmero de Golpes			COTA (m)			
Apoio/Pilar	Carga (tf)	Dimensões (cm)			Taxa (kgf/cm²)	20 cm	20 cm	20 cm		Data	Tratativa	CAF (m)
AP4	27	70	x	70	5,51	68	70	25/3cm	23,57	22/12/2015	Escavar 40cm	23,17
AP5	18	60	x	60	4,44	3/0cm	–	–	23,35	22/12/2015	–	23,55
AP6	27	70	x	70	5,51	60	120	160	23,31	22/12/2015	Escavar 20cm	23,11
AP8	15	60	x	60	4,17	3/0cm	–	–	23,94	22/12/2015	–	23,94
AP15	26	70	x	70	5,31	140/17cm	–	–	23,94	22/12/2015	–	23,94
AP16	38	80	x	80	5,94	140/20cm	–	–	23,26	22/12/2015	–	23,26
AP19	42	85	x	85	5,81	80/15cm	–	–	23,28	22/12/2015		
AP25	25	65	x	65	5,92	100/18cm	–	–	23,93	22/12/2015	–	23,93
AP26	23	65	x	65	5,44	6/1cm	–	–	23,86	22/12/2015	–	23,86
AP35	57	100	x	100	5,7	60	60/11cm	–	23,54	22/12/2015	Escavar 20cm	23,34
AP36	42	85	x	85	5,81	20/1cm	–	–	23,33	22/12/2015	–	23,33
AP37	57	100	x	100	5,7	60/11cm	–	–	23,55	22/12/2015	–	23,55
AP38	53	95	x	95	5,87	40/3cm	–	–	23,69	22/12/2015	–	23,69
AP39	29	70	x	70	5,92	20/2cm	–	–	24,00	22/12/2015	–	24,00
AP44	30	75	x	75	5,33	60/7cm	–	–	23,80	22/12/2015	–	23,80
AP45	15	60	x	60	4,17	20/2cm	–	–	23,84	22/12/2015	–	23,84
AP46	15	60	x	60	4,17	5/1cm	–	–	23,83	22/12/2015	–	23,83
AP47	21	60	x	60	5,83	71	49/5cm	–	23,85	22/12/2015	Escavar 20cm	23,65
AP54	25	80	x	80	3,91	20/2cm	–	–	23,77	22/12/2015	–	23,77
AP55	35	95	x	95	3,88	40	60/12cm		23,86	22/12/2015	Escavar 20cm	23,66
AP56	16	65	x	65	3,79	40/2cm	–	–	23,75	22/12/2015	–	23,75
AP57	19	70	x	70	3,88	100/18cm	–	–	23,80	22/12/2015	–	23,80
AP60	24	80	x	80	3,75	60	29/4cm	–	23,90	22/12/2015	Escavar 20cm	23,70
AP67	30	90	x	90	3,7	40/1cm	–	–	23,80	22/12/2015	–	23,80
AP68	15	65	x	65	3,55	100/13cm	–	–	23,99	22/12/2015	–	23,99
AP69	15	65	x	65	3,55	53	80	47/7cm	23,86	22/12/2015	Escavar 40cm	23,46

In general, the footings were dismounted 24 hours after concreting without performing the cure the concrete. The footings' necks were then executed and, 24 hours after their concreting, they were dismounted and the backfilling of the footings were initiated.

The backfill was performed using compacted material with mechanical socket, both in clay soils and in sandy soils. After the execution of the footings, grade beams were executed connecting them.

Upon completion of each step presented, a trainee was responsible for its inspection. This is done by completing the service check form of footings provided by the construction company.

Since this form includes the inspection of several items, if the trainee fills it correctly, it is unlikely that there will be any nonconformity in executing the footings. To ensure the correct completion, the construction engineer must fill out a model form and give the necessary guidance. In addition, monthly visits of quality teams are scheduled to verify that services are being performed correctly and that service check forms are being filled in properly.

Inconsistencies in execution and quality control

One of the main difficulties found during the execution of the footings was the occurrence of intense rains in the period of its execution. According to the initial schedule of the enterprise, the footings of Block 1 would be executed in 5 weeks and the footings of Block 4 in 4 weeks. Nevertheless, the footings of Block 1 were only effectively executed in 12 weeks and the footings of Block 4 in 6 weeks.

An example of the situation of Block 4 after a night of heavy rainfall can be seen in Figure 2. Often it was necessary to use pumps to drain the water and remove the soil that was deposited in the excavation. It was also necessary to relocate the footings that did not have the lean concrete executed.

Figure 2 – Flooding on Block 4 excavation. Source: Author (2016)

In order to avoid the occurrence of flooding during the execution of the shoes, it is valid to prioritize the scheduling of these activities for the months with lower precipitation.

One of the consequences of redoing some steps is the negligence in the re-inspection. This occurs because once an activity is approved in the service check form of footings, the trainees do not return to re-inspect it.

In the execution of the footings of Block 4 occurred an error in locating a footing, in which the base of the footing was displaced in 5 cm. The solution found by the foreman to hit the location of the footing’s neck was to cut the bars from the left and glue them to the right using an epoxy-based adhesive (Figure 3).

This solution is not appropriate, as the footing's neck is not centered with its base and its main bars do not reach the bottom of the footing. Therefore, it is very important to follow the whole execution of the service, because if the trainee had not observed this, the concreting of the column would be executed and it could have compromised the performance of the structure. Finally, it was necessary to demolish this footing and repeat its execution.

Figure 3 – Inappropriate solution for footing location correction. Source: Author (2016)

PRACTICAL ASPECTS IN EXECUTION AND QUALITY CONTROL OF STEEL PILES

The execution of the steel piles was also carried out by an outsourced company. The stages of execution of the steel piles were: location of the axis of the piles; pile driving using the pile-driver equipment and carrying out the measurement of pile set and elastic rebound; execution of welding and splicing, if necessary; preparation the top of the pile to connection to the pile cap; and execution of the pile cap.

Execution techniques and quality control

As in footings, the company contracted to elaborate the foundation projects provided a project with details and specifications for steel piles. In this project it were presented the specifications for the execution of the steel piles, details of the splice of steel profiles using welded splints and details of the connection of the steel profiles with the pile cap.

In the case of steel profiles, the quality sector of the construction company did not elaborate an execution procedure. Therefore, engineers and construction staff should study the project with details and specifications for the execution of the services correctly. However, this project was rarely consulted during the execution by engineers and foremen.

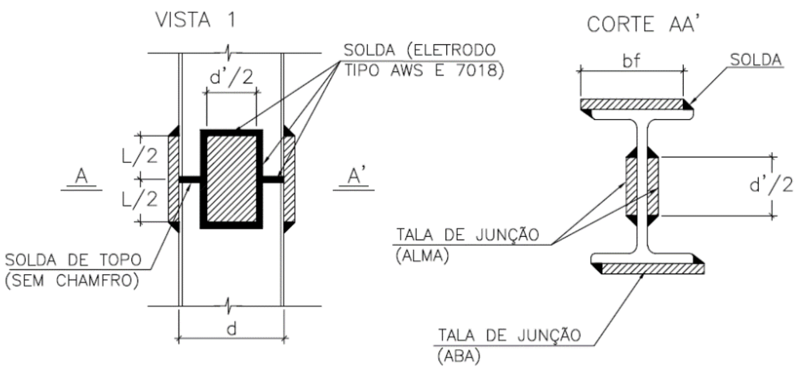
The location of the steel piles was made by a worker of the construction company, which uses benchmarks located by an outsourced topographer to mark the alignment of the foundation elements by contour method using the project of loadings of each building. After the conference by the engineer responsible for the project and an external engineer, the materialization of the coordinates of the piles in the ground was authorized. This service was made by a worker of the construction company and conferred by a trainee.

The execution plan of piles driving was defined by the foundation consultant with the construction engineer. Usually the pile driving was initiated by the edge of the building.

It were used two pile driving equipment, one had a hammer of 3,500 kg and a dropping height of 0.8 m and the other had a hammer of 5,000 kg and a dropping height of 0.6 m. They were responsible for driving the W150x37.1 profiles and the W200x59.0 profiles.

The main control made during the pile driving was the verification of the verticality of the pile by a worker of the construction company, using a plumb bob.

The splicing of the piles was performed in the field using metal splice made from the profile itself. The detail used by the outsourced welder can be seen in Figure 4.



DIMENSÕES DAS TALAS

PERFIL	d'/2 (mm)	L (mm)	bf (mm)
W150X37,1	59,5	200	154
W200X59,0	79,0	200	205

Figure 4 – Detail of splicing of steel piles. Source: Foundation project (2015)

During pile driving, the outsourced foreman of steel piles was responsible for completing the steel pile driving register, according to the model provided by the foundation consultant, with information such as type of pile, hammer weight, pile identification, number of blows, pile set and elastic rebound. In addition, stacking controls were filled in, where all the driven piles in the project were registered per building.

The piles should be driven to the depth indicated by the foundation consultant. However, it was necessary to respect the maximum pile set of 3 millimeters per 10 blows, which is obtained by averaging the final five groups of ten hammer blows and provide the elastic rebound of the final ten hammer blows.

After completing the pile cutoffs, the trainees and the construction company foreman measured the eccentricities of the piles. This is done by stretching the wires in the contour gauge on both directions to obtain the pile's project location and materializing its axis with a plumb line. Then, the distance between the executed pile and its designed location was measured.

The NBR 6122 (ABNT, 0 201) establishes the need to perform load tests on a sample of the piles to verify its load capacity and condition of integrity. In construction site it was performed the PDA dynamic load tests on 15 steel piles. The main information obtained in this test was mobilized load, maximum displacement recorded, energy transferred to the pile and its integrity.

The connection between the pile and the pile cap was similar to the alternative solution proposed in ABMS/ ABEF (2009), in which the last 50 centimeters of the pile were wrapped in helical stirrups in a concrete block, as can be seen in Figure 5. Finally, the pile cap was executed above this element.

Figure 5 – Connection between piles and pile caps. Source: Author (2016)

In Blocks 1 and 4, which had steel piles and footings, grade beams were executed connecting the pile caps and the footings, and finally a 10-centimenter slab was executed. In Blocks 2 and 3, which had only piles, a 30-centimeter slab was executed on the pile caps.

Upon completion of each service, a trainee was responsible for its inspection. The inspection results should be recorded on the service check form of steel piles. It was important to fill up the form correctly, including comments and describing the issues faced, so the recurrent problems could be determined and the critical piles identified. In these piles it was recommended to realize the load test.

Inconsistencies in execution and quality control

During the execution of the steel piles in the project, a series of failures were observed in the service control. Among them were wrong profiles drilling, buckling of profiles, splices with inadequate welds, inadequate pile set and high eccentricities.

In the cases where a profile of W150x37.1 was driven instead of a profile of W200x59.0, the foundation consultant determined the addition of two profiles, ensuring the coincidence between the center of the pile cap and the pillar. When a W200x59 profile was driven instead of W150x37.1, the pile was approved. The nonconformities occurred resulted in the loss of steel profiles and the increase in the number of driving in 16 reinforcing piles. It is concluded that the steel pile foreman was not accompanying the execution using the foundations project.

Also, buckling problems occurred in W150x37.1 profiles hammered with the 5,000 kg with a dropping height of 0.60 m, in cases where the soil was showing great resistance to pile driving (Figure 6-A). In this case the steel pile foreman should stop the pile driving before the permanent deformation of the profile. According to the foundation consultant, one of the causes of profile buckling was the non-uniformity of the stresses generated by the impact of the hammer on the helmet, so the hammer-helmet system should have been set and the worn hammer cushion (Figure 6-B) replaced.

(a) *(b)*

Figure 6 – a) Buckling of a pile b) Worn hammer cushion. Source: Author (2016)

Another problem encountered was the poor quality of welds on steel profiles, which in some cases did not follow the model mentioned in the foundation project. In Figure 7, the weld of the splice is poor in quality and has no splice joints. The improper execution of welds compromises the integrity of the pile, which may lead to pile breakage or load transfer problems. Therefore, the control of all welds executed is fundamental and should be inspected not only by the outsourced of steel piles, but also by the construction company.

Figure 7 – Amendment executed improperly. Source: Author (2016)

There was also a misunderstood made by the outsourced foreman of steel piles in the criteria to stop pile driving. It was confused that the last ten blows obtained should be lower than 3 millimeters and not that the average of the last 5 groups of ten blows should be inferior to this value. In Table 2, in which is presented the pile set of the pile E3061A, this misunderstanding is perceptible and the average of the last 5 pile sets was 9 millimeters. Due to this confusion, it was necessary to repeat the pile set and elastic rebound in 16 stakes of Block 3.

Table 6 – Pile set of the pile E3061A. Source: Construction Company (2016)

Nº GOLPES	QUEDA DO PILÃO(m)	PENETRAÇÃO (mm)	Nº GOLPES	QUEDA DO PILÃO (m)	PENETRAÇÃO (mm)
10	0,50	16 mm			
10	0,50	10 mm			
10	0,50	10 mm			
10	0,50	6 mm			
10	0,50	3 mm			

Although the error was made by the outsourced foreman, the foundation consultant or construction engineer should have instructed this worker previously to service execution. In addition, the record of pile driving was delivered daily to the construction engineer, so it should not have been necessary to repeat the registration of pile set of many piles.

Eccentricity problem also occurred due to the displacement of the pile during its driving. It would be important that the outsourced foreman noticed this displacement, which was visible due to the cavities created by the pile driving. Therefore, it should have been backfilled the cavities with sand as recommended by the foundation consultant.

The piles with high eccentricities were checked individually by the foundation consultant and piles that exceeded the limits stipulated during the structural design required reinforcements. However, the reinforcement report was received by the construction team after assembling the frame of pile caps. Therefore, it was necessary to replace it, delaying the concreting of the pile caps.

Therefore, in addition to the construction company foreman and the outsourced foreman supervise any displacements during pile driving, it is fundamental that the construction engineer informs the eccentricities to the foundation consultant so he can decide the solution to be adopted.

Finally, the NBR 6122 (ABNT, 2010) requires that a static load test be performed on every 100 steel piles or, alternatively, five dynamic load tests can be performed to replace the static load test, as long as the maximum number of steel piles is 200. Above this value it would be necessary to perform at least one static load test.

Since the enterprise has 272 stakes, it would be necessary to perform a static load test and ten dynamic load tests. However, it was performed fifteen dynamic load tests and no static load tests were performed. It is observed, then, that NBR 6122 (ABNT, 2010) was not fulfilled.

PRACTICAL ASPECTS IN EXECUTION AND QUALITY CONTROL OF MICROPILES

An outsourced company carried out the execution of the micropiles, since this service requires a qualified team with specific equipment. The stages of execution of micropiles were: location of the foundation axis; placement of the first section of steel drill and boring the additional casing segments under supporting drilling fluid; assembling and inserting the reinforcement; cement grout injection under pressure; removal of casing segments; and preparation of the top of the micropiles.

Execution techniques and quality control

The company hired to elaborate the foundation projects elaborated a project with details and specifications of micropiles. It presented the assembled reinforcement, the cement grout, details of the pile cutoff and the pile connection to the pile cap.

In parallel, the quality sector of the construction company provided a guideline regarding the execution of micropiles. This procedure contains a description of the materials and equipment, construction sequence and quality control items.

Both documents are rarely considered by the construction team before and during the execution of the construction. In addition, engineers and foreman usually do not study the projects in advance. Moreover, the engineer often delivers the projects to his team only at the moment that the foundation elements start to be executed.

The location of the micropiles was done by a worker of the construction company, using the contour method. After its conference by the construction engineer and by an external engineer, the materialization of the micropiles on the ground could be started. This service was made by a worker of the construction company and checked by a trainee.

The execution sequence was defined by the foundation consultant with the construction engineer. Factors such as pile diameter, non-obstruction of vehicle entry, the exit of drilling equipment from the construction site and the distance between piles should be considered.

Figure 8 – Drilling equipment used in the construction site. Source: Author (2016)

For the execution of the micropiles, it was used a drilling equipment (Figure 8) with a steel drill casing of 410 millimeters diameter. The drilling was performed under the injection of water.

At the end of the drilling, internal cleaning of the casing segments was performed using water circulation until the returning material had no excessive soil. Then the reinforcement was inserted, which had already been assembled by the outsourced company of reinforcement and inspected by the trainees. The reinforcement was settled at the bottom of the pile and should the surface level by 80 centimeters.

The cement grout was then injected from the bottom of the pile until the surface level, being interrupted only when the cement grout emerged clean. While the casing segments were removed, it was applied pressure blows in the system. This pressure applied was specified by the foundation consultant.

During the micropile execution, the outsourced foreman of the micropiles was responsible for completing the micropile execution record for each pile. This document contains information such as pile identification, diameter, drilling depth and material classification, drilling time, cement proportion, injected volumes and reinforcement used.

The verticality of the pile was verified by the outsourced company responsible for the micropiles execution. The eccentricities of the micropiles were obtained in a similar way that the steel pile. Therefore, they were measured by the trainees with the aid of the foreman by stretching the wires in the contour board in both directions to obtain the designed pile axis and compare with the actual axis.

The verification of the integrity of the micropiles was made through an excavation of about 3.0 meters around a sample of micropiles. This excavation can be seen in Figure 9.

Figure 9 – Verification of the integrity of micropiles. Source: Author (2016)

Before executing the pile cap on the micropiles, it was necessary to demolish the cement located above the cutoff level. According to the project of foundation, 80 centimeters of the longitudinal bar of the pile reinforcement should be anchored in the pile cap. The Figure 10 demonstrates the top of some piles after demolition of excess cement.

After completion of each activity, a trainee was responsible for its inspection. This was done by completing the service check form of micropiles by trainees. In order to ensure that the form was completed properly, the construction engineer filled a service check form model with the trainees.

Figure 10 - Top of piles after demolition of excess cement. Source: Author (2016)

Inconsistencies in execution and quality control

During execution of the micropiles, not many quality control failures were observed. The outsourced company presented a large domain of services and filled in the micropile execution record properly. A total of 10 micropiles were performed in 8 days.

In general, the failures observed were the responsibility of the construction company. Among them it is the lack of spacers in the reinforcement steel, the lack of cement to fill the micropiles and the damage to the top of some piles.

As the piles had a diameter of 410 millimeters and the outside diameter of the reinforcement steel was 280 millimeters, the placement of the reinforcement steel should be guaranteed through the use of spacers. However, the outsourced company responsible for the reinforcement assembly did not install the spacers, which may have caused the reinforcement displacement. Trainees and the construction company foreman should have demanded the reinforcement installation when they checked it.

Another irregularity observed was the lack of cement in the construction site, which interrupted the activities during three days, delaying the completion of the service. The worker in charge of material requests should have identified the need for replacement in advance.

Finally, due to the absence of isolation of the location where the micropiles were executed, heavy machinery circulated over the micropiles, damaging the longitudinal bars (Figure 11). In order to repair the micropiles, it was necessary to replace the damaged section of the rebars and to demolish the length of cement damaged. The section demolished was filled with cement of superior resistance than the one used in the micropile execution. This failure caused delays in the execution of the pile caps.

Figure 11 – Heavy machinery circulated over the micropiles. Source: Author (2016)

CONCLUSIONS

From the analysis of the execution techniques implemented in the foundations of the case study, it is observed that the construction company presents a good control of the services in the construction site. Since these services are outsourced, the main responsibility of the construction company is to provide a framework for the outsourced companies to execute the service with quality, presenting the project guidelines, providing materials, monitoring the execution of the services and inspecting them.

Therefore, analyzing the practices adopted in the construction site under study it is possible to identify the main measures to be considered by a construction company toward minimizing execution errors in a foundation construction. The development of a document with the execution procedure for each type of foundation with a step-by-step description of the necessary activities is essential to standardize the execution of the service in the various construction sites of a construction company. Engineers, as well as trainees and foremen, should be responsible for studying the execution procedure provided by the construction company and transmitting it to the rest of the team, including outsourced companies.

It is also important that the construction engineer studies the projects with the help of the foundation consultant in order to identify possible project inconsistencies, inadequate solutions and lack of details, preventing delays and inadequate solutions in the foundations.

The engineer must schedule a meeting with the outsourced company responsible for the execution of a service. This meeting aims to discuss the execution procedure, the particularities of the project, the quality standards required by the construction company and other matters relevant to the properly execution of the service.

The concern with the location of the foundation elements of the buildings in the enterprise also represents a best practice. The verification of the location by the construction engineer and also by an engineer working in another construction site prevents the occurrence of errors in the location of the elements, which could generate rework, delay and extra costs.

Filling out the service check forms by trainees is also a best practice to ensure the quality of the services. A strategy implemented by the company to ensure that the trainees would fill out the form properly was the requirement that the engineer fill out a service check form model with trainees for each service started.

In the case of footings, an interesting practice to know the resistance of the layer where the footing is settled is the execution of tests such as the Manual Dynamic Penetrometer test, used in soils. As foundation consultants often make sporadic visits to the construction sites, organizing the results on a spreadsheet and attaching photographic records of the surface on which the footings would be settled has proven to be an efficient method to expedite the consultant approval. This way, the consultant presents a greater control of the service that is being executed in the construction site.

In the case of piles, using execution records for each pile and completing execution control for every pile facilitates tracking the activities. It makes material consumption analysis, productivity and measuring for payment simpler.

The performance of the load tests also represented an excellent method of quality control of piles. Performing these tests allows the foundation consultant to verify whether the piles were executed correctly by analyzing the load mobilized and its integrity.

The adoption of these practices is not a guarantee that a construction will present excellence in terms of the quality of its foundation. The presence of specialized, motivated and properly trained employees of the construction company, including engineers, foremen, supervisors, technicians, trainees and other employees is essential.

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Quality and Satisfaction – The case of Nautical Tourist Services in the Region of Alto Douro Vinhateiro – Portugal

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ABSTRACT

Purpose – Organizations of tourist services, in the context of económica and financial crisis, seeking to combine the concept of quality to the satisfaction of internal customers (employees) and external customers (tourists), so as to ensure the provision of a personalized service excellence. This paper aims to provide an overview of the quality of the tourist services effected in the nautical Alto Douro Vinhateiro (ADV) – Portugal.

Design/methodology/approach – This project work was applied to 117 internal customers (employees), through the application of a survey of various nautical tourist services organizations in the ADV.

Findings – The results obtained demonstrate that there are aspects to be improved in these organizations, so that employees feel satisfied, namely: concern for employees; specific training; working conditions; greater dialogue between supervisors and employees; allocation of workload and time off.

Originality/value – The employees´ satisfaction (internal customers) hasn´t been studied in nautical tourist services, due to the fact that the main approach has been to analys the external customers satisfaction.

Keywords: Quality, Satisfaction, Nautical Tourist Services, Region of Alto Douro Vinhateiro - Portugal

Paper type: Case study

INTRODUCTION

The concept of tourism has been studied by several authors (eg Hall, 2005; Page and Connell, 2006), since it is an area that is constantly growing and is considered as an increasingly expressive leisure activity of the current society. Tourism is a global sector that establishes relationships with several sectors, such as political, social and environmental, which spreads to other economic activities, generating a revenue and expenditure cycle and contributing to employment, increased income and the development of regions and the country. According to Cunha (2013), tourism encompasses activities carried out by people traveling and staying in places outside their usual setting for a successive period of not more than one year for recreational, business or other purposes.

Regarding quality, Martín (2000) and Watkins (2006) consider that quality is a purpose of both social life and organizational management and it is a substantial condition of competitiveness. Quality in the tourism sector has been a major concern of the organizations managers, due to the high competition between the various tourist services and the need to obtain competitive advantages, namely in terms of professionalism, innovation, human resources, information and communication technologies and marketing (Dias et al., 2009).

According to Sousa (2002), and since 2001, this region is considered a World Heritage Site by UNESCO, being the first wine-growing region in the region of Alto Douro Vinhateiro (ADV) demarcated and controlled in the World.

Tourism service organizations are constantly looking for to apply quality tools to their services because only quality and personalized services will enable organizations to achieve a level of stability and development that will allow them to survive and remain competitive (Gouthier et al., 2012). To this end, tourism service organizations will have to consider and meet the needs and expectations of both internal (employees) customers and external (tourist) customers, as these are the essence of organizations (Arnett and McLane, 2002 , Lashley et al., 2005, Noone et al., 2003, Wall set al., 2011).

Bearing in mind what was mentioned above, it is intended to evaluate quality in the tourist services, more specifically the nautical services, offered by the ADV region. Thus, this research has as main objectives: 1) verify if there is quality in the nautical tourist services in the opinion of the internal clients (collaborators); 2) recognize quality in tourism through the variables under analysis (Safety, Hygiene, Accessibility, Transparency, Authenticity and Harmony); and 3) Analyze if the gender of the employees influences the quality in the provision of nautical tourist services.

In order to achieve the proposed objectives, a questionnaire survey was conducted for employees, a sample of tourism companies from the ADV region and interviews with the hierarchical superiors, in order to recognize the quality of nautical tourism services in the region. ADV. This instrument of data collection was adapted from the study of Eraqi (2006).

THEORETICAL BACKGROUND

Quality in Tourist Services

In the tourism industry two terms prevail: customer satisfaction and the quality of services. These terms are relevant since, in order to achieve the quality of tourist services, customer satisfaction and the satisfaction of the employees of the organization must be related, since only then can a personalized and excellent service be provided for all (Salleh et al. al., 2009).

Employees who are more motivated and satisfied assume a greater commitment to service delivery, performing them with more quality, commitment, efficiency and greater concern with customers (Yoon and Suh, 2003).

The motivation and the satisfaction of the employees will also affect the profitability of the organizations, since they increase the future intentions of purchase and the loyalty of the clients; influence customer behavior; and make customers willing to pay higher prices for the same services. For this reason, the quality of services results from a process that implies meeting the needs, requirements and expectations of the customers, at an acceptable price and according to the determinants of quality: safety, hygiene, accessibility, transparency, authenticity and harmony (World Tourism Organization - WTO, 2003).

According to Ko and Pastore (2004), the quality of services can be understood either through its tangibility, because it is what the client sees and feels, or through its intangibility, that is, the affability and cordiality of the employees, who attend customers. For this purpose, it is essential that employees feel always motivated, satisfied and that the organization knows how to optimize the talent of its employees (Castelli, 2003).

While that in the prespective of Zeithaml et al. (2009) and Kotler et al. (2013), the quality of services is the comparison between satisfaction of needs and overcoming customer expectations, that is, the comparison between the subjective evaluations of the clients and the expectations of the service and the realistic perceptions of the performance of the service.

For Eraqi (2005) and Yang (2007), the quality of services is a crucial factor for the competitiveness of the tourism industry, since it promotes tourist products and tourism activities, developing tourism in a sustainable way, creating increasing productivity, lowering costs, and increasing market share.

The tourism services face several challenges that require frequent change and innovation, in order to conquer an increasingly competitive market and with more offer (Hu et al., 2009). Orfila-Sintes and Mattsson, 2009). These challenges will become profitable for tourism services and for clients, as they will reduce costs, lessen the competitive market, improve employee performance and increase sustainability.

The theme of quality related to the area of tourist services and the perspective of employees is a scarce area, in terms of studies carried out both in the national panorama and in the international panorama. Table 1 presents some international studies on the subject under study.

From the studies analyzed, it can be concluded that the quality of the service is related to satisfaction, since the perceived quality of the clients can be boosted, through the positive behavior of the employees, in order to generate good practices of human resources management and a service excellence. However, in the studies of Sharpley and Forster (2003), Eraqi (2005) and Yunus (2012) there was a low satisfaction or even a dissatisfaction of the employees, due to the lack of encouragement and recognition of the hierarchical superiors so that their workers can be creative, innovative, participate in the decision-making process, feel self-fulfilling, and make a commitment to the company.

Table 1 – Summary of Scientific Studies

Authors/ Year	**Studies**	**Country**	**Objectives**	**Methodologies**	**Findings / Conclusions**
Sharpley e Forster (2003)	*The implications of hotel employee attitudes for the development of quality tourism: The case of Cyprus*	Cyprus	Evaluate and value the importance of employees to increase the competitiveness of the organization; Ascertain their attitudes in the role of service delivery and to meet customer needs	Application of questionnaires to employees	Employees only work for money, (without any kind of commitment). This is due to the fact that the hotel industry in the country is the one that offers the best salaries; Managers have to think of intrinsic rewards for employees to feel self-fulfilling and to make commitment to the company

Tsaur e Lin (2004)	*Promoting service quality in tourist hotels: The role of HRM practices and service behavior*	China	Relate the management of human resources, the degree of knowledge of the service and the perception of quality service in hotels	Application of questionnaires to 203 employees and 272 clients (tourists) of the hotels.	HRM practices have an indirect effect on customer perception and a direct effect on employee behavior
Tsaur, Chang e Wu (2004)	*Promoting Service Quality with Employee Empowerment in Tourist Hotels: The Role of Service Behavior*	China	Analyze the relationship between employee *empowerment* and quality services in tourist hotels	Application of questionnaires to 203 employees and 272 clients (tourists) of the hotels.	Employee *empowerment* is related to quality in services and four dimensions of quality in services: reliability, responsiveness, assurance and empathy
Snipes, Oswald, LaTour e Armenakis (2005)	*The effects of specific job satisfaction facets on customer perceptions of service quality: an employee-level analysis*	USA	Determine which specific aspects of job satisfaction have the greatest effect on the client regarding the quality of services	Application of questionnaires to 351 employees and 8667 clients of Higher Education	The aspects that have the greatest influence on job satisfaction are: customer satisfaction, satisfaction through benefits and satisfaction with work itself
Eraqi (2005)	*Tourism services quality (TourServQual) in Egypt The viewpoints of external and internal customers*	Egypt	Identify from the perspective of internal customers (employees) and external clients (tourists) the quality of tourist services in Egypt	Application of questionnaires to 500 employees and 700 tourists	Quality can serve as a guideline in the tourism sector and influence the decision-making of tourism services; Low internal and external customer satisfaction
Yee, Yeung e Cheng (2008)	*The impact of employee satisfaction on quality and profitability in high-contact service industries*	China	Recognize the impact of employee satisfaction on their operational performance, in the services sector with direct contact with customers	Empirical study with 206 industries in the service sector	Employee satisfaction is intertwined with service quality and customer satisfaction playing a significant role in the organization

Yee, Yeung e Cheng (2009)	*An empirical study of employee loyalty, service quality and firm performance in the service industry*	China	Observe the relationship between employee loyalty, quality of service, customer satisfaction, customer loyalty and the organization's profitability	Application of questionnaires to 210 service industries	The effect of the employee's loyalty was reflected in the organization's profit, since it is through the quality service provided that originates the satisfaction of the customer and their loyalty to the company
Ivyanno e Nila (2012)	*The Influence of Service Quality and Tourist Satisfaction on Future Behavioral Intentions: The case study of Borobudur Temple as a UNESCO World Culture Heritage Destination*	Indonesia	To study the influence of service quality and the satisfaction of tourists on the future behavior of domestic tourists	Application of questionnaires to 200 domestic tourists	The quality of the service has a positive influence on the satisfaction of the tourists, being the tangible dimension the most relevant in the quality of the service
Yunus (2012)	*The Relationship between Internal Satisfaction and External Satisfaction amongst Hotel Customers in Malaysia*	Malasya	Understand the relationship between internal satisfaction (employees) and external satisfaction (clients)	Application of 120 questionnaires to employees and clients (tourists) of hotels	Little satisfaction or lack of it either in internal customers (employees) or in external clients (tourists)

RESEARCH METHODOLOGY

Problems and Objectives

The problematic of this study is the global analysis of the following key question: Is there quality in the nautical tourism services offered by the ADV region of quality? On the other hand, we also want to know if the gender of the employees influences the quality in the provision of nautical tourist services?

Thus, the present study intends to provide an overview of the quality of the nautical tourist services carried out in the ADV region, with the internal clients (collaborators). To this end, the following specific objectives have been defined:

1) Verify if there is quality in the nautical tourist services in the opinion of the internal clients (collaborators);
2) Recognize quality in tourism through the variables under analysis (Safety, Hygiene, Accessibility, Transparency, Authenticity and Harmony);
3) Analyze if the gender of the employees influences the quality in the provision of nautical tourist services.

Method

Participants

This survey was attended by 117 employees of the nautical tourism services, referring to all nautical tourism services organizations operating in the ADV region. The sample consists of a significant number of employees belonging to the male gender; single; aged 30-39 years; with secoundary school qualification; with fixed term contract; having the job of waiters / bar; who have worked in the same tourist service for at least 2 years; other professional activity; and have between 1-10 years of professional experience.

Study Variables

The variables of the study are formed by the six tourism quality standards (Protection and Security, Hygiene, Accessibility, Transparency, Authenticity and Harmony), which according to the World Tourism Organization (2003) should be considered in tourism products / services decisions, in order to create consistency and harmony in the quality process, and as Eraqi (2006) verified in his study (see Table 2)

The **variable Protection, Safety and Hygiene** is related to the norms of protection, safety and hygiene established by law, which should not neglect the integrity and life of employees and all corporate stakeholders and should be considered as standards for quality.

According to the European Agency for Safety and Health at Work (EU-OSHA, 2014), effective management of occupational safety and health is one of the main factors of constant success of companies, ie companies should invest on the protection, safety and hygiene in the workplace, so as to guarantee stability in productivity, as well as quality of services provided and satisfaction of both external and internal customers.

Hamel and Prahalad (1993) argue that long-term competitiveness and survival of companies depend on the attitudes and behavior of managers, since they must maximize benefits, take advantage of new opportunities and minimize negative effects on protection, safety and hygiene of all members of the company.

Table 2 – Variables in study

Variable	Statements in the Survey
Protection, Safety and Hygene	**Q20** - The physical appearance of co-workers is important for the work they do **Q27** - The company offers all the necessary tools (uniform, mobile phone, transport, etc.) to work
Accessibility	**Q8** - The work I do is flexible. **Q13** - The internet, computer, mobile phone and other information and communication technologies help to reduce costs for the company **Q14** - New technologies help to communicate with your colleagues **Q15** - Communication among all helps maintain good customer service **Q19** - The company premises (Wc, lockers, cafeteria, etc.) are good **Q21** - Flexibility at work makes my colleagues perform better **Q22** - The service provided will be more credible if there is good communication **Q26** - Work shifts are selected based on preferences
Transparency	**Q3** - Effective leadership results in rewards and praise **Q6** - The compliments of the tasks performed are carried out in front of my colleagues **Q7** - The praises of the tasks performed are done in a particular way **Q11** - Praise from customers gives me motivation **Q12** - Praise from my bosses gives me motivation **Q16** - The training required for this job was given at the beginning of the contract **Q17** - Training to focus on the services I provide to clients was also given **Q23** - The exchange of information influences the attitude of my colleagues at work
Autenticity	**Q9** - The work done by me adapts to the customer needs **Q24** - My colleagues have the appropriate skills / abilities to meet the expectations **Q25** - The work environment allows to create something new (innovation) for the company **Q29** - Mycolleagues will make this job their professional career
Harmony	**Q1** - The relationship with my colleagues is good **Q2** - The relationship with all members of the company is good (including bosses) **Q4** - Salary is not the only reward I receive at the end of the month **Q5** - My salary is paid on the agreed date **Q10** - Respect prevails both in the relationship with clients and in the relationship between colleagues **Q20** - The behavior of colleagues is also important **Q28** - Tasks should be done right at the first time **Q30** - empresaMy colleagues' opinions are important to the company **Q31** - My colleagues are happy to work for this company

In business, the human resources department is responsible for safety, security and hygiene and it must implement people management policies so that responsibilities are shared by all members; effective responses to these responsibilities; ensure that all members take part in policies and business measures (CCOHS, 2005).

The **variable Accessibility** is related to the accessibility of both communication and physical barriers and services, ie all members of companies should be able to freely access and use tourism products and services.

For Bueno (2009), the survival of modern companies requires a constant process of improvement and qualification of communication, since good communication encompasses permanent involvement and commitment on the part of all members (Cunha et al., 2007).

Companies must invest on the conditions that boost individual and organizational skills, considering people as a key element of success. To this end, companies must develop human capital through training, flexibility, interest and commitment; to develop structural capital, that is, to define internal structures that allow the exchange of knowledge, to sustain the relational networks of the members, both vertically and horizontally, and to develop relational capital, in order to obtain a more valuable knowledge, innovation and creativity (Santos, 2004).

The **Transparency variable** is related to the legitimacy of the expectations and needs of clients and employees, that is, the actions performed by hierarchical superiors and employees must be transparent and clear, so as not to raise doubts and to be well understood by all.

Human resources management must implement transparent and clear actions, ranging from recruitment and selection activities; retention of human capital through policies tailored to the needs of the company and its members; empowerment through training to the development and motivation of employees through incentives, rewards, praise, feedback, among others (Kaya et al., 2010).

The **variable Authenticity** is related to the satisfaction of customers and employees, that is, the service provided must be of authentic, true and innovative quality.

Akdere (2009) states that companies are responsible for ensuring the evolution of human capital, improving productivity and organizational performance, so that the services delivery is carried out with quality, differentiation and innovation. These factors will lead companies to a path of success and stability, as well as ensuring the satisfaction of customers and employees.

The **Harmony variable** is related to the harmony in the work environment and the harmony in the relationship between employees, including the hierarchical superiors. The relationship must be guided by respect, recognition, satisfaction and commitment.

Harmony in the work environment encompasses the rational component and the emotional component, that is, in addition to the organizational objectives that must be achieved, companies must also consider the emotions, well-being, empathy, involvement and satisfaction, both personal and professional (Goleman et al., 2002).

Thus, it is intended to determine if these variables in study influence the quality of tourism services in the ADV region and how this will be reflected in the perspective of internal customers (employees).

Collection Tools

As a method of application the questionnaire survey was used using a Likert scale from 1 to 5 (1 - I totally disagree 2 - Partially disagree 3 - Neither agree nor disagree 4 - Partially agree 5 - I totally agree), so that the employees can show their degree of agreement and two interviews were carried out with an owner and a managing partner of an establishment located in the ADV region, where the responses were grouped according to the variables studied in the survey by questionnaire.

RESULTS

Characterization of the Alto Douro Vinhateiro Region

The region of Northern Portugal is a region with a vast wealth, where diverse cultural and natural heritage, in particular the Atlantic and Mediterranean cultures. Most of its territory is located in the watershed of Douro, Minho, Lima, Cávado and Ave rivers (Turismo de Portugal, 2012).

According to the North Regional Coordination and Development Commission (CCDRN, 2015), the Northern region is composed of 86 municipalities and 1426 parishes. The municipalities are divided into eight Inter-Municipal Communities (CIM), which form the level III of the Nomenclature of Territorial Units for Statistical Purposes (NUTS), which includes the Douro region. This region of the Douro encompasses the ADV region, which comprises 13 municipalities and represents 10% of the Douro Demarcated Region, corresponding to approximately 25,000 ha (Regional Directorate of Agriculture and Fisheries of the North - DRAPN, 2015).

Instituto Portuário e de Transportes Marítimos (IPTM, 2015) reports that in the waterway of the Douro River, which extends over 210 km, there are approximately 52 vessels to operate, with a capacity of up to 350 people.

In 2001, the ADV region was classified by UNESCO as a World Heritage in the category of "Cultural, Evolutionary and Living Landscape" (DRAPN, 2015) and encompasses diverse natural values (scarcity of fertile soil, scarcity of water, vegetation and Mediterranean crops; (river, vineyard, light, color and the famous river Douro) and cultural values (railroad, imposing landscape, terraces and walls in shale and different techniques of planting of the vineyard) (Cristovão et al., 2005; Perafita, 2007; DRAPN , 2015).

Nautical tourism has as its main motivation "to enjoy an active trip in contact with water, with the possibility of performing all kinds of nautical activities, in leisure or in competition" (Turismo de Portugal, 2006, p.9). According to the same entity, the main activities of nautical tourism are: sailing, windsurfing, surfing, diving, rowing and cruise travel. The nautical tourism market comprises two aspects: the nautical recreation and the nautical sport. In the present study, recreational boating is considered, since the main objective is to analyze tourism service companies that provide recreational boating services. The nautical recreation is related to nautical sports experiences, as a form of leisure and entertainment and represents approximately 85% of all nautical trips (Turismo de Portugal, 2006).

For Jesus et al. (2004), CCDRN (2015) and Pessoa (2008), the ADV region has a high potential to be one of the main regions of nautical tourism. To this end, the unique landscapes, traditions, culture, wines and gastronomy of the region contribute.

Analysis of the results obtained in the inquiry by questionnaire

Regarding the variables that should be considered in the tourism services decisions, in order to create consistency and harmony in the quality process, it is emphasized that the collaborators agree with most of the statements presented in the questionnaire survey, except with the affirmation Q27 - "The company offers all the necessary tools (clothes, mobile phone, transport, etc.) to work", this means that although there are positive factors in companies (satisfaction, respect, good communication, good facilities, among others) to be improved by companies, such as: concern for workers; specific training (languages); concern with working conditions (diversification of menus, more plans of activities: visits to the museum, parks, rock engravings, sport fishing, sailing, rowing); more dialogue between managers and employees; frequent maintenance of vessels and this shoulf be done in the low season; assignment of hours and breaks and age discrimination.

Regarding the highest averages of statements for both men and women, they are in Q11 - "Customer praise gives me motivation" and Q20 - "The behavior of colleagues is also important ", which means that employees think in a similar way about work situations, in particular the praise they receive from customers and the behavior of colleagues, regardless their gender.

The lowest averages of affirmations in the masculine gender are in Q4 - "Pay is not the only reward I receive at the end of the month" (3.00) and Q27 - "The Company offers all the necessary tools (uniform, mobile phone, transport, etc.) to work "(3.02). In women, the lowest averages are in Q16 "The training required for this job was given at the beginning of the contract" and in Q27 - "The company offers all the necessary tools (uniform, mobile phone, transport, etc.) to work "(3.00).

The lessons that can be drawn are that in both the male and the female gender, the respondent employees feel that the compliments made by the clients impart motivation to them to continue with the provision of a personalized and quality service. It is also important for employees to feel that peer behavior is appropriate for the workplace, ie behavior based on respect, good communication and flexibility.

On the other hand, the aspects with which male respondents are in less agreement are the fact that wages are the only reward they receive at the end of the month and that the company does not offer all the necessary tools to provide the service.

In female respondents, the aspects with which they are in less agreement are related to the training that is not provided at the beginning of the contract and to the fact that the company does not offer all the necessary tools to provide the service. As seen earlier, these are some of the aspects that companies need to change to please the internal customers (employees) and consequently the external customers.

The objective of this paper is to verify the differences, to know to what extent they are statistically significant and to determine the relationship between the respondent employees' gender and the quality of nautical tourism services in the ADV region. For this purpose, a hypothesis test (t-student test) was performed on the difference of means for each statement (see Table 3).

The hypotheses defined for the t Student test are the following:

- H0: The average of the perceptions of the male workers is equal to the average of the perceptions of the female workers
- H1: The average of the perceptions of the male workers is different from the average of the perceptions of the female workers

The test values do not allow rejection of the null hypothesis (H0) in the statements of the questionnaire, since *p-value* > 0,05, in other words, the average employee of the perceções genus male is not significantly different from the average of the employees perceptions of the female gender. Despite the averages of both statements did not show significant differences, female employees are mostly above the averages of the collaborators of the masculine gender.

Table 3 – Test t-student

	Descriptive Statistics				Statistic T	Significance Probability (Sig)	Confidence Interval at 95%	
	Male		Female					
	Mean	Standard Deviation	Mean	Standard Deviation			Inf.	Sup.
Q1	4.14	0.654	4.12	0.840	0.136	0.892	- 0.255	0.292
Q2	3.83	0.904	3.94	0.810	- 0.669	0.505	- 0.427	0.211
Q3	3.71	0.890	3.78	0.945	- 0.423	0.673	- 0.410	0.265
Q4	3.00	1.265	3.16	1.173	- 0.686	0.494	- 0.609	0.296
Q5	4.00	0.823	4.20	0.775	- 1.311	0.193	- 0.492	0.100
Q6	3.58	0.946	3.57	0.985	0.040	0.968	- 0.348	0.363
Q7	3.30	1.022	3.12	1.125	0.931	0.354	- 0.209	0.580
Q8	3.83	0.870	3.94	0.810	- 0.685	0.495	- 0.420	0.204
Q9	4.14	0.821	3.96	0.848	1.131	0.260	- 0.132	0.483
Q10	3.80	0.845	3.88	0.791	- 0.517	0.606	- 0.383	0.224
Q11	4.21	0.775	4.25	0.627	- 0.321	0.749	-0.307	0.221
Q12	4.05	0.867	3.98	0.905	0.395	0.694	- 0.261	0.391
Q13	3.85	1.011	3.86	0.895	- 0.079	0.937	- 0.370	0.341
Q14	3.92	0.882	4.22	0.730	- 1.097	0.059	- 0.594	0.011
Q15	4.09	0.799	4.22	0.832	- 0.823	0.412	-0.425	0.176
Q16	3.33	1.155	3.00	1.233	1.503	0.136	- 0.106	0.773
Q17	3.33	1.086	3.20	1.200	0.647	0.519	- 0.283	0.557
Q18	3.61	0.892	3.73	0.723	- 0.778	0.438	- 0.423	0.185
Q19	3.82	0.959	4.06	0.925	- 1.366	0.175	- 0.590	0.108
Q20	4.18	0.763	4.47	0.612	- 2.209	0.029	- 0.548	- 0.030
Q21	3.70	0.822	3.88	0.887	- 1.169	0.245	- 0.500	0.129
Q22	3.95	0.793	4.22	0.757	- 1.802	0.074	- 0.548	0.026
Q23	3.89	0.747	3.96	0.720	- 0.488	0.627	- 0.338	0.205
Q24	3.73	0.921	3.55	0.832	1.082	0.281	-0.148	0.504
Q25	3.38	1.049	3.41	1.023	- 0.170	0.865	- 0.416	0.350
Q26	3.05	1.115	3.02	0.990	0.130	0.896	- 0.367	0.418
Q27	3.02	1.00	3.00	1.114	0.077	0.938	- 0.373	0.403
Q28	3.89	0.914	3.82	0.865	0.423	0.673	- 0.259	0.400
Q29	3.48	0.808	3.29	1.026	1.125	0.263	- 0.145	0.527
Q30	3.38	1.034	3.47	1.027	-0.478	0.634	- 0.473	0.289
Q31	3.67	0.810	3.76	0.790	- 0.656	0.513	- 0.394	0.198

Analysis of the results obtained in the interviews

Here we present two interviews with an owner and managing partner of an establishment located in the ADV region. Table 4 shows the responses according to the quality variables in tourism analyzed in the present study and with the aspects that should be improved for a quality service delivery.

As can be seen, the aspects to be improved so that the nautical tourism service in the ADV region increases, in a sustainable and qualitative way, are related to the improvement of the infrastructures, both roads and accomodation establishments; investment or updating in new technologies, namely related with social networks and programs of dissemination of the existing tourist offer; training of employees, namely table / counter service training and languages); reinforce advertising through the word of mouth; improvement of the service provided and the good image of the company; establishment of a working schedule that respects the legislation and is not only seasonal, as well as the equitable distribution of working hours, considering days off and weekends.

Table 4 – Interviews

Variable	Interviewee 1	Interviewee 2
Protection, Safety and Hygene	Improvement of infrastructures	Improvement of infrastructures (e g trains, Road 222, increasing of the numebr of bed-places)
Acessibility	Increase the supply with good quality New technologies help reducing communication costs among all members of the company	Dissemination on the Internet of information about the ADV region. Internet promotion of the diverse tourist offer in the ADV region.
Transparency	Lack of training of nautical operators	Lack of employee training (eg table service and counter service). Increased advertising through "word of mouth"
Autenticity	Improvement of service provided so as to meet the costumer's needs	Improvement of the company's good image in order to attract more tourists
Harmony	Establishment of a non seasonal work schedule Implementation of working hours according the legislation.	Establishment of a non seasional work schedule that is not seasonal. Improvement of working conditions. Equal distribution of working hours.

DISCUSSION AND CONCLUSION

In the current context, where the economic and financial crisis takes on a global dimension, few sectors of activity are able to survive, one of them is the tourism sector, which is expected to continue to have a successful path.

In order to survive in an increasingly competitive sector, such as tourism, organizations need to opt for quality and a sustainable development strategy, considering details that may stand out their services, such as: personalized service; a good marketing plan; benchmarking; training of employees and adaptability to change.

After comparing the results obtained in the study of Eraqi (2005) with this study, it was concluded that, in both studies, it is essential to meet three requirements: satisfaction of internal customers (employees), satisfaction of external customers (tourists) and process efficiency. Eraqi (2005) concluded that employees were dissatisfied and unmotivated due to the lack of recognition and encouragement of hierarchical superiors, as they did not create oportunity for their employees to be creative, innovative, involved in the decision-making process, feel self-fulfilling and commitment themselves to the company. It also happens in this study, where there is a lack of concern with the employees and the lack of dialogue between managers and employees.

The studies of Snipes et al. (2005) and Cunha (2013) also meets this study, which shows that satisfaction is divided into two aspects: personal and organizational. The personal side includes factors such as concern for employees and customers. The organizational side includes factors such as salary, working conditions, peer-to-peer dialogue and assigned workload.

Regarding the personal and professional formation of employees, this is a factor that hierarchical superiors should not overlook, since it brings added value to the organization, such as: skills improvement; performance improvement; increased self-esteem; motivation; provision of quality service; sustainable development; competitiveness and increase in overall profit (Reed et al., 2000, Cardim, 2005, Costen and Salazar, 2011, Eurico et al., 2012). In the operationalization of the statements in the questionnaires and after analyzing the occurrences, it was verified that the highest averages of the affirmations were in the Q11 - "The praise from the clients gives me motivation" and in the Q20 - "The behavior of the colleagues is also important "for both genders, which means that the co-workers think in a similar way, regardless of their gender, as verified by the t-Student test.

The present study corroborates the studies of Tsaur and Lin (2004) and Cunha (2013), arguing that human resource management practices indirectly influence client perception and directly the behavior of employees, ie the quality perceived by clients is promoted, through the positive participation of employees, which leads to a service of excellence and, consequently, getting recognition by the customers.

Regarding the behavior of colleagues, employees feel that the behavior adopted by colleagues is relevant, as this will influence labor relations and teamwork. This aspect is also described in the studies of Perles (2002) and Marras (2005), which highlight the relevance of teamwork in hotel organizations. In order to achieve good teamwork, it is crucial to see the needs of satisfied employees (salaries and benefits, working conditions, involvement in the planning of the objectives), in order to be able to provide excellent service to clients. The lowest averages of the questionnaire statements were in Q4 - "The salary is not the only reward I get at the end of the month", in Q27 - "The company offers all the necessary tools (uniform, mobile phone, transport, etc.) to work, in Q16 - " The training required for this job was provided at the beginning of the contract "and in Q26 -" Work shifts are selected according to preferences ". In the lower averages, a gender discrepancy was already evident, that is, the male gender did not agree or did not identify themself with Q4 and Q27 and the female gender did not agree or did not identify themself with Q16 and Q27.

For the male gender, the issue of salary and the availability of the necessary tools to work are aspects that organizations must improve. For women, on the other hand, the question of the training provided in the beginning of the contract and the fact that the company does not provide the necessary tools for the provision of the service are aspects that need to be improved. The issue of wages is a long-standing problem, as are working conditions that are sometimes precarious, overworked hours, lack of time off or weekends, which influence the level of employee satisfaction. This study is in line with the studies conducted by Nebel (1991), Sharpley and Forster (2003), Katt and Condly (2009) and Smith and Shields (2013), in which the tourism sector was seen as a sector in which the remuneration are not equitable and equivalent to the work done and concludes that employees also like to be rewarded in other ways, such as personal and professional recognition and delegation of responsibilities.

The studies of Breiter and Bloomquist (1998), Hjalager (2001) and Neves (2011) argue that the delegation of responsibilities is essential to achieve quality in services, since the hierarchical superiors demonstrate a sense of trust, which will lead the workers to commi to the organization.

In spite of the averages of the statments of both genders do not show significant differences, the averages of the female workers are, mainly, superior to the average of the male workers . This means that the perceptions of the female gender tend to be closer to the subjects under study: quality and nautical tourism than the perceptions of the male gender.

With this study it can be concluded that quality can be a guide in the tourism sector and influence the decision-making of tourist services. On the other hand, there are aspects that should be improved to make customers feel pleased, as previously mentioned. If the human resources management, together with the hierarchical superiors and the other workers manage to fill these aspects, then the quality will subsist in the tourist services, which will lead to the satisfaction of the internal and external clients and, consequently, to obtain competitive advantages and profit.

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The influence of a Lean Six Sigma Green Belt Course on European students. A practical case

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ABSTRACT

Purpose – The Lean Six Sigma Green Belt course developed for the European Students of Industrial Engineering and Management association, ESTIEM, is meant to offer a new blended learning approach for teaching to Industrial Engineering and Management students across Europe. This paper aims to investigate the impact that the participation of such a course had on students, and how it can empower them. The paper will focus on the impact that the Lean Six Sigma Green Belt Course has on students by investigating and comparing students from different countries that experienced different educational system structures.

Design/methodology/approach – Previous studies are going to be used to create a bit of background about Lean Six Sigma and to show the benefits of the blended learning method applied in the Lean Six Sigma Green Belt Course (Rajala, Jarrett, and Turtiainen, 2017). An analysis of what benefits an optimized educational system that seems to maximize the learnings for a student can bring follows. Here, the authors aim to further understand the implications and the impact that such optimized methods have on students and universities.

Findings – The authors aim to show what the reality is showing in a more formal and thoughtful way. Data was collected through a survey spread out to around 200 students of Engineering and Management across Europe. So far, the collected data is quite promising, confirming the reality. The main goal still is to improve a collaboration between Universities and students, hence to increase the engagement level of students and the social return on investment for Universities (expressed in a greater visibility among companies). At the same time, it proves that learning Quality Management, in an international environment, facilitates the personal development as well

as increases the likelihood of getting better opportunities by having a greater freedom of choice. By aiming to be a rather empirical confirmation of the Blended Learning Method, this paper does not intend to be disruptive, or a paradigm shift, but rather a confirmation that combining the Blending Learning Methods with Lean Six Sigma is exponentially beneficial for students, by improving in different areas simultaneously.

Research limitations/implications – The main limitation is the number of received answers to the survey. A sample size of 32 out of 200 possible can be analysed. For further research, the sample size should be increased. As the course is ongoing around Europe, the database is growing continuously. However, gathering this number of students going through the Course in the first year may already emphasize some of the points made. In the future, the survey should be extended. Shedding light on the premises at universities as well as gathering feedback for the course design (i.e. blended learning approach) may be investigated. Moreover, collaboration possibilities between student's associations or individual students for bringing such courses to their universities and further developing the Course prompt another interesting aspect. The third party, the companies, should be included in the research as well. One of the major parts of the teaching is the application of the learnt methods, tools and approaches. Every participant of the course needs to finish a practical project (e.g. Green Belt Project) for finalizing the course participation with receiving the Green Belt Certificate. Surveying the companies which accompanied and offered the practical project of at least one student would give insights on how well students learn and give insights to practical applications.

Originality/value – This paper describes the current situation and proves research regarding the impact of education in Lean Six Sigma and Quality Management from around 31 European countries. It enables to see the benefits of the blended learning method in combination of the Lean Six Sigma Knowledge from an Industrial Management and Engineering student perspective.

Keywords: Lean Six Sigma, Green Belt, ESTIEM, European Educational System, Industrial Engineering, and Management.

Paper type: Research paper

RESEARCH ON LEAN SIX SIGMA

A brief history of Lean Six Sigma

The evolution of production systems in the automotive industry has been the common denominator for the development of both Lean and Six Sigma theories. Close to the end of the first half of the 20th century, new demands have been appearing: Customers started demanding more variety, and the production systems in place were not designed to comply with such demand, since they were focused on standardized, high volume products; as consequence, product's life cycles started to decrease. After funding the known today as Toyota Motor Company in 1935, Kiichiro Toyoda, Taiichi Ohno, and other founders had started building on Ford's production line management principles, introducing simple innovations, which provided both continuity in process flow and a wide variety in product offerings (Holweg, 2007). By introducing these simple innovations, they invented what was known as the Toyota Production System, foundation of the Just in Time (JIT), which later gave birth to the Lean Management philosophies, born in the 1980s in companies collaborating with Japanese counterparts (Holweg, 2007). Building up through continuous improvement of the JIT philosophy and through refinement of Total Quality Management, Lean Six Sigma was born. As pointed out in different occasions by Gregory H. Watson, Lean Six Sigma is about combining the best of Just in Time and Total Quality Management, laying its foundation of two main ideas from both theories, no waste and reduction of the variance of the output; which allow process simplifications, but not too many (Methuen, 2004). Today, Lean Six Sigma is still an extremely valuable philosophy to follow to reach excellence, flexibility, and scalability. More and more businesses are applying the philosophy principles and businesses do not limit themselves by applying Lean Six Sigma only to production lines, but also to services industry as IT or finance.

The research topic

The data from the European Commission Report (Vansteenkisten, 2014) prove that not surprisingly European education systems vary in their structure and offering. Countries have different perspectives in educating students, which therefore also create different opportunities for student's development and careers. Even though there are these differences, there is also the effort of harmonizing higher-education in Europe. The Bologna Declaration in 1999 is undoubtedly a milestone for this development and is widely known (The Bologna Declaration of 19 June 1999, 2007). Over the past two decades, the European Union and several other non-EU countries have created a framework for translating educational standards rather than harmonizing the educational systems themselves. As Bjørnåvold (2007) states there is a great diversity of educational institutions and systems in Europe, but this reflects the recognition of different needs on a local, regional and national level. The developed framework, the European Qualifications Framework for lifelong learning (EQF) promotes one of the most important goals of the EU, the mobility of people in Europe.

The presented ESTIEM Lean Six Sigma course (Rajala, Jarrett, and Turtiainen, 2017), using blended learning, is an opportunity to overcome the differences in European education using a new approach. The course does not aim to harmonize education systems but to offer a comparable education in a specific field. In addition, further investigations may be conducted to show how the practical application of the course learnings is different between locations in Europe. The course has started in November 2016 and so far, met with the interest of 296 European students from 31 nations (www.ESTIEM.org, n.d.) However, the impact of the course should be discussed given its influence on students to see what attracts them and how international learning can integrate students aiming for similar outcomes in their education.

Such a course as the ESTIEM Lean Six Sigma Course can be held against its impact on students and Universities alike. To investigate this, a hypothesis must be formulated.

The authors aim to investigate the research question by taking into consideration a hypothesis (hypothesis, or hypothesis 1, in the text) regarding the potential benefits for students. A second hypothesis will be investigated through further research, which should investigate apparent benefits from the University side. The hypothesis 1 considers the relationship between students (participants) and the ESTIEM Lean Six Sigma Course. A brief introduction to the research on benefits for universities is given by hypothesis 2. However, the research on this hypothesis is not finalised and therefore, only a short introduction to the topic is presented.

Hypothesis 1 - Benefits for students

Students from the field of Industrial Engineering and Management participate in the Course earning different benefits for their personal and career developments. ESTIEM integrates 8000 students from 31 European countries, all of them have a possibility to attend the course during international or local course training. Based on those students, authors want to see how they see the Course as the opportunity to give an understanding of the educational power of that blended learning. To investigate the benefits for students, their perception about their potential improvements was analysed. To do so, a survey has been built and then sent out to participants of the ESTIEM Lean Six Sigma Course (LSS) . The survey is made up of a set of questions focusing on the impact that the ESTIEM Lean Six Sigma Course has on participants per different areas of interests. The survey covers three main areas:

a. Knowledge acquisition. The Course broadens students' education (sub-hypothesis: the Course has a strong positive influence on acquiring a broader education);

b. Knowledge transferring. The Course influences the way students communicate their knowledge through teaching sections (sub-hypothesis: the Course has a strong positive influence on students to learn how to teach and facilitate);

c. Knowledge leveraging. The Course boosts students' career. (sub-hypothesis: the Course has a strong positive influence to boost students career opportunities, both nationally and internationally (the Course is held in English));

The three areas of analysis of the chosen hypothesis are divided according to the *Unified Model of Knowledge Creation* of Nonaka, Toyama, and Konno (2000).

Findings resulted from the analysis of this survey are reported in the "Influence of the Course on Students' Development". Finally, the chosen hypothesis focuses on the role of the LSS Course in positive impacting participants, by stating that participants effectively gain some particular intrinsic benefits after attending the ESTIEM LSS Course. This is mainly due to the way the Course is built (Rajala, Jarrett, and Turtiainen, 2017).

The first topic that the survey covers is knowledge acquisition. The way the course is built (ibid.) is correlated to how students learn. Moreover, by the expansion of their knowledge base students are empowered directly and indirectly; directly by increasing their knowledge base, indirectly by moving into the second area of interest, Knowledge Transferring, through teaching and proactive learning (*Applying phase*, ibid.). In this phase, consolidation of theoretical principles allows students, later on in the process, to be able to transfer the LSS body of knowledge to others. In practice, this is achieved by making students continue their lean six sigma journey. Firstly, by performing an internship that again allows consolidating theoretical principles, and secondly by enabling students to share their knowledge with other students as Lean Six Sigma Instructors.

The clear nature of the ESTIEM Lean Six Sigma Course is boundless knowledge transferring, hence through its blended learning method (ibid.), the ESTIEM Lean Six Sigma Course leads to intercultural exchanges of knowledge. Speculations may be held that the implication of what described above may go beyond the simple teaching of a course, and be applicable to any organization. This would be true if we define organizations as a group of entities gathered toward a common objective, in our case the learning, transferring, and leveraging the Lean Six Sigma knowledge.

To understand why this paper claims benefits for students, the above-mentioned concepts are the foundation of the positive impact the Course has. Continuing through the analysis of the Students-Course relation, benefits appear in the area of personal development as well (Hypothesis 1, "a" and "b"). For the above-mentioned reasons, the authors are led to believe that participants of the course would notice an exponential boost in their professional lives, increasing their employability through their knowledge base and improved skills.

Hypothesis 2 - Benefits for Universities

To investigate the influence of the ESTIEM Lean Six Sigma Green Belt Course on Universities a survey was addressed to the deans and professors of Universities connected to ESTIEM.

The main parts of the hypothesis 2 can be presented as:

a. ESTIEM Lean Six Sigma Course may have a strong positive influence on Integration of Lean Six Sigma in European Universities in the area of Quality Management

b. ESTIEM Lean Six Sigma Course has a strong positive influence on the access to the high-level content which was not available before to universities

The survey aims on the one side to investigate the current status of Lean Six Sigma teaching at Universities in general, and on the other side on the opportunities of collaboration between the here presented course and Universities. Insights on benefits for Universities offering LSS Courses may be already investigated as well. The initial findings are presented in the section on hypothesis 2.

METHODOLOGY

The authors base the argumentation on two main sources of support: academic literature and surveys as well as feedback about the ESTIEM Lean Six Sigma Green Belt course itself.

Academic literature will be taken into account to fill the gap between empirical data and the research problem, what allows to present a sound result that finds its roots in multidisciplinary studies; from psychology to network theory. European Commission Reports provide the holistic knowledge of so far achievements in European studies integration (Vansteenkisten, 2014). Moreover, Holger Daun (2011) has researched on how European Union concept has impacted on education systems the integration of education among its members.

The survey has been shared among around 250 European students of Industrial Engineering and Management who went so far through the ESTIEM Lean Six Sigma Green Belt course and are therefore able to provide the experiences they gathered through the course. The final sample size is of 32 participants. The students come from 31 European countries representing 25 European universities. The survey investigates through quantitative assessments the level of empowerment that students have perceived because of the participation to the Lean Six Sigma course and how the course impacted their overall lives and academic career. Moreover, surveys will be sent out to Universities to investigate on their perception about the course given the various outcome of the learning experience. In both cases, surveys will be used to verify our hypotheses. A first survey to representatives of Universities connected to ESTIEM is included in this paper. 16 deans, assistant professors or professors filled in the survey representing 16 European Universities. As this is a rather small sample the authors introduce the findings regarding this limitation. Due to time constraints, this second more specific research should be further expanded to understand the impact of the Course on the Universities and to present a more analytical analysis to identify specific correlations/casualties.

MAIN FINDINGS

Influence of the Course on Students' development

The students were asked to answer 11 questions. So, to provide a holistic perspective regarding their so far experiences and achievements, gained through the Lean Six Sigma course provided by ESTIEM. So far, 32 respondents answered to the survey questions representing 22 European Universities.

In the survey, the first four questions refer to the strong positive influence of the ESTIEM Lean Six Sigma Course on acquiring a broader education than offered to the students. To the question, if their University provides such education within the curriculums the answer was in 71% negative confirming that Lean Six Sigma Green Belt course does not exist or is not available for the most of students from those universities (appendix, Figure 1). Moreover, the second question which asks whether the students would be interested to participate in such Lean Six Sigma Green Belt course anyway provided by NGOs as in this case is ESTIEM the answer was in 100% of cases positive out of those who answered to this question (78% of the overall respondents answered to this question. The following question regarded the form of learning and whether participants of the course evaluated the Lean Six Sigma methodology as beneficial. The outcome showed 67% of respondents prefer to learn into an international student's environment, while proactively participate in the course. 26% of students confirmed that they would prefer to attend the ESTIEM Lean Six Sigma course being organized in their universities with local students (appendix, Figure 2). Figure 3 (appendix) shows answers to the question “How much did the ESTIEM LSS course broaden your educational background comparing with the previous knowledge of Quality Management”: 41% respondents answered that it greatly affected their knowledge of Quality Management, 37% that it definitely supported their knowledge, 19% of the respondents stated that it helped on average and 3% stated that there was only a little impact to the previously possessed knowledge of Lean Six Sigma methodology. The interviewed sample seems to support the hypothesis that a Lean Six Sigma Course is highly beneficial to students. The Course appears to have a strong positive influence on students in their learning of how to teach and facilitate since former course participants facilitate the sessions for other students attending the course. Of the analysed sample, 67% of the respondents stated that they did not teach before, and 38% stated that they would like to experience becoming a Lean Six Sigma Instructors. Next, to the question regarding students’ interest in becoming an Instructor or in proceeding as a teacher for the Course, the responses were positive in 89% of the cases (appendix, Figure 4).

Apart from the above-mentioned questions, the research went deeper into asking which actual benefits for personal development were acquired for students teaching ESTIEM Lean Six Sigma courses. The development of the soft skills and the learning more about the content of the subject were the most common answer. This part of the research indicates that the Hypothesis 1b is supported. Hypothesis 1c challenged whether ESTIEM Lean Six Sigma Course has a strong positive influence to boost students’ career opportunities was achieved through answers to two main questions. First, whether the participation in the Course has already proved to boost their career; prospects from students has been confirmed by 75% of the respondents. However, 74% of the respondents answered that the Course did not help yet in going through the actual Green Belt project in order to receive the Green Belt certificate. This answer gives the overview on the difficulty in acquiring the Green Belt project (internship positions) for students in Europe. The further investigations could be made on the perception of such students from the European company’s side. Indeed, a collaborative approach towards an integration between Universities, students, and companies could lead to better results, and projects such as the ESTIEM LSS Course one has proven to boost such integration. Lastly, in the section for research regarding benefits of the Course brought for European students were carried out in order to check the appropriateness of the following hypothesis: “ESTIEM Lean Six Sigma Course has a positive influence on the students to work in a different country than their own. This is given mostly by the increased chance to get an internship/job position abroad.” In the last question of the survey, the respondents were asked whether the participation in the course will help to build a possibility for finding the job abroad. 89% of the responding students stated that they do believe in a better prospect of finding the job abroad thanks to the participation in the course. The high quality of the Course, or better the perceived quality, seems to be fairly supported by participants. Again, further investigations could be investigated from a companies' perspective.

The students were asked to answer 11 questions. So, to provide a holistic perspective regarding their so far experiences and achievements, gained through the Lean Six Sigma course provided by ESTIEM. So far, 32 respondents answered to the survey questions representing 22 European Universities. In the survey, the first four questions refer to the strong positive influence of the ESTIEM Lean Six Sigma Course on acquiring a broader education than offered to the students. To the question if their University provides such education within the curriculums the answer was in 71% negative confirming that Lean Six Sigma Green Belt course does not exist or is not available for the most of students from that Universities (appendix, Figure 1). Moreover, the second question which asks whether the students would be interested to participate is such Lean Six Sigma Green Belt course anyway provided by NGOs as in this case is ESTIEM the answer was in 100% of cases positive out of these who answered to this question (78% of the overall respondents answered to this question. The following question regarded the form of learning and whether participants of the course evaluated the Lean Six Sigma methodology as beneficial. The outcome showed 67% of respondents prefer to learn into an international student's environment, while proactively participate to the course. 26% of students confirmed that they would prefer to attend the ESTIEM Lean Six Sigma course being organised in their universities with local students (appendix, Figure 2). Figure 3 (appendix) shows answers to the question *"How much did the ESTIEM LSS course broaden your educational background comparing with the previous knowledge of Quality Management"*: 41% respondents answered that it greatly affected their knowledge of Quality Management, 37% that it definitely supported their knowledge, 19% of the respondents stated that it helped on average and 3% stated that there was only a little impact to the previously possessed knowledge of Lean Six Sigma methodology. The interviewed sample seems to support the hypothesis that a Lean Six Sigma Course is highly beneficial to students. The Course appears to have a strong positive influence on students in their learning of how to teach and facilitate, since former course participants facilitate the sessions for other students attending the course. Of the analysed sample, 67% of the respondents stated that they did not teach before, and 38% stated that they would like to experience becoming a Lean Six Sigma Instructors. Next, to the question regarding students' interest in becoming an Instructor or in proceeding as a teacher for the Course, the responses were positive in 89% of the cases (appendix, Figure 4).

Apart from the above-mentioned questions, the research went deeper into asking which actual benefits for personal development were acquired for students teaching ESTIEM Lean Six Sigma courses. The development of the soft skills and the learning more about the content of the subject were the most common answer. This part of the research indicates that the Hypothesis 1b is supported.

Hypothesis 1c challenged as whether ESTIEM Lean Six Sigma Course has a strong positive influence to boost students' career opportunities was achieved through answers to two main questions. First, whether the participation in the Course has already proved to boost their career; prospects from students has been confirmed by 75% of the respondents. However, 74% of the respondents answered that the Course did not help yet in going through the actual Green Belt project in order to receive the Green Belt certificate. This answer gives the overview on the difficulty in acquiring the Green Belt project (internship positions) for students in Europe. The further investigations could be made on the perception of such students from the European company's side. Indeed, a collaborative approach towards an integration between Universities, students, and companies could lead to better results, and projects such as the ESTIEM LSS Course one has proven to boost such integration. Lastly, in the section for research regarding benefits of the Course brought for European students were carried out in order to check the appropriateness of the following hypothesis: *"ESTIEM Lean Six Sigma Course has a positive influence on the students to work in a different country than their own. This is given mostly by the increasing chance to get a internship/job position abroad."* In the last question of the survey, the respondents were asked whether the participation in the course will help to build a possibility for finding the job abroad. 89% of the responding students stated that they do believe in a better prospect of finding the job abroad thanks to the participation in the course. The high quality of the Course, or better the perceived quality, seems to be fairly supported by participants. Again, further investigations could be investigated from a companies' perspective.

Influence of the course on Universities

Even though the authors researched the influence of ESTIEM Lean Six Sigma on Universities, the findings do not yet get full support from data, mostly because of the small sample reached. However, the intermediate results from a survey addressed to the deans and professors of Universities connected to ESTIEM can be presented. In the future, the survey will help in developing and supporting the hypothesis 2, which focuses on the benefits that universities can gain from the Lean Six Sigma Course held by ESTIEM. The first findings should be discussed in the following way. In total, sixteen answers were given by deans, professors and associate professors in the survey so far. In nearly all of the approached Universities, Quality management is an important study and thus courses are taught in the field. Over 40% stated a high relevance of the study of Quality Management (appendix, Figure 6). These courses sometimes entail a lean and or six sigma part, but also at some Universities it is already taught as a separate course. However, certifications are not always included or free of charge (appendix, Figure 7a and b).

Apart from the existing courses, the interest in collaborating with students on a course seems rather promising and may result in mutual benefits, as Universities do not yet trust the content from the here developed course but show interest in it (appendix, Figure 8 and 9).

For further development of the course, the students working on the course may benefit from input on their content and teaching. By benchmarking the ESTIEM Lean Six Sigma Course with courses held at the Universities both sides may gain in viewpoints on teaching. To measure the influence of the course on Universities, the amount of successful conducted Green Belt Projects by students of a particular University may be a key performance indicator for the courses' influence. The Green Belt projects represent the link between the theoretical learning and the practical application in real world conditions, which universities may struggle to offer otherwise.

Additionally, the rating of the course by students may be introduced as an indicator for the success of the course. The course may be rated according to the Universities students feedback system, if existing, and thus a benchmark to other courses at the University, as introduced before, is possible.

ACKNOWLEDGMENTS

We would like to acknowledge Gregory H. Watson for the development of the body of knowledge for the ESTIEM Lean Six Sigma Green Belt course and to Professor Paulo Sampaio for the support in being able to write this research paper. Further research should be conducted from both the University and Companies point of view, to strengthen the findings and show that the combination of Lean Six Sigma in a Blending Learning contest is a win-win-win situation.

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APPENDIX

Figure 1

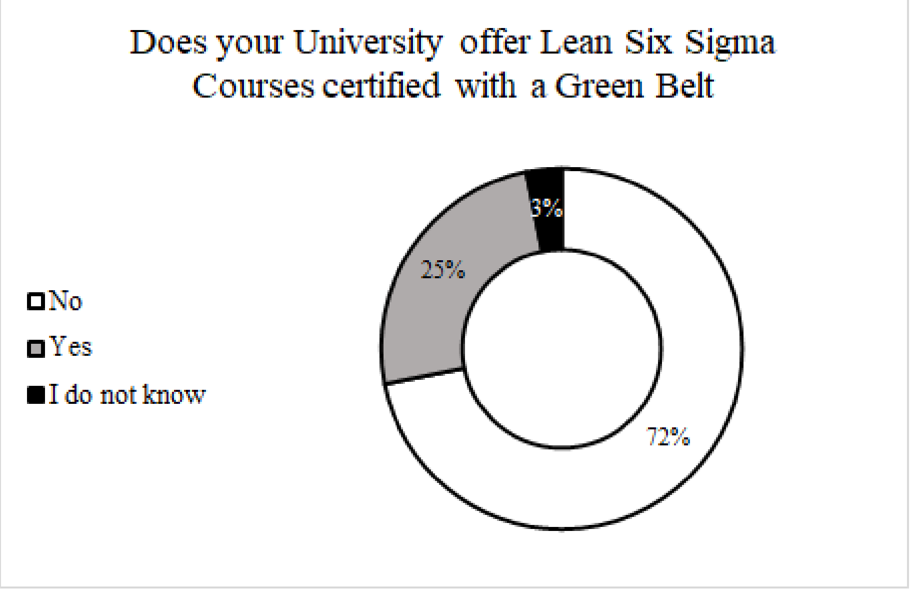


Figure 2

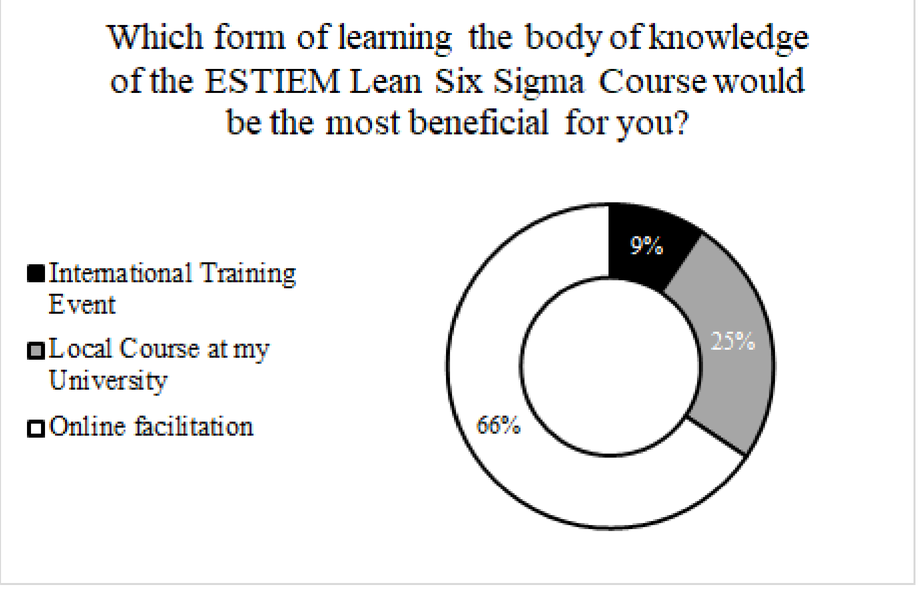


Figure 3

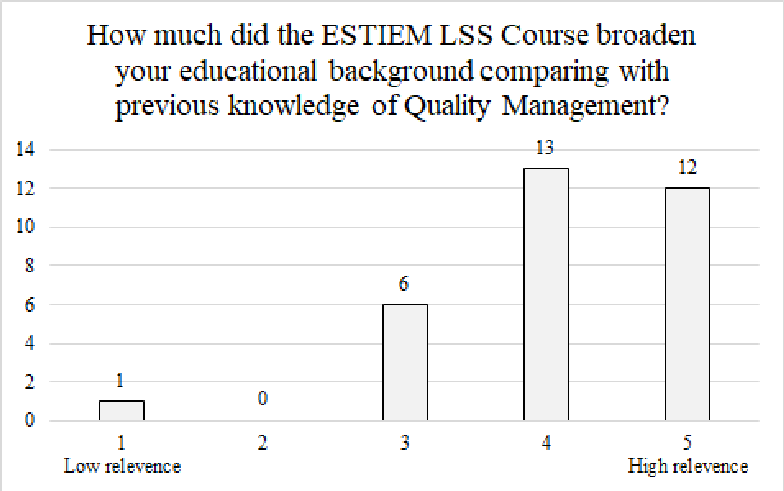


Figure 4

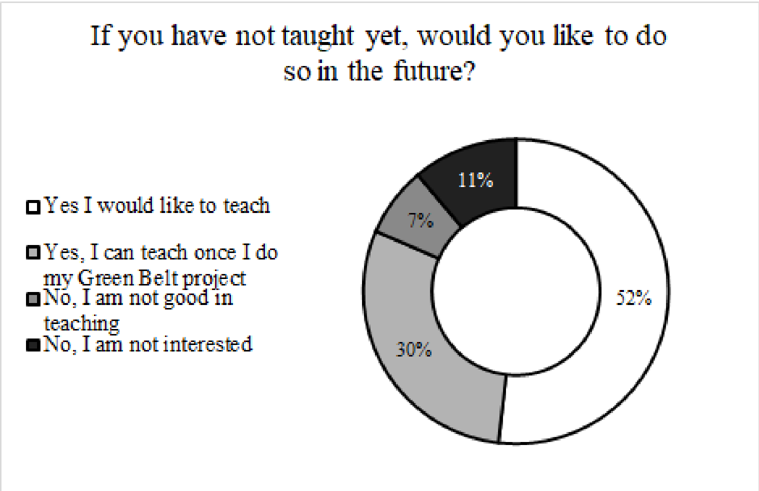


Figure 5

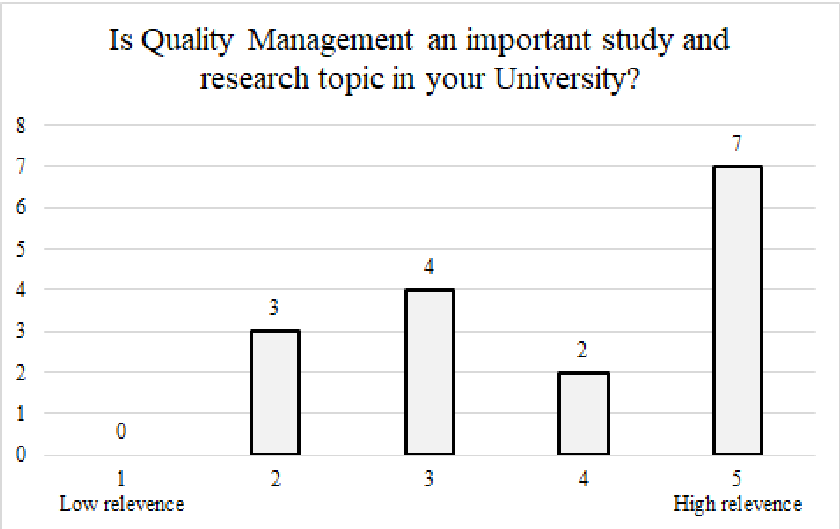


Figure 6

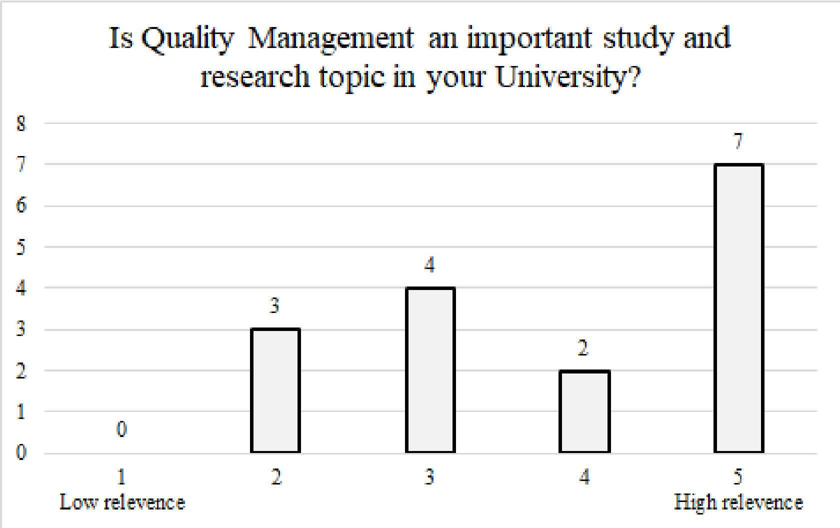


Figure 7a

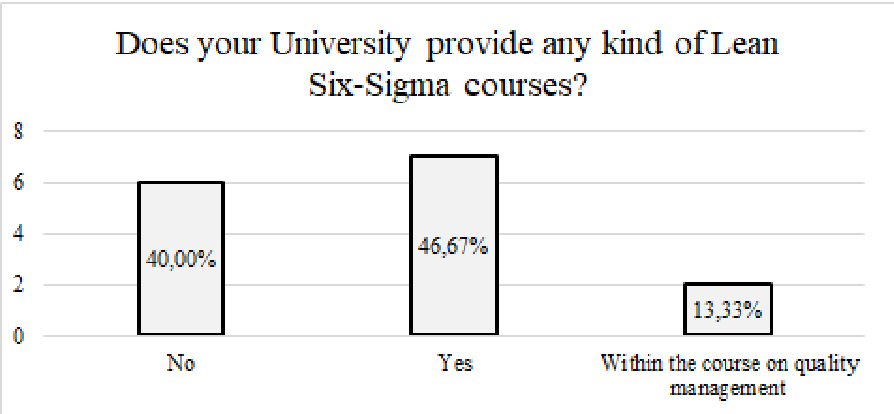


Figure 7b

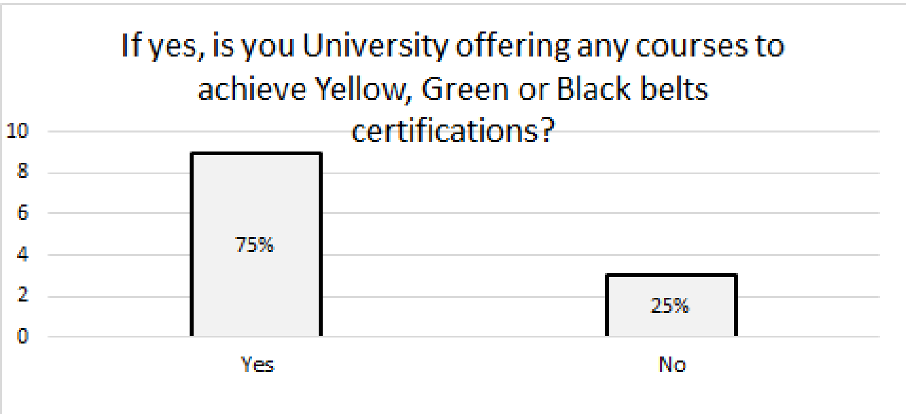


Figure 8

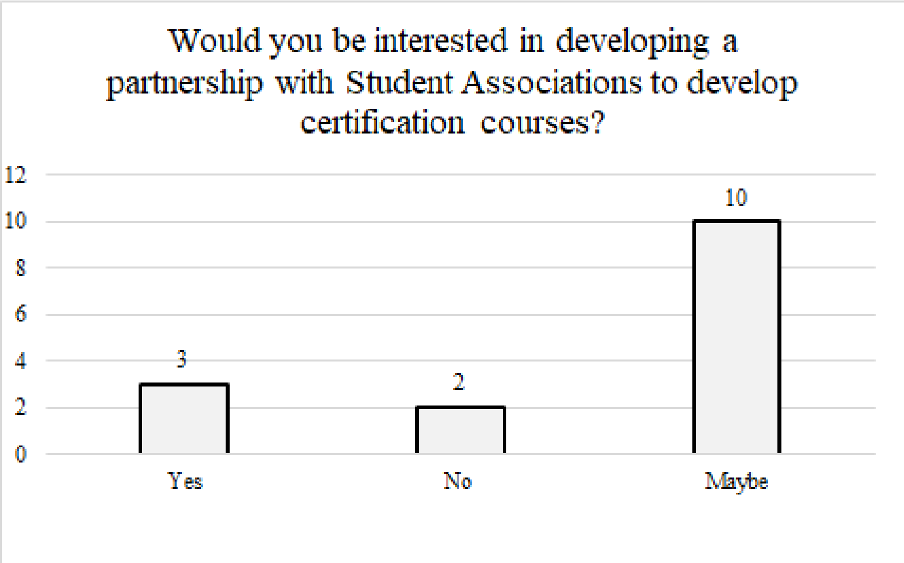
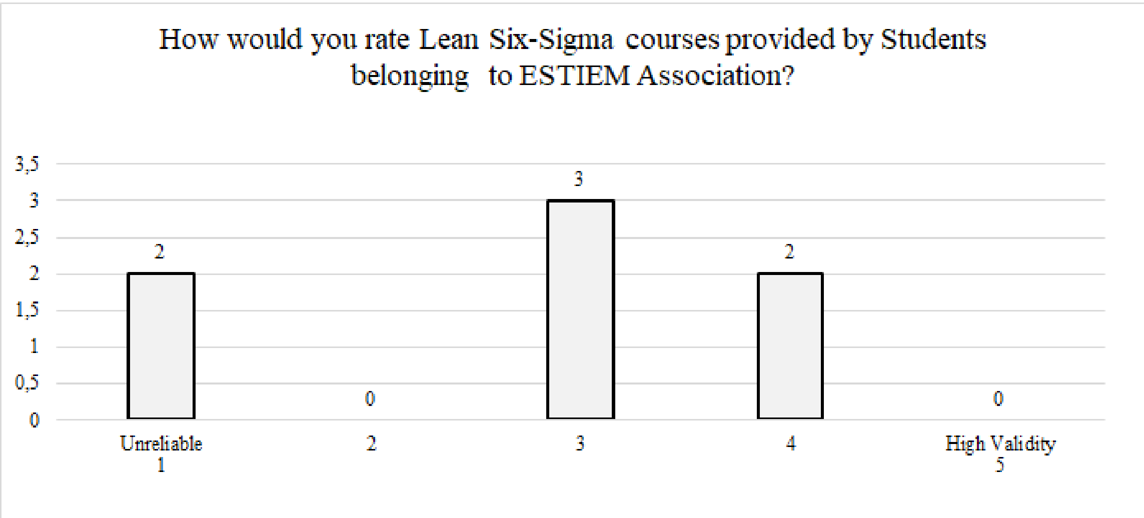


Figure 9



Economic production lot-sizing model in an imperfect production system with maintenance

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ABSTRACT

Purpose – We develop economic production lot-sizing model, determine optimal manufacturing quantity and investigate its properties to minimize an expected cost when a random defective rate for product is considered.

Design/methodology/approach – We investigate an optimal manufacturing quantity for economic production lot-sizing model with a random defective rate and preventive maintenance service for manufacturing machinery. If a manufacturing machinery produces defective items which more than a certain threshold, lot tolerance percent defective, then this indicates that a machine shifts from an *in-control* condition to *out-of-control* condition and maintenance services should be provided to decrease the possibility of producing imperfect-quality products. A mathematical model is developed to find optimal manufacturing quantity, optimal production run time and optimal preventive maintenance schedule.

Findings – The elapsed times until process shifts get shorter as the machine deteriorates. We consider a process which is finished at the earlier time between the optimal production time and lot tolerance percent defective-exceeded time. The economic manufacturing quantity and optimal preventive maintenance schedule are obtained and they help policymakers make appropriate decisions for company.

Originality/value – We believe this approach is novel because the economic manufacturing quantity model is developed with preventive maintenance service and lot tolerance percent defective for manufacturing facility. *Out-of-control* condition and *in-control* condition are also considered for the optimal maintenance schedule for the manufacturing facility.

Keywords: Economic manufacturing quantity, Out-of-control, Preventive maintenance, Process deviation

Paper type: Research paper

INTRODUCTION

In the classical economic manufacturing quantity (EMQ) model, researchers have not considered the possibility of process deterioration and the existence of defective items in the production lot [1]. Suppose all the produced items are of perfect quality in the classical EMQ model, an optimal manufacturing quantity and optimal economic lot size were investigated. However, the use of machine inspection was not considered for maintenance and restoration purposes. Since then different kinds of models have been developed with relaxed assumption that the production process can manufacture items of imperfect quality and a number of research has been carried out to address EMQ model with imperfect-quality products (See, e.g. Zhang and Gerchak [2], Chung [3], Hayek and Salameh [4]).

The defective rate is defined as a proportion of defective items among total manufacturing products. A lot tolerance percent defective (LTPD) is defined by the defective rate threshold which is least satisfactory level by a customer. If the defective rate of produced items exceeds the LTPD, then a production process is in *out-of-control* condition, otherwise it is in *in-control* condition. *In-control* condition is defined by that manufacturing process is stable and produces smaller number of defective products which is less than the LTPD. When the defective rate exceeds the LTPD, then we check the manufacturing process and provide kinds of maintenance services such as repair service and/or replacement service. It is necessary to check the production process continuously and provide maintenance actions when a defective rate exceeds the LTPD. It indicates that if a manufacturing process works in *out-of-control* condition, then we provide a repair and inspection action to make it fix using the control chart. Although the production process may begin in an *in-control* condition, it could shift to an *out-of-control* condition resulting in the production of defective items. Defective items are produced among products and they can be reworked or be scrapped. Further, the manufacturing process is interrupted when a breakdown occurs. Then the minimal repair service as a corrective maintenance is provided for the breakdown. Under this policy, the defective rate for items exceeds the LTPD or it comes to the optimal manufacturing quantity, then a production run is aborted. In this paper, the EMQ model is investigated when an imperfect maintenance service is considered. We study the properties of optimal economic manufacturing quantity to minimize an expected cost when a random defective rate for product is considered. If a manufacturing machine produces some proportion of defective items which is larger than the LTPD, then it is assumed that a machine shifts from an *in-control* condition to *out-of-control* condition and some actions should be given to a manufacturing machine. The PM service is needed to maintain the quality level of produced item by manufacturing machine. Most previous studies used idea of perfect maintenance in their work. Perfect maintenance assumes that a machine is back to ‘as-good-as-new’ condition after maintenance. After Pham and Wang [5] introduced imperfect maintenance, the idea of imperfect maintenance is that machine is in condition of between ‘as good as new’ and ‘as bad as old’ after repair. Deteriorating production processes have been employed to generalize the traditional EMQ models. Rosenblatt and Lee [6] initially studied the effect of process deterioration on the optimal EMQ using Maclaurin series to approximate an exponential function to the second manufacturing. Djamaludin *et al.* [7] utilized lot size to control the warranty cost per time for products under free-repair warranty. Yeh *et al.* [8] described the deteriorating process of a production system considering Markov chain under free minimal repair warranty. EMQ model was studied by Sheu and Chen [9] for the joint determination of both economic production quantity and level of PM for an imperfect production process.

We determine an optimal manufacturing quantity using the concept of imperfect production and imperfect maintenance. If a production process is in *out-of-control* condition, it produces some proportion of defective items. The elapsed time until process shift to *out-of-control* condition decreases stochastically as production cycle repeats. So each production cycle has different expected elapsed time until process shifts. Therefore, it is essential to consider production cycles when determining an optimal manufacturing quantity. A machine is always maintained perfectly before a production cycle starts. If a machine is in *out-of-control* condition, it is not repaired immediately during a production cycle but, it is repaired after a production cycle ends. A setup is required before each production run. During a production run, if a defective rate exceeds the LTPD, then it indicates that the system deteriorates from an *in-control* condition to an *out-of-control* condition. These defective items are assumed to be reworked or scrapped. We consider both the optimal production time which implies the time for the economic manufacturing quantity and the time when the percent of imperfect-quality items exceeds the LTPD and check the process at the earlier time either the optimal manufacturing quantity or LTPD-exceeded time. If a process has some problems by special causes or avoidable causes, then the process should be checked, not continuing to keep going the process by the statistical process control chart. If a process is *out-of-control*, we are supposed to check the manufacturing process and investigate the special cause for the *out-of-control*. In this paper, the EMQ model is considered to determine the optimal economic manufacturing quantity by minimizing the long run expected cost rate (ECR) incurred. The elapsed time between two successive replacements forms a production run of the product from the perspective of the customer and such elapsed times are random variables.

This paper aims to find an optimal manufacturing quantity that will minimize average cost. We develop economic production lot-sizing model, determine optimal manufacturing quantity and optimized maintenance cycle under maintenance policy and investigate its properties to minimize an expected cost when a random defective rate for product is considered. We believe this approach is novel because the economic manufacturing quantity is developed with preventive maintenance service and lot tolerance percent defective for manufacturing facility unlike other studies from existing literature. Further, *out-of-control* condition and *in-control* condition are considered for the optimal maintenance schedule.

This paper is organized as follows. Next, we conduct literature review about the related topics and develop a mathematical model to determine an optimal manufacturing quantity and optimal production time. Then, numerical example shows properties of an optimal manufacturing quantity when parameters are changed. Lastly, concluding remarks are given.

LITERATURE REVIEW

Rosenblatt and Lee [10] developed the EMQ model which is applicable to an imperfect production process. In the imperfect production process, a machine turns to '*out-of-control*' condition at random time interval, so that a machine manufactures defective items. Tseng [11] incorporated a preventive maintenance (PM) policy into an imperfect EMQ model to improve the reliability of the deteriorating production process. However, a two-dimensional search procedure was needed to obtain the optimal production run-length and maintenance schedules. Based on the Tseng's [11] study, Wang and Sheu [12] provided useful properties for obtaining an optimal production policy. Lee and Park [13] reformulated the work of Lee and Rosenblatt [1] to consider the possibility that a defective item after its sale incurs a warranty cost greater than the reworking cost of a defective item before its sale. Without considering any inspection and maintenance actions during a production run, Djamaludin *et al.* [7] utilized lot size to control the warranty cost per item for products under a free-repair warranty, where the production system can go into an *out-of-control* condition with a given probability each time an item is produced. Moreover, Yeh and Lo [14] studied the effect of free repair warranty policy on the optimal production lot size and the optimal burn in time. Recently, Yeh *et al.* [8] reformulated Djamaludin *et al.*'s [7] model to consider that the production process is subject to a random deterioration from an *in-control* condition to an *out-of-control* condition in which the shift time is exponentially distributed. Lin *et al.* [15] developed integrated EMQ models with the joint effects of maintenance policy by inspection and the production-inventory system including raw materials on the cost of operating a single facility. Ben-

Daya and Hariga [16] studied the effect on imperfect production processes on the economic lot sizing problem. Sana [17] investigates an economic production lot sizing model in an imperfect production system in which the production facility may shift from an *in-control* state to an *out-of-control* state at any random time. Chen *et al.* [18] extends the literature to consider that the selling price of the product sold with warranty policy is a function of the length of the warranty period for an imperfect production system.

Park *et al.* [19] investigate the integrated process between process control and statistical techniques, explaining process controllers, process efficiency, and economic cost designs because the integration of process control and economic cost design successfully reduced process output variability and improved process efficiency. In Park *et al.* [20, 21]'s study, they developed two-dimensional approach extending the age replacement policy with repair service and replacement service. Statistical process control is very useful to monitor the manufacturing process via control chart and automatic process control is practical to give actions for the problematic processes. The strength of the control chart is to find the starting point and ending point for the manufacturing process. It is meaningful to consider the optimal production time and LTPD-exceeded time for the optimal economic manufacturing quantity. The manufacturing process may concurrently deteriorate due to aging and be disrupted due to the machine breakdowns. If the manufacturing process produces defective products by special causes, then the process should be investigated, not keeping going the manufacturing process. However, in the previous literature for the EMQ models, it is assumed that the manufacturing process keeps going even though the process is *out-of-control*. When the process is *out-of-control*, the process should be checked to investigate causes for *out-of-control* condition and to provide some actions make process *in-control* condition. We consider the defective items in the production process and machine breakdown for the equipment. The effect of deteriorating and equipment failure are investigated on the decisions of the optimal production time and lot size. The EMQ model is checked under the policy that the process may deteriorate from an *in-control* condition to an *out-of-control* condition. We consider *in-control* condition and an *out-of-control* condition for the EMQ model in this paper and develop the LTPD for the maintenance policy to increase the quality of produced items.

RESEARCH METODOLOGHY

In this paper, the EMQ model is considered to determine the optimal economic manufacturing quantity by minimizing the long run ECR incurred during the production run of the product. The cost model with the repair service and replacement service has been discussed in Park *et al.* [20].

We investigate the EMQ and optimal production time as decision variables in this study. The elapsed time between two successive replacements forms a production run of the product from the perspective of the customer and such elapsed times are assumed to be *random variables*.

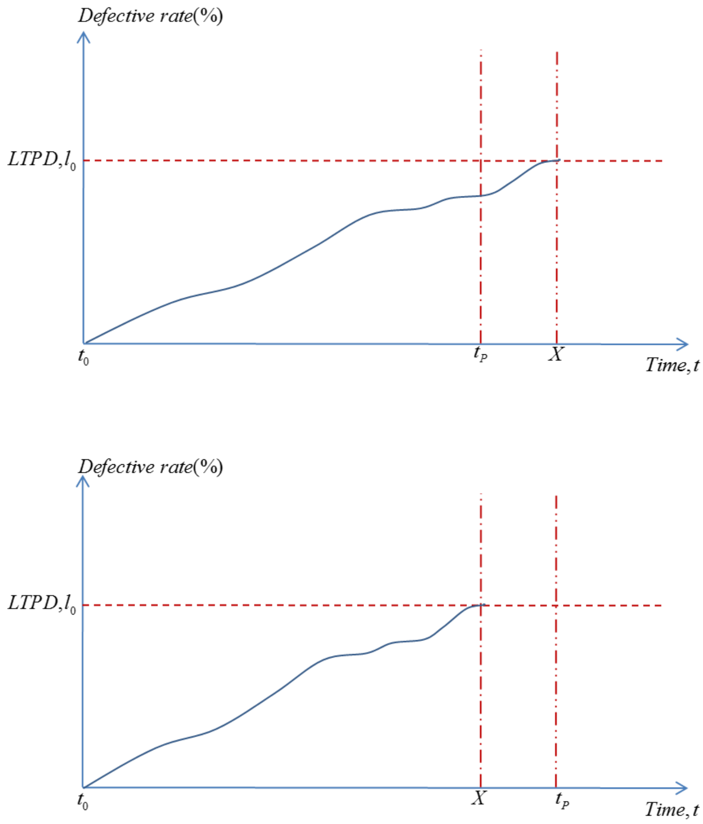

Figure 1 – Defective rate with optimal manufacturing quantity and LTPD: manufacturing process should be checked at earlier time between the shifted time X from *in-control* condition to *out-of-control* condition and optimal manufacturing quantity time t_p

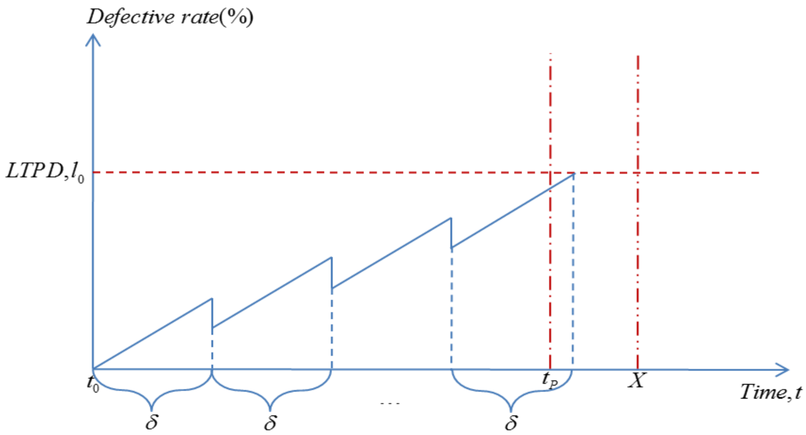

Figure 2 – Preventive maintenance with the LTPD in the EMQ model

Whenever a failure for manufacturing machine occurs, the defective rate of the produced items may accumulate and it could become higher than LTPD in Fig. 1. The minimal repair is provided whenever a product fails and is delivered to the customer center. In Fig. 1, when a defective rate exceeds the LTPD, then the process should be checked and some actions are supposed to provide. We develop the EMQ model with PM service considering *in-control* condition and *out-of-control* condition. Whenever PM service is conducted, then the defective rate of the produced items decreases as described in Fig. 2. We develop the EMQ model considering the LTPD with *out-of-control* process. Let T and Y denote random variables representing failure time and repair time of the product, respectively. Let t_p denotes the time to produce a lot Q and let X be the elapsed time until a process shifts from *in-control* condition to *out-of-control* condition. Then, the production run, denoted by $L\left(t_p\right)$ is given by

$$L\left(t_p\right)=\begin{cases} X & X \le t_p \ \& Y > l_0 \\ t_p & X > t_p \ \& Y \le l_0 \end{cases} \tag{1}$$

With consideration of the LTPD, l_0, let $e\left(t_p\right)$ be the expected length of time elapsed before reaching the time to produce a lot Q. We denote $\mu\left(0,t\right)=\int_0^t h\left(u\right)du$ as the expected number of product failures during the interval $\left(0,t\right)$. Let $f\left(\cdot\right)$ and $F\left(\cdot\right)$ be the *pdf* and *cdf*, respectively, of failure time T and $g\left(\cdot\right)$ and $G\left(\cdot\right)$ be the *pdf* and *cdf*, respectively, of warranty service time Y. Then, $P\left\{L\left(t_p\right)\ge t\right\}$ is given by [21]

$$\begin{aligned} &P\left\{L\left(t_p\right)\ge t\right\} \\ &=\frac{\mu\left(0,t\right)^0 e^{-\mu\left(0,t\right)}}{0!}+\frac{\mu\left(0,t\right)^1 e^{-\mu\left(0,t\right)}\left\{G_{l_0}\left(y\right)\right\}}{1!}+\frac{\mu\left(0,t\right)^2 e^{-\mu\left(0,t\right)}\left\{G_{l_0}\left(y\right)\right\}^2}{2!}+\frac{\mu\left(0,t\right)^3 e^{-\mu\left(0,t\right)}\left\{G_{l_0}\left(y\right)\right\}^3}{3!}+\cdots \\ &=e^{-\mu\left(0,t\right)}\sum_{k=0}^{\infty}\frac{\left[\mu\left(0,t\right)\cdot G_{l_0}\left(y\right)\right]^k}{k!} \\ &=\left\{\bar{F}\left(t\right)\right\}^{\bar{G}_{l_0}\left(y\right)} \end{aligned} \tag{2}$$

Next, the expected length of production run $E\left[L\left(t_p\right)\right]$ can be given by

$$\begin{aligned} E\left[L\left(t_p\right)\right] &= \int_0^{t_p} t\cdot q\left(t\right)dt+\int_{t_p}^{\infty} t_p\cdot q\left(t\right)dt \\ &=\int_0^{t_p}\left[\bar{F}\left(t\right)\right]^{\bar{G}_{l_0}\left(y\right)}dt+t_p\cdot\bar{Q}\left(t_p\right) \end{aligned} \tag{3}$$

Let *P, Q, D* be production rate, production lot size and annual demand, respectively. Because the EMQ time t_p is equal to Q/P, the expected length of production run can be developed by

$$E\left[L\left(Q/P\right)\right]=\int_0^{Q/P}\left[\bar{F}(t)\right]^{\bar{G}_{l_0}(y)}dt+\bar{Q}\left(Q/P\right)\cdot Q/P \tag{4}$$

Let $N_{l_0}(a,b)$ denotes the number of minimal repairs with the LTPD l_0 in the interval (a,b) when a defective rate for a product and failure time for manufacturing machine are considered. Then, the minimal repair cost, denoted by $C(t_p)$ can be expressed as

$$C\left(t_p\right)=\begin{cases}c_M\cdot N_{l_0}\left(0,x\right) & X\le t_p\ \&Y>l_0\\ c_M\cdot N_{l_0}\left(0,t_p\right) & X>t_p\ \&Y\le l_0\end{cases} \tag{5}$$

Since all the failures for manufacturing machine are only minimally repaired until the optimal production quantity is produced or a defective rate exceeds the LTPD l_0. The expected number of minimal repair service for a machine during (a,b) with the LTPD l_0 is given by

$$E\left[N_{l_0}\left(a,b\right)\right]=\sum_{k=1}^{\infty}k\cdot\frac{\mu\left(a,b\right)^k e^{-\mu(a,b)}\left\{G_{l_0}\left(y\right)\right\}^k}{k!}$$

Using the fact that $\bar{F}\left(t_p\right)=e^{-\int_0^{t_p}v(u)du}$, it can be given by

$$\begin{aligned}E\left[N_{l_0}\left(0,t_p\right)\right]&=G_{l_0}\left(y\right)\cdot\left\{e^{-\int_0^{t_p}v(u)du}\right\}^{\bar{G}_{l_0}(y)}\cdot\int_0^{t_p}h\left(u\right)du\\&=G_{l_0}\left(y\right)\cdot\left\{\bar{F}\left(t_p\right)\right\}^{\bar{G}_{l_0}(y)}\cdot\int_0^{t_p}h\left(u\right)du\end{aligned} \tag{6}$$

Similarly, given $L\left(t_p\right)=\tau$, the expectation of $N_{l_0}\left(0,\tau\right)$ can be obtained as

$$E\left[N_{l_0}\left(0,L\left(t_p\right)\right)\middle|L\left(t_p\right)=\tau\right]=\left[\int_0^{\tau}v\left(u\right)du\right]\cdot G_{l_0}\left(y\right)\cdot\left\{\bar{F}\left(\tau\right)\right\}^{\bar{G}_{l_0}(y)} \tag{7}$$

Then, it can be shown that

$$e\left(t_p\right)=E\left[L\left(t_p\right)\middle|Y\le l_0\right]=\frac{\int_0^{t_p}\left\{\bar{F}\left(t\right)\right\}^{\bar{G}_{l_0}\left(t_p\right)}dt}{1-\left\{\bar{F}\left(t_p\right)\right\}^{\bar{G}_{l_0}\left(t_p\right)}} \tag{8}$$

We investigate an optimal manufacturing quantity to minimize total expected cost during a machine cycle. The machine cycle is defined as a length when a machine runs to produce items. When a machine deteriorates and a defective rate exceeds LTPD, the machine discontinue to manufacture an item. To investigate an optimal manufacturing quantity, we calculate the number of defective items at production cycle. The total cost is investigated during manufacturing process considering the cost incurred by defective items. The total expected cost is computed and an optimal manufacturing quantity is derived to minimize the expected cost rate. The setup cost c_s and inventory holding cost c_h are given by

$$c_s + c_h \frac{(P-D)Q}{2P} \tag{9}$$

The rework cost c_r and scrapped cost c_c are given by

$$c_r\left[Y(1-\theta)\cdot Q\right] + c_c\left[\theta \cdot Y \cdot Q\right] \tag{10}$$

where θ is the scrapped rate for defective products. Let c_{pm} and c_m be preventive maintenance cost and minimal repair cost, respectively. Let k be the number of PM service during the production run. If we consider just one product cycle and Q/P is used instead of optimal product time t_p, then the total expected cost can be given by

$$\begin{aligned} &TC(Q/P) \\ &= c_s + c_h \frac{(P-D)Q}{2P} + c_r\left[Y(1-\theta)\cdot Q\right] + c_c\left[\theta \cdot Y \cdot Q\right] + c_m \cdot N_{l_0}\left(0, Q/P\right) + c_{pm}\cdot k \end{aligned} \tag{11}$$

If the elapsed time to *out-of-control* X is less than the optimal production time, then the total expected cost can be given by

$$TC(X) = c_s + c_h \frac{(P-D)X}{2} + c_r\left[Y(1-\theta)\cdot P \cdot X\right] + c_c\left[\theta \cdot Y \cdot P \cdot X\right] + c_m \cdot N_{l_0}\left(0, X\right) + c_{pm}\cdot k \tag{12}$$

To determine the periodic PM service, we utilize Canfield’s [22] PM model, under which each PM reduces the failure rate to that existing during time units prior to the current PM time. Such time units are referred to as the level of restoration that is less than or equal to the PM interval. The failure rate function of the product with the PM action under Canfield’s [22] model can be expressed as

$$h_{PM}(t) = \begin{cases} h(t) & \text{for } 0 \le t \le \delta \\ \sum_{i=1}^{k}\left\{h\left((i-1)(\delta-\alpha)+\delta\right) - h\left(i(\delta-\alpha)\right)\right\} + h(t-k\alpha), & \text{for } k\delta < t \le (k+1)\delta \end{cases} \tag{13}$$

where $h(t)$ denotes the initial failure rate of the product before the first PM is conducted and δ is the PM interval which is equal to the length of time elapsed between two successive periodic preventive maintenances. Here, α denote the level of restoration with $0 \le \alpha \le \delta,$ which measures the PM effect and the number of PM service, respectively. Then, *pdf* and *cdf* of *T* can be expressed as functions of $h_{PM}\left(t\right)$ from Eq. (13) as follows,

$$\begin{aligned} f_{PM}\left(t\right) &= h_{PM}\left(t\right)\cdot \exp\left\{-\int_0^t h_{PM}\left(t\right)dt\right\}, \\ F_{PM}\left(t\right) &= 1-\exp\left\{-\int_0^t h_{PM}\left(t\right)dt\right\}, i=1,2,\cdots,N_R \end{aligned} \tag{14}$$

where $h_{PM}\left(t\right)$ is the failure rate under Canfield's [22] PM model, which is given in Eq. (13).

When EMQ time t_P comes earlier than the time when shift occurs from *in-control* condition to *out-of-control* condition, then the total expected cost at time *t* is given by

$$\begin{aligned} &EC(Q/P) = c_s + c_h\frac{(P-D)Q}{2P} + c_r\left[E\left(Y\right)\left(1-\theta\right)\cdot Q\right] + c_c\left[\theta\cdot E\left(Y\right)\cdot Q\right] \\ &+c_m\cdot\int_0^{Q/P} h_{PM}\left(u\right)du\cdot G_{l_0}\left(y\right)\cdot\left\{\bar{F}_{PM}\left(Q/P\right)\right\}^{\bar{G}_{l_0}(y)} + c_{PM}\cdot k \end{aligned} \tag{15}$$

When EMQ time t_P comes later than the time when shift occurs from *in-control* condition to *out-of-control* condition, then the total expected cost is given by

$$\begin{aligned} &EC(X) \\ &= c_s + c_h\frac{(P-D)E\left(X\right)}{2} + c_r\left[E\left(Y\right)\left(1-\theta\right)\cdot P\cdot E\left(X\right)\right] + c_c\left[\theta\cdot E\left(Y\right)\cdot P\cdot E\left(X\right)\right] \\ &+c_m\cdot\int_0^{X} h_{PM}\left(u\right)du\cdot G_Y\left(l_0\right)\cdot\left\{\bar{F}_{PM}\left(X\right)\right\}^{\bar{G}_Y(l_0)} + +c_{PM}\cdot k \end{aligned} \tag{16}$$

If we let $N_{l_0}\left(a,b\right)$ denote the number of minimal repairs in *out-of-control* with the LTPD l_0 in the interval $\left(a,b\right)$. Then, ECR is given by

$$\begin{aligned} &ECR(Q/P) \\ &= \frac{\left\{\begin{aligned} &c_s + c_h\frac{(P-D)Q}{2P} + c_r\left[E\left(Y\right)\left(1-\theta\right)\cdot Q\right] + c_c\left[\theta\cdot E\left(Y\right)\cdot Q\right] \\ &+c_m\cdot\int_0^{Q/P} h_{PM}\left(u\right)du\cdot G_Y\left(l_0\right)\cdot\left\{\bar{F}_{PM}\left(Q/P\right)\right\}^{\bar{G}_Y(l_0)} + c_{pm}\cdot k \end{aligned}\right\}}{\int_0^{Q/P}\left[\bar{F}_{PM}\left(t\right)\right]^{\bar{G}_Y(l_0)}dt + \bar{Q}_{PM}\left(Q/P\right)\cdot Q/P} \end{aligned} \tag{17}$$

Next, we implement the proposed approach using a field data for numerical example. The data came from Rosenblatt and Lee [10] and Silver and Peterson [23]. The manufacturing product is 3-ohm resistor. The demand rate *D* is 200 units per month and a production rate *P* is 300 units per month. For a production cycle, \$20 is needed as a set-up cost c_s and a holding cost c_h per unit is \$5.

The defective rate for produced items would decrease after a maintenance service for manufacturing machine. Y_i denotes defective rate for a produced item after i^{th} PM service. If a machine turns to *out-of-control* condition, 5% of the products are defective items and a scrapped cost of \$10 and rework cost of \$3. We investigate the change of an optimal manufacturing quantity when each parameters are changed. We use a Weibull distribution for the repair time and power-law process for the rate of occurrence of failure. As for the failure time, we may use the power-law model in conjunction with the intensity function which is given by

$$f(x;\lambda,\kappa) = \frac{\kappa}{\lambda}\left(\frac{x}{\lambda}\right)^{\kappa-1} e^{-(x/\lambda)^{\kappa}} \tag{18}$$

For the purpose of numerical calculations for this example, we consider various values of cost parameters and the length of warranty period to find the optimal maintenance policies and to investigate the pattern changes of the length of maintenance period and its resulting expected cost rate per unit time during the production run of the system. Throughout this example, we use a year as the unit of time. The repair time is assumed to follow two-parameter Weibull distribution which is given by

$$g(y) = \frac{\nu}{\lambda}\left(\frac{y}{\lambda}\right)^{\nu-1} e^{-\left(\frac{y}{\lambda}\right)^{\nu}},\ y \ge 0,\ \nu,\lambda > 0 \tag{19}$$

Table 1 shows the optimal values of economic manufacturing quantity denoted by $Q*$ and its resulting values of $ECR\left(Q^*\right)$ for different combinations of c_h, c_r, c_s, c_c and c_m. Here we assume that $l_0 = 1/12$. When κ is given by 1 in Table 1, $\lambda = 2$ is given for failure time and $\beta = 1,\ \eta = 2$ are given for repair time. For instance, in Table 1, when the holding cost c_h is equal to 5 and $c_r = 3,\ c_s = 20,\ Q*$ is equal to 436. Its expected cost rate is equal to 5570.71. As holding cost, set up cost, and rework cost increase, then the ECR increases. However, as holding cost and scrapped cost do not affect the EMQ severely. As scrapped cost increases, the EMQ increases.

Table 1 – Optimal economic manufacturing quantity and ECR for different values of cost parameters c_h, c_r and c_s with $l_0 = 1/12$, $c_m = 2$, $c_c = 10$, $c_{pm} = 1$ and $\kappa = 1$, $\lambda = 2$, $\beta = 1$, $\eta = 2$, $k = 1$

c_h	c_r	c_s	Q^*	ECR	c_h	c_r	c_s	Q^*	ECR
5	3	20	436	5570.71	5	3	20	436	5570.71
		30	437	5583.90			30	437	5583.90
		40	438	5597.06			40	438	5597.06
		50	439	5610.19			50	439	5610.19
		60	440	5623.29			60	440	5623.29
		70	441	5636.36			70	441	5636.36
10	3	20	435	6050.31	5	5	20	435	7412.37
		30	436	6063.51			30	436	7425.58
		40	437	6076.68			40	437	7438.77
		50	438	6089.82			50	438	7451.94
		60	439	6102.93			60	438	7465.08
		70	440	6116.02			70	439	7478.20
15	3	20	435	6529.91	5	7	20	435	9254.02
		30	436	6543.11			30	436	9267.25
		40	437	6556.29			40	436	9280.45
		50	438	6569.44			50	437	9293.64
		60	439	6582.57			60	438	9306.81
		70	440	6595.66			70	438	9319.95
20	3	20	435	7009.51	5	9	20	434	11095.7
		30	436	7022.72			30	434	11108.9
		40	437	7035.90			40	435	11122.1
		50	438	7049.06			50	436	11135.3
		60	438	7062.20			60	436	11148.5
		70	439	7075.31			70	436	11161.7

RESULTS

In this paper, we define that if the percentage of imperfect-quality items exceeds the LTPD then the manufacturing machine is in out-of-control condition, otherwise it is in *in-control* condition to determine the optimal manufacturing quantity and optimal lot size that minimizes the total expected cost rate. According to Rosenblatt and Lee [10], it assumes an imperfect production which means a machine turns to *out-of-control* condition at random time intervals and makes some proportion of defective items. Times between failures are assumed to be arbitrarily distributed. We develop the EMQ model by adding the assumption of imperfect maintenance. Under the assumption of imperfect maintenance, the elapsed times until process shifts get shorter as a machine deteriorates. We include the whole production run of a machine in calculating average cost function to incorporate the effect of machine deteriorating. We consider both the optimal production time which implies the time for the economic manufacturing quantity and the LTPD-exceeded time at the moment that the defective rate exceeds the LTPD. We check the process at the earlier time between the optimal production time and LTPD-exceeded time.

We investigate an optimal manufacturing quantity for economic production lot-sizing model with a random defective rate and preventive maintenance service for manufacturing machinery. If a manufacturing machinery produces defective items which more than a certain threshold, LTPD, then this indicates that a machine shifts from an *in-control* condition to *out-of-control* condition and maintenance services should be provided to decrease the possibility of producing imperfect-quality products. A mathematical model is developed to find optimal manufacturing quantity, optimal production run time and optimal preventive maintenance schedule. The elapsed times until process shifts get shorter as the machine deteriorates. We consider a process which is finished at the earlier time between the optimal production time and lot tolerance percent defective-exceeded time. The economic manufacturing quantity and optimal preventive maintenance schedule are obtained and they help policymakers make appropriate decisions for company.

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Multi-objective Mathematical Model for a Sustainable Supply Chain Considering Customer Satisfaction and SR Concepts: NSGAII approach

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ABSTRACT

Purpose – Up to now, researchers have focused on the evaluations of Social Responsibility (SR) in different ways. To best of our knowledge, this is the first study to focus on the Customer Satisfaction and SR concepts simultaneously among the competitive priorities and Sustainable Supply Chain (SSCM).

Design/methodology/approach – This study proposes a mathematical model with four objective functions. Since the nature of the problem is NP-hard, the NSGAII algorithm has been used to solve the problem. Numerical example is applied to test the performance of the mathematical model.

Findings – The comprehensive proposed model helps decision-makers to make efficient decisions and trade-off between costs and customer satisfaction. By applying the non-dominated sorting and also consideration the crowding distance, the final result is obtained. The results are broadly consistent with the theoretical concepts of customer satisfaction, social responsibility and cost of poor quality in sustainable supply chain management. The model included 4 objective functions: Maximizing customer satisfaction, minimizing total cost, minimizing environmental impact, maximizing job opportunities. The results show there is a logic relation between 4 objective functions theoretically. When customer satisfaction is very low (Z_1= 0.61), the total cost is too high (Z_2=3.54×10^{10}). The optimum solution is Z_1= 0.91, Z_2= 2.06×10^{10}, Z_3= 2304384 and Z_4= 207. It means when customer satisfaction is high (0.91), the total cost is in the lowest amount (2.06×10^{10}), the environmental impact is moderated (2304384) and job opportunities are increased to maximum value (207).

Originality/value – One of the most significant gaps of former researches that they have focused on only the cost of quality, production costs and cost of environmental effects. In this study, we combined the different type's costs from literature. Additionally, this is the first study to maximize customer satisfaction and job opportunities simultaneously. Also, the model minimizes total costs including Quality and SR costs, production costs, purchasing cost and transportation costs and minimizes the environmental effects of transportation and production.

Keywords: Sustainable Supply Chain; Customer Satisfaction; Social Responsibility; Quality concepts; Environmental Effect; NSGAII algorithm.

Paper type: Research paper

INTRODUCTION

Supply chain sustainability has reached considerable interest for the last decade both in academia and for practitioner. The integration of environment and social aspects with economic considerations, triple-bottom-line dimensions of organization sustainability (Elkington, 1999, 2006), has obtained relevance for managerial decision making in supply chain management (SCM) (Dekker, et al., 2012). Opposite to the traditional supply chain management, typically concentrated on economic and financial business performance, Sustainable SCM is recognized by explicit integration of environment and/or social objectives to develop the economic dimension (Seuring and Müller, 2008). SSCM has been introduced just like the management of material, information and capital flows as well as the cooperation among companies along the supply chain while integrated goals from the economic, environmental and social areas and derived from customer and stakeholder requirements (Mentzer et al., 2001). Corporate Social Responsibility (CSR) which includes such elements as environmental protection, social equity ethics, respect for people and economic growth, has a strong affinity with the founding principles of quality management.

Some key examples of this affinity include the philosophies of Philip Crosby, W. Edwards Deming, Joseph M. Juran and Kaoru Ishikawa. Crosby talked of integrity, saying “The chief executive officer is dedicated to having the customer receive what was promised, believes that the company will prosper only when all employees feel the same way and is determined that neither customers nor employees will be hassled.” (Crosby, 1986). Deming’s 14 points highlighted the “driving out of fear” to release the ability to ask questions and express ideas, break down barriers between staff, encourage pride in workmanship and establish self-improvement for everyone. Deming supported an organizational climate where dealings between managers, employees and customers were conducted on an ethical basis. (Deming, 1986). Based on Deming's teachings, the organizational structure—and, importantly, the reward and recognition system—must promote organizational values and not create contradictions. This results in a culture of trust and openness both inside and outside the organization, ultimately improving corporate reputation. Juran spoke of a system of values, beliefs and behaviors that are necessary for organizational success. He espoused the view that quality is recognized for its focus on people through work life and employee satisfaction. (Juran, 1993). Ishikawa made a particularly strong statement on behalf of CSR when he said, “The first concern of a company is the happiness of the people connected to it. If the people do not feel happy, that company does not deserve to exist.” (Ishikawa, 1985). “ASQ believes that being socially responsible means that people and organizations behave ethically and with sensitivity toward social, cultural, economic and environmental issues. Trying for social responsibility helps individuals, organizations and governments have a positive impact on development, business and society.” (ASQ White Paper, 2007). Ethics and values are essentials on which businesses are founded and through which success can be achieved and communities developed. CSR has always been a significant influence in the business world and is growing in importance as it is increasingly supported by business models and standards. ISO 26000 provides a broad, no prescriptive framework in which to work, for example, a set of guidelines that can be incorporated into the Malcolm Baldrige and European Quality Award criteria and supported and integrated with ISO 9001, ISO 14001, OHSAS18001 and SOX. Quality management has been established in business management theory and practice and is recognized as having a strong ethical focus while significantly contributing to the achievement of organizational goals. So, CSR can be advanced more quickly if it can be incorporated into established quality management models and methodologies. This places the quality profession at the forefront of CSR. With CSR being embraced by many as the means of assuring values based corporate governance, the quality community now has the opportunity and responsibility to take leadership in promoting ethical business practices and driving CSR to get back to consumer confidence. Four key elements make up the quality management environment with CSR at the core: (Leonard and Mc-Adam, 2003). The binary approach of tracking quality costs by failure (internal, external) or conformance (preventive, appraisal) is inadequate for CoSR. Even if the product or service works as designed and intended, its interaction with society at large cannot be quantified solely by the CoQ model. Although failures can be limited by the scope of the declared uses of the product or service, SR violations are dependent upon the use of that product or service by and impact on stakeholders. To govern expectations effectively and respond to deficiencies, investments are required in the supplemental areas of extended monitoring and reporting; governance; oversight; mitigation and contingencies; treatment, recovery, and remediation; advocacy; and adoption (Zrymiak, 2016). Tools and techniques, which include problem solving tools and management systems such as ISO9000 and ISO 14000.• Quality models, such as the Malcolm Baldrige Criteria for Performance Excellence, which coordinate and drive quality tools.• Corporate strategy, which establishes the direction and means through which the organization will achieve its goal and with which the quality tools and models are aligned.• Philosophies, which are the most important element and are the heart of quality management. Built upon the teachings of Deming, Juran and others, these philosophies make quality management unique among business theories and practices. They influence and guide the formation of organizational values and ultimately the corporate vision and mission. They form the ethical, or CSR, foundation of quality, as shown in Figure 1.

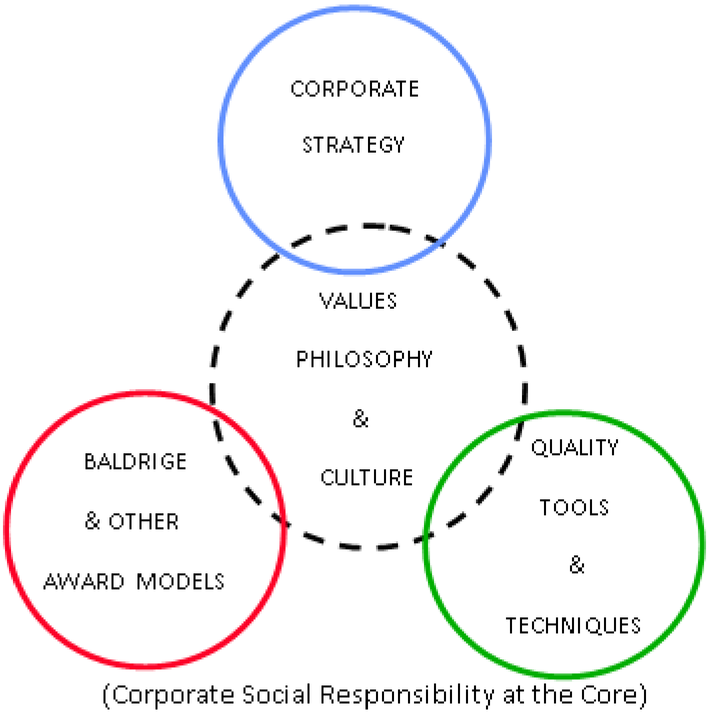

Figure 1 – The Quality Management Environment

Leaders provide the vision, determine the mission and create the cultural values on which the strategy is established. It is critical the vision supports not simply what is good for the company but also what is good for its employees, local communities and society as a whole. Leaders with this sort of vision are needed to drive CSR. In the wake of the Enron, WorldCom, Tyco and Global Crossing scandals five years ago that shook consumer confidence in business leaders and the economy, there was a resurgence of interest in CSR on the corporate landscape with increased public awareness on the topic. The scandals back then resulted in calls for a tighter focus on ethics and governance across the spectrum of business and politics. The need for CSR has certainly not faded. In fact, the need for more attention to CSR has since been underscored with scandals about lead-tainted toys and toxic pet food and more recently scandals regarding airbags and car emissions.

There is a danger of fading momentum for CSR as the attention of the public, governmental, professional and other groups could be refocused on more pressing issues. It was critical that the lessons learned not be forgotten, discussions continue and action be taken quickly. This study proposes a new mathematical model with four objective functions. The paper is structured as follows. Section 2 describes the literature review. The problem definition and the proposed mathematical model are presented in section 3. The description of solution method is provided in section 4. Finally, the paper ends with Section 5 concludes remarks and suggestions for future research.

LITERATURE REVIEW

.Zavvar Sabegh et al. (2016) analyzed the influence of both external and internal parties on green supply chain management (GSCM) practices in Turkish business firms. One of the important inferred results is that the third party logistics service providers influence organizations to have a proactive green behavior. Buyukozkan and Cifci (2013) addressed the components of Sustainable Supply Chain management (SSCM) and how they serve as a base for an assessment framework. By using Quality Function Deployment (QFD) as a product or system planning and improvement tool, an effective SSCM structure can be obtained. Zhang etal (2016) proposed sustainable objectives, i.e., reducing economic cost, enlarging customer coverage and weakening environmental influences, for designing the multiple distribution channels supply chain network (MDCSCN). The MDCSCN model is creative and pioneering as it satisfies the latest requirements and outperforms the conventional Supply Chain Network (SCN). A bi-level programming model introduced in which the supply chain director determines optimal performance levels of Corporate Social Responsibility (CSR) and compensation for all SC actors, thus maximizing total SC profits. (Che-Fu ,2015). Raut et al. (2017) presented an approach to identify the critical success factors (CSFs) of motivation and encouragement, for the appropriate implementation of SSCM practices in Indian oil and gas industries. Govindan et al. (2016) presented a novel hybrid optimization approach that is applied to strategically design a sustainable forward supply chain network (SCN) with stochastic demand in order to minimize the total costs and environmental effects, simultaneously. Zhang et al. (2016) proposed a hierarchical structure of sustainable supply chain management and develops a multi-item evaluation scale to reflect the specific management practices of sustainable supply chain management. Genovese et al. (2017) verified of a potential improvement of sustainable supply chain management practices by aligning them to circular economy concepts. By applying a case-based approach (adopting examples from the chemical and food industries) the study has investigated the environmental involvements related to the implementation of circular production systems, providing a comparison with traditional linear production alternatives. Jauhar et al. (2017) presented a case study for Indian Institute of Technology Roorkee (IIT Roorkee), a higher educational institute (HEI) of India, for which the performance is measured in terms of teaching and research while considering the environmental aspects (sustainability criteria). Wan et al. (2016) addressed the internal factors of SSCM practices in the oil and gas (O&G) industry. It explores the influence of commitment to sustainability and management preparedness on sustainability strategy of four supply chain functional areas: supplier and production management, product stewardship and logistics management. Gosling et al. (2016) proposed a conceptual framework on how focal organizations assuming a leadership role initiate and disseminate sustainable practices in their supply chains. Costantini et al. (2016) focused on the studying the environmental impact of the spread of environmental technologies, the role of inter-sectoral linkages in production systems also has to be properly accounted for. On the one hand, inter-sectoral linkages donate to the process of technology diffusion and foster knowledge spillovers and positive externalities. Motevali Haghighi et al. (2016) proposed new network DEA model to rank all recycling companies in order to determine the most efficient units (i.e. benchmarked units) at each echelon of related supply chain networks. The proposed DEA model is able to deal with qualitative and quantitative indicators simultaneously while it can also accounts for desirable and undesirable outputs.

Xu et al. (2016) analyzed the decision behaviour and coordination mechanisms for a two-echelon sustainable supply chain under a cap-and-trade regulation. In a make-to-order setting, carbon emissions are generated primarily by the downstream manufacturing process, and the market demand of the supply chain is affected by two decision variables, the sustainability level and the selling price. Balaman and Selim (2016) proposed model to minimize the costs for local bio-energy supply chains integrated with DHS and thermal energy storages, and maximize the service level that is defined as the level of meeting heat demand of a specified area. Limited and seasonally variable resources and fluctuations in the system parameters are considered in the model in a multi period structure. The proposed model applied FGP to handle inherent uncertainties. Gu et al. (2016) proposed a dynamic sustainable supply model was used to measure whether a sustainable resource supply of the electronics industry can be achieved using secondary-resources recycled from Waste electrical and electronic equipment (WEEE). Dubey et al. (2016) argued for using the Total Interpretive Structural Modeling (TISM) in sustainable supply chain management (SSCM). Lin and Tseng (2016) addressed a hierarchical structure and linguistic preferences to identify the competitive priorities under SSCM in electronic focal manufacturing firms in Taiwan. Cruz (2013) developed a framework for the modeling and analysis of a complex global supply chain network with corporate social responsibility (CSR) through integrated environmental decision-making and risk management. Tseng et al. (2018) proposed valuable support for sustainable service supply chain management (SSSCM) regarding the nature of network hierarchical relations with qualitative and quantitative scales. Also, they indicated the practical implementation and enhance management effectiveness for SSSCM. Luthra et al. (2016) proposed a structural model for evaluating the barriers associated with the adoption of sustainable consumption and production (SCP) initiatives in a supply chain. Initially, four categories of barriers and fifteen specific barriers related to the adoption of SCP initiatives were identified from the literature and from experts' inputs. Govindan et al. (2014) proposed a multi- objective optimization model by integrating sustainability in decision-making, on distribution in a perishable food supply chain network (SCN). The research aimed to solve a two-echelon location-routing problem with time-windows (2E-LRPTW) for sustainable SCN design and optimizing economic and environmental objectives in a perishable food SCN. Ding et al. (2016) developed the mechanism for the government to drive businesses (producers in the supply chain context) to take initiatives to effectively control and prevent pollution. Also, they analyzed supply chain firms' operations strategy decisions for producing EFPs through the development of an integrated supply chain model that incorporates government regulation and incentives as well as consumers' environmental concerns. Govindan et al. (2016) proposed comprehensive approach by using indicators for measurement of aforementioned aspects and by applying fuzzy mathematical programming to design a multi-echelon multi-period multi-objective model for a sustainable reverse logistics network. According to the literature, researchers have not proposed a comprehensive model to include quality and SR concepts simultaneously among the competitive priorities and Sustainable Supply Chain (SSCM). Zavvar Sabegh et al. (2016) presented a mathematical model that consists of a new quality loss function and adds maintenance costs to the ordering and inventory holding costs commonly considered in the classical model. The model is applied to a real-world case study to demonstrate the effect of initial settings of the mean quality characteristic. Zavvar Sabegh et al. (2017) presented mathematical model in pharmaceutical supply chain for natural disaster response. But the gap of study is they didn't consider the customer satisfaction index. In this study, we proposed a new multi-objective mathematical model that includes four objective functions. We combined the different type's costs from literature. Additionally, this is the first study to maximize customer satisfaction and job opportunities simultaneously. Also, the model minimizes total costs including Quality and SR costs, production costs, purchasing cost and transportation costs and minimizes the environmental effects of transportation and production.

PROBLEM DEFINITION AND ASSUMPTIONS

This paper proposes a new mathematical model for a sustainable supply chain including suppliers, manufacturing plants, distribution centers to support customer markets as shown in Figure 2. In the supply chain, raw materials are purchased from suppliers by manufacturing plants. A single acceptance sampling plan (SSP) using rectifying inspection method is applied for monitoring quality level of raw materials. Then, the desirable raw materials are processed to provide products in manufacturing plants. The products are inspected at the end of production line. The non-defective products will transport to the distribution centers`. Also, the rework able defective products will send to the rework center. Next, the reworked products are inspected. The non-defective reworked product will transport to the distribution centers too. The distribution centers will transport the products to the customer markets.

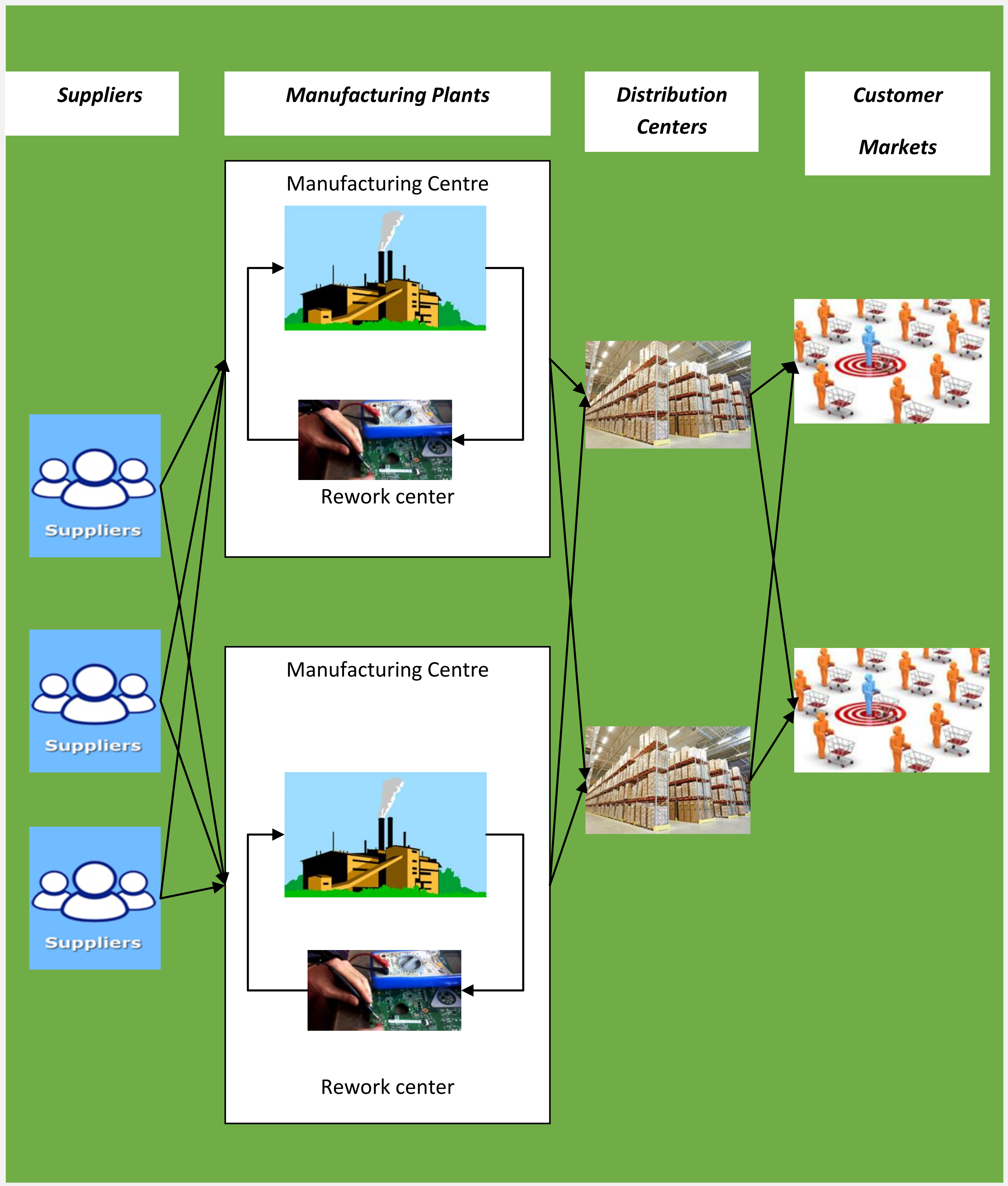

Figure 2 – Structure of supply chain

We considered the following assumptions:

- Identifying elements and links in the existing quality management system, has been used to resolve a customer satisfaction index using a scale which allows expressing also a pleasant surprise, while expected value may not be in the middle of the scale.

- A single stage rework center has been assigned to the manufacturing plant
- The products have same weights and sizes
- The demand of the customer market is deterministic
- Shortage of demand and supply are not allowed
- The similar type of the transportation vehicles is considered to transport.
- Number of suppliers, manufacturing plants, distribution centers and customer markets are deterministic

The quantity of transported productions in each transportation is less than or equal to the capacity of transportation vehicle.

MODEL DESCRIPTION

The following notation is applied in the formulation of the new proposed model.

Indices

s	Index of suppliers	$s = 1, \dots \dots ., S$
p	Index of potential locations for manufacturing plants	$p = 1, \dots \dots, P$
d	Index of potential locations for distribution centers	$d = 1, \dots \dots, D$
c	Index of customer markets	$c = 1, \dots \dots, C$
t	Index of different production technologies for manufacturing plants	$t = 1, \dots \dots, T$
l	Index of various products	$l = 1, \dots \dots, L$
m	Index of various raw materials	$m = 1, \dots \dots, M$

Parameters

CSI_c : Individual Satisfaction of customer markets c for a defined service

W_c : Weight (importance) of a service for customer markets c

CP_{lpt} : The cost of production product l at the manufacturing plant p using technology t

CB_{ms} : The cost of raw material m purchased from supplier s

CF_{pt} : The fixed cost of opening manufacturing plant m using technology t

CG_d : The fixed cost of opening distribution centre d

CRE_{lp}: The cost of reworked product l at the rework center of the manufacturing plant p

CTM_p: The cost of transporting raw material m per kilometre

CTL: The cost of transporting product l per kilometer

Cap_{pl}^{t}: The capacity of product l at the plant p using technology t

Cap_{sm}: The capacity of supplier s for preparing raw material m

Cap_d : The capacity of distribution center d

QD_{ps}: The returned raw material from the manufacturing plant p to the supplier s

EI_{lp}^{t}: The environmental effects of product l at the manufacturing plant p using technology t

EI_T: The environmental effects of each transporting per kilometre

NDI: The total opened distribution centers (including deterministic job opportunities)

n_d: The number of additional job opportunities if distribution centre is located at distribution centre d

D_{pd}: The distance between manufacturing plant p and distribution centre d

D_{sp}: The distance between supplier s and manufacturing plant p

D_{dc}: The distance between distribution center d and customer market c

DE_c^l: The demand of customer market c for product l

N_s: The volume of lot size prepared in supplier s

C_p: The criteria for acceptance sampling in plant p

$\overline{P_d}$: The fraction of defective items for lot size (N_d) in supplier s

VC_p': The variable inspection cost of raw material m at the manufacturing plant m

CA_{mp}: The cost of accepting a defective raw material m at the manufacturing plant p

P_a^p : The probability of acceptance for lot size (N_s) in manufacturing plant p

$$P_a^p = p(x \le C_p) = \sum_{i=0}^{C_p} \binom{n_p}{i} (p_d)^i (1-p_d)^{n_p-i}$$

FC_p': The fixed cost of promoting safety

FC_p: The fixed cost of inspection for product at the manufacturing plant m

VC_p: The variable inspection cost of product (per unit of product) at the manufacturing plant p

EC_p^m : The error inspection cost of raw material m at the manufacturing plant p

EC_p^l : The error inspection cost of product l at the manufacturing plant p

PC_p : The fixed cost for prevention activities (personnel education, designing quality procedures, etc)

CS_p : The fixed cost of services includes employers at the manufacturing plant m (insurance, Sick leave, etc)

N_p: The number of employers at the manufacturing plant p

R_{relp}^t : The percentage of defective and rework able products l at the manufacturing plant m using technology t (after the first inspection)

R_{glp}^t : The percentage of non-defective product l at the manufacturing plant p using technology t

R_{reglp}^t: The percentage of reworked non-defective product l at the manufacturing plant p using technology t (the second inspection after reworking)

D_T: The total distance travelled for the transportation of raw material / product in the entire supply chain in kilometres

$R\ T_{glpd}^t$: The percentage of non-defective product l is transported from the manufacturing plant m using technology t to distribution centre d

RT_{reglpd}^t : The percentage of reworked non-defective product l is transported from the manufacturing plant m using technology t to distribution center d

EI_l^{max} : The maximum of acceptance limit for environmental effect for manufacturing product l

EI_T^{max} : The maximum of acceptance limit for environmental effect in total transportation of supply chain network

Decision variables

Q_{lpt} : The product quantity l is produced at the manufacturing plant m using technology t

Q_{ldc} : The product quantity l is transported from distribution center d to the c

Q_{msp} : The amount of raw material m is transported from supplier s to the manufacturing plant p

Y_{pt}: $\left\{ \begin{array}{c} 1 \quad \text{if a plant with technology } t \text{ is opened at location } p \\ 0 \; otherwise \end{array} \right\}$

Y_{d}: $\left\{ \begin{array}{c} 1 \quad \text{if a distribution center is opened at location d} \\ 0 \; otherwise \end{array} \right\}$

$\boldsymbol{Y_{s}}$: $\left\{ \begin{array}{c} \mathbf{1} \quad \textbf{if a supplier center is opened at location s} \\ \mathbf{0} \; \boldsymbol{otherwise} \end{array} \right\}$

MATHEMATICAL MODEL

$$\boldsymbol{Max\ Z_1} = \sum_{c=1}^{C} \boldsymbol{CSI_c} \times \boldsymbol{w_c} \quad (1)$$

$$\boldsymbol{Min\ Z_2} = \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{t=1}^{T} CP_{lpt} \times Q_{lpt} + \sum_{m=1}^{M} \sum_{s=1}^{S} \sum_{p=1}^{P} CB_{ms} \times Q_{msp}$$
$$+$$
$$\sum_{p=1}^{P} \sum_{t=1}^{T} CF_{pt}\, Y_{pt} + \sum_{d=1}^{D} CG_d \times Y_d + \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{t=1}^{T} CRE_{lp} \times Q_{lpt}\ \ R_{relp}^{t} +$$
$$CT\left[\sum_{m=1}^{M} \sum_{s=1}^{S} \sum_{p=1}^{P} D_{sp} \times Q_{msp} + \sum_{p=1}^{P} \sum_{s=1}^{S} D_{sp} \times QD_{ps}\left(1 - P_a^p\right) + \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{d=1}^{D} \sum_{t=1}^{T} D_{pd} \times \right.$$
$$\left. Q_{lpt} \times R_{glp}^{t} + \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{d=1}^{D} \sum_{t=1}^{T} D_{pd} \times Q_{lpt} \times R_{relp}^{t} R_{reglp}^{t} + \sum_{d=1}^{D} \sum_{c=1}^{C} \sum_{l=1}^{L} D_{dc} \times Q_{ldc}\right]$$
$$+ \sum_{p=1}^{P} \sum_{l=1}^{L} FC_p + \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{t=1}^{T} Q_{lpt} \times VC_p + \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{t=1}^{T} Q_{lpt} \times R_{relp}^{t} +$$
$$\sum_{p=1}^{P} \sum_{m=1}^{M} n_p \times VC_p' + \sum_{m=1}^{M} \sum_{s=1}^{S} \sum_{p=1}^{P} \sum_{d=1}^{D} \left[\left(Q_{msp} - n_p\right)\right] \times \frac{Q_{msp} \times \overline{P_d}}{N_d} \times CA_{mp} \times P_a^p +$$
$$\left(1 - P_a^p\right) \times \left[\left(n \times VC_p'\right) + \left(Q_{msp} - n_p\right) \times VC_p'\right]$$
$$+ \sum_{p=1}^{P} \sum_{t=1}^{T} FC_p' \times Y_{pt} + \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{t=1}^{T} EC_p^{l}\, Y_{pt} + \sum_{m=1}^{M} \sum_{p=1}^{P} \sum_{t=1}^{T} EC_p^{m} \times Y_{pt} +$$
$$\sum_{p=1}^{P} \sum_{t=1}^{T} PC_p \times Y_{pt} + \sum_{p=1}^{P} \sum_{t=1}^{T} N_p\ CS_p Y_{pt}$$

(2)

$$\boldsymbol{Min\ Z_3} = \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{t=1}^{T} EI_{lp}^{t} \times Q_{lpt} \times Y_{pt} + \sum_{t=1}^{T} EI_T\, D_T \quad (3)$$

$$\boldsymbol{Max\ Z_4} = NDI + \sum_{d=1}^{D} n_d \times Y_d \quad (4)$$

Subject to

$$\sum_{d=1}^{D} Q_{ldc} = DE_c^{l} \qquad \forall\, c, l \quad (5)$$

$$\sum_{p=1}^{P} \sum_{t=1}^{T} Q_{lpt} \times R_{glp}^{t} \times R\, T_{glpd}^{t} + \sum_{p=1}^{P} \sum_{t=1}^{T} Q_{lpt} \times R_{relp}^{t} \times R_{reglp}^{t} \times RT_{reglpd}^{t} = \sum_{c=1}^{C} Q_{ldc} \qquad \forall\, l, d \quad (6)$$

$$\sum_{p=1}^{P} Q_{msp} \leq Cap_{sm} \times Y_s \qquad \forall\, m, s \quad (7)$$

$$\sum_{l=1}^{L} \sum_{c=1}^{C} Q_{ldc} \leq Cap_d \times Y_d \quad (8)$$

$$\sum_{p=1}^{P} \sum_{t=1}^{T} Q_{lpt} \times R_{glp}^{t} \times R\, T_{glpd}^{t} + \sum_{p=1}^{P} \sum_{t=1}^{T} Q_{lpt} \times R_{relp}^{t} \times R_{reglp}^{t} \times RT_{reglpd}^{t} \leq Cap_{pl} \times Y_{pt} \quad (9)$$

$$\sum_{t=1}^{T} Y_{pt} = 1 \qquad \forall\, p \qquad (10)$$

$$\sum_{p=1}^{P} \sum_{t=1}^{T} EI_{lp}^{t} \leq EI_{l}^{max} \qquad (11)$$

$$EI_{T} \times D_{T} \leq EI_{T}^{max} \qquad (12)$$

$$0 \leq w_{c} \leq 1 \qquad (13)$$

$$Y_{pt}\,, Y_{d}, Y_{s} \in \{0,1\} \qquad (14)$$

$$Q_{lpt}, Q_{ldc}, Q_{msp}, QD_{ps}, D_{T}, D_{sp}, D_{pd}, D_{dc}, DE_{c}^{l}, C_{p} \geq 0 \qquad (15)$$

The first objective function maximizes the satisfaction of customer markets. To use the customer satisfaction index is necessary to know the view of customer Markets on their importance. There is used variety of scales, for example. Grading, scoring, respectively, percentage for concretization of satisfaction. In the second objective function ($\boldsymbol{Z_2}$), we minimize the total costs. These costs include 15 terms. The first term $\sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{t=1}^{T} CP_{lpt} \times Q_{lpt}$ shows production costs. The second term $\sum_{m=1}^{M} \sum_{s=1}^{S} \sum_{p=1}^{P} CB_{ms} \times Q_{msp}$ represents purchasing costs. The third term $\sum_{p=1}^{P} \sum_{t=1}^{T} CF_{pt}\, Y_{pt}$ shows the opening manufacturing plant costs. The fourth term $\sum_{d=1}^{D} CG_{d} \times Y_{d}$ determines the opening distribution centers costs. The fifth term $\sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{t=1}^{T} CRE_{lp} \times Q_{lpt}\ R_{relp}^{t}$ shows rework costs. The sixth term $CT\left[\sum_{m=1}^{M} \sum_{s=1}^{S} \sum_{p=1}^{P} D_{sp} \times Q_{msp} + \sum_{p=1}^{P} \sum_{s=1}^{S} D_{sp} \times QD_{ps}\left(1 - P_{a}^{p}\right) + \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{d=1}^{D} \sum_{t=1}^{T} D_{pd} \times Q_{lpt} \times R_{glp}^{t} + \sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{d=1}^{D} \sum_{t=1}^{T} D_{pd} \times Q_{lpt} \times R_{relp}^{t} R_{reglp}^{t} + \sum_{d=1}^{D} \sum_{c=1}^{C} \sum_{l=1}^{L} D_{dc} \times Q_{ldc}\right]$ determines total transportation costs. The seventh, eighth, ninth, tenth eleventh and thirteenth terms show the appraisal costs. The twelfth term $\sum_{p=1}^{P} \sum_{t=1}^{T} FC_{p}^{\prime} \times Y_{pt}$ shows fixed cost of promoting safety in manufacturing plant. The fourteenth term represents fixed cost of prevention activities. Finally, the fifteenth term determines fixed cost of services.

In the third objective ($\boldsymbol{Z_3}$), first part $\sum_{l=1}^{L} \sum_{p=1}^{P} \sum_{t=1}^{T} EI_{lp}^{t} \times Q_{lpt} \times Y_{pt}$ minimizes the environmental effects of products at the manufacturing plant and the rest minimizes the environmental effects of transportation.

The final objective function ($\boldsymbol{Z_4}$), maximizes job opportunities.

Constraint (5) determines that the products transported from distribution centres should satisfy demand in customer markets. Constraint (6) assures equilibrium between input and output flows in distribution centres. Constraints (7-9) are capacity constraints for network facilities. Constraint (10) guarantees that only one manufacturing plant with certain capacity and certain technology will be located in each spot. Constraints (11) and (12) determine maximum allowable limit for environmental effects. Constraint (10) determines the allowable limit for Weight (importance) of a service for customer markets c. Constraints (14) and (15) determine non-negativity and binary conditions for variables.

SOLUTION METHOD

Multi-Objective Problems (MOPs)

The majority of problems in different areas are involved satisfying of many objectives simultaneously, which are called Pareto-Optimal set. In a typical multi-objective problem (MOP), there is not a solution in respect to all objectives and these objectives are conflicting in nature. The MOPs can be puzzled out by two main tasks. In the first place, a Pareto-Optimal solutions set is generated. The next phase, the most promising solutions are chosen which satisfy all the objectives. Multi-objective optimization can be formulated as follows:

$$min[f_1(x), f_2(x), \ldots, f_n(x)]$$

$$x \in S \ and \ n > 1$$

Where S is the set of constraints defined above.

Classical methods restated multi-objective problems into single objective problems, and then they were solved as single-objective problems; therefore, they worked with a single solution in per iteration. On other hand, another way to solve MOPs, which find the approximation of the whole Pareto front in one run, is Evolutionary Multi-Objective Optimization (EMO) (Deb, 2001).

NSGA II

In 1995, Srinivas and Deb, introduced NSGA (Non-dominated Sorting Genetic Algorithm) and the improved algorithm put forward in 2000 (Li etal, 2012). As you can see, Figure 3 illustrates the NSGA II steps.

As Semi code shown, NSGA II process can be divided into 3 phases; the process begins with generating the population. In this phase, Firstly, a population is produced based on the predefined range of values for each parameter. Next, *Mutation* and *Cross Over* operator is employed to create a new offspring pool, and the parents and offspring are aggregated before partitioning the new combined pool into fronts. During this phase, we also allocate ranks based on the objective functions. In addition to rank which is assigned to each individual, a new score is computed for each member of population which entitled crowding. This measure refers to the distance between each two neighbours. In the second phase, a crowding distance for each member is computed and in order to spread the solutions out of the Pareto front, this value is used in the selection process. At the end of process, we select the solution which satisfied all objective functions. It is vitally important to compute both crowding distance and rank (.Zitzler etal. 1998).

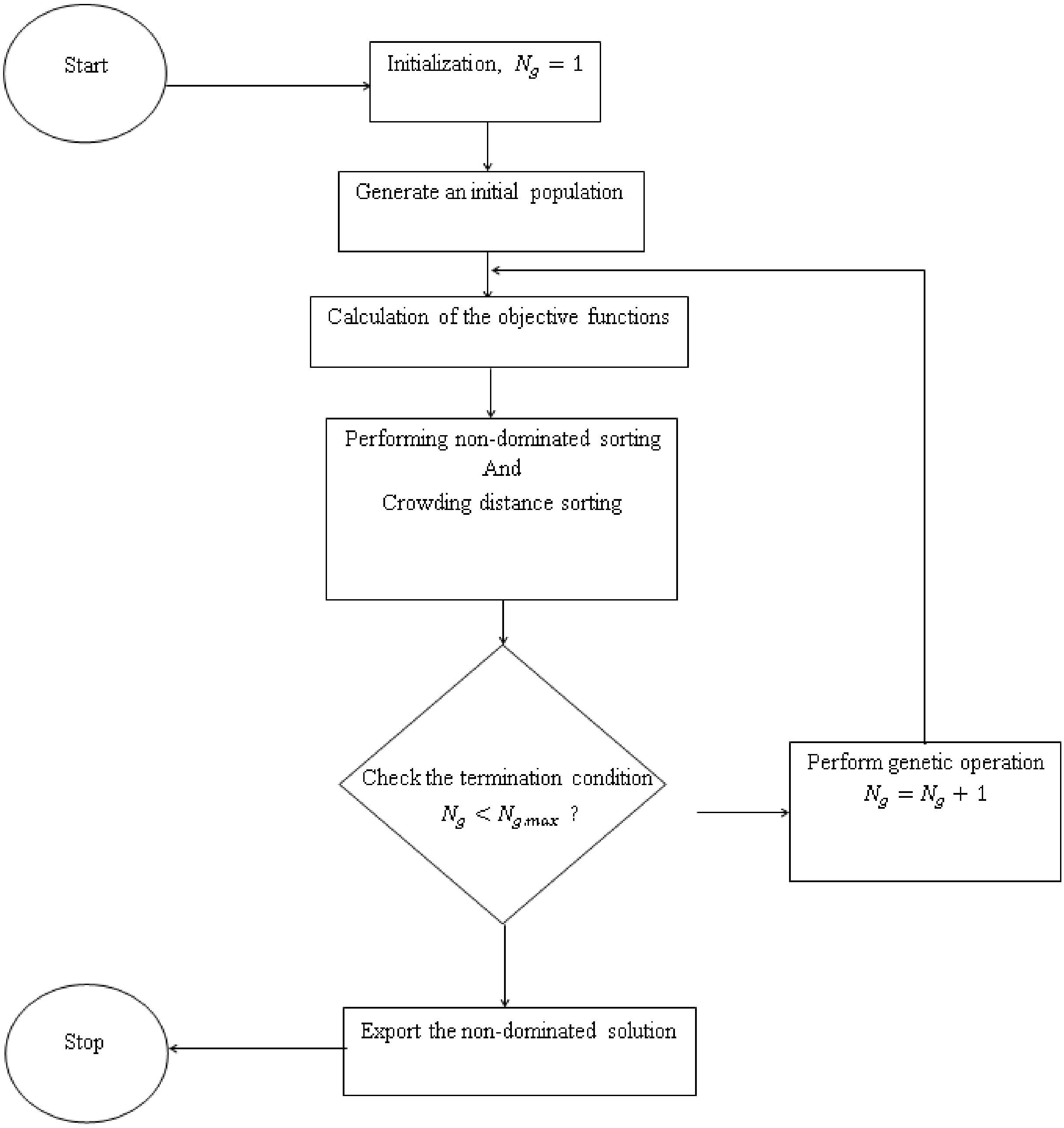

Figure 3 – The NSGA II steps

Step 1: Generate the initial Population for parameters based on the predefined value ranges

Step 2: Evaluation the objective functions

Step 3: Perform non-dominated sorting

- Allocate rates according to Pareto dominance Sort

  Solution x_1 is called the dominated solution to the other solutionx_2, if

  1. The solution is no worse than the other in all objectives

     $f_j(x_1) \nprec f_j(x_2) \qquad for\ \ j = 1, \ldots., M\ objectives$

  2. The solution is better than in at least one objective

     $f_j(x_1) \nprec f_j(x_2) \qquad for\ \ j = 1, \ldots., M\ objectives$

Step 4: Generate Child Population

- Allocate rates according to Pareto dominance Sort

Step 5: recombination and Mutation

Step 6: **for** i=1 to N_g do

For each parent and child population do

- Allocate rates according to Pareto dominance Sort
- Create a collection of non-dominated vectors
- Loop by adding solutions to next generation starting from the first front until N' individuals found determine crowding distance between points on each front

End for

Step 7: Select points on the lower front and are outside a crowding distance.

Following that, fundamental parts of the process are described in detail.

- **Population Generation.** As mentioned before, the initial population was generated based the problem range and constraint. Additionally, there two operators which used to generate offspring from population member. They are included:
  - **Cross Over.** NSGA II employs the simulated Binary Crossover. This operator mates two parent solutions to generate two offspring. There are three steps involved in order to offspring generation. First, a random number $u \in [0,1]$ is chosen. Next, equation 1 is calculated. Finally, offspring is generated by equation 2.

$$\beta_i = \begin{cases} (2u)^{\frac{1}{\mu_c+1}} & u \leq 0.5 \\ \left(\frac{1}{2(1-u)}\right)^{\frac{1}{\mu_c+1}} & u > 0.5 \end{cases} \tag{1}$$

$$x_i^{(1,t+1)} = 0.5\left[(1+\beta_i)x_i^{(1,t)} + (1-\beta_i)x_i^{(2,t)}\right] \tag{2}$$

$$x_i^{(2,t+1)} = 0.5\left[(1-\beta_i)x_i^{(1,t)} + (1+\beta_i)x_i^{(2,t)}\right] \tag{3}$$

- **Mutation.** Unlike the Crossover operator, the mutation operate is applied on individuals. It changes the vectors based on a given mutation rate. There are different types of mutation operators. In this research, initially, a population member is chosen randomly. Then, the mutation operator is described as follows:

  $$y_i^{(1,t+1)} = x_i^{(1,t+1)} + sigma \times \delta_i \quad (4)$$

  Where δ_i is selected at random (Schott, 1995).

Crowding Distance. Addition to a rank which is assigned to each population members based on objective functions, crowding distance is calculated for each member. The rank and crowding distance play complementary role in sorting the population members. As mentioned before, this measure helps in better diversity in the population.

DISCUSSION

In this section, solving the problem is examined by a numerical example. The algorithm is used to solve the problem with the population which is sized 10 instances. The parameters are described in Table 1and the solutions which are obtained by NSGA II, are shown in Table 2.

Table 1– Input parameters.

	Itr_1	Itr_2	Itr_3	Itr_4	Itr_5	Itr_6	Itr_7	Itr_8	Itr_9	Itr_{10}
CP_{lpt}	102	217	181	123	174	195	126	134	118	200
CF_{pt}	2763	1988	1454	2737	2685	1919	2247	4247	2693	1930
CRE_{lp}	19	12	12	15	13	12	13	15	17	12
CTL	15	12	19	18	19	15	14	16	17	15
Cap_{pl}^{t}	4.61×10^{8}	3.33×10^{8}	1.96×10^{8}	2.03×10^{8}	3.26×10^{8}	3.25×10^{8}	4.52×10^{8}	3.47×10^{8}	3.29×10^{8}	3.18×10^{8}
QD_{ps}	22	13	23	26	23	18	21	23	22	17
EI_{lp}^{t}	156	399	232	231	232	225	165	360	198	216
n_{pt}	123	193	188	187	146	184	189	148	125	163
D_{pd}	12	11	13	13	12	13	11	13	12	11
C_p	5	5	2	4	3	4	5	3	4	2
VC_p'	47	66	65	48	60	60	53	72	51	65
CA_{mp}	18	21	17	25	18	21	19	21	18	19
P_a^p	0.706817	0.912583	0.666755	0.757047	1	1	1	0.765206	1	1
FC_p'	71	87	69	82	80	72	78	67	74	82
FC_p	87	72	65	69	66	76	83	91	69	77
VC_p	57	62	49	67	53	61	58	75	53	62
EC_p^m	55	62	64	58	62	61	59	55	57	62
EC_p^l	70	87	72	54	84	77	72	52	75	84
PC_p	403	363	438	471	473	409	387	721	452	402
CS_p	554	560	547	691	548	558	558	688	552	554
N_p	83	97	53	83	79	94	90	71	82	60
R_{relp}^{t}	35	25	30	22	30	27	31	39	33	31
R_{glp}^{t}	80	98	63	91	67	91	97	62	80	96
EI_l^{max}	576	755	545	602	590	722	605	522	586	716
RT_{reglpd}^{t}	96	71	94	80	94	71	83	93	94	75
$R\ T_{glpd}^{t}$	86	80	83	94	94	82	84	85	92	81
R_{reglp}^{t}	75	69	51	50	52	66	72	70	53	67
Y_{pt}	1	1	1	1	1	1	1	1	1	1
Q_{lpt}	1781	2553	1312	2104	1323	1494	1791	1339	1364	2493
CB_{ms}	77	48	57	66	57	55	70	48	58	56
CTM_p	3	7	7	8	6	7	5	8	4	7
Cap_{sm}	826	931	927	956	929	930	829	971	842	930
D_{sp}	22	19	20	24	24	19	21	27	22	22
N_s	816	946	826	860	847	847	882	943	837	848
$\overline{P_d}$	0.05776	0.278109	0.128317	0.226109	0	0	0	0.22453	0	0
Y_s	1	1	1	1	1	1	1	1	1	1
Q_{msp}	705	618	759	543	649	677	693	673	676	666
CG_d	171	357	337	495	161	343	309	184	165	350
Cap_d	504	627	694	780	670	644	532	594	629	634
n_d	10	9	6	9	6	9	9	7	10	8
D_{dc}	5	5	6	6	6	6	5	6	5	5
Q_{ldc}	$4.61E\times10^{8}$	3.33×10^{8}	1.96×10^{8}	2.03×10^{8}	1.98×10^{8}	3.27×10^{8}	3.79×10^{8}	3.47×10^{8}	4.37×10^{8}	3.32×10^{8}
Y_d	1	1	1	1	1	1	1	1	1	1
DE_c^l	$4.61E\times10^{8}$	3.33×10^{8}	1.96×10^{8}	2.03×10^{8}	2.39×10^{8}	3.16×10^{8}	4.08×10^{8}	3.47×10^{8}	4.13×10^{8}	2.76×10^{8}

Table 2 – The solutions obtained by the NSGA II

Z_1	Z_2	Z_3	Z_4
0.610	3.54×10^{10}	2277836	138
0.910	2.06×10^{10}	2304384	207
0.800	2.28×10^{10}	3018647	199
0.830	2.25×10^{10}	2486024	201
0.725	4.62×10^{10}	2446960	171
0.725	4.62×10^{10}	2446960	171
0.738	3.63×10^{10}	2789210	178
0.680	3.41×10^{10}	2482040	160
0.725	4.62×10^{10}	2446960	171
0.725	4.62×10^{10}	2446960	171

The results show logical relations among objective functions theoretically. For example, when customer satisfaction is very low (Z_1= 0.61), the total cost is too high ($Z_2=3.54\times10^{10}$).

CONCLUSIONS

The Social Responsibility (SR) and Quality concepts have key roles to move toward sustainable supply chain and should be considered. However, the literature has not thoroughly examined the role of quality specially customer satisfactions and SR concepts simultaneously among the competitive priorities and Sustainable Supply Chain (SSCM). For this purpose, a new mathematical model has been proposed by combining the different type's costs from literature considering customer satisfaction simultaneously. The model included 4 objective functions: Maximizing customer satisfaction, minimizing total cost, minimizing environmental impact, maximizing job opportunities. The NSGAII algorithm has been used to solve the model since the complexity of model is NP-hard. The numerical example has given to illustrate the solution steps. By applying the non-dominated sorting and also consideration the crowding distance, the final result is obtained which is shown in Table 3.

Table 3 – NSGA II result

Z_1	Z_2	Z_3	Z_4
0.61	3.54×10^{10}	2277836	138
0.91	$\mathbf{2.06\times10^{10}}$	**2304384**	**207**
0.80	2.28×10^{10}	3018647	199
0.83	2.25×10^{10}	2486024	201

The results show there is a logic relation between 4 objective functions theoretically. When customer satisfaction is very low (Z_1= 0.61), the total cost is too high ($Z_2=3.54\times10^{10}$). The optimum solution is Z_1= 0.91, Z_2= 2.06×10^{10}, Z_3= 2304384 and Z_4= 207. It means when customer satisfaction is high (0.91), the total cost is the lowest amount (2.06×10^{10}), the environmental impact is moderated (2304384) and job opportunities are increased to maximum value (207). Managerial implications of this research focus on improving the efficiency and effectiveness of the model. For future studies, some parameters such as demand, purchasing costs, transportation costs and production costs can be considered in uncertainty environment. In this case, some uncertainty methods can be used such as fuzzy logic and other solution methods can be used such as PSO.

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Hassan's Approach: Novel 5-Step model transforming 'Performance' to 'High Performance'

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ABSTRACT

Purpose – Quality of performance is recognized as moving beyond compliance towards true excellence. In this context, this article introduces the novel Hassan's Approach, an innovative model developed by the Quality Management expert and international consultant Hassan Hamwi, showing the effective role of Hassan's Approach in supporting the changing the tend of the Senior executives from think about corporate culture as a topic that's hard to measure and hard to change. As a result, many choose not to invest in it despite all the evidence that, when skilfully managed, culture can be a powerful and enduring source of competitive advantage. Hassan's Approach is based essentially on establishing 'Quality Performance 'through the adjoining of five major elements "Steps": Deming's principles, PDCA, Golden Rule, MSS Guidelines, and Five Partners of Quality. Following this approach ensures that the organization is eventually highly qualified not only to seamlessly select the most relevant quality management system to adopt, but also to successfully implement this QMS with minimum mental and physical effort. Typically, Hassan's Approach is applied through "Integrated Implementation Methodology for Management Systems and Standards (IMS2)".

Findings – Upon following Hassan's Approach throughout the implementation of ISO 39001:2012 RTSMS, Alfa Telecom- Lebanon showed a remarkable improvement in their performance, achieving a successful shift to 'Quality High Performance'.

Social implications – Interestingly, following the Deming's Principles essentially through Hassan's Approach might have an additional positive impact on improving the corporate culture and personality of individuals, which ultimately contributes to the advancement of society.

Originality and value – To the best of our knowledge, Hamwi is the first to consider the development of a methodology linking both the corporate culture, moral and practical aspects during the implementation of a QMSs at the level of individual employees.

Paper type: Case study

Keywords: Hassan's Approach, ISO 39001, Alfa- Lebanon,5-Step model, transforming 'Performance' to 'High Performance'

INTRODUCTION

Today, the environment in which organizations operate is changing rapidly and continuously, it is hectic. Not only do organizations have to be agile and innovative, but they also have to maintain good performance, possibly through a range of standards including ISO MSS, and yet still meet their customers' expectations (Manders et al., 2016). Establishing this equation is not an easy task, especially with so many methodologies and frameworks available (Charvat, 2003).Thus, the excellence journey is not only a challenge, but it is also a way to remain competitive, and to continuously learn, understand and manage the risks, capitalize on strengths, and turn weaknesses into new opportunities. It is every organization's ambition to stand out in market by being equipped with a competitive advantage. Thus, moving beyond abstract compliance towards true excellence can be established through shifting to 'Quality Performance' (Kitapçi and Çelik, 2014).

In an attempt to improve the performance of an organization into 'Quality High Performance', the novel Hassan's Approach is introduced by the QM international expert Hassan Hamwi as an additional, yet vital support to any organization wishing to start its excellence journey. The major focus of Hassan's approach is the fitting of the organization on the corporate culture, ethical and moral levels as a preparatory phase prior to adopting any quality management system standard.

One of the most recent and most successful experiences demonstrating the role of Hassan's Approach was the implementation of ISO 39001:2012 (Road Traffic Safety Management System Standard) in Alfa Telecom, Lebanon. This particular experience is rather interesting, given that Alfa Telecom-Lebanon is the first telecommunication establishment in the Middle East to implement and achieve ISO 39001:2012 Certificate [https://www.alfa.com.lb/en/media-center/press-releases/alfa-1st-telecom-operator-in-mena-to-receive-iso-39001-in-road-safety].

Overview of Alfa Telecom - Alfa is the brand name of the first Lebanese mobile network managed by Orascom Telecom Media and Technology (Orascom TMT). Alfa capitalizes on the vast know-how and international expertise of Orascom TMT in order to deliver quality and professional solutions for the mobile sector in Lebanon. Alfa has been focused since 2009 under Orascom TMT's management on technology innovation being the first operator to introduce latest global mobile technologies in Lebanon [https://www.alfa.com.lb/en/about/overview].

Alfa is a forerunner in the field of adopting RTSMS, being the first telecommunication company in the Middle East region to implement Road and Traffic Safety according to ISO39001:2015 international standards.

Overview of Road Traffic Safety Management System - RTSMS is a part of the management system, which sets the conditions and factors related to road traffic crashes and other road traffic incidents that have an impact on, or have the potential to have an impact on death or serious injury of road users. ISO 39001, the world's first international standard for Road Traffic Safety Management, has been recently developed to help organizations improve the safety of road users and minimize the risks of disruptions (Johansson, 2012). ISO 39001 is important for road safety since organizations must develop road traffic safety plans to ensure smooth operation within their working environment, as they aim to improve the safety of their drivers, increase legal compliance, reduce injuries and deaths, reduce work absences, and reduce crash-related costs [https://www.iso.org/standard/44958.html].

ISO 39001 specifies requirements to plan, establish, implement, operate, monitor, review, maintain and continually improve a management system, to prepare for, respond to and deal with the consequences of road incidents when they occur. The key clauses of ISO 39001:2012 include:

- *Clause 4: Context of the organization*External and internal issues that affect the organization's ability to achieve intended outcome(s) of its RTS management system shall be determined.
- *Clause 5: Leadership*Top management is accountable for demonstrating leadership and commitment, establishing a Road Traffic Safety policy and communicating the assigned roles and responsibilities within the organization.
- *Clause 6: Planning* It relates to the identification of the RTS performance factors, defines actions to address risks and opportunities, and states RTS objectives for achieving.
- *Clause 7: Support*A range of management functions are required in order to effectively implement and sustain a successful Road Traffic Safety Management System, including: Coordination, Resources, Competence, Awareness, Communication, Documented information.
- *Clause 8: Operation*Planning and control of the organization's operations and processes shall be determined and implemented to address the RTS performance, objectives and targets. The organization shall also prepare and respond to actual death and serious injuries caused by traffic incidents, based on its emergency procedures.

- *Clause 9: Performance Evaluation* by monitoring, measuring, analyzing and evaluating the RTSMS, investigating road traffic incidents, andconducting internal audits and management reviews.
- *Clause 10: Improvement*An organization is required to practice procedures for identifying nonconformities and taking corrective and preventive actions. These nonconformities shall then be reacted upon and dealt with by taking relevant actions to eliminate their causes, thus assuring continual improvement of the RTSMS.

Overview of Deming's Principles - W. Edwards Demingis the father of Quality Management Revolution. He introduced his ideas in the USA after the WWII, but they were not adopted. He was invited to Japan to deliver several speeches in the middle 50's, among which he advised the Japanese industrialists: "If you adopt the philosophy of quality management, you will rule the world's markets in five years" (Best and Neuhauser, 2005).

Deming's major concern is 'Good Performance' rather than abstract 'Performance'. This concept is clearly reflected in Deming's Total Quality Management Ethics and Principles that basically include customer focus (internal and external), role of good leadership in the success of quality performance, human resources sharing, strategy of processes, strategy of management system integrity, improvement and consistent improvement, strategy of fact-dependent decision making, and participating with suppliers (Jurow and Barnard, 1993).

In this context, the golden rule "Write what you do, do what you write" now forms the basis of all Total Quality Management ISO standards (Joubert, 1998).

Four Tools of Quality (PDCA)–The Golden Rule can be put into a simple cycle: Plan, Do, Check, Act. Complying with this cycle, commitment to continuously applying it, and documentation of all steps, are the key to achieving excellence (Johnson, 2002).

RESEARCH METODOLOGHY

Background - The World Health Organization has classified roads in Lebanon as among the most dangerous in the world in 2015 [World Health Organization, 2016. Lebanon health profile 2015]. Lebanon has the highest rate of victims of traffic accidents in the world, 24 per 100 thousand people, with about 5000 accidents annually, killing 600 people and 6,700 injured. Of the victims, 70% are car accidents, 26% motorcycles, 6% trucks, 38% drivers, 22% passengers and 38% infantry. While the governorate of Mount Lebanon received 42% of these incidents, Beirut received

15%. Of the affected group recorded, 38% were between 15 and 30 years old, and 26% between 30 and 44 years old. Males were the majority of the victimsby76% (Choueiri et al., 2015).

In early 2015, the new Traffic Law was introduced in Lebanon. In addition, the National Traffic Safety Council, the National Traffic Safety Committee, the Traffic Unit and the Training Institute for the Security Forces were established (Choueiri et al., 2017).Since 2015, many campaigns have been launched to raise awareness about traffic safety and improve mass education (Akl, 2005).

The number of road collisions, according to the Internal Security Forces, for the period between 22-25 June, 2015 (two months after the introduction of new Traffic Law) compared to the same period in 2014, shows a decrease in the number of collisions and victims by 72% and 40% respectively, While those ratios dropped to 42% and 24% between 2014 and 2015.

According to statistics from the Internal Security Forces in Lebanon, exceeding the maximum speed was the first cause of traffic accidents from 2009 to 2013, while being distracted during driving was the first cause of traffic accidents in 2014.Statistics show that 7 out of 10 drivers talk on the phone or send short messages while driving. The other three either did not receive a call or do not own a cell phone, which indicates that 100% of drivers who own cell phones use them while driving.

Considering all these circumstances, enforcement of strict Traffic Law in Lebanon became essential. In addition, spreading traffic awareness through nationwide campaigns by various companies became a national concern. One of these companies is Alfa Telecom, which not only participated in traffic awareness campaigns, but also sought to adopt ISO 39001:2012 RTSMS within its own organization. Moreover, Alfa decided to integrate Hassan’s Approach during this process for best RTSMS implementation results –according to Alfa.

Hassan’s Approach–Mr. Hassan Hamwi is an international consultant and has a wide experience in quality management field. Concerned with ‘Quality of Life’, and faced by countless situations where the individual employee performance in an organization was defined by the employees as “complicated”, “tedious”, or “incomprehensible”, Hassan Hamwi set a direct objective of achieving ‘Quality High Performance’ instead of ‘Performance’.

Hassan Hamwi proposed a simplified approach that might assist the system-implementing organization to overcome the common difficulties and intellectual barriers that obstruct good performance, or at least that make it costly as well as time and effort-consuming. Hassan’s Approach identifies all the elements involved in the Quality Management System framework and sets a simplified comprehensible relationship between them. Most importantly, Hassan’s Approach provides an answer to “Why?” and “How?” questions, by focusing on building a corporate culture include moral basis as a qualifying stage. These five integrated elements include setting a strong base of corporate culture include principles and ethics, providing adequate tools to implement these principles, setting a golden rule that reflects and summarizes the principles and tools, adopting a relevant documented guideline through which these principles and tools are adequately established, and finally measuring the satisfaction of all the Five Partners of Quality. This ultimate feedback from the Five Partners of Quality is the Key Performance Indicator (KPI) which not only shows the degree of success of performance, but also pinpoints the defects and limitations of performance, which can be easily overcome by starting over a more thorough review of the corporate culture, principles and ethics and attempting improvement. This clearly demonstrate show Hassan's Approach is distinct from any other previous strategies that focused merely on 'Performance by ISO Management Standards Only', which is always subject to success or failure. On the other hand, Hassan's Approach is oriented towards 'Quality High Performance' which is subject only to continuous improvement.

By joining the mentioned elements into one collective methodology, the system-implementation process becomes more understandable, people's involvement, commitment and executable. Consequently, this saves more time, effort, and money.

Figure 1 is a collective illustration of Hassan's Approach, showing its five elements:

Novel 5-Step model transforming 'Performance' to 'High Performance'

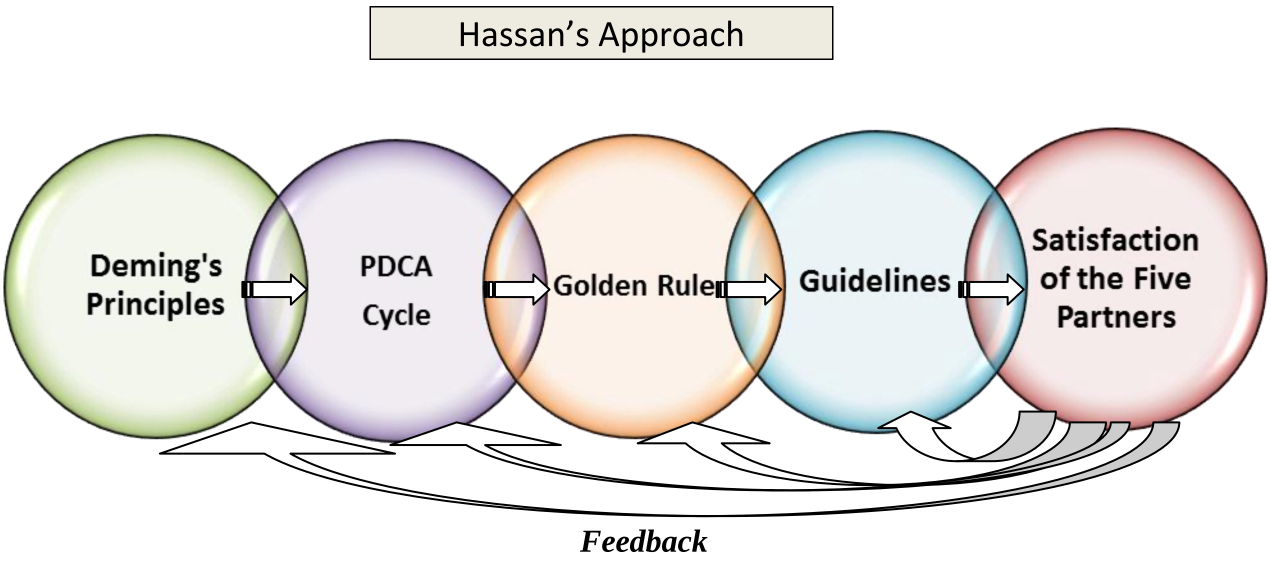

Figure 12 – A diagram summarizing Hassan's Approach. The overlapping in the sequential relationships reflects the focus of Hassan's Approach on integration and consistency of its phases.

1- Deming's Eight Principles

Hassan proposes that the first thing that any organization has to apply to ensure the quality among its system is to set a base of corporate culture, ethics and principles and deeply understand them and believe in them by all levels of the organization . He selected Deming's eight principles of TQM, being the most recognized in this context. Deming's ethics and principles that helping Hassan to build a strong and solid corporate culture are summarized as follows:

1st: Customer Focus organization (internal and external)

Customer focus means the orientation of an organization toward serving its clients' needs. Having a customer focus is usually a strong contributor to the overall success of a business and involves ensuring that all aspects of the company put its customers' satisfaction first. Also, having a customer focus usually includes maintaining an effective customer relations and service program. According to many presentations by the smartest business personalities, the four performance standards that are important for any customer are Time, Place, Quantity, and Quality (Jurow and Barnard, 1993).

2nd: Role of good leadership in the success of quality performance

There are many sources that explain the theory of the Total Quality Management (TQM) process of the organization. Leadership puts these principles into action. Without sound leadership, the quality control process would be likely far less effective. An organization may have all the industry "best practices" employed, but it takes internal leadership to take quality management to a level that will put the firm in the best possible position to succeed (Jurow and Barnard, 1993). The role of good leadership is maintained by:

- Creating the proper environment
- Leading by example
- Crafting a strategy, then being flexible with it

3rd: Employee involvement

Employee involvement is not the goal nor is it a tool, as practiced in many organizations. Rather, it is a management and leadership philosophy about how people are most enabled to contribute to continuous improvement and the ongoing success of their work organization.This involvement increases ownership and commitment, retains the organization's best employees, and fosters an environment in which people choose to be motivated and contributing (Best and Neuhauser, 2005).

4th: Processes approach

The process approach is one of the eight quality management principles upon which the entire ISO series of standards is based. This principle says a desired result is achieved more efficiently when activities and related resources are managed as a process. It is the elemental core of ISO's view of a QMS. Thus, a QMS can be thought of as a single large process that avails many inputs to generate many outputs.ISO promotes the process approach to managing an organization, and requires the QMS to consider the organization as a series of interlinked processes (Best and Neuhauser, 2005).

5th: System approach to management (integrated system)

System approach to management views organization as a unified, purposeful system composed of interrelated parts. This approach also gives the manager to see the organization as a whole and as a part of the larger external environment.System-oriented manager would make decision only after they have identified impact of these decisions on all other departments and the entire organization. They must intertwine departments with the total organization and communicate with all other departments, employees and with each other (Jurow and Barnard, 1993).

6th: Continual improvement

A continual improvement process is an ongoing effort to improve products, services, or processes. These efforts can seek "incremental" improvement over time or "breakthrough" improvement all at once. Delivery (customer valued) processes are constantly evaluated and improved in the light of their efficiency, effectiveness and flexibility. Some see continual improvements as a meta-process for most management systems (such as business process management, quality management, project management, and program management). Deming saw it as part of the 'system' whereby feedback from the process and customer were evaluated against organizational goals. The fact that it can be called a management process does not mean that it needs to be executed by 'management'; but rather merely that it makes decisions about the implementation of the delivery process and the design of the delivery process itself (Sujová, Marcineková, 2015).

7th: Fact-based decision making

As the term implies, fact-based decision making involves putting considerable initial emphasis on the gathering of facts, figures, data and evidence. This is mainly done at the first stage of the often cited 4-step decision-making process of (1) Establishing the issue; (2) Weighing of considering the possibilities; (3) Interpreting and Sifting the options, and finally (4) Making a final judgment or Deciding. However, it is important to maintain focus on the facts at all four stages as unsupported assumptions and untested intuition can come to dominate the thinking as time goes by in many situations (Best and Neuhauser, 2005).

8th: Mutually beneficial supplier relationship (Supplier partnership)

Supplier Partnership is the discipline the strategically planning for, and managing, all interaction with third party organization that supply goods and services to the organization, in order to maximize the value of that interaction.Supplier Partnership also means that in quality control, extended relationship between buyers and sellers is based on confidence, credibility, and mutual benefit. The buyer, on its part, provides long-term contracts and assurance of only a small number of competing suppliers. In reciprocation, the seller implements customer's suggestions and commits to continuous improvement in the quality of product and delivery (Best and Neuhauser, 2005).

2- PDCA Cycle

This is the second element of Hassan's Approach. PDCA cycle is the tool proposed by Hassan Hamwi, being the widely approved quality management tool. Any organization that intends to achieve high quality services or products has to put the four steps of PDCA cycle within its priorities. PDCA cycles steps are:

Plan: During the planning phase, every detail in the production process should be specified and planed, starting from the source and inputs, through the required standards to be applied and followed, till specifying the lower and the higher limit of the product quality(Johnson, 2002).

Do: to apply what was planned and to execute after gaining precise data, and to improve the quality of the data where necessary (Johnson, 2002).

Check: to re-study the whole process and measure the success by analyzing the result and facts, and also to check if everything is done according to the plan. That's by verifying that work is executed as planned; if yes, then a further effort and development must be done to enhance the work even more. If it's not done according to the plan, points of defect must be investigated and corrected (Johnson, 2002).

Act: In the Act stage, every organization has to ask itself if the process can be planned in a better way, and to optimize the current process, also to study the new plan according to Deming's eight concepts (Johnson, 2002).

3- The Golden Rule

This is the third element of Hassan's Approach, whichcollectively summarizes the all the previous elements into a simple one-line Golden Rule. Following the Golden Rule helps an organization to reach its quality target (Joubert, 1998).All employees as well as the leader in an organization should understand and believe in the Golden Rule:

"Write what you will do, Do whatever you wrote, Check, and then Act"

4- Guideline

After building a solid foundation of corporate culture, learning the basic ethics and principles, setting the necessary tools, and understanding the Golden Rule, an organization will be ready to seamlessly implement any proper documented guideline into practice, which brings us to the fourth element of Hassan's Approach where it is noticed that this is when the employees actually start practically executing what they have believed and learned so far into the adopted guideline. Each organization can select any of the eighteen ISO MSS Management System Standards (or any other guideline, like GxP of FDA …), and pick one or more that fit with its management development objective, system and mission in order to apply it as a standard guidelines, and train its employees to follow and maintain it. Each ISO MSS has its own requirements that must be applied to ensure the quality through the whole system and the Hassan's approach and steps was already prepared the company to implement, maintain and continuously developed in a best corporate culture environment.

5- The Five Partners of Quality

This is the first, last and most critical element of Hassan's Approach. The Five Partners of Quality are all the interested parties involved in the Management System (Goetsch and Davis, 2014). High quality products and services require a good corporate culture, corporation and satisfaction of all the parties that participate in production, and consuming and use of the products and services. Hassan's Approach clearly identifies the main objective of the QMS implementation process; being the 'Satisfaction of the Five Partners of Quality'. Thus, the implementation of any Quality Management System cannot be declared 'successful' unless the quality expectations of each of the Five Partners of Quality are adequately met. These partners are;

- **Customers:** Expect certain services on certain quality level with respect to the time, place, quantity, and quality.

- **Workers:** Expect improvement in their abilities to maintain their job quality, and to be promoted and praised for their achievements.
- **Leadership:** Expect achieving their objectives, creating an excellent reputation of their organization with a continual improvement and maximizing productivity with minimizing costs.
- **Supplier:** Expect to receive clear, detailed and specified requests to avoid any probable confusion. Also expect fair prices and strong, long-lasting relationship with their clients
- **Society:** Expect ethical and moral communication with support community development and environment-friendly organization. Also expect to provide job opportunities.

Hassan’s approach contains all the required steps that are necessary to be applied and followed by any organization that seeks to improve its services and products’ quality. Understanding this approach will establish ‘Quality Performance’, which guarantees less failure and less losses in effort and cost to any organization.

Case study: The contribution of Hassan’s Approach in the implementation of Road Traffic Safety Management System in Alfa Telecom according to ISO 39001:2012 - Hassan’sApproach was applied as a methodology facilitating the implementation of RTSMS according to ISO 39001 international standard. Concrete steps to establish RTSMS in Alfa are:

Implementation of a RTSMS with IMS2 Methodology

Considering the well-documented benefits of implementing a Road Traffic Safety Management System based on ISO 39001 makes the proposal easier to decide on.Most companies now realize that it is not sufficient to implement a generic, “one size fits all” road safety plan. For an effective response, with respect to maintaining the Road Traffic Safety Management System, such a plan must be customized to fit to a company. A more difficult task is the compilation of an implementation plan that balances the requirements of the standard, the business needs, and the certification deadline.There is no single blueprint for implementing ISO 39001 that will work for every company. However, there are some common steps that will allow a company to balance the frequent conflicting requirements and be prepared for a successful certification audit.

Recognizing the necessity of adopting such a flexible and customizablemethodology for implementing a management system, Qualitas International Certification Ltd. UK., the leading certification body/registrar world-wide Quality organization, training providerand consultant, has further developed the “Integrated Implementation Methodology for Management Systems and Standards (IMS2)”[http://qualitascert.co.uk/about.php]. IMS2 is based on applicable best practices and PAS 99 Guide Line and the guidelines of ISO System Standards (MSS),while it meets the requirements of ISO 39001 (Karapetrovic, 2002). Table 1 demonstrates the key points to implementing IMS2.

Table 7 – Elements of each stage of PDCA Cycle.

Plan	**Do**	**Check**	**Act**
1.1 Initiating the RTSMS	2.1 Organizational Structure	3.1 Monitoring, Measurement, Analysis and Evaluation	4.1 Treatment of Non-conformities
1.2 Understanding the organization	2.2 Document Management	3.2 Internal Audit	4.2 Continual Improvement
1.3 Analyze the Existing System	2.3 Design of Controls and Procedures	3.3 Management Review	
1.4 Leadership and Project Approval	2.4 Communication		
1.5 Scope	2.5 Training, Awareness & Competence		
1.6 Safety Policy	2.6 Incident Management		
1.7 Risk Assessment	2.7 Operations Management		
1.8 RTS Performance Factors			

IMS2 is also based on the PDCA cycle, which consists of four phases; Plan, Do, Check and Act. Each phase has between 2 and 8 steps for a total of 18 steps. In turn, these steps are divided into 101 activities and tasks. This ‘Practical Guide’ considers the key phases in the implementation project for a company from start to finish and suggests the appropriate ‘best practice’ for each one, while directing the company to further helpful resources as it embarks on its ISO 39001 journey (Karapetrovic, 2002). Figure 2 shows a layout of the sequence development of IMS2.

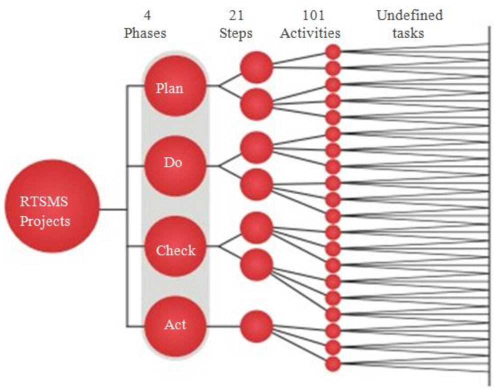

Figure 13 – A diagram demonstrating the stepwise progression of IMS2 during the practical implementation of RTSMS Projects.

Interestingly, the sequence of steps can be changed (inversed, merged). For example, the implementation of the management procedure for documented information can be done before the understanding of the organization. Many processes are iterative because of the need for progressive development throughout the implementation project; for example, communication and training.

By following such a flexible, company-customizable structured and effective methodology, an organization assures all minimum requirements for the implementation of a management system is covered. For any methodology to be most effectively applied, it is highly recommended that the organization adapts it to its particular context (requirements, size of the organization, scope, objectives, etc...) and not to apply it like a cookbook.

Concrete steps to establish traffic safety in Alfa

Focus on concerned parties – Alpha contributes to the delivery of an awareness message to the largest group of Lebanese, knowing that the company as a mobile operator wishes to use its services more by subscribers but has made the right decision to save the human being.

As part of its role as a responsible company for the community, several road safety awareness campaigns have been launched with associations with other parties such as Kon Hadi and the National Traffic Safety Council from 2013 until now .

Participation with suppliers – In the beginning of 2015, the company's commitment to the Lebanese International Academy for Traffic Safety (LIRSA) to improve the fleet of the company "Alpha" and training its drivers to ISO 39001 standards to be the first company in Lebanon and the Middle East to receive the ISO 39001 traffic safety management.

Good leadership – The leadership's commitment to the quality management policy and its announcement by the Chairman of the Board in December 2015:

> "*We are at the beginning of a road that runs thousands of miles and not just a thousand miles. Last September, the United Nations announced its goals for sustainable development for the next ten years, without waiting for local laws, or having suffered more human or material losses to make our commitment to them*".

Continuous Improvement - Alfa's fleet of 120 vehicles has registered only one traffic accident in 2015 and the company is scheduled for 2017 to announce its fleet safe and free from traffic clashes.

Human Resources Participation – Training a thousand employees in the first quarter of 2017, after all the drivers and administrators were trained in the principles of precautionary leadership in 2016 under the supervision of the National Traffic Safety Council.

RESULTS

According to Clause 9 of ISO 39001:2012 (RTSMS), the outcome of RTMS implementation in an organization can be determined by monitoring, measuring, analysing and evaluating the RTSMS, investigating road traffic incidents, and conducting internal audits and management reviews. In reference to the methodology details discussed in the previous section, it was found that applying the novel Hassan's Approach, along with the recently-developed IMS2 strategy, had a tangible contribution to the successful implementation of RTSMS in Alfa Telecom-Lebanon. This success could be measured by observing Alfa's remarkable shift from 'performance' to 'quality performance'. The key benefits of this shift appeared in the creation of new organizational culture, the marked improvement and update of the mechanism of task accomplishment, and the overall improvement of workers' efficiency. Eventually, these benefits were reflected by achieving excellence and significant satisfaction of the Five Partners, being the ultimate goal set in this context.

Impact of adopting Hassan's Approach on the individual employees throughout the implementation of ISO 39001:2012 can be noticed in by measuring the KPI of Alfa Telecom, which shows the rapid and seamless implementation of RTSMS in Alfa, in addition to the measurable changes observed on the employees' culture and behavior concerning road safety. These changes include:

- To leave the phone alone when they are behind the wheel.
- Know and obey applicable traffic laws.
- Take steps to ensure their safety and the safety of their passengers.
- Follow company safe work policies and procedures.
- Make sure their vehicle is licensed, insured, operated and maintained.
- Avoiding exceeding the maximum speed.
- Avoiding driving under the influence of alcohol.
- Putting the helmet on motorcyclist.
- Avoid driving when tired.
- Putting on seat belts.
- Avoiding use the phone when driving.

Moreover, adopting ISO 39001:2012 standards effectively in Alfa will have future benefits in a number of areas, includingprotection of people by reduction of death and serious injury, increase confidence in Alfa and gaining respect of interested parties leading to better understanding of Alfa and protection of its reputation and brand, conformity through regulatory and contract compliance, cost reduction through maintenance of vital activities of the organization while gaining competitive advantage, increase timely delivery of products and services by generating predictable and effective response to road, legal compliance and avoidance of liability actions, and the ability to correctly consider the implications for health and safety legislation and duties of care.

Participation with Suppliers

In the beginning of 2015, Alfa committed to the recommendations of Lebanese International Academy for Traffic Safety (LIRSA) to improve the fleet of the company and train its drivers to ISO 39001 standards, becoming the first Telecommunication Company in Lebanon and the Middle East to adopt the ISO 39001 traffic safety management standard.

Good Leadership

Alfa's leadership committed to the quality management policy, which was announced by the Chairman of the Board in December 2015.

Continuous Improvement through Society

Alfa's fleet of 120 vehicles has registered only one traffic accident in 2015, and the company has scheduled to announce its fleet safe and free from traffic clashes in 2017.

Human Resources Participation

HR participation was represented by training a thousand employees in the first quarter of 2017, after all the drivers and administrators were trained in the principles of precautionary leadership in 2016 under the supervision of the National Traffic Safety Council.

CONCLUSIONS

This article introduces Hassan's Approach, addressed through the recently-developed IMS2 strategy, as novel facilitative tools applied throughout the implementation of RTSMS according to ISO 39001:2012 in Alfa Telecom-Lebanon.

The results showed significant outcome regarding successful shift of Alfa from 'performance' to 'quality high performance', in addition to fulfillment of the satisfaction of the Five Partners of Quality.

These results suggest that the adoption of Hassan's Approach might be of a noteworthy value during the process of management system implementation in an organization.

The successful adoption of Hassan's Approach through is expected to highly improve the outcome of the implementation of a Quality Management System through an organization. Integration of moral values with practical execution of the QMS standard requirements has promising implications on the shifting of the organization's performance from ordinary 'Performance' to 'Quality High Performance' in a smooth manner that is also enjoyable and understandable by the employees. Understanding Hassan's Approach will establish quality high performance, which guarantees less failure and fewer losses in effort or cost.

As a newly-introduced model, Hassan's Approachefficiencyis still limited to the cases it was applied in many Middle East organizations and one in Sweden “ New Life Assurance AB" with a Quality Management Systems implemented.

Naturally, more relevant case studies on more diverse organizations and various management systems are recommended to verify the efficiency of Hassan's Approach. Similarly, comparative case studies could be considered in the future to further explore the variety of response to Hassan's Approach among diverse organizations and different management systems, paying special attention to investigating the possibility of predicting how an organization would respond based on given characteristics of both the organization and the management system to be implemented.

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Theoretical Comparison of Universitary Quality Assurance Maturity Models

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ABSTRACT

Purpose – Internal quality assurance (IQA) systems are nowadays one of the main concerns for modern higher education institutions (HEIs). Several frameworks have been proposed to provide guidance on how to implement such systems. However, little research has been done, so far, on maturity models (MMs) tailored for such realm. To partially cope with this gap, the aim of the present study is to provide a comprehensive comparative review on existing MMs within the domain of QA for HEIs.

Design/methodology/approach – Following an accepted systematic data processing approach for conducting effective reviews, the paper uncovers MMs originated both from academia and practice. Subsequently, they are classified using as a foundation a generic theoretical attribute-based framework for MMs.

Findings – During the study, a total of 18 MMs are identified analysed and classified based on the previous framework.

Research limitations – While being comprehensive in nature, we cannot exclude the possibility of having missed some single relevant MM for the review, which may represent a risk for the achieved results.

Practical implications – The study has practical implications for both researchers and practitioners, by presenting a reference survey of existing MMs for QA in HEIs, and thus, enhancing their transparency and reusability. It also provides basic insights on how to improve future new developments.

Originality/value – To the best of the authors' knowledge, this paper represents the first attempt to develop an in-depth theoretically-oriented comparative review on MMs for QA in HEIs.

Keywords: Quality assurance systems, Higher education, Maturity models, Comparative review.

Paper type: Literature review

INTRODUCTION

Quality assurance (QA) initiatives and policies are currently among the major concerns for higher education institutions (HEIs) around the world (Klenk and Seyfried, 2016, pp. 217–218; Steinhardt et al., 2017, p. 222). Within the scope of the Bologna process in Europe, HEIs have the obligation to set up (i.e. design, implement and monitor) an internal quality assurance (IQA) system based on the standards established at the Part I of the "Standards and Guidelines for Quality Assurance in the European Higher Education Area" (ESG) (ENQA, 2015). The ESG provide a common frame of reference and assistance for HEIs in developing their own IQA system, but are not prescriptive in nature nor provide concrete specifications on its structure and contents (Manatos et al., 2017a). Therefore, HEIs are allowed to "*develop the systems and procedures that are consistent with their own strategic and operational objectives and requirements*" (Kettunen, 2012, p. 525). Therefore and over the last decade, a plethora of time and effort has been spent by quality units in order to design and implement those systems, as central artifacts for HEIs in order to achieve success in their core practices in the provision of teaching and learning as well as to develop an institutional culture of quality enhancement (Sá et al., 2012, p. 171.6).

After several years since the first developments, it could be expected that a maturing of the running IQA systems in several HEIs has occurred (Monkienė and Lamanauskas, 2014, pp. 47–48). Hence, the challenge has shifted now to assess the stage to which IQA systems have been implemented in the different educational settlements. Although several frameworks, procedures and models have emerged from research and practice aiming at measuring (from different perspectives) several aspects of "quality" in HEIs (Dahl Jørgensen et al., 2014; Kamat and Kittur, 2017), few of them lay stress on measuring the maturity or the quality of the IQA system "itself". In this vein, literature reveals that nowadays there is neither an appropriate nor a commonly agreed framework for assessing the maturity of IQA system implementations and thus, calls for further research in this area are increasingly emerging (Hrnčiar and Madzík, 2017; Kamat and Kittur, 2017, pp. 524–525).

To alleviate such gap in research and practice, in this work we present a comprehensive review of maturity assessment models – hereafter referred as maturity models (MMs) – for QA in HEIs. MMs are instruments suitable to "*rate capabilities of maturing elements and select appropriate actions to take the elements to a higher level of maturity*" (Kohlegger et al., 2009). Despite the great number of available MMs as well as their application in a broad spectrum of domains (Becker et al., 2009, p. 214; Wendler, 2012), they still have not gained much attention within the field of QA for HEIs.

Hence, the main goal of this paper is to uncover the status quo of such artifacts as well as to establish a comparative review among them, aiming to identify their main strengths and weaknesses. In such a way, we want to contribute to the current body of knowledge by providing improved understanding on existing instruments for assessing IQA systems implementation maturity in HE. Compared with previous existing reviews on MMs (Duarte and Ventura Martins, 2013; Kohlegger et al., 2009; Tarhan et al., 2016; Wendler, 2012) or in the field of QA for HEIs (Brookes and Becket, 2007; Dahl Jørgensen et al., 2014, 2014; Fischer et al., 2015; Kamat and Kittur, 2017; Manatos et al., 2017b; Steinhardt et al., 2017; Tarí and Dick, 2016), the novelty of our contribution relies on the fact that we use MM theory as a foundation for analysis and comparison. Hence, we contribute by improving understanding and transparency providing an initial abstract reference survey of existing MMs for QA in HEIs as well as a presenting a clear description based on several attributes, and therefore, making them much more communicable, retrievable and reusable for practioners. In addition, our work might also represent a meaningful basis for researchers in order to develop new (and better) MMs for QA in HEIs, based on the deficiencies uncovered in the study. To the best of our knowledge, no similar in-depth theory-based comparative review integrating both streams of research in such an interdisciplinary way has already been done.

The remaining of the paper is structured as follows. First, we provide the theoretical background on MMs, as the main topic of the study. Next, the research methodology adopted for conducting the review is presented and justified. Subsequently, findings derived from literature analysis are discussed in terms of salient structural components and properties of the MMs considered. Finally, we end up the paper with a conclusions and further research section.

THEORETICAL BACKGROUND

In general terms, MMs can be characterized as an organized set of constructs describing the development over time of certain maturity aspects of an entity, or a targeted domain (Kohlegger et al., 2009; Ofner et al., 2015). Such entity could be any object of interest – i.e. a person, a process, a technology, an organizational function or even a social system – describing certain maturity aspects of a targeted design domain (Domingues et al., 2014, p. 2; Mettler, 2011, pp. 83–84). Hence, MMs define a set of sequential and discrete maturity levels for a class of objects representing an anticipated, desired or logical path, from an initial stage to a final maturity stage (Becker et al., 2009, p. 213; Pöppelbuß and Röglinger, 2011, p. 2). MMs can be valuable instruments for organizations as they represent an especial class of dynamic conceptual model capturing and supporting organizational learning and change "*insofar as they represent an instrument for* *decision-makers to assess an organization's actual state, derive actions for improvement, and evaluate these actions afterwards in terms of their effectiveness and efficienc*y" (Ofner, Otto, & Österle, 2015, pp. 4–5).

From a Design Science Research perspective (Gregor and Jones, 2007; Hevner et al., 2004), MMs can be further decomposed into two main structural components (Mettler, 2011; Ofner et al., 2015, p. 6; Tarhan et al., 2016): (i) a (reference) model, which focuses on reproducing the evolution of state descriptions of some aspects of a physical or social reality (i.e. "the what"), acting therefore as a reference schema against which the current status is appraised during an assessment initiative; and (ii) an assessment method (or model), which focuses on the specification of improvement, that may be appropriate activities or procedures to address o achieve a determined set of goals (i.e. "the how"). The assessment method "*is not necessarily unique [and hence] an assessment against a single maturity model can be performed using different assessment methods with varying scope, detail, and precision*" (Tarhan et al., 2016, p. 129) . In addition, (iii) MMs can also take the form of an instantiation, if the underlying MM's reference model and assessment method(s) are operationalized through a prototype or some kind of working system, like an operational software tool (Mettler, 2011). There is no single best way to systematically build and construct a rigorous MM and several theoretical process models are discussed in the literature (Mettler, 2011, p. 89). Finally, authors like De Bruin et al. (2005) or Pöppelbuß and Röglinger (2011) provided notable contributions on theoretically-sound design principles for building MMs, presenting several frameworks that can be used as a theoretical lens to test their applicability and usefulness. In this vein, MMs may be classified as descriptive (i.e. assessing the *as-is* situation), prescriptive (enabling road-map for improvement towards a desired "to-be" position) or comparative (i.e. internal and/or external benchmarking).

RESEARCH METODOLOGHY

To review the current state–of–the–art and –practice of existing MMs for QA for HEIs, we performed a qualitative literature review following the guidelines described by Levy and Ellis (2006) to undertake effective literature reviews. Due to the multidisciplinary nature of our targeted research field (Pratasavitskaya and Stensaker, 2010; Steinhardt et al., 2017), to initially identify relevant literature we opted for an online search strategy including both academic databases as well as regular search engines. With such strategy, we aimed to avoid source bias as well as the omission of potential valuable contributions emerged from praxis (Adams et al., 2016). Informed by previous existing reviews (Manatos et al., 2017b; Steinhardt et al., 2017; Tarí and Dick, 2016), we initially searched for English-written literature though the digital databases/searchers of (in alphabetical order) Emerald, Google, Google Scholar, ProQuest Central, Science Direct, Scopus, Springer Link, Web of Science (WoS) and Willey & Sons. We used the combined keywords *[“quality management” or quality assurance”] and [“maturity”] and [“higher education” or university*]* as a search string in title, abstract and keywords. Since we wanted to identify as many as possible MMs, in favour of inclusivity we did not apply further temporal restrictions to the search. Then, following Webster and Watson (2002), we also traced (forward and backward) the references within the retained resources in order to identify both additional MMs and (primary) relevant sources.The whole search and document collection processes were performed between 10.12.2017 and 23.12.2017.

Perusal of documents yielded from the search made us aware of the existence on several MMs targeted to HEIs, but as initially expected, almost none of them were explicitly tailored to an IQA system. Hence, for the purposes of the review we took a rather “broad view of QA” and as a general criteria we set the research scope to MMs targeting any aspect of the quality of an educational system at institutional level. However, to keep the homogeneity among items to be compared, MMs within a scope with different levels of granularity than institutional (i.e. course- , teaching- or academic library service-oriented MMs) were explicitly excluded.

Moreover, and during the scanning process of documentation retrieved from the search, we also learned that several national/regional QA agencies have developed specific guidelines and hand-on toolkits to assist HEIs in their IQA system’s implementation and certification processes. As we believed that their analysis would be valuable for the purposes of the review, we decided to contemplate them. Nonetheless, as the potential number of relevant proposals could be large, for the present review we considered only contributions from countries like Finland, Portugal or Spain, where particularized “lighter touch” procedures focussed in auditing/certifying HEI’s IQA systems have been conceived (Cardoso et al., 2017, pp. 330–331; Manatos et al., 2017a, p. 343), as they suit perfectly with the main goal of the review. All in all, and notwithstanding the aforementioned limitations, whilst not claiming for the exhaustiveness of the review we believe that the technique used turned to be fruitful in terms of comprehensiveness and the amount of MMs found.

FINDINGS AND RESULTS

In total, 18 MMs were finally considered for analysis on the basis of a total set of 40 reviewed documents (see Figure 1). By considering a heterogeneous set of resources, our study reveals interesting instances of MMs used for QA-oriented issues in HEIs not evident in the academic literature; which in turn, allowed us to study a sample of artifacts similar to comparable field studies (see Table 1). However, peer-reviewed items – articles (8) and conference papers (16) – still represent together 60% of the items reviewed in the paper. In addition, and from a more temporal perspective, many contributions lay within the threshold among 2010-2017 (72.5% of the reviewed sources) which we interpret as a consistent finding with the increasing number of publications in QA for HEIs over the last years.

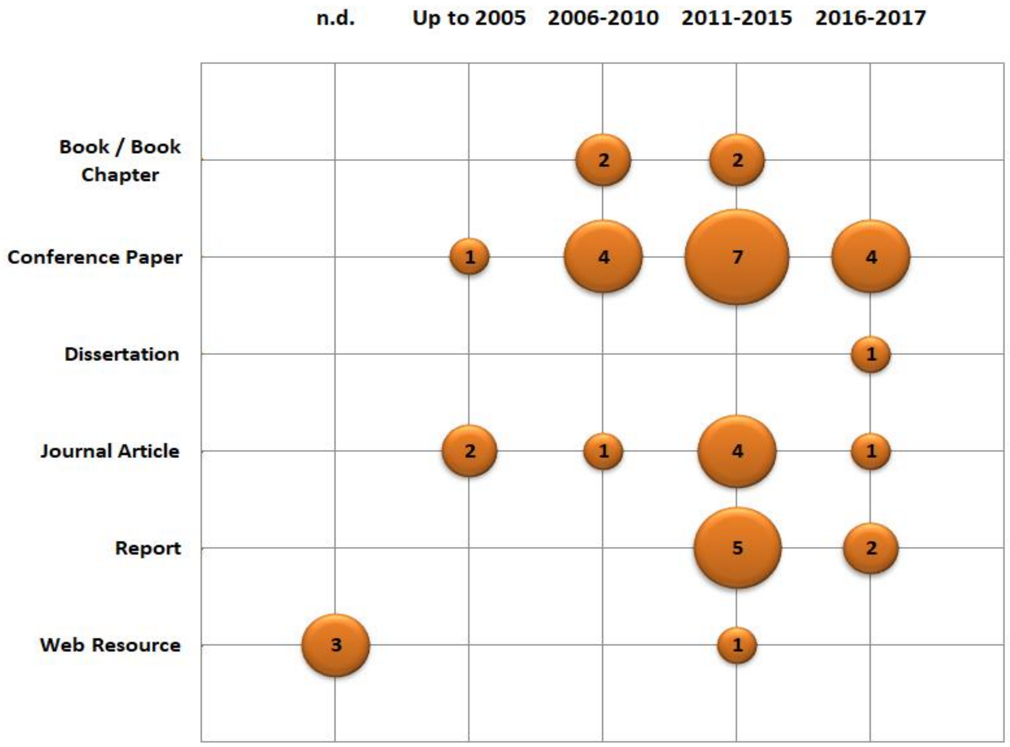

Figure 14 – Reviewed items/documents in the study segmented by type and periods.

DISCUSSION

For the comparison of our selected MMs, we followed a concept-centric approach according to Webster and Watson (2002), as more author-centric oriented approaches tend to fail to summarize existing literature (2002, p. xvi). In so doing, we built our conceptual framework for analysis by drawing on the initial broad scale instrument for characterising MMs proposed by Mettler et al. (2010). We used it as a (theoretical) analytical lens for our comparative purposes, as it defines an attribute-based approach representing the relevant properties of MMs made up of 3 dimensions, namely: (1) *MM general descriptive attributes*, (2) *MM design attributes*, and (3) *MM use attributes*. We slightly modified the original instrument by adapting it on the basis of the content that progressively emerged from the scrutiny of our collected sources. Next, and adopting a rather deductive approach, we categorized and classified all the information retrieved for the identified MMs for QA in HEIs, as shown in Table 2. It reveals the existence of a set of MMs differing from the perspective of the 3 major dimensions that configure the schema chosen for analysis. Due to space limitations, in the remaining of the article we only discuss the results achieved from the aggregate perspective of the 3 main dimensions of the framework. Further details on the individual attribute categorization of each one of the reviewed MMs, the complete description of such attributes and their associated categories, as well as the complete list of the sources reviewed can be found in the additional supplementary material (https://goo.gl/fCsGJG) complementing this paper.

Table 4 – List of MMs reviewed in the manuscript (continues …)

IDENTIFICATION				DEFINITION ATTRIBUTES											
#MM	Maturity Model Name	Acronym	Year	Scope							Origin			Cost	
				QA System-oriented	Educ. System-oriented	General issue /adapted	Specific subject-matter	Local	Regional / national	International	Academia	Practitioners	Government	Free	Charged
1	University of Žilina Education Quality Self-assessment Tool	–	2017	■			■	■				■		■	
2	Common Assessment Framework – Education	CAF/EFQM	2000/13	■		■				■		■	■	■	
3	Technical University of Madrid Generic Maturity Model	–	2009	■			■	■				■		■	
4	Quality Assurance Maturity Model	–	2013	■			■		■				■	■	
5	Education Quality Work - Maturity Ratings	EQW	1997/2010	■			■			■			■	■	
6	ASIIN Maturity Model	–	2016	■			■			■		■		■	
7	Quality Assurance and Enhancement Marketplace European Project Model	QAEMP4HEI	2014	■			■			■		■	■	■	
8	A3ES Portuguese Auditing IQA Systems Model	A3ES	2013	■			■		■				■	■	
9	AQU Cataluña IQAS Certification Model	AQU	2015/16	■			■		■				■	■	
10	Audit framework of the quality systems of HEIs in Finland	FINHEEC	2008/15	■			■		■				■	■	
11	Educational Capability Maturity Model	E-CMM	2006		■		■			■	■			■	
12	Academic process improvement implementation Maturity Model	–	2007		■		■			■	■			■	
13	Capability Maturity Model for Engineering Education System	E^2-CMM	2010		■		■			■	■			■	
14	Engineering Education Capability Maturity Model	EECMM	2004		■		■			■		■		■	
15	Maturity Model for Learning Ability in Engineering	–	2009		■		■			■		■		■	
16	SPICE-conformant Education Capability Maturity Model	EduSpice	2012		■	■				■		■		■	
17	CDIO educational framework	CDIO	2001/2015		■		■			■	■	■		■	
18	Maturity Assessment of Strategy Implementation in HEIs	–	2016		■		■			■	■			■	
∑	–	–	–	**10**	**8**	**2**	**16**	**2**	**4**	**12**	**5**	**9**	**7**	**18**	**0**

Table 1 – List of MMs reviewed in the manuscript (… continued)

	DEFINITION ATTRIBUTES																	USE ATTRIBUTES							
#MM	**Concept of maturity**			**Composition of the model**				**Architecture typology**					**Maturity principle**			**Reliability**		**Disse-minat.**		**Support application**			**Practicability**		
	Process-focussed	Object-focussed	People-focussed	Maturity levels	Descriptors	Level description	Assessed items	Grid/ / textual description	Likert-like questionnaire	Hybrid model	Structured CMM-like	Unclear	Staged	Continuous	Unclear / others	Evaluated	Explicitly theory-based	Open	Exclusive	No supporting materials	Textual description or handbook	Software assessment tool	Implicit improvement activities	Explicit recommendations	Unclear / not defined
1	■			5		■	17					■			■			■		■					■
2	■	■	■	5	■	■	80		■					■		■		■				■	■		
3	■			5	■	■	N/A					■			■			■		■					■
4	■			5	■	■	N/A				■		■					■			■			■	
5	■	■		5	■	■	N/A			■				■				■			■		■		
6	■	■	■	5	■	■	167			■				■				■			■		■		
7	■	■	■	6	■	■	28x6	■						■		■		■				■	■		
8	■	■	■	4	■	■	13x4	■						■				■			■		■		
9	■	■	■	3	■	■	24x3	■						■				■				■	■		
10	■	■	■	4	■	■	12x4	■						■				■			■		■		
11	■			5	■	■	N/A				■		■					■		■				■	
12	■			5		■	N/A				■				■			■		■					■
13	■			5	■	■	234				■		■	■		■		■			■			■	
14	■			5	■	■	N/A				■		■					■		■				■	
15	■	■		5	■	■	N/A				■		■					■				■		■	
16	■			6	■	■	72				■			■				■		■			■		
17	■	■		6	■	■	12x6	■						■		■	■	■			■		■		
18	■			5		■	N/A				■		■	■				■		■			■		
∑	**18**	**9**	**6**	**—**	**15**	**18**	**—**	**5**	**1**	**2**	**8**	**2**	**6**	**11**	**3**	**4**	**1**	**18**	**0**	**7**	**7**	**4**	**10**	**5**	**3**

General attributes of MMs

From the perspective of the definition attributes that characterize a MM, the *scope* defines to which concrete domain it is targeted and applied. Scope also allows to explicitly distinguish a MM from other existing similar ones. Broadly speaking, in terms of the *focus or breadth* 10 of the 18 uncovered MMs (#MM1-10) could be targeted as frameworks oriented to assess or measure the maturity of a HEI's IQA system; whilst the remaining 8 (#MM11-18) could be considered as more directed to measure the quality (in global terms) of the processes that conform and educational HE system. Regarding the *depth* or *level of analysis*, nearly all of the reviewed models are specific subject-matter MMs, except the CAF/Education Model (#MM2) and the EduSpice MM (#MM16) representing in both cases an adaptation for the education domain of generic MMs. In terms of *range of application*, the MMs studied have been mainly built with the aim of being applied at national or international level rather than for being used locally or in a particular institutional context.

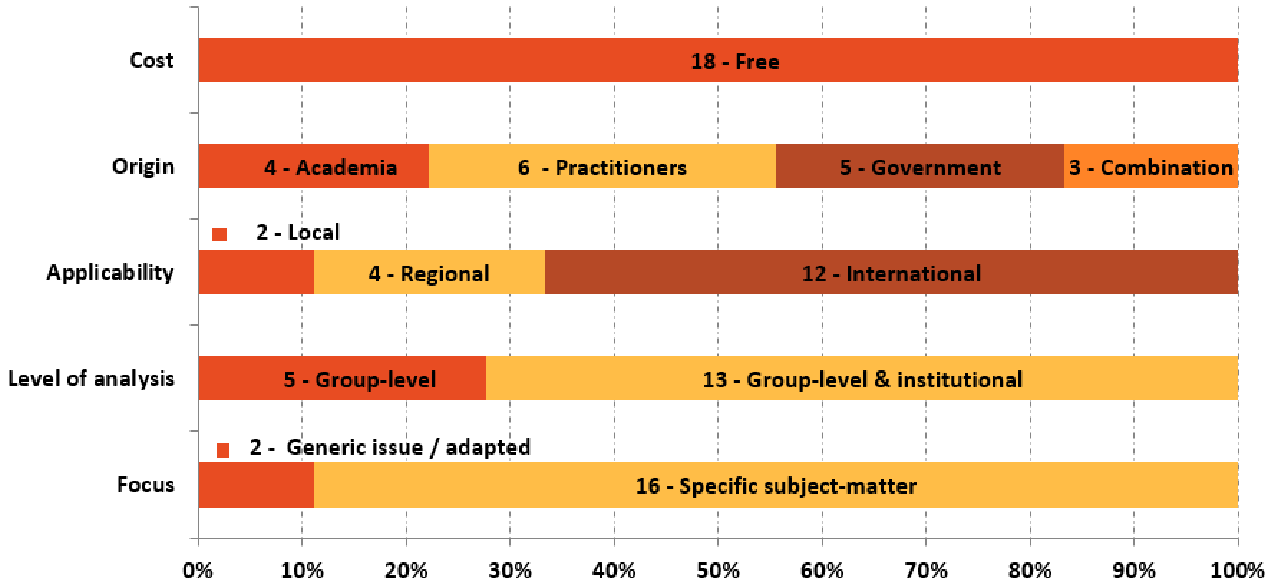

Figure 15 – Global results for definition attributes.

In terms of the *origin* of the analysed models, the documentation picked up revealed us a relatively acceptable balance among practitioner- and academia-originated models. Caution should be taken, however, in this interpretation as it may be argued that in HEIs an individual can easily play a role both as a practitioner (i.e. participating actively in QA oriented activities) as well as an academic (i.e. teaching and research activities). In addition, and as it was expected, a clear tendency of government-originated models can be detected if we exclusively focalize our attention upon the subset of models oriented to measure the maturity of a HEI's IQA system (#MM1-10), as they are usually sponsored or proposed by QA bodies or agencies. A common pattern also discovered during our analysis was that the *target audience* of the proposed MMs is frequently omitted in the documentation distributed for disseminating the models. Thus, future developments should explicitly address this issue identifying clearly to whom is devoted the proposed MM. Finally, and to conclude with this set of definition attributes, we also found that all the MMs reviewed in the study are freely available with no paying or *cost*.

Design attributes of MMs

MMs can be communicated in a two-dimensional way (Netland et al., 2007, p. 4), where one axis describes the items to be measured for maturity (i.e. *concept of maturity*) and the other one outlines the degree of maturity (i.e. *goal function*). Under such premise, our analysis revealed a clear over-emphasis in terms of process-focussed definitions of the concept of maturity as all reviewed MMs include such dimension. If we exclusively consider those MMs specifically directed to assess the maturity of an IQA system, things differ notably. This subset of MMs presents a more holistic approach by combining process-, object- and people-focussed aspects for conceptualizing maturity to be measured. A deeper content analysis of the concrete MM's dimensions would probably provide us with additional insights in this vein, but this is beyond the scope of this paper.

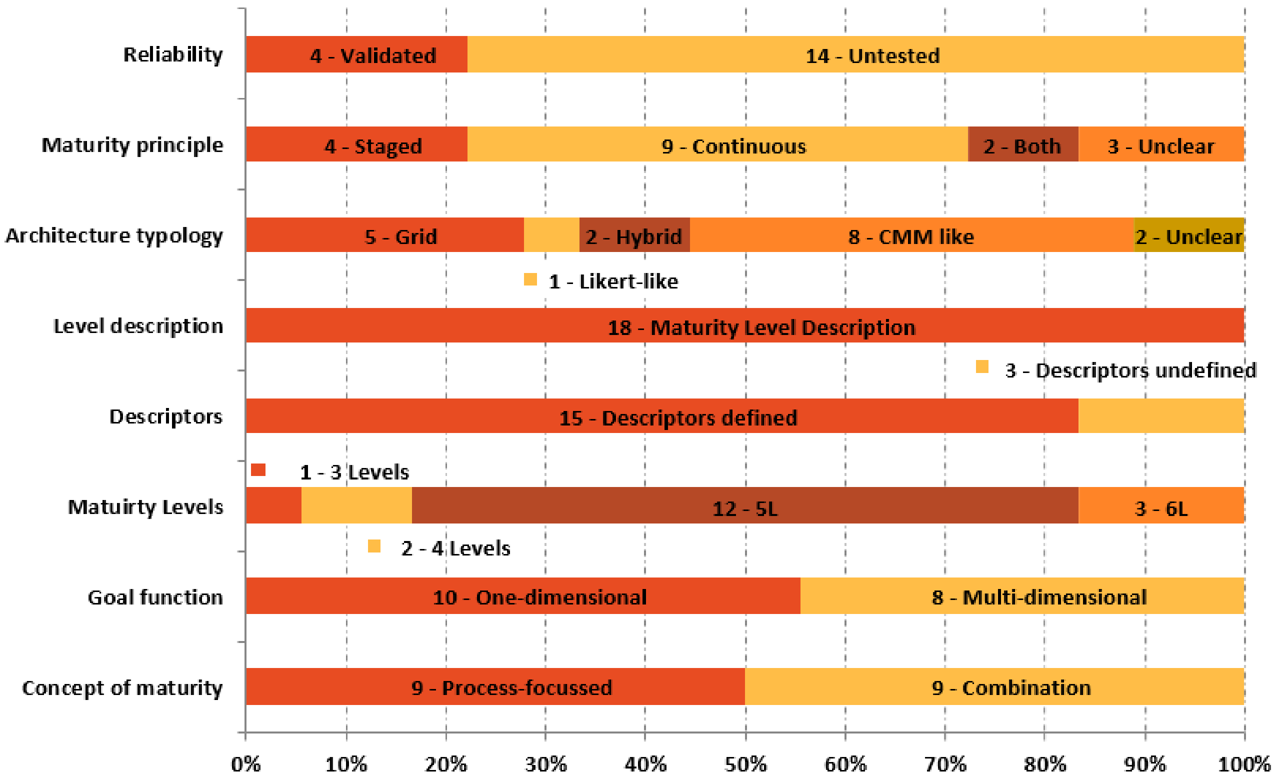

Figure 16 – Global results for design attributes.

Regarding the *composition of the models*, our scrutiny showed us a great level of homogeneity in terms of the *number* of defined *maturity levels*, as well as their associate *level's descriptor* and *description*. The number of maturity levels defined by the models ranges from 3 to 6 and two thirds of them define 5 maturity levels. All frameworks provide the pertinent maturity level description and only 3 models (#MM1, #MM12 and #MM18) do not define an associate level descriptor. Unfortunately, in most cases such maturity level descriptions tend to be rather descriptive and somewhat vague or imprecise. Therefore, they usually do not provide useful prescriptive information in terms of what to do in order to improve or step up to greater levels of maturity. Finally, and in terms of *maturation path*, we also found a tendency in favour of posing continuous-oriented MMs, with only 2 models allowing simultaneously continuous and staged configurations (#MM13 and #MM18).

Previous homogeneity cracks noticeably when we turn our attention to the concrete *architecture type* as well as the *design procedure/process method* followed for the conception of the MMs. On the one hand, we discovered that in the 45% of the cases, proposed MMs are just no more than a simple derivation of already existing CMM-like models (Ahern et al., 2008), but tailored to the particular domain of HEIs. Such pattern can be mainly associated to the subset of models directed to address the quality of an educational system (#MM11-18). Moreover, such a derivation-process is commonly undertaken in a rudimentary or sketchy way, leading to quite simple or incomplete CMM-like MMs, remaining on a very abstract level of detail. Furthermore, as in many occasions these models do not define concrete items for assessment, their practical utility and applicability in real contexts becomes extremely compromised.

On the other hand, another 38% of the studied MMs can be characterized as textual grids or either as a hybrid configuration between textual grids and Likert-like questionnaires. In this case, they could be more related with the subset of MMs oriented to address the quality of IQA systems (##MM1-10). From an architectural point of view, their structural architecture can be resumed as follows: first, a set of dimensions (commonly from 9 to 12) are fixed in order to configure the boundaries of the practices and processes related with an institutional IQA system. These dimensions are commonly related to a standard, which is taken as a reference point for constructing the reference (assessment) model. Second, a text-based grid (rubric) is defined in order to check and assess the maturity of factors belonging to each dimension, and within a higher or lower level of granularity depending on the concrete model. From the perspective of MM's theory and practice concerns may arise regarding such architectural configuration: on the one hand, it does not take into account possible inter-dependencies among the distinct constitutive dimensions of the MM, nor on how the maturity of each impacts in the aggregate resulting maturity; on the other hand, its reference model does not provide much information on the dynamics or the possible paths of the evolution of the IQA system's maturity as a whole. In other words: whilst structural simplicity of maturity grids or textual MMs generally can play a positive role in terms of usability of the MM, our perception is that such architectural configuration rather limits the potential of these MMs as decision-making tools for improvement – which is one of the main *raisons d'être* of a MM –. Hence, we clearly see these MMs as descriptive frameworks for assessing the current situation in terms of conformance to a standard; but we appreciate in them less "prescriptive power" in order to derive actions and measures for continuous quality improvement.

Finally, our findings also disclosed that few quality-oriented MMs for HEIs have been developed using a theoretically-sound design procedure, which can be interpreted as an indicator of lack of rigour. Such lack of rigour can also be perceived in terms of the *reliability* of the reviewed MMs as formal validation is rarely addressed (see Table 1) far away than simple illustrative assessments in the form of case studies or surveys. We noticed this latter pattern especially for MMs based on textual-oriented forms and maturity grids formats.

Usage attributes of MMs

As already suggested, our analysis revealed that MMs under study provide a moderate support in terms of their practical use and applicability. A deeper analysis in terms of *practicability* can provide us with additional insights in this sense.

Concretely, we identified 5 MMs providing explicit recommendations for improvement. According to data in Table 1, this subset of MMs can be mainly archetyped as (i) staged-based models, with a (ii) process-focussed conceptualization of maturity and (iii) for being directed towards addressing the quality of an educational system. Consequently, although they provide clear and concrete explicit recommendations for improvement, they just have a limited span of coverage, as they are only circumscribed to process-oriented efficiency improvement measures.

On the contrary, those MMs with a scope more centred on measuring IQA systems maturity tend to be more (i) textual grid-oriented, (ii) based on a continuous path of maturity evolution, and (iii) having a more comprehensive conceptualization of maturity, considering several dimensions of analysis and taking into consideration the complexity of a HEI's IQA system. Our view is that this subset of MMs just offers implicit generic recommendations for improvement, often inferred from their own subjacent architectural or their measurement scale's structure. Next, additional actions should be undertaken to appropriately contextualize such measures before being effectively applied in a concrete educational settlement. Furthermore, the information regarding the relative priority of execution of measures derived from a MM is always less clear in continuous-oriented models than in stageds one.

Whatever the case, and considering again the whole set of MMs, high levels of abstraction or low levels of granularity should be considered as inhibitors in terms of practical use and applicability.

Regarding the *method of application*, we found no MM that formally required third-party assessment or serving exclusively for certification; although it must be noted that artifacts born under the auspices of governmental QA agencies were sometimes conceived as rather supporting toolkits devoted for external accreditation/audit panels. Given the fact that all MMs are freely available, we assume that (at least) some kind of self-assessment should always be possible. Finally, the reviewed MMs often fall short in providing helpful guidelines/handbooks as well as software toolkits in order to *support the practical application* of the MMs. Concretely, we only found evidence for 4 MMs (#MM2, #MM7, ##MM9, #MM15) incorporating some kind of automated artefact for speeding up such assessment.

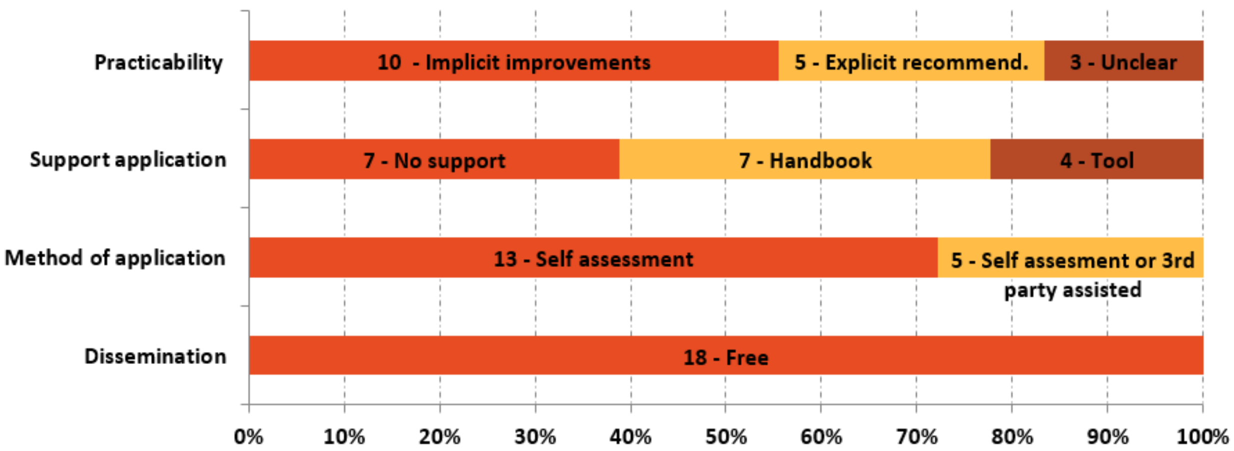

Figure 17 – Global results for use attributes.

To sum up, we conclude that our study pinpoints room for improvement in terms of the realization of prescriptive design principles in MMs targeted for QA in HEIs. To be fair, however, we must acknowledge that the lack of prescriptive support for practical application is a common criticism found in the specialized literature in MMs, highlighting that it applies to most kinds of existing models, independently of their concrete scope or domain of application (Becker et al., 2009; De Bruin et al., 2005; Mettler, 2011).

CONCLUSIONS, LIMITATIONS AND OUTLOOK

In this paper, we have provided an overview of the current state of conceived MMs targeting the domain of QA for HEIs. Using Mettler's and colleagues' well-accepted framework for comparing MMs as an analytical lens, we identified and documented up to 18 different MMs. Our initial findings reveal a certain degree of structural heterogeneity among them, as well as an excessive level of abstraction in the concrete configurations and definition of the models. Furthermore, notable concerns arise in terms of design rigour or with the practical utility and applicability of the evaluated MMs.

Several limitations may be considered in the present study. On the one hand, the classification presented in this paper should not be considered definitive. Hence, the analysis performed could be extended by either considering additional attributes included in subsequent versions of the analysis framework employed or by using generic design principles for MMs as the reference analytical lens. In addition, a comparative analysis in terms of content of the MM's dimensions and the underlying maturity constructs could also have help to extend the obtained results regarding their comprehensiveness and level of detail. On the other hand, potential limitations derived from the research methodology employed should also be considered. The use of a relatively specific search query may have omitted other relevant search terms, being therefore inherently incomplete. This fact, combined with a rather restrictive exclusion criterion adopted for selecting information sources and the MMs to review, could have resulted in missing some (single) relevant model in the results produced. Finally, and given the subjective nature inherent to any literature review, concerns regarding interpretive validity of the sources analysed might also arise. Whatever the case, we feel confident on the comprehensiveness of the undertaken review, covering a large amount of publicly available MMs tailored for QA issues in HEIs.

Moreover, we believe this work could also be valuable for researchers. Our study puts forward that there is a tremendous room for future investigation in MMs for QA in HEIs. Such research should pay special attention on the theoretical foundation of the envisioned MMs, as for example, grounding their structural configuration on well-accepted (design) theories (Gregor and Jones, 2007). This will lead to more innovative and well-suited artifacts for continuous quality enhancement, which, combined with current IQAs accreditation/certification practices, could be useful for quality policy-makers in HEIs as, inter alia, flexible, simple, cost and time-effective diagnosis/decision tools for better managing their institution's IQA systems during the temporal intervals between external-oriented evaluation rounds. In this vein, our future work will concentrate on envisioning such an artifact in the form of a focus-area MM for assessing the maturity of running IQA systems implementations in different HEIs.

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Quality and innovation in the hospitality industry: A literature review

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ABSTRACT

Purpose – The purpose of this paper is to determine the enablers of quality and innovation management in the hospitality sector.

Design/ methodology/ approach – This work is based on an extended literature review that was conducted by using the phrases service innovation, service quality, tourism and hospitality as keywords. Emerald, Scopus and Tailor and Francis are some of the databases used in order to have access to high ranked journals.

Findings – This paper presents the findings of a literature review about quality and innovation management enablers in the hospitality industry, which lead to specific conclusions about what influences both quality and innovation in a global sector like hospitality.

Research limitations – The findings of this work are based solely on the results of previous researches. Consequently, the paper's research questions need to be empirically validated in a quantitative or/and qualitative future research.

Research implications – This paper expands the theoretical links between service innovation and service quality in the hospitality sector.

Originality/ value: There is still a lack of theory-based frameworks in the literature regarding service innovation in the hospitality sector. The main contribution of this paper is that it links service innovation and service quality management in tourism, which opens up new, promising avenues for further research.

Paper type: Literature Review

Keywords: Innovation Management, Quality Management, Hospitality

INTRODUCTION

The tourism sector is one of the most growing and dynamic sectors worldwide (Metaxas and Koulouriotis, 2017; de la Pena et al., 2016; del Mar Alonso-Almeida et al., 2011). Competition and economic crisis force firms in the tourism sector to adapt to the constantly changing environment. Especially the hospitality industry is the largest sub-category of tourism (Pappas,2015) and demands a constant upgrade in order to achieve long term stability and profitability (Ottenbacher,2007). However, despite the sectors' importance in the global economy, specific hospitality and tourism theories and models are scarce (Baker and Magnini,2016).

The combination of innovation and quality is considered by many authors to be the best way to gain competitive advantage in the tourism industry (Souto,2015; Nicolau and Santa-Maria,2013; Metaxas and Koulouriotis,2017; Campo et al.,2014), since service quality alone cannot ensure customers' satisfaction. Service innovation is a popular strategy for decoding the information gained from customers, competitors and the firm itself (Bettencourt et al.,2013). According to Chang et al. (2011), hospitality organizations attain to improve their products' quality; reduce costs; increase efficiency, sales and profits; eavesdrop their customers' needs; gain larger market segment; and stand out from their competitors.

Considering the importance for the hospitality firms to be innovative, some researchers attempted to examine and further understand a variety of facets of the hospitality innovation (Nicolau and Santa-Maria,2013; Camison and Monfort-Mir, 2012; Campo et al.,2014). Nevertheless, many authors notice that there are certain literature gaps in terms of hospitality and tourism theories, models, frameworks and practices (Bakes and Magnini, 2016; Chen,2017; Ottenbacher,2007; Hjalager,2010; Chang et al, 2011; Camison and Monfort-Mir,2012; Martinez-Roman et al.,2015). Consequently, more empirical investigation and quantitative knowledge is needed in order to identify the determinants of innovation in this sector (Souto,2015; Nicolau and Santa-Maria,2013; Qin et al,2015; Martinez-Roman et al.,2015).

In the struggle to remain competitive in such a complex and global sector, service quality is the main asset for a hospitality business (Eraqi,2006). However, implementing quality practices alone doesn't guarantee the same quality deployment and firm performance in all cases (Llach et al.,2016). This may happen, by virtue of the customers' heterogeneity and the way each management team interprets quality management (Llach et al., 2016). Although competitive differentiation can be achieved through service quality (Crawford,2013), Calvo-Mora et al.(2013), cited 18 different quality management factors that are repeated in studies, and none of them have the same effect on the firm's performance.

Different authors use different patterns to study quality and innovation management in hospitality, complicating the creation of a single framework. In line with the aforementioned observations, the following research questions are formulated:

RQ1: What factors (enablers) influence quality management in the hospitality industry?

RQ2: What factors (enablers) influence innovation management in the hospitality industry?

Thus, the objective of this paper is to determine the enablers of both quality and innovation management in the hospitality context, aiming to reveal those factors that are most frequently used in literature and are common to most studies.

RESEARCH METHODOLOGY

The research conducted in order to achieve the above aim consisted of two phases: (1) a literature review to gather all relevant information and data and (2) a careful analysis and processing of the information that was gathered. The first phase started by setting the main pillars under study. The next step included searching and selecting the related papers and journals from online databases. A keyword-based search was implemented using electronic databases and library services. The papers were either downloaded from the "Emerald", "Elsevier", Springer", "Science Direct", "Scopus" and "Tailor and Francis" databases, or directly requested from their authors via "Research Gate". The search yielded 170 papers, based on abstracts and keywords. The full text of the papers was then reviewed in order to eliminate those articles that were not related to this paper's subject, leading to a total number of 56 papers for further examination.

Considering that this study is oriented toward a specific sector, most journals searched are specialized on tourism and hospitality, like "Tourism Management", "Annals of Tourism Research", "Cornell Hospitality Quarterly", "International Journal of Hospitality Management" etc. The keywords used alone or in combination to search for articles were: quality management, service quality, innovation, innovation management, service innovation, performance, business excellence, tourism, hospitality and hotel industry. No paper was found to combine all three areas of interest (quality management, innovation and hospitality). Instead, papers were selected from either one or combinations of two of these areas.

The information that responded to the research's goal was carefully organized, in order to answer the basic research question and draw substantial conclusions. First, it was noticed that the various authors in literature do not use a common terminology about the factors that influence quality and innovation management. In order to identify and decode the authors' different points of view, an affinity diagram was created. The data collected were arranged into two groups of common themes, namely Quality Management Enablers and Innovation Management Enablers. The goal was to encompass in these categories every quality and innovation enabler that was used in previous researches in the hospitality industry. The findings are gathered in tables and presented in the next section.

RESULTS

Innovation and Quality in Hospitality

In the tourism context, competition is not limited in specific geographical borders (Souto,2015). In such a saturated and hectic sector like tourism, being oriented toward innovation and quality is the most prosperous strategy (Binder et al., 2016). This allows the firm to exploit every opportunity and turn it into success (Chen,2011). Regarding results, much has been published about the individual effects of quality and innovation on hospitality business performance. Nevertheless, there is no consensual approach about how quality and innovation interact in order to influence financial and organizational performance. No answer can be given, unless quality management and innovation enablers are foremost determined. In this context, the aim of this review is to specify these enablers through an assessment of the related literature.

Quality Management Enablers in Hospitality

Implementing quality practices is the fundamental way to ensure managerial success in the long run in this sector (LLach et al.,2016). Many authors studied the effects of quality practices on performance in the hospitality industry, both individually and comprehensively. In order to express the elements that facilitate quality management each author used a different terminology, like critical factors (Avcikurt et al.,2011; Alvarez-Garcia et al.,2017), readiness factors (Arasli,2002), enablers (Benavides-Velasco et al.,2014; Benavides-Chicon and Ortega,2014), determinants (Yadegaridehkordi et al.,2018) etc. In this study, the term enablers is used, according to the EFQM model. In the remaining of this section the enablers found in the hospitality literature are presented and, in the end, summarized in Table 1.

Leadership is considered to be one of the most important enablers of quality management, as it is related to the culture, vision, mission and goals of the firm (Arasli,2012). Skillful leaders create harmonious and a peaceful environment in the organization context (Amin et al., 2017), which helps the establishment of a good relationship with the employees (Yadegaridehkordi et al.,2018), the customers and all the interested parties (Arasli,2002). Hence, successful leadership leads to stakeholders' satisfaction (Benavides-Velasco et al., 2014). Arasli (2002) and Wang et al. (2012) used long term quality plans, sufficient quality goals, motivating employees and striving for change as leadership determinants. Other researchers used the level of the directors' involvement in continuous improvement, meetings, seminars, training programs on quality and excellence, professional associations, actions to recognize and award the employees' performance (Benavides-Velasco et al.,2014; Benavides-Chicon and Ortega,2014). In addition, Alvarez-Garcia et al. (2017) focused on managing the quality program and reviewing the results; communicating the quality commitment to the staff; encouraging the employees to implement changes and make their own decisions; motivating the personnel and helping them to fulfill their work at a high level; appreciating the employees' efforts and improvements; maintaining contacts with customers, suppliers and other external agents anticipating to alliances and improvement actions; and, finally, identifying, promoting and reviewing changes that are aiming to improvement.

Human capital is the most highlighted quality management enabler in the hospitality literature. In this sector, having the appropriate personnel entails better possibility of success (Amin et al.,2017) and implementing the right practices can create more quality oriented attitudes and improve employee satisfaction (Llach et al., 2016). While handling in the right way the human capital is commonly known to be essential, there are many different perspectives of the appropriate way to do so. The most referred enablers in the literature are training, teamwork, empowerment, motivation, employee fulfillment and participation. Indicatively, Benavides-Velasco et al.(2014) used the following determinants in their research: the frequency of developing quality training programs; the level of employee involvement and responsibility in quality issues; the level of improvement of the employees' knowledge of topics related to safety and health at work; and the environment through diverse communication means. Alvarez-Garcia et al.(2017) focused on whether human resources management is aligned with the firm strategy and plans; the management and employees are trained on quality principles; the employees are trained in problem solving skills, teamwork and adjustment in future plans; the staff is encouraged to make decisions and be responsible; the employees' performance is evaluated and rewarded; the personnel is communicating at all levels; and evaluations on human resource management are implemented.

Partnership and resources are related to the collaborations and alliances that a firm can establish, with intermediaries (Molina-Azorin et al.,2015;, Wang et al.,2012; Tari et al., 2010; Pereira-Moliner et al.,2016), suppliers (Benavides-Velasco et al, 2014; Llach et al.,2016; Molina-Azorin et al., 2015; Bagur-Femenias et al.,2014; Wang et al., 2012; Tari et al.,2010; Amin et al.,2017; Pereira-Moliner et al.,2016) and even customers (Llach et al.,2016; Bagur-Femenias et al.,2014).

Managing resources according to quality principles is equally important for the hospitality industry (Alvarez-Garcia et al., 2017; Benavides-Velasco et al, 2014; Benavides-Chicon and Ortega,2014).

Quality management is mostly associated with the organizational and administrated part of a company (Prajogo et al.,2006) and it can help firms improve their market share and competitiveness (Molina-Azorin et al.,2015). One of the most important drivers of quality management is quality commitment (LLach et al.,2016), as the lack of commitment by both top management and employees can hinder its success. This explains the frequency of using the associated enablers in the hospitality literature, like communicating quality policy (Molina-Azorin et al.,2015; Pereira-Moliner et al.,2016), upper management commitment (Claver-Cortes et al.,2008; Bagur-Femenis et al.,2014), quality culture (Bagur-Femenis et al.,2014) and quality policy/planning (Alvarez-Garcia et al.,2017).

The hospitality industry is utterly customer-oriented and its main objective is to create the best possible experience for the guests. Hospitality customers evaluate all components of a travel experience in order to decide whether their expectations were met (Dortyol et al.,2014). Internal and external customer satisfaction (Arasli,2012; Metaxas and Koulouriotis,2017; Eraqi,2006); quality improvement based on customers’ needs, complaints and suggestions evaluation (Molina-Azorin et al.,2015; Tari et al.,2010; Pereira Moliner et al.,2016); satisfaction surveys (Molina-Azorin et al.,2015; Pereira Moliner et al.,2016) and value for money (Dortyol et al.,2014) are the most common enablers met which are related to the customer satisfaction practices in the literature.

A healthy and quality-oriented organization focuses on constant improvement in terms of processes and services/products; aiming to mistakes minimization and continual development. This way, internal and external customers will be more satisfied and organization performance will be improved. The significance of this enabler is seen in many papers (Arasli,2012; Wang et al.,2012; Tari et al.,2010; Alvarez-Garcia et al.,2017; Amin et al.,2017; Molina-Azorin et al.,2015; Pereira-Moliner et al.,2016) by testing benchmarking, internal audits and the existence of a system which uses quality indicators.

Process Management is related to optimizing business processes design, so that productivity and enhanced business results can be attained. Hence, the achievements of objectives has to be monitored, and possible deviations must be corrected (Bagur-Femenia et al.,2014; Tari et al.,2010); service delivery processes should be improved on a regular basis (Tari et al.,2010; Bagur-Femenia et al.,2014); and quality must be highlighted in policies and procedures (Molina-Azorin et al., 2015; Pereira-Moliner et al.,2016).

Table 1 – Quality management enablers in hospitality

A/A	Quality Management Enablers	Authors
1	Leadership	Arasli(2012), Wang et al.(2012), Benavides-Velasco et al.(2014), Arasli (2002), Alvarez-Garcia et al.(2017), Amin et al.(2017), Benavides-Chicon and Ortega(2014)
2	Human Capital	Benavides-Velasco et al.(2014), Alvarez-Garcia et al.(2017), Benavides-Chicon and Ortega(2014), Arasli(2012), Arasli(2002), Molina-Azorin et al.(2015), Metaxas and Koulouriotis(2017), Claver-Cortes et al.(2008), Llach et al.(2016), Tari et al.(2010), Pereira-Moliner et al.(2016), Wang et al.(2012), Amin et al.(2017), Dortyol et al.(2014), Eraqi(2006)
3	Partnership and resources	Benavides-Velasco et al.(2014), Alvarez-Garcia et al.(2017), Benavides-Chicon and Ortega(2014), Molina-Azorin et al.(2015), Claver-Cortes et al.(2008), Pereira-Moliner et al.(2016), Wang et al.(2012), Tari et al. (2010), Eraqi(2006), Bagur-Femenias et al.(2014), Llach et al.(2016), Amin et al.(2017), Metaxas and Koulouriotis(2017)
4	Quality commitment/ culture/ strategy	Claver-Cortes et al.(2008), Llach et al.(2016), Tari et al.(2010), Pereira-Moliner et al.(2016), Bagur-Femenias et al.(2014), Alvarez-Garcia et al. (2017), Molina-Azorin et al.(2015), Benavides-Velasco et al.(2014), Eraqi(2006)
5	Customer focus	Wang et al.(2012), Amin et al.(2017), Arasli(2012), Metaxas and Koulouriotis(2017), Eraqi(2006), Molina-Azorin et al.(2015), Tari et al. (2010), Pereira-Moliner et al.(2016), Bagur-Femenias et al.(2014), Llach et al.(2016), Benavides-Velasco et al.(2014),
6	Continuous improvement	Arasli(2012), Wang et al.(2012), Tari et al.(2010), Alvarez-Garcia et al. (2017), Claver-Cortes et al.(2008), Amin et al.(2017), Molina-Azorin et al.(2015), Pereira-Moliner et al.(2016), Bagur-Femenias et al.(2014), Benavides-Chicon and Ortega(2014)
7	Process management	Wang et al.(2012), Benavides-Velasco et al.(2014), Alvarez-Garcia et al.(2017), Amin et al.(2017), Benavides-Chicon and Ortega(2014), Molina-Azorin et al.(2015), Arasli(2012), Pereira-Moliner et al.(2016), Tari et al.(2010)
8	Organizational learning	Wang et al.(2012), Alvarez-Garcia et al.(2017), Amin et al.(2017), Molina-Azorin et al.(2015), Pereira-Moliner et al.(2016)
9	ICT/ IT use	Metaxas and Koulouriotis(2017), Pereira-Moliner et al.(2016), Claver-Cortes et al.(2008), Molina-Azorin et al.(2015), Benavides-Chicon and Ortega(2014), Eraqi(2006)

10	Innovation	Benavides-Velasco et al. (2014), Pereira-Moliner et al.(2016)
11	Environmental management	Metaxas and Koulouriotis(2017), Claver-Cortes et al.(2008)
12	Service standardization	Avcikurt et al.(2011)

Organizational learning is related to internal and external information; converting the personnel's experience into knowledge; developing and storing new knowledge; using this knowledge every day etc. Through this process new skills, ability, knowledge, behaviors or values are gained. Since all these are acquired via training, observation and personal experiences they are unique and can't be imitated, which leads to a great competitive advantage. Learning is considered important in the hospitality industry and it is mostly related to specialized training (on managers and employees), and understanding the basic organizational processes and mission (Wang et al.,2012; Alvarez-Garcia et al.,2017; Amin et al.,2017). ICT (Information and Communications Technology) and IS (Information System) can be combined with organizational learning, as the information and knowledge gained about stakeholders and business performance are the basis for decision-making (Claver-Cortes et al.,2008). Thus, the existence of an IS (Claver-Cortes et al.,2008; Metaxas and Koulouriotis,2017); quality data/information availability to all employees during the day in all firm areas; using quality data/information for quality improvement; and quality effects evaluation with financial and operational indicators are reasonably being considered quality management enablers (Pereira-Moliner et al.,2016; Molina-Azorin et al.,2015).

Finally, less attention has been paid in other enablers like innovation, environmental management and service standardization. Regarding innovation, Benavides-Velasco et al. (2014) used the frequency of innovations in management, personnel politics and organizational structure; and the frequency with which product/service innovations are developed according to the customers' needs as quality management enabler. This is totally rational considering that the hospitality sector is human-driven and constantly changing, which makes innovativeness integral to addressing the stakeholders' expectations. Concerned with environmental management, there is a number of parallels with quality management (Molina-Azorin et al.,2015). These similarities often incite firms to implement both systems. Quality management is usually developed first, as the environmental management is more successful when it is integrated into a quality management system (Claver-Cortes et al.,2008). Therefore, environmental management is found in the literature to be accounted as a quality management enabler (Metaxas and Koulouriotis, 2017; Claver-Cortes et al.,2008). The last important enabler mentioned in this study is service standardization (Avcikurt et al.,2011). This allows the firm to arrange a sequence in its processes, reduce potential limitations and improve functionality and technical quality (Yadegaridehkordi et al.,2018).

Innovation Management Enablers in Hospitality

Global and intense competition, along with being customer-oriented, force the hospitality organizations to develop innovative services in order to address the highly individualized customer expectations, gain competitive advantage and improve business results (Binder et al.,2016). This can be achieved by modifying and updating their portfolio mix (Ottenbacher,2007); improving their processes aiming to enhanced efficiency and productivity (Hjalager,2010); investing in new technologies (Orfila-Sintes et al.,2005); creating new marketing concepts (Gomezelj,2016); and implementing new methods in organizational management (Nicolau and Santa-Maria et al.,2013). In this section, innovation management enablers in the hospitality industry are first presented and, after that, summarized in Table 2.

Management is one of the most important enablers of developing innovation culture in an organization, as it is responsible for developing the appropriate leadership, encouraging the employees to be creative, creating a talented and well-trained pool of employees, motivation for "out of the box thinking" and involvement in networks that may boost innovative thinking (Dervitsiotis,2011). In the hospitality research context the innovation enablers of management are expressed as leadership, management personalities, style and employees' motivation (Smith et al.,2008); innovation encouragement, innovation acceptance, penalizing people for new ideas that do not work (Tajeddini and Trueman,2012); owners managing the business (Martinez-Ros and Orfila-Sintes,2009; Tugores and Garcia,2015); being part of a chain or operating independently (Orfila-Sintes et al.,2005); organizing process revision and being quality certified (Tugores and Garcia,2015); communicating the vision, sharing information, promoting teamwork and supporting innovation (Chen, 2011).

The hospitality industry is characterized as a supplier-dominated sector in terms of innovation, as the most technologies they use are elements developed by others (Orfila-Sintes et al.,2005). Based on the provided technologies and the knowledge they own, hospitality industries usually choose to improve, upgrade or differentiate their services/products. Hence, the suppliers' bargaining power must be considered in innovation management (Martinez-Lopez and Vargas-Sanchez,2013). Additionally, networks and clusters are supported to be a very important tool for the tourism firms, as they provide them with innovative opportunities (Gomezelj,2016; Hjalager,2010). Regarding resources (financial, human, and physical), the following are found to be very significant: utilization of slack resources; planning and management of resources; knowledge resources; technology resources and financial resources (Smith et al.,2008).

Table 2 – Innovation enablers in hospitality

A/A	Quality Management Enablers	Authors
1	Management	Tajeddini(2010), Hjalager(2010), Martinez-Ros and Orfila-Sintes(2009), Tugores and Garcia(2015), Tajeddini and Trueman(2012), Martinez-Lopez and Vargas-Sanchez(2013), Orfila-Sintes et al.(2005), Chen(2011), Hu et al.(2009), Smith et al.(2008), Martinez-Roman et al.(2011), Ottenbacher and Gnoth(2005), Pikkemaat et al.(2018)
2	Suppliers, Networks and Resources	Martinez-Lopez and Vargas-Sanchez(2013), Gomezelj (2016), Nieves and Segarra-Cipres(2015), Martinez-Roman et al.(2011), Smith et al. (2008), Orfila-Sintes et al.(2005), Tseng et al.(2015), Hjalager(2010), Pikkemaat et al.(2018)
3	Human capital	Chen(2011), Ottenbacher and Gnoth(2005), Nieves et al. (2014), Nieves and Segarra-Cipres(2015), Martinez-Roman et al. (2011), Orfila-Sintes et al.(2005), Tugores and Garcia(2015), Monica Hu et al.(2009), Chang et al.(2011), Ottenbacher(2007), Smith et al.(2008)
4	Knowledge Management	Gomezelj(2016), Nieves et al.(2014), Martinez-Roman et al. (2011), Tseng et al.(2015), Smith et al.(2008), Hu et al. (2009), Fraj et al.(2015)
5	Market factors and competition	Orfila-Sintes et al.(2005), Martinez-Roman et al.(2011), Ottenbacher(2007), Tseng et al.(2015), Martinez-Ros and Orfila-Sintes(2009), Ottenbacher and Gnoth(2005), Martinez-Lopez and Vargas-Sanchez(2013), Mattsson and Orfila-Sintes(2014), Tajeddini(2010), Tajeddini and Trueman(2012), de la Pena et al.(2016), Pikkemaat et al.(2018)
6	Organizational factors	Martinez-Roman et al.(2011), de la Pena et al.(2016), Pappas (2015),Tugores and Garcia (2015), Nieves et al. (2014), Martinez-Ros and Orfila-Sintes(2009), Tajeddini and Trueman(2012), Fraj et al.(2015), Chang et al.(2011),
7	Technology	Gomezelj(2016), Hjalager(2010), Tseng et al.(2015), Smith et al(2008), Ottenbacher and Gnoth(2005)

Employees are another element of innovation success in the hospitality industry, as they interact with the customers and are the utter moderator for differentiating services (Ottenbacher,2007). Moreover, having good personnel can lead to better “capacity to handle the complex processes that accompany change and create new knowledge" (Nieves and Segarra-Cipres,2015). Thus, staff training and attitude; criteria for promotion and rewards; and promoting risk taking are very important in this industry (Martinez-Roman et al.,2011). Nieves et al. (2014) considered that having employees who are highly skilled, the best in the industry, creative and bright, experts in their fields and able to develop new ideas and knowledge are the human capital's enablers for innovation, while Smith et al. (2008) focused on employees skills, education, personalities, training and motivation.

The importance of knowledge and knowledge management, is already mentioned above, as it refers to organizational learning, internal and external knowledge (Smith et al.,2008); knowledge transferring and knowledge absorptive capacity (Gomezelj,2016). Knowledge can be integrated in the employees' minds and attitudes, in routines, processes, organizational structures and relationships with external organizations (Nieves et al.,2014). Another aspect is that of Martinez-Roman et al. (2011) who used the firm capability to incorporate new members as external source of organizational knowledge; the ability of learning and capacitation through training, work learning and experimentation; and the evaluation of internal effort to gain knowledge and innovations of a technological nature (R&D).

In order to be competitive in such a turbulent environment as the hospitality industry, organizations need to understand the importance of satisfying their customers by providing them a unique, memorable and "innovative" experience (Tajeddini and Trueman,2012). Nevertheless, customer focus is not used as an innovation management enabler in the hospitality literature. In some cases it is included in the category "Market focus and competition", as market orientation and level of collaboration with the main customers (Martinez-Roman et al.,2011); specialized departments responsible for market research and firm awareness of customer requirements and preferences (Tseng et al.,2015); service/product customization according to the characteristics of the guests (de la Pena et al.,2016); developing products based on customers' needs and wants (Ottenbacher and Gnoth, 2005); developing products based on good market and customer information, knowing how customers value the offered services/products (Tajeddini,2010). In the same category, equally important factors focusing on market and competition are the following: intensity of market competition for new services (Tseng et al.,2015); benchmarking the competitors (Tajeddini,2010; Ottenbacher and Gnoth,2005); and targeting specific market segments (Ottenbacher and Gnoth,2005).

In this category organizational characteristics that influence innovation management are included. Specifically, some of the characteristics tested in the literature are the firm's size (Tugores and Garcia,2015; Nieves et al.,2014; de la Pena et al.,2016; Martinez-Ros and Orfila-Sintes,2009;

Martinez-Roman et al.,2011; Tajeddini and Trueman, 2012; Mattsson and Orfila-Sintes,2014; Nieves and Segarra-Cipres, 2015; Orfila-Sintes et al.,2005), age (Martine-Roman et al.,2011; Fraj et al., 2015; Tugores and Garcia,2015; Nieves et al.,2014; Martinez-Ros and Orfila-Sintes, 2009; Tajeddini and Trueman,2012), location (Martinez-Ros and Orfila-Sintes,2009; Pappas,2015; Fraj et al.,2015; Tugores and Garcia,2015), category (Pappas,2015; Orfila-Sintes et al.,2005; de la Pena et al.,2016; Fraj et al.,2015), existence of quality standards (Martinez-Roman et al.,2011), and type of organization (Tajeddini and Trueman, 2012; Mattsson and Orfila-Sintes,2014; de la Pena et al.,2016).

In many cases technology in the innovation process is considered as a result, but in this context it is an influencing factor. Smith et al. (2008) tested the utilization of technology, the technology strategy, the technical skills and education. Tseng et al. (2015) focused on the capability to forecast and evaluation of external forces that impact technological innovation (aiming to reducing uncertainty and risk) and the degree of entrepreneurship with respect to technological innovation.

CONCLUSIONS

It's apparent that quality management and innovation management are two very important strategies in the hospitality context. Notwithstanding, the literature is lacking of specific theories, models, practices and frameworks in the hospitality industry, and more specifically, little knowledge exists about innovation in this sector. This rises from the fact that the empirical work and quantitative research are still scarce, despite the importance of this industry in the global economy.

Based on the findings of this review in the hospitality sector, the paper concludes that although there is a number of studies that examine how quality and innovation can individually influence a company's financial or organizational performance, there is no single study, to the best of our knowledge, to examine their combination and its effect on organizational performance. Although, some efforts have been made in order to clarify the connection between quality and innovation, there is, nevertheless, no elucidation about whether innovation is a prerequisite for quality practices implementation or, quality is a requirement for creating the appropriate environment and conditions to innovate. As regards combining these two management approaches it is even more complicated and requires further research.

Regarding the two research questions the results proved that there are many common enablers (human capital, leadership/management, knowledge management/organizational learning, focusing on customers, technology, suppliers, partnerships/network and resources) between quality and innovation management in the hospitality industry. Other enablers like, environmental management and service standardization are related only to quality management, while organizational factors seem to be more important to innovation management. Moreover, firms that implement them both aim at achieving better organizational performance. Therefore, their similarities in terms of critical factors and enablers prove the significance of managing and assessing them together.

Another inference drawn from the hospitality literature is about the type of innovation that is preferred. Among the four main types of innovation addressed in the literature (product/service, marketing, organizational, process) it is not very clear which one is mostly implemented. According to the industry's special characteristics, it seems like developing a new service or creating more sophisticated marketing techniques are more suitable, but there is no empirical evidence supporting or rejecting this assumption.

Still it is not clear whether quality management and innovation management can be implemented in parallel. Having common enablers does not entail adopting the same approaches. For example, human capital in quality management refers to implementing the right practices in order to create more quality oriented attitudes and improve employee satisfaction, while in innovation management the main concern is hiring skilled, creative and out-of-the-box thinking employees. Moreover, quality certification is commonly held as a sign of quality in many hospitality enterprises. According to the literature, quality certification seems to hinder innovation, due to the bureaucracy that it entails.

Consequently, it is still unclear how innovation and quality can be integrated into a coherent strategy, taking into consideration that quality is confronted as a conformance to standards, whilst innovation is basically about creating something novel. Having common enablers may complicate the procedure of implementing them in parallel even more. Thus, developing new instruments for quality and innovation management in tourism companies is vital, in order to consider the multidimensional nature of this industry and collect the necessary information that will unveil the so far unknown aspects of tourism.

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Potentials of Blockchain Technology for the Quality Management of Interconnected Processes

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ABSTRACT

Purpose – The purpose of this paper is to analyze and demonstrate application potentials of blockchain technology in the context of production and quality management (QM).

Design/methodology/approach – This paper systematically investigates the characteristics of blockchain technology and process management within QM, subsequently interrelating the findings to formulate future application propositions. The resultant propositions are discussed for implementation and feasibility purpose in form of a use case in the automotive sector.

Findings – Blockchain can impact QM through its wide assortment of application potentials creating new opportunities for quality improvement, collaborative quality management as well as traceability and documentation. We found that a prospective quality management will significantly benefit from blockchain technology, especially in the context of process interoperability and complexity.

Research limitations/implications – This research is limited to blockchain applications in the context of QM, complex processes, and manufacturing. In our research we excluded work related to finance, government and public administration.

Practical implications – Our research is valuable for scholars and practitioners to identify new use cases of blockchain technology and to understand its future impact on quality and process management.

Originality/value – This is the first paper to investigate the impact and implication of blockchain technology from a quality management perspective.

Keywords: Blockchain, quality management, interconnected processes, process complexity

Paper type: Research paper

INTRODUCTION

Blockchain technology has the potential to become the new engine of growth in digital economy (Crosby et al., 2016), revolutionizing our way of doing business similar to the introduction of the steam engine in the 1890s or the internet in the 1990s (Tapscott and Tapscott, 2016). The first application concept of blockchain was published in 2008 under the name of Satoshi Nakamoto and described a peer-to-peer electronic payment system named Bitcoin (Nakamoto, 2008). However, the application potentials of blockchain extend far beyond the area of digital currencies and financial assets (Abeyratne and Monfared, 2016), spanning business-to-business (B2B) and machine-to-machine applications alike (Korpela et al., 2017). A wide assortment of integration concepts has been discussed in literature, leading to use cases in Supply Chain Management (SCM), finance as well as government and administration. Nonetheless, blockchain applications are still at an early stage and we found no published paper that investigates this new technology from a quality management perspective. The goal of this work is to examine the relevance of blockchain technology for QM leading to a deeper understanding of this technology and possible use cases in the context of quality management. We hypothesize that blockchain technology will be especially relevant in this context due to the inherent characteristics that complement QM principles and approaches. In this research, we focus on QM from a process management and value generation perspective as we consider them key pillars with the presumable highest application potentials similar to the use cases shown by SCM and Internet of Things (IoT) literature.

This paper is structured as follows. In the first chapter, we give an introduction into process management within QM outlining its current practices and challenges. In the next step, we examine blockchain technology explaining its structure, functionalities and characteristics. Then we derive potential application cases from a QM perspective and describe possible implementation designs. One application case is validated exemplarily using the example of a manufacturing process in the automotive supplier industry. Finally, we evaluate the impact of blockchain technology for a modernized quality management.

QUALITY MANAGEMENT WITHIN INTERCONNECTED COMPLEX PROCESSES

Some years ago, most business processes were stable, standardized and fully controlled by one company, but trends like mass customization, globalization and connectivity reshaped the process structure significantly. In today’s economy, processes are becoming increasingly complex and interconnected. Every day, billions of products are manufactured and shipped through complex process chains that extend to all parts of the world (Abeyratne and Monfared, 2016). Additionally, digitization enabled an increase in data and machine intelligence, leading to smart processes that reshape autonomously based on real-time events. Connectivity on an organizational, operational and informational level gives rise to new challenges and chances for their management. Quality management needs to create value in order to achieve satisfaction of intermediate and final customers (Foster, 2008) while simultaneously keeping those increasingly complex processes error-free and transparent. A company´s success now highly depends on its ability to fully leverage those complex processes; however, many new challenges hamper effective process management. In the following, we describe three issues that arise in the context of process complexity and its corresponding coping approaches that can be observed in QM.

The Multi-Stakeholder Issue

Originally, QM aimed at achieving high customer satisfaction through understanding customer requirements and translating them into measurable product features. More recently, QM has developed a stakeholder perspective instead of a purely customer perspective adapting to the requirements of multi-stakeholder value generation processes (Conti, 2010). In those multi-stakeholder networks, the value generation process needs to be coordinated incorporating multiple partners such as suppliers, service providers or customers. Processes have to be managed in a way that satisfies not only customers but other stakeholders as well in order to maintain a high-quality brand image. This is due to the enrichment of the perception of quality with new quality-relevant features such as sustainability, production ethics or working conditions. As for now, the coordination of multi-stakeholder process networks is achieved through supply chain quality management (SCQM) and the application of holistic stakeholder-oriented business excellence models like TQM and EFQM (Sandbrook, 2001).

The Trust Issue

One of the key aspects in multi-stakeholder networks is the issue of trust. Business processes always involve different trust issues that can be addressed in different ways (Weber et al., 2016), however, the more complex a process becomes, and the more parties involved, the harder it will be to establish and maintain trust. Accordingly, a company is only as trustworthy as all its business partners combined, making trust an important factor for a process network to function effectively (Francisco and Swanson, 2018). Building trust and visibility is one of the key aspects of successful process management within QM. In order to build trust, quality management mostly relies on certification and audits, as well as careful supplier selection and testing. Supplier certification assists with pursuing stakeholder relevant requirements at the source, while quality controls help to monitor product and process issues (Fish, 2011). Verifying the integrity of the certification claims is a costly process that requires strenuous auditing (Abeyratne and Monfared, 2016).

Various scandals in the last years concerning environmental damage, unethical labor and counterfeit products have resulted in an enhanced demand for transparency in complex process chains. Standards and certifications are still important tools establishing trust; however, stakeholders have to accept this information without being able to verify it and the credibility of those standards is constantly at risk. (Abeyratne and Monfared, 2016; Tian, 2016)

Additional to certification and audits, traceability promises to establish trust. However safe data capture, handling and storage systems are required, whereby heterogeneous data sources and systems need to be harmonized. Consequently, in most cases, a trusted third party takes the role to validate, safeguard and preserve traceability data (Crosby et al., 2016; Tian, 2016), which leads to the next problem; sensitive and valuable information is handled by one actor, who gains in power over the participants sharing data. People's privacy is particularly at risk in this centralized model as companies can illegitimately exploit central databases (Conoscenti et al., 2016). Even without exploitation attempts, a centralized system can always become a single point of failure endangering the integrity of the entire value chain (Weber et al., 2016). Henceforth, the establishment of trust, visibility and traceability in multi-stakeholder environments needs to be addressed. Nevertheless, the state-of-the-art strategies revealed to be vulnerable to fraud and exploitation and therefore require continuous monitoring and investment.

The Data Issue

In order to establish trust and traceability effectively, reliable data and documentation is needed. The acquisition, analysis and control of data has been a key pillar of QM for decades, which manifests itself in the strong orientation of many QM methods as well as the ISO guidelines (e.g. ISO 9001:2015) on data and documentation. Reliable data should guide quality improvements and decision-making, whereas sensitive data needs to be managed by a system that is mutually beneficial to all stakeholders involved (Fish, 2011). Accordingly, the choice of an appropriate information technology is an important decision to fulfill today's requirements for data quality and documentation. To this day, data management is either done centrally by one trusted agent as described above or a wide assortment of heterogeneous documentation systems and information technologies are used leading to data discontinuities and non-transparent process flows.

In conclusion, it can be observed that QM developed towards a stakeholder-oriented process management. Additionally, QM has always emphasized data quality, documentation and traceability; however, in increasingly complex process environments conventional QM approaches reach their limits. Blockchain technology promises to resolve the issues presented in this chapter, possibly making it a valuable support for prospective quality management in complex processes.

BLOCKCHAIN TECHNOLOGY

Blockchain can be defined using three perspectives; technically seen, a blockchain is a database maintaining a distributed ledger, from a business point of view, it is an exchange network for value between peers and from a legal perspective, the blockchain serves as a transaction validation mechanism without an intermediary (Mougayar, 2016). In general, blockchain validates, safeguards and preserves transactions of digital events in a decentralized and immutable peer-to-peer system (Crosby et al., 2016). Accordingly, blockchain manages the creation, ownership and transfer of digital items which have value on their own (e.g. cryptocurrency) or represent a valuable good in the real world (e.g. product) (Drescher, 2017).

The information on the blockchain is stored in so-called blocks that are interlinked together chronologically using cryptographic hashes. A hash is the output of a mathematical function that transcribes the original data to a deterministic and pseudoranonymous value. It serves as a unique fingerprint of data, giving evidence that the data was not altered while simultaneously keeping the original data content protected. Accordingly, data can be stored in a change-sensitive manner, as data alterations would lead to an invalid reference chain. In a peer-to-peer system, everyone can connect and submit new transaction data; however, the right to transfer ownership needs to be restricted to the owner. (Drescher, 2017) In order to do so, blockchain technology uses so-called asymmetric cryptography, in form of a pair of public and private keys. The public keys serve as publicly visible addresses, to which everyone can send assets or messages. The private key is only known to the user. It can be used as a password to access a user’s own account and as a signature to authorize transactions from the user’s account to other accounts. To execute a transaction, both keys are combined, as shown by the popular blockchain example of Alice and Bob in Figure 1.

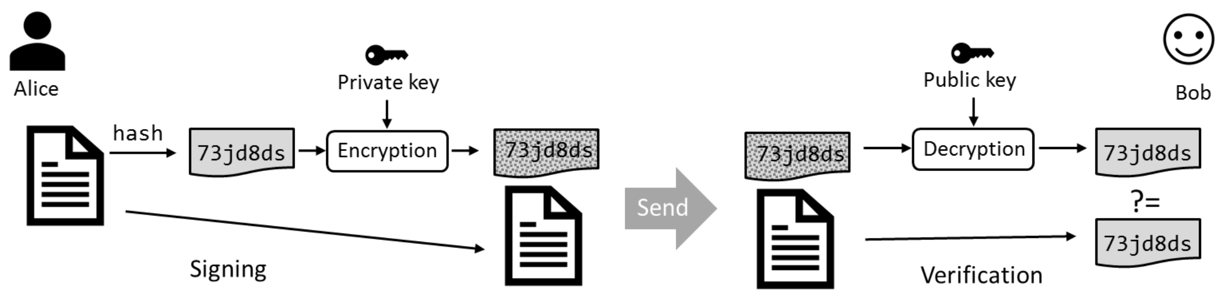

Figure 3 - Digital signatures in the blockchain (Zheng *et al.*, 2017)

Alice first generates the hash value from her transaction data, which is then encrypted with her private key. As only Alice knows her private key, this encryption proves that she initiated the transaction, similar to a signature. Bob receives the original transaction data and the encrypted hash value. He now uses the original data to calculate the hash value himself. Additionally, he decrypts Alice's hash using Alice's public key. Bob then compares the self-created hash value with the decrypted hash value. As they only match, when decrypted with the corresponding private public key combination, Bob can now authorize the transaction. The successful decryption proved that the owner of the private key initiated this transaction.

Figure 2 shows how a transaction is mined to a block of the blockchain. First, the transaction of data is requested by broadcasting it to the neighboring nodes in the network. They check the transaction request for validity, discarding invalid transactions. Over a specific amount of time valid transactions are collected, ordered and packaged into a timestamped candidate block. In a process called mining, one node is chosen through a consensus process in the network to broadcast the block back to the network. All nodes in the network then verify that the candidate block consists of valid transactions and check its hash references to the previous block in the chain. After verification, the block is added to the chain and the transactions in it are being executed. (Christidis and Devetsikiotis, 2016; Burgwinkel, 2016; Crosby et al., 2016).

Depending on the use case, the rights of participants to write and validate transactions can be open to all participants or restricted to a certain group. For applications in cryptocurrencies, public blockchains with a permissionless ledger are used. The process is fully decentralized. All participants can participate in reading, writing and consensus mechanisms. For blockchains in organizations, permissioned ledgers are used, in which a private shared ledger controls the writing access and confines it to the organization. As an intermediate solution, inter-organizational blockchains sometimes give the possibility for anyone to read transactions but limit the consensus process to a specific group of nodes. (Burgwinkel, 2016).

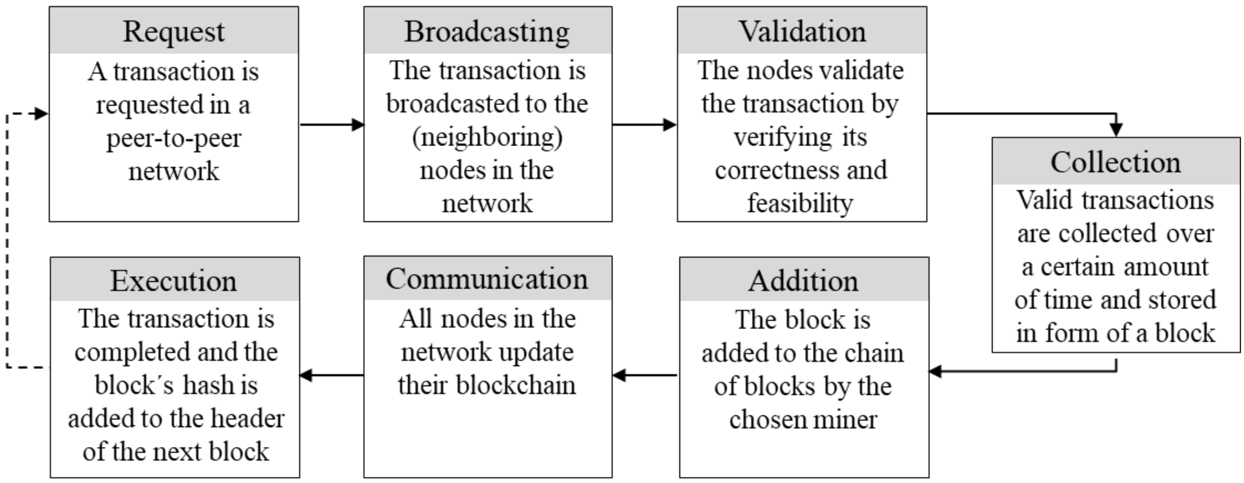

Figure 4 - Basic principle of a blockchain transaction

In addition to storing data and conducting transactions, blockchains can also run program code that triggers automatic and deterministic actions. Accordingly, blockchain can incorporate pieces of self-executing digital contracts, which are called smart contracts and were first introduced by Nick Szabo in 1997 (Szabo, 1997). The blockchain's distributed ledger structure provides the ideal framework for the application of such contracts. As shown in Figure 3, a smart contract can be initiated through input from external users or from the blockchain itself.

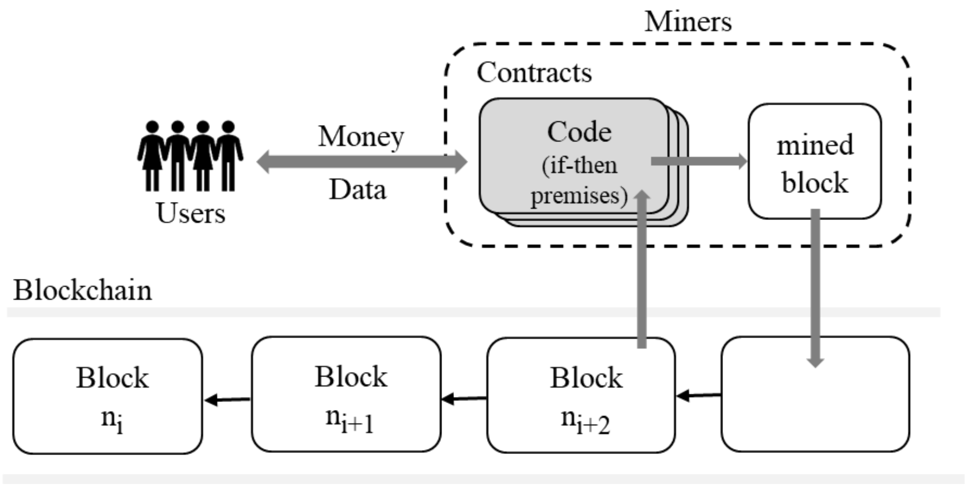

Figure 5 - Smart contract (Kosba, 2016)

If the requirements of the contract are met, a new block is mined including the relevant data of the executed contract and linked to the chain (Kosba et al., 2016). As smart contracts can address a high variety of objects and conditions, they can be used for a wide range of applications, such as paying rent or transferring the money for a bought product (Drescher, 2017). Smart contracts work on automatic if-then premises, making it impossible for participants to break contractual agreements.

Exemplarily, a customer could be charged with an agreed rate that is automatically withdrawn from his account when a certain delivery condition eventuates.

APPLICATION POTENTIALS OF BLOCKCHAIN

The idea of blockchain is being adapted to a large field of applications extending widely beyond the execution of cryptocurrencies (Yli-Huumo et al., 2016), spanning finance, government, administration, IoT and SCM alike. Many articles and papers suggest, that blockchain will introduce a new industrial revolution, nevertheless, blockchain is only known to few practitioners and even fewer pursue implementation plans (Kersten et al., 2017). In this chapter, we analyze possible applications that could be relevant in the context of process management and QM, which were defined by systematically searching blockchain application papers, as well as non-scientific articles and blogs. The results are displayed in Table 1, whereas in most cases the column application composes pilot projects or project ideas, which are not fully implemented yet.

Table 8 – Application potentials of Blockchain

Topic	Description	Application	Paper
Traceability	Blockchain enables traceability of any transaction of data, goods and financial resources, allowing proof of origin and path in retrospective. This application is especially relevant for high-quality products, items that are exposed to fraud and safety-critical products. A blockchain can be applied, if an immutable traceability increases customer´s willingness to pay.	Backward tracing in diamond industry (Everledger) Expensive wine, watches, art or handbags Pharmaceutics (Blockverify, Chronicled)	Abeyratne and Monfared, 2016; Kersten et al., 2017; Tian, 2016; Francisco and Swanson, 2018; Bahga and Madisetti, 2016
Tracking	Blockchain allows visibility and transparency of the process flow (data, goods, finance) in real-time (forward tracking). Using blockchain, all stakeholders can follow and trace the process flow. Eventually, the combination of tracking and tracing with blockchain allows reducing profit losses from counterfeit and gray market trading.	Food item tracking (Walmart) Coffee beans tracking (Bext360) Tracking of a vehicle’s life cycle events (BigchainDB)	Abeyratne and Monfared, 2016; Kersten et al., 2017; Tian, 2016; Francisco and Swanson, 2018; Hackius and Petersen, 2017; Pilkington, 2016; Bahga and Madisetti, 2016; Christidis and Devetsikiotis, 2016

Customer-to-Machine Transaction	Machines could have their own account on the blockchain network. This would allow customers to interact with machines without an intermediate party involved. Customers could order products or services directly from the machine and pay the machine automatically over a smart contract using cryptocurrencies.	Renting cars or houses with smart electronic lock (Slock.it) Direct ordering at automated machines (3D printers, CNC)	Bahga and Madisetti, 2016; Christidis and Devetsikiotis, 2016
Machine-to-Machine Transactions	Blockchain can serve as a platform for a marketplace of services between devices. A machine could order a component or service from another machine and get compensated via a micro-transaction of cryptocurrencies using a smart contract.	IOTA HDAC Filecoin EtherAPIs ADEPT, Filament	Bahga and Madisetti, 2016; Christidis and Devetsikiotis, 2016; Crosby et al., 2016;
Machine Maintenance	Blockchain can be used to monitor the state of machines and diagnose problems autonomously. Using a smart contract machines could request maintenance services and pay for the service with their cryptocurrency wallet.	Automated maintenance request through (Ethereum-based) Smart Contracts	Bahga and Madisetti, 2016
Certification & Provenance	Blockchain can be applied for product and process certificates, eliminating the need for physical labels and facilitating auditing. Certificates can be signed digitally by certifiers and standard organizations making certification transparent to all network stakeholders.	Provenance of high-value items, e.g. diamond certification (Everledger)	Abeyratne and Monfared, 2016; Kersten et al., 2017; Hackius and Peter-sen, 2017; Bahga and Madisetti, 2016; Crosby et al., 2016;
Inventory & Property Management	Blockchain can keep a formal registry of assets, inventory and products and track their possession through different process points and points in time. This allows the network to maintain an indisputable record of ownership for each asset.	Physical property (e.g. products) and non-physical property (e.g. company shares)	Bahga and Madisetti, 2016; Crosby et al., 2016; Abeyratne and Monfared, 2016;
Data Storage	Blockchain can be used to create a secure, durable, and decentralized data storage system. Combined with the *customer-to-machine transaction* application, people can share unused internet bandwidth and disk space on their personal computing devices using micropayments.	Peer to peer cloud storage (STORJ) Management of metadata Management of contracts	Conoscenti et al., 2016; Crosby et al., 2016
Black Box Data Sharing	Blockchain can be used to store identity data in a black box, which only gives away the particular information that is required to do something.	Digital identity containing sub identities with different permissions (HELIX)	Tapscott, 2016

Monitoring Changes	Blockchain can be used to record transfer of assets, inventory, or product. A fast comparison of changes is facilitated through the compression of complex data to hash values.	Fraud and tampering detection in supply chains (IBM, Deloitte)	Drescher, 2017
Process Digitization	Blockchain can be used to augment physical process flows, eliminating the need for manual paper records. Each process item (product, machine) is represented by a digital equivalent in the blockchain network. Administrative costs are decreased through automatized transactions and smart contracts.	Reduce paper labels and work and therefore costs in container shipping (Maersk)	Bahga and Madisetti, 2016; Abeyratne and Monfared, 2016; Hackius and Petersen, 2017; Kersten et al., 2017
Process Optimization	Blockchain increases process visibility, creating a more holistic understanding about multi-stakeholder processes. Complex process relations become more transparent facilitating holistic optimization.	Optimize in-process buffers Process forecasting (IBM)	Hackius and Petersen, 2017; Kersten et al., 2017; Weber et al., 2016
Cross Process Inter-operability	Blockchain could be used to automate process interface management. Using smart contracts, autonomous actions and payments can be triggered based on real-life events.	Reimbursement after product return. Automated payment after delivery registration	Weber et al., 2016; Kersten et al., 2017
Customer Data Amplification	Smart products could report lifecycle events to the blockchain. This information could be shared among the network for multiple improvement cases without compromising the anonymity of the customers involved.	Tokenized data exchange for cars (TRI, Bigchain DB); Lifecycle Management (Rain RFID)	Mattila, 2016
Usage-based Pricing	Blockchain could be used to send promotions and discounts to users based on their usage behaviors without disclosing their personal information.	Usage-based insurance based on how you drive (Toyota Research Institute)	Pilkington, 2016
Direct Trade	Blockchain can replace business models that comprise an intermediate role, breaking up hubs of power and allowing customer and producer to exchange value directly.	Disposal of handicraft in rural India Bypassing middlemen fees in coffee farming (Bext360)	Pilkington, 2016

Table 1 shows the wide range of tasks and application potentials that can be covered through blockchain. However, we found that most authors state the possibility of an application without validating it through a detailed interrelation of blockchain features and a suggested application design. Many applications are considered isolated and synergies are not merged into a holistic use case. Moreover, we found no published research looking at blockchain applications from a quality management point of view. In this work, we close this research gap by developing a holistic use case from a QM perspective. This use case demonstrates how different application potentials can be used in an integrated scenario. To give researchers and practitioners a more detailed insight on our application ideas, we consider possible blockchain implementation designs and the technical preparation measures to be taken. We further evaluate on a suitable industry for blockchain application and describe how the identified blockchain functionalities and application potentials can be used to resolve current issues within that industry. We conclude our use case by interrelating the current issues of QM with blockchain, deriving its impact on a prospective quality management.

IMPLENTATION OF BLOCKCHAIN – AN AUTOMOTIVE SUPPLIER USE CASE

In order to implement blockchain applications, some technical preparation measures have to be taken. First, a blockchain type (e.g. private blockchain or public blockchain like Bitcoin) is chosen and different blockchain members are created. Every member group is characterized by specific rules, privacy settings and data responsibilities, for example registering new members to the system, mining new blocks for the blockchain or simply reading and updating product information (Abeyratne and Monfared, 2016). Every unit that acts within the process flow, for example through product transformation or transaction of ownership, needs to be augmented to the blockchain. To link a physical object within a process to its digital representation, the object needs to be made uniquely identifiable through a data capture technique, which could be bar codes, radio frequency identification (RFID), magnetic stripes, quick response codes (QR), bluetooth low energy (BLE) or near field communication (NFC). Some companies already specialized in the development of blockchain specific tags like CryptoSeal by Chronicled or CryptoChips by Riddle&Code. The latter compose a combination of different technologies (non-removable adhesive, NFC, BLE, Web, Arduino compatible, cryptographic computing capabilities) and possesses its own asymmetric pair of keys, allowing autonomous interaction with the blockchain (Riddle&Code, 2017).

Depending on the chosen blockchain design, a different application depth and scope can be reached. Considering the blockchain's characteristics and the consequential application potentials shown above, we developed three options to obtain different degrees of integration of the production system into the blockchain. From option 1 to option 3, the difficulty of implementation and the necessary technical maturity level are increasing. The developed options were further discussed for verification and feasibility with experts from the field of computer science. Figure 4 displays the developed results of our analysis.

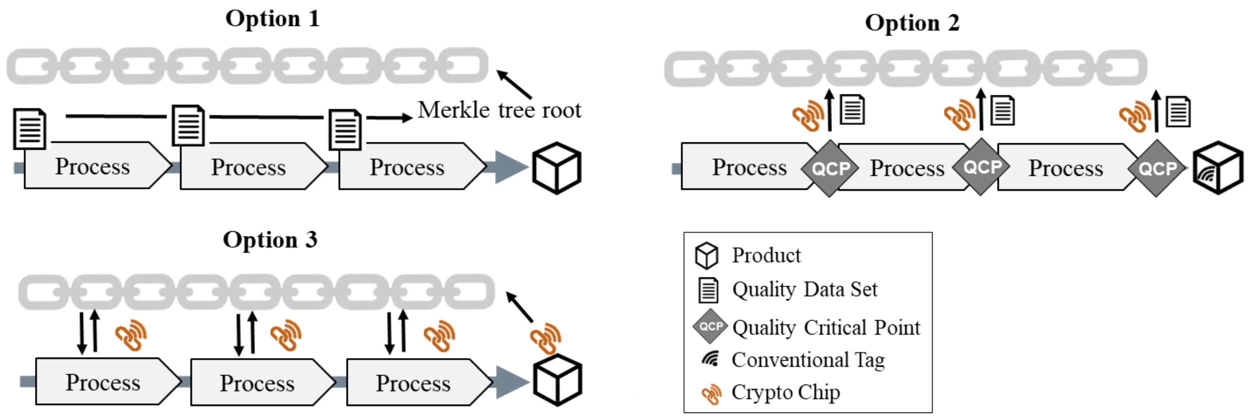

Figure 4 – Blockchain implementation options

Option 1 aims at using blockchain for safe data storage exclusively. It is cost-efficient and more convenient to implement, but only leverages a few advantages afflicted with blockchain. Instead of feeding entire process and product data into the blockchain, merkle tree roots (the hash of all previously hashed and paired data) are used to merge data to an encrypted value. The root of the tree is saved in a public blockchain ensuring trust and security of data content. If product data is altered afterwards, the new root will not be the same as the one saved in the blockchain. Therefore, a merkle tree can detect fraud and inconsistencies in previously saved data. As only the root of hashed data is saved in the blockchain (e.g. one merkle tree per finished product), the amount of data transferred to the blockchain is minimized. However, transparency, trust and traceability remain limited as the actual primary data is stored in conventional centralized databases.

As option 2, we define a system, in which quality critical data is saved in the blockchain in its primary form at important process points. Quality critical points (QCP) are identified along the process flow and equipped with cryptographic-enabled computers to become nodes of the blockchain. A QCP should compose an important mark along the value chain, which could be a machine, a critical assembly point, a transshipment point or a quality inspection area. Those points need to be IoT and blockchain-enabled to interact autonomously as part of the peer-to-peer network. In this option, not only the hash or root is saved in the blockchain, but the actual primary data as well. This way, a partial traceability over the blockchain is possible and trust is increased. Additionally, all QCPs can interact with each other autonomously using smart contracts. To implement option 2, not all machines or devices have to be blockchain ready and the amount of data transferred is kept low.

For comprehensive traceability and visibility as well as a maximum use of the steering opportunities of blockchain, all machines, devices and participants in the production process must become part of the blockchain through suitable hardware and software, which we define as option 3. The nodes use one distributed database, but with different accessibility to the contents. The amount of data transferred in the network is high, as every step in the process is constantly monitored and updated to the blockchain. The complete transparency of the network ensures a high trust and the possibility for the network to implement self-optimization. This option requires the highest infrastructural investments, as well as a high IoT maturity and computing capabilities. Therefore, it is the most advanced one to implement.

All three developed implementation designs allow companies to use blockchain to a varying benefit within their processes. The choice of the appropriate option highly depends on the focus industry, its inherent issues, its technical maturity level, and goals to be achieved through blockchain. While the first option can already be implemented for most industries using state-of-the-art production technologies, we hypothesize that the third and most mature option will still need several years and innovations to be applicable and would especially require improvements in the field of Big Data handling, IoT and process automation. For the third option, the production flow should be automated to the maximum level, allowing machine-to-machine actions and the automated execution of smart contracts. All machines and workstations need to be internet-enabled, while precise and secure machine-to-machine communication has to be ensured. Therefore, a stable and fast internet connection over the entire value chain constitutes a major requirement. Furthermore, data standard formats and protocols need to overcome current barriers of missing data interoperability. Additionally, all physical objects need to be smart and augmented to the blockchain over identification technology, while tags must be non-removable, cost-efficient in storing increasing amounts of data and impossible to tamper with. Automated capture technology (e.g. RFID gates) has to be installed through the entire process, as no data entries should be executed manually in order to prevent faulty entries into the blockchain.

In this work, we developed a use case for the hybrid option (option 2) as many blockchain advantages can be leveraged with this option, while simultaneously keeping technical maturity, time to implementation and investment costs at a reasonable level. We decided on the automotive electrical and electronic component suppliers (E/E industry), or more specifically the wiring harness industry as the focus industry for our use case. Wiring harnesses make up all electronic components of mechatronic systems enabling the communication and information flow, the energy and signal processing, as well as the steering and control signal transmission. In the age of electrification and autonomous driving, wiring harnesses are one of the most safety critical components in the automotive industry, as they control safety critical functions such as steering and breaking. Quality management becomes increasingly difficult, as product errors can lead to catastrophic consequences, possibly entailing material damage, hazards to human's physical integrity or threats to the public or environment. Harnesses are produced in complex and highly interconnected multi-partner networks that encompass many companies, production sites and even countries. The partners involved often work according to different standards and data is often lost or manually changed at process interfaces. As harness production becomes increasingly complex, traceability and visibility become a key competitive advantage to improve process quality.

In addition, process automation and digitization will have to increase significantly in the context of autonomous driving. Manual production and data recording are prone to human failure and will not fulfill the increasing customer expectations and normative requirements (ASIL, ISO 26262 and upcoming laws). We hypothesize that a technology which allows safe and non-changeable data storage and transaction will become a key stakeholder requirement. The implementation of blockchain would also allow machine collaboration and coordination as an additional benefit, helping to lower transaction costs and deal with the increasing cost pressure. In conclusion, the wiring harness industry composes a very interesting use case blockchain application from a QM perspective, as new trends in this industry raise the issues of trust, data quality, holistic process optimization, traceability and transparency. Subsequently, we developed a use case for the year 2025, as at this point the technologies of autonomous driving, production automation and blockchain will have reached a sufficient maturity level to be applied in conjunction. In the following, we demonstrate how blockchain paves the way for contemporary quality management of harness production processes for autonomous vehicles. In 2025, harness production is connected to the blockchain over the implementation and equipment of QCP. By applying the implementation design of option 2, sufficient traceability can be reached, while investment costs for this cost-sensitive industry are kept to a feasible level. In this use case, we implement QCP at major process interfaces of harness production, which are major manufacturing steps such as *cutting, pre-assembly, final assembly,* as well as *critical logistic points* and *quality inspections*. All those points are equipped with cryptographic microcomputers, which include an active transponder to detect smart objects. All QCPs are then registered to the blockchain, which we chose to be a private Ethereum network. A set of asymmetric keys is created for them, enabling them to transfer product ownership, update product information and interact with other CPQs over smart contracts. Like in a regular database, each QCP can be searched for certain products, location data, certificates, audit or maintenance data and processing parameters, which can be used for process optimization. Nodes with a high computing power are selected as miners and a convenient and cost-efficient mining approach is chosen.

The process of harness production starts with an OEM request for an individualized harness. All supplier components are ordered and material batches are labeled upon arrival, thus creating uniquely referable identities. At the first QCP, the *inbound logistic*, the components and materials are registered to the blockchain trough automated tag scanning using an active transponder gate. At this point, the first quality relevant data is securely stored, which could be supplier details, arrival time and quality inspection results. The next QCP is in the cutting area, where highly automated machines first cut the cables to the appropriate lengths, strip the cable sheath and attach seals and terminals to the cable. When a product is transferred from the inbound logistic QCP to the cutting machine's QCP, the transaction is signed by both acting QCPs using their asymmetric key pair. After verification, this transaction will be added to the next block of the blockchain by a miner node. All QCPs can now see the updated product status within the process flow. In the next production step, the cables are bundled and retagged as components, agglomerating the parts' historic data to a new product data set. Robots and automated machines then manufacture cable kit modules, while technologies like crimping, welding and automated housing insertion are applied. The *pre-assembly* QCP can now add new information to the product, which could be processing parameters (e.g. crimping or mounting force) as well as environmental production and sensor data (e.g. machine vibrations or room temperature). Though this system, quality and safety relevant parameters are immutably saved in the blockchain, while non-critical process parameters can remain in a centralized database. In the final assembly, the complete harness is assembled and encapsulated. Each quality-relevant plug contact is confirmed though in-line quality control and the test results are encrypted and saved to the blockchain. At the end of line, the electric functionality is tested on a test desk. When the individualized harness is completely assembled, tested and packed, a Just in Sequence (JIS) delivery is triggered by the *outbound logistic* QCP using a smart contract.

This would cause an autonomous logistic transportation device (e.g. autonomous truck) to pick up all ordered harnesses to transport them to the OEM. Over a market platform, the autonomous truck and the outbound logistic QCP can agree on a shipping contract, which is compensated using a micropayment of cryptocurrencies, in this case Ether, which is exchanged directly between the independent nodes. At the car manufacturer's inbound logistic area, the first QCP of the OEM accepts the delivery by signing the digital contract. Until the harness is fully implemented and connected to the car, further QCPs collect quality relevant product, process and environmental data and save them to the blockchain. The principal structure and rationale behind this use case is summarized in Figure 5.

The use of smart contracts in the context of harness production can be extended to various applications. Exemplarily, a quality inspection QCP could identify a defective clip and order a new one from a 3D printer. Furthermore, all QCP could monitor their own condition and request maintenance or part replacement over the blockchain, when certain conditions are met (e.g. through monitoring cp and cpk values). Any conditional agreement between two nodes could be written into a smart contract, allowing the nodes to autonomously steer the process. Through enforcement automation, transaction costs are decreased and trust is high, as machines are unable to break software protocol conditions. To monitor the products' entire lifecycle, the final product (the harness in the car) could be connected to the blockchain over a crypto chip, which reports relevant data to the network. This holistic blockchain life cycle integration would allow the final product to become the last CQP in this process flow, leading to maximum visibility and new opportunities for preventive quality management in the context of autonomous driving. When a product reaches the end of its lifecycle, blockchain could be used to monitor its safe shutdown and recycling.

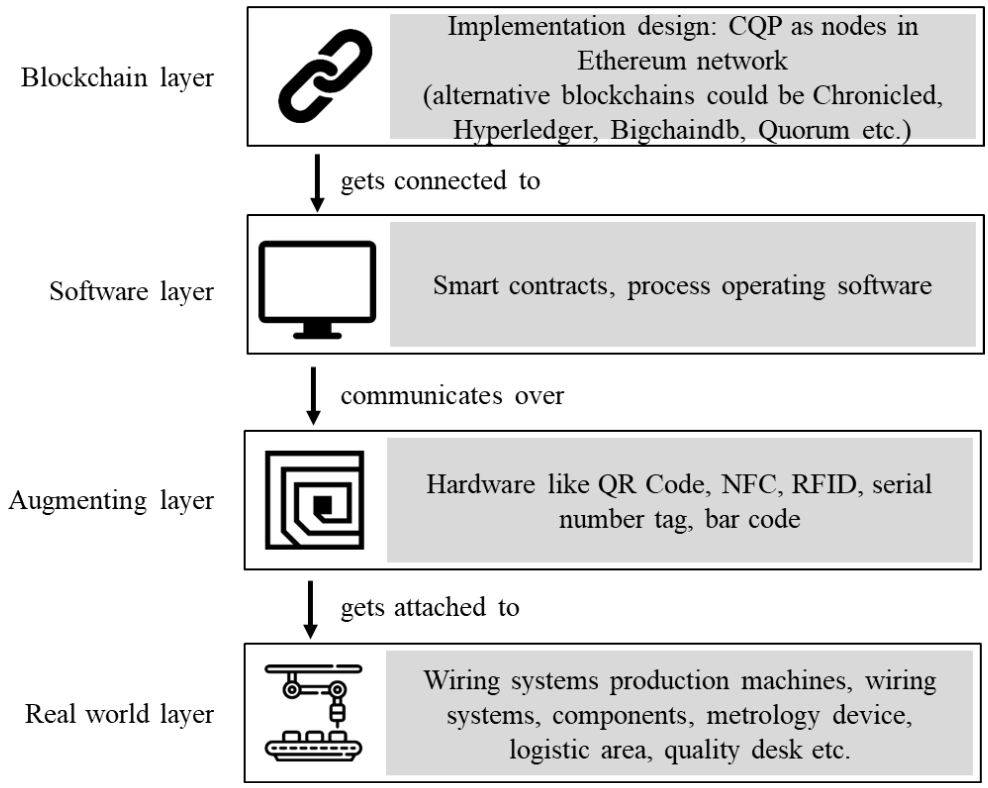

Figure 5 – Structure of the use case

The major prerequisites to implement this use case from a technical perspective are advances in process digitization and automation. From an organizational perspective, however, the challenges are equally high. The deployment of an inter-process technology like blockchain would require strong inter-organizational cooperation as well as negotiations concerning changeover costs and agreements on standards and architecture. This will compose a difficult task in an industry, which has been driven by fierce competition and imbalances in power in the past. The future of autonomous driving will now depend on the organizations' abilities to overcome those barriers and initiate the necessary technological and organizational advancements.

FUTURE IMPACT OF BLOCKCHAIN ON QUALITY MANAGEMENT

Quality management within interconnected and complex processes will benefit significantly from effective blockchain application. The topics of impact and synergy are described in the following.

Trust: Maintaining trust and integrity in a complex multi-stakeholder system composes a great challenge. Through blockchain, customers can trust claims made about a product. This can be used to increase the perceived quality of that product, leading to enhanced communication and customer relation management. Additionally, trust among suppliers and process partners is increased, which facilitates cooperative and interdisciplinary QM activities.

Visibility: The increased visibility can be used to reduce costs for extensive auditing and monitoring. In addition, it allows enhanced real-time management and improvement.

Traceability: Through blockchain, QM can benefit from an improved traceability. An unforgeable traceability assures proof of origin, allowing fast recalls and a good position in liability processes.

Risk Management and Safety: Blockchain can support risk management activities, as fraud risks are minimized. Counterfeit products are identified and product liability is accurate.

Digitized Documentation: All relevant process actors are augmented to the blockchain. Digitized documentation reduces the number of manual records, decreasing data cost and the possibility of data errors. Subsequently, the overall data quality and documentation quality can be improved.

Certification and Auditing: Blockchain provides an immutable and transparent record for inspection. Standards organizations can define standard schemes for certifications seals and check their fulfilling. Through blockchain, certifiers can provide certifications to companies allowing them to participate in the certified network. As documentation cannot be tampered with, auditing can be done automatically and from anywhere.

Inter-Process Standardization: Smart Contacts can standardize arrangements at process interfaces (e.g. at CQPs) and enable their successful transaction. Partner management can be done more cost effective as transactions details are definite and no further discussion is needed. Accordingly, QM can benefit from standardized, automated and overall-accepted term execution.

Quality Improvement and Forecasting: Through blockchain QM can benefit from reliable and interconnected data, which can be analyzed using advanced data analytics. With blockchain, data not only from inside the organization but across departments, production sites, companies and countries along the complete product life cycle can be used. This new form of interconnected data facilitates holistic quality improvement throughout process interfaces and predictive analytics can be used to anticipate parameter relations and quality results across complex process chains.

CONCLUSION

Even the biggest organizations lack the power and capability to deploy end-to-end data integration (Korpela et al., 2017), however with the introduction of blockchain, a new era of interconnected and digital process management has begun. Our research showed, that blockchain features do not only complement current QM activities but help to design a modernized quality management overcoming current issues of complex process management. Blockchain has the potential to decentralize process management and interlinks relevant quality data across process interfaces, enabling holistic process improvement. Additionally, it facilitates typical QM tasks like monitoring, auditing, certification and documentation. We focused our research on complex and interconnected process chains, as for now, blockchain can be leveraged most in untrusted multi-stakeholder networks with distributed process interfaces. In this context, we developed an implementation design using quality critical points as important marks along the value chain, which become part of the blockchain network. However, as blockchain implementation is still new in the context of manufacturing, further research is needed to investigate application potentials, as well as motivators and barriers for blockchain adoption. In this context, blockchain enabling technologies and research fields such as IoT, capture technologies, Big Data research and advanced data analytics should be studied from a blockchain implementation perspective to outline synergies and common direction of development. With blockchain research still being in a mostly conceptual phase, more empirical data is needed to validate and further improve those concepts, which could be accomplished through case studies investigating industry applications or the development of demonstrators for distinctive application use cases.

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Quality Management Potentials – A Future Trend Based Analysis and Strategy

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ABSTRACT

Purpose – This paper explores the future challenges for quality management. It focuses on the role of an innovative quality management for the future viability of companies within rising megatrends such as digitization, individualization, globalization, new ecology and new work.

Design/methodology/approach – Future trends and their impact on quality management are analyzed. Within an expert panel, the changes are transferred to a comprehensive understanding of quality. Finally, a change management approach is derived to transform the role of quality managers.

Findings – The paper shows, that the current role of quality management in companies, based on continuous improvement and guaranteeing the ISO 9001 certificate, needs to be evolved to a role up to the strategic management level again for staying competitive. Within this process, quality management methods should be enriched by technological developments and innovation approaches to guarantee the competitiveness within a world of revolutionary changes.

Practical and social implications –The trend analysis implicates possible fields of action like developing new and adapted quality methods, utilizing innovative potential or ensuring adequate just-in-time education for required new competencies, methods and technical understanding. By exploiting these potentials, quality management has the opportunity to play a leading role within change processes to gain in importance again.

Originality/value – The paper emphasizes the role of quality management as a holistic approach that holds a tremendous potential to shape the future of a company. It proposes a strategy to strengthen the role of quality management.

Paper type: Conceptual Paper

Keywords: quality management, future trends, digitization, strategy

INTRODUCTION

Our volatile, uncertain, complex and ambiguous (VUCA) world (Hicks and Nicholas, 2002), resulting from the overarching megatrends *globalization*, *digitization*, *individualization*, *new work*, and *new ecology* necessitates paradigm shifts for companies. These shifts are characterized by technology disruption and unexpected competitors sprouting up from the ground. Agile competitiveness with focus on high quality product experiences becomes a decisive factor, whether a company achieves a long-lasting success or vanishes from the marketplace. Therefore, a company with a comprehensive quality management thinking can play a key role in taking the lead on future markets. However, instead of using this potential, quality management is often pushed to the verge and perceived as necessary matter of course (Castiglione, 2011). This paper analyses the current and future role of quality management within companies, proposes a novel understanding of quality management and recommends actions to face upcoming challenges on a highly embattled market.

THE CURRENT ROLE OF QUALITY MANAGEMENT

Quality management is a professionalized and established part of companies nowadays. Starting with quality control in 1900, quality management reached its climax in the successful establishment of concepts like total quality management and business excellence, which is still a desirable goal for companies. Nevertheless, quality management itself acts more and more on the border of operational value chains and the organizational offside of solely documenting and guarding the DIN EN ISO certificates. Quality strategies are often not an integral part in the companies' strategy (Vahs, 2018). Officially, the quality management representative is a member of the organizational management. However, in most cases there is no involvement of the quality management representative in leading processes. Hence, quality management and quality awareness can be stated as neglected success factor, preventing business excellence. Especially the effect of quality culture as basement is often perceived as weak or neutral, e.g., in a study of the German Corporation of Quality (DGQ) (Vahs *et al.*, 2018), approximately 60% of respondents (mostly quality managers) perceive the effect of the quality culture within their companies as weak or neutral. Even the term quality is interpreted differently as no common understanding of quality is defined or exemplified. One reason are missing role models in management positions, equipped with quality awareness and a multitude of quality skills. Another aspect in this context is the missing understanding of quality management as flywheel. Currently, new and innovative ideas in the context of product and process improvement are not encouraged and only play a tangential role (Vahs *et al.*, 2018). For a long-term leading role on a market, which becomes more dynamic and unpredictable, every unused potential needs to be exploited and an innovative and exemplified quality culture is one of the basic key players in this challenge.

FUTURE TREND MAPPING TOWARDS QUALITY MANAGEMENT

As stated before, the current way of quality thinking needs to be extended, as quality management is also affected by future impacts. Figure 6 illustrates the impact of megatrends on quality management. According to the modern futurology of John Naisbitt, a megatrend represents a long-term future development of a minimum of 25 to 30 years, which globally affects all areas of society and economy (Naisbitt, 1982). Within an expert workshop in combination with a literature review, first, the five megatrends *digitization*, *globalization*, *individualization*, *new work*, and *new ecology* are identified as main impact factors on the future development of quality management. These megatrends impose challenges that can be faced with quality management principles. According to the DIN EN ISO 9000:2015, this includes the dimensions customer, product, process, people, and leadership (DIN EN ISO 9000:2015). The mapping to these dimensions are described more in detail in the following sections.

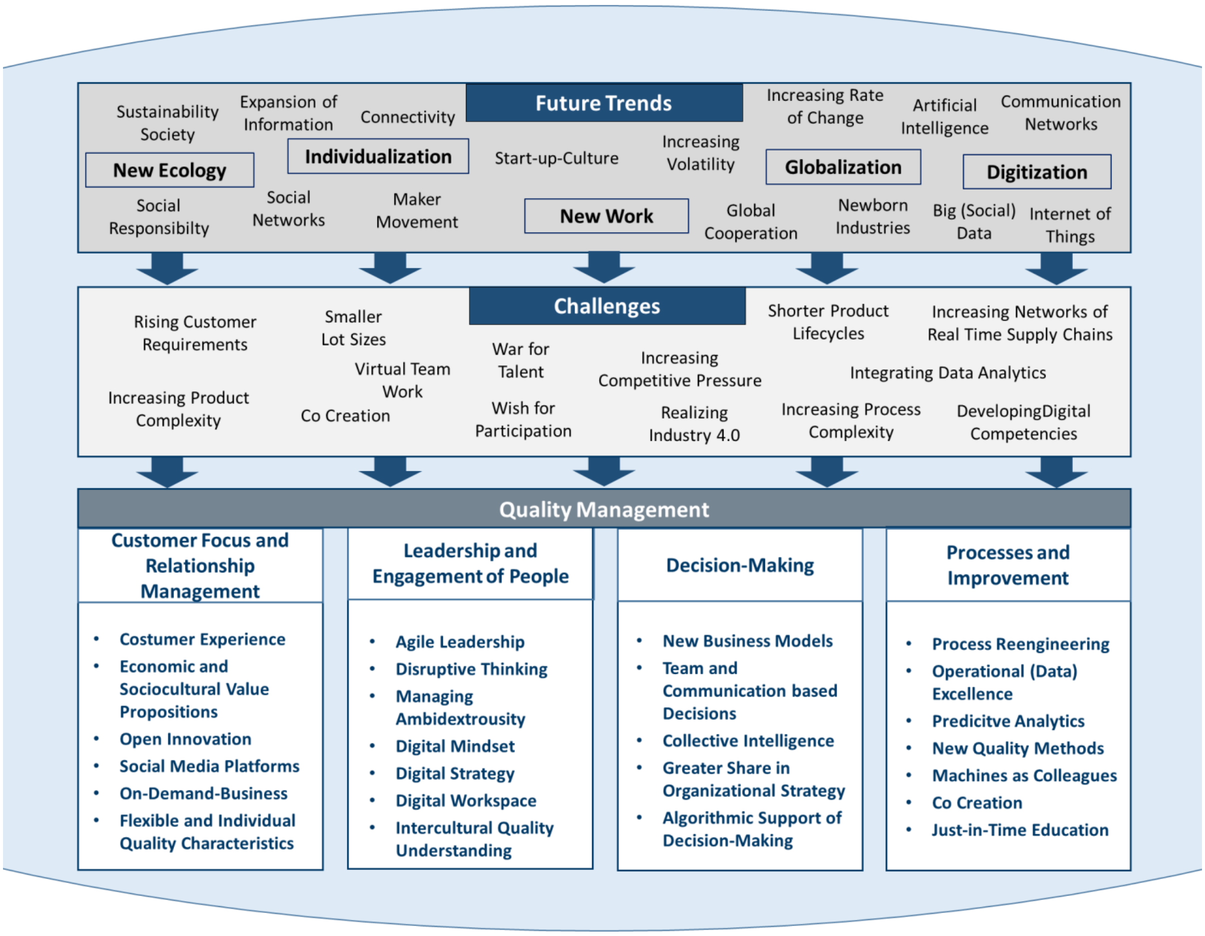

Figure 6 – The impact of megatrends and trends on quality management

Customer focus and relationship management

The focus on the customer as key point within quality management becomes more important than ever before. Providing purely functional products doesn't create enthusiasm anymore and becomes a basic fulfillment of needs according to the Kano model (Pfeifer and Schmitt, 2014). This aspect is summarized in the challenge of *rising customer requirements* in Figure 6. It can be seen as a result of the interaction of the megatrends *globalization*, *individualization*, *new ecology* and *digitization*: The globalization in combination with digitalization, e.g. in form of online platforms or forums, tangibly expands the visible marketplace and possibilities for costumers (Heinonen and Strandvik, 2017). The increasing diversification of products consequently necessitates unique features and a real product experience that addresses the customers' emotions. As humans are characterized by their heterogeneity, only individual ways of reaching their emotional attention via certain touchpoints can be successful (Lemon and Verhoef, 2016). Hence, individual values have to be focused aside from the functional aspects of a product. Especially the megatrend *new ecology* influences these values. Topics like *sustainability* and *social responsibility* need to result in economic and sociocultural value propositions of a product (Bennett and James, 2017; Li *et al.*, 2018). From a quality management perspective, measuring and ensuring quality becomes more complex, as feelings and values are more difficult to quantify. Consequently, quality characteristics become more complex.

Another aspect of the complexity increase of quality characteristics is the fact of individually designed products, resulting in *smaller lot sizes*. In this context, *open innovation* platforms offer the opportunity of directly innovating products and directly or indirectly reveal customer information about their quality criteria. Of course, these criteria can differentiate and result in multi-variant products. Consequently, products also necessitate *flexible quality characteristics* that represent the costumers' requirements. These individual quality footprints should be tracked in real time during the production or service providing process. Within times of *on-demand-business* and the *increasing volatility* (see Figure 6), the time factor additionally aggravates this challenge, as costumer requirements can change quickly and likewise the quantification of the quality footprint and associated processes should ideally follow these changes. *Agility* is also important as key competence of employees and leaders within a future-oriented company to guarantee permanent quality to the customer. However, this is not the only challenge that needs to be taken: Additionally, the ways of communication and making decisions is changing. Therefore, the next section focuses on leadership, the engagement of people and decision-making.

Leadership, engagement of people and evidence-based decision-making

Regarding the changes according to Figure 6, enabling people and organizations for flexibility and adaptability to ensure high quality products is one of the biggest challenges for leaders (Uhl-Bien and Arena, 2018; Lord *et al.*, 2016). They require the ability of a creative and flexible adaption to this rapidly changing environment to ensure competitive and value generating products for the customer. According to Petry, this ability consists of the four characteristics agility, participation, networking and openness, based on trust as important requirement (Petry, 2016). These aspects specifically affect leaders as they act as role model within a company. In this context, *agile leadership* in combination with *disruptive thinking*, as a result of *increasing rates of change* and *volatility* according to Figure 6, is characterized by providing a basic strategic direction and at the same time keeping options open (Buchholz and Knorre, 2017). This is accompanied by balancing pragmatic experimentation and detailed analysis and planning in strategic decisions. In the VUCA world, central decision making needs to be overcome by faster processes and more comprehensive evidence than one person can cover (Petry, 2016). Therefore, decisions should be balanced with *collective intelligence* and an open space for *participation*, resulting in more intrinsic motivation and a *greater share in organizational strategy* (see Figure 6) as side effect. This participation is also desired from employees according to Haufe (Haufe Online Redaktion, 2014). The third characteristic *networking* is accompanied by this approach, as the transmission of decision processes to teams and communities requires alternative global communication processes and platforms. *Social communication networks* within companies are changing the way of communication and enable collective decision-making based on collective intelligence and emergent and shared leadership (Hoch and Dulebohn, 2017; Scott *et al.*, 2017; Cullen-Lester and Yammarino, 2016). They also support the fourth characteristic “openness”. Employees favor leaders that communicate openly, give and receive direct feedback and are open for criticism. As mentioned before, the explained four characteristics are relevant for every employee as a result of the described trends. Nevertheless, an open agile leadership, nearly solely at a physical distance in *global collaboration* does not necessarily indicate that everybody can do as he pleases. Leadership should be understood as pendulum between strong hierarchies and no hierarchies as extremes (Petry, 2016). The challenge is managing the right mix between these extremes in the form of an *ambidextrous leadership*, where control is relinquished and leadership is retained in form of coaching and motivating. In addition, the necessary personal connection required for this, needs to be build and kept through heterogeneous channels, including the new technical ones, e.g. in form of digital workplaces, which also require a *digital mindset*.

Process approach and improvement

According to the DIN EN ISO 9000:2015, a quality management system follows a process-oriented approach combined with continuous improvement efforts. It implies, that efficiency is reached by deploying the right processes, combined with the appropriate resources and managed with responsibility. Increasing competitive pressure as a result of the increasing connectivity of the world market, requires *shorter product life cycles* and shorter production times. Therefore, a sequential process flow is no longer reasonable. Processes need to be thought in parallel, internal processes as well as external processes within the *increasing networks of supply chains* (Herczeg *et al.*, 2018). Along with the digitization and the data communication in real time, lots of existing processes need to be incrementally changed or radically *reengineered*. This change depends on the potentials, whether processes can be supported, streamlined or totally automated by data-driven approaches (Wallace, 2015). Hence, the goal of business excellence automatically implies the goal of *data excellence* in the future. A combination of permanent monitoring, data transparency, data analysis and prediction of processes supports quality improvement processes on the one hand and provides confidence to interested parties through communication platforms on the other hand. Of course, the selection of relevant quality data and appropriate data analytics tools becomes challenging, especially when every machine and process step is continuously tracked. The selection of quality relevant data requires business and data understanding as demanded, e.g., in the CRoss-Industry Standard Process for Data Mining (CRISP) (Wirth and Hipp, 2000), to provide a good basis for data analytics. In this context, machines are nowadays referred to as "*new colleagues*", e.g., to monitor processes or to automate routine tasks (Quigley and Chalmers, 2017). Specifically, for tasks in the field of quality assurance, it is conceivable that machines play a dominate role in measuring, analyzing, predicting and improving quality data with new algorithmic-based quality methods, like, e.g., for failure analysis according to Kang *et al.*, 2017. Hence, machines, equipped with artificial intelligence, become valuable resources taken into account within quality and process management. Therefore, the indication of the DIN EN ISO 9000:2015, that quality management is based on the understanding of the organization's capabilities and determination of resource constraints reaches a new level, as the digitization offers new ways of providing and managing resources. Closing the circle, new technologies also enable the use of the customer itself as a resource. This also supports the participation demand of customers within the *maker movement* and initiates improvement processes in the development of new or modified products and services (Morgan *et al.*, 2018; Zhang *et al.*, 2017). In this context, innovation is of major importance in order to be competitive (Muratovski, 2015; Goodman and Dingli, 2017). Hence, the method portfolio of quality management needs to be extended and combined with innovation methods close to the customer, e.g., to design positive emotional experiences (Brown and Kātz, 2009).

Controlling processes to reach quality goals and improving or reengineering processes in the context of the described megatrends require *new key competencies* of leaders and employees. On the one hand, nonlinear thinking of innovative, creative and entrepreneurial competences becomes more important. On the other hand, the ability of understanding data analytics results and drawing conclusions as basis for decision making, will play a pivotal part. (Petry, 2016) Ensuring and training these new competencies to achieve improvement objectives is a challenge resulting in *just-in-time education* to keep up with technological progress (Kohnke, 2017). Furthermore, new dimensions of the above mentioned improvement objectives need to be considered and transformed into appropriate key performance indicators.

QUALITY MANAGEMENT POTENTIALS: THE HOUSE OF QUALITY MANAGEMENT

Quality and quality management can be designated as future key player within successful organizations. The gap between the stated current and the future leading role needs to be overcome by actively triggering and inter-divisional supporting the quality mindset at all organizational levels – similar to transferring the TQM movement in the mid-90s to the challenges of today. The basic quality management understanding shown in Figure 7 still remains, but has to face new challenges according to the described trend analysis. It consists of a quality promoting basis, the customer focus on the top, the strategical perspective on the left and the operational perspective on the right, described in more detail with focus on the described trends of the previous section.

Quality basis: Culture and infrastructure

The model is based on the quality culture, including a quality mindset. This mindset implies a clear definition of what quality means to the company and its employees and which values are connected to that. Every action should follow this understanding, with management and leaders as role models. In terms of trends like the digitization, this mindset is accompanied by a digital openness that enables an adequate usage of technological innovations. In addition, the communication infrastructure should support these quality-oriented and high value generating actions and processes. According to the previous chapter, the information architecture comprises people-based as well as technological-based infrastructures that enable the provision of the right information at the right time. Technology offers new ways of storing and accessing information e.g. in maintaining a quality management manual.

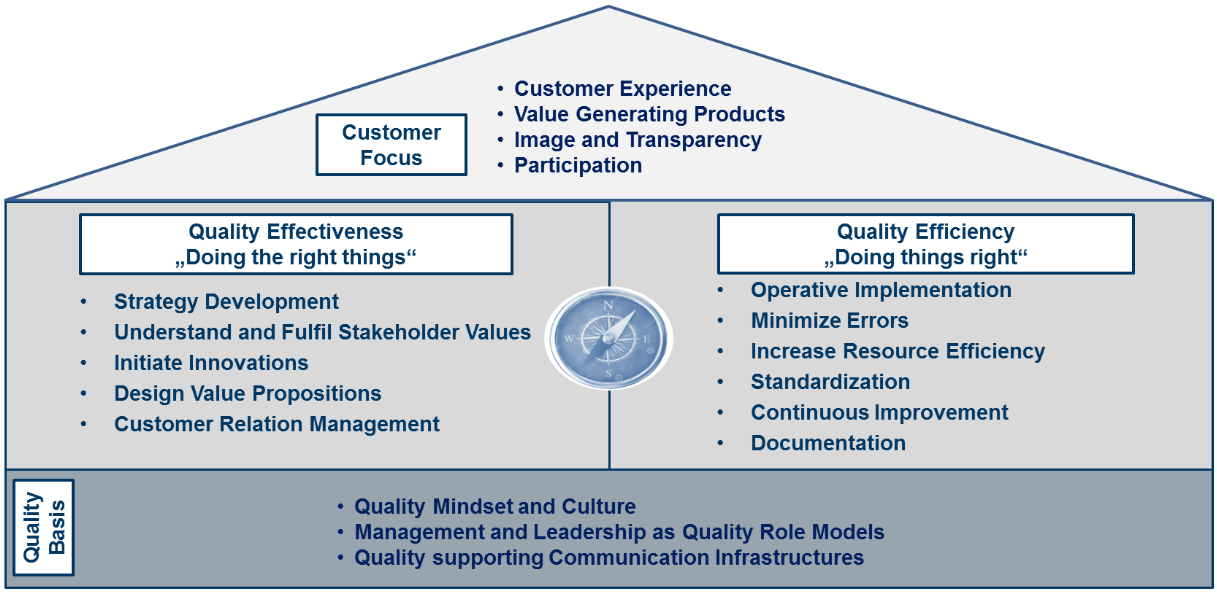

Figure 7 – House of quality management

Quality focus: Customer

The aim of quality management is the identification and fulfillment of the customers' requirements. Nowadays, this means providing a product or service and additionally addressing the customers' emotions by taking him to a customer journey. Within this journey, triggering the right thoughts and feelings depends on the underlying beliefs and values. Especially sociocultural and economic values are key players according to the megatrend combination of new ecology and globalization, as described in the trend section above. Furthermore, new technological possibilities lead to new ways of directly involving the customer in the product development process, e.g., via open innovation platforms. In addition, they enable transparency and real time information throughout the entire product life cycle, e.g., via tracking and tracing methods or multiple communication platforms, where they can be directly transferred to the user. Immediate user feedback e.g. via sentiment analysis on social media platforms is also a new feature that enables a faster reaction on customers' needs.

Quality effectiveness: "Doing the right things"

The role of quality management in a strategic context is depicted in the left pillar in Figure 7. Nowadays, new business areas and opportunities within the digitization lead to an increasing importance of developing a digital strategy. This digital strategy can focus three main objectives, namely operational excellence, customer experience or a fundamental new business model, combining both, changes in internal processes and customer interaction (Petry, 2016). Regarding these possibilities, the right strategy should always be developed with target to the customer.

Customer interaction should ideally include user-oriented methods for creating additional value to the customer. For example, the user can be involved in the product innovation via agile product development. The way of initiating innovations could be based on an open and adventuresome innovation culture. This aspect can play a crucial role in exploiting the potential of the current fast pacing developments, especially on a technological level.

Quality efficiency: "Doing things right"

The right pillar addresses the operational part of quality management. It focuses on "doing things right", based on the strategic goals on the left. This comprises the classical tasks of quality management like continuous improvement of processes while minimizing errors and increasing resource efficiency, including the documentation. New in this pillar are the methods of accomplishing these tasks. Data analytics and predictions play a crucial role in this context as production or service data is tracked, traced, analyzed and predicted throughout the whole lifecycle. Therefore, decisions concerning the value chain of the product are made automated or semi-automated with machines as "new colleagues".

Quality management: "Keeping the balance"

Based on this model, the superordinate role of quality management is keeping the balance between the rethinking and adaption of the strategy and the continuous improvement concerning the quality efficiency with central focus on the customer. This balance-keeping is a major challenge within the described changes in the future trend section. Especially the significance and potential of disruptive approaches concerning completely new business models needs to be taken into account, even though these new possibilities must be balanced against associated risks and rewards. Figure 3 points out these strategic views.

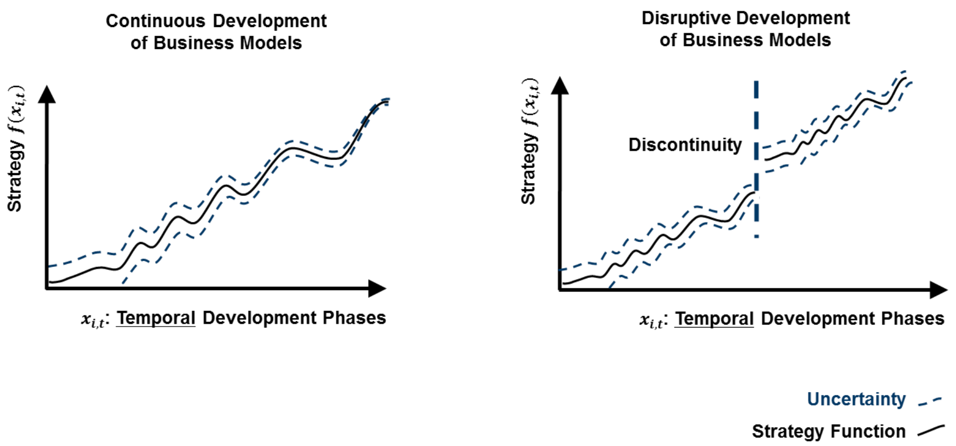

Figure 8 – Continuous improvement vs. disruptive development of products and processes

LEVERAGING QUALITY MANAGEMENT: ONE POSSIBLE STRATEGY

According to the impact of the described trends in the previous chapter, quality management has now the opportunity to recover its image of former times. Expected quality competencies like a crosslinking process view and detecting improvement potentials based on quality analysis, form a perfect basis for being a key player within necessary trend-induced transformation processes (Castiglione, 2011). To exploit these opportunities, a possible strategy was developed within an expert workshop in the field of quality management. It is based on practical experiences combined with change management approaches. According to Figure 9, the strategy consists of four steps, namely *Quality Assessment*, *Convincing the Management*, *Successful Project Realization* and *Best Practices Establishment within the whole Company*, which has the potential of perceiving quality management again as important partner of internal change management.

Figure 9 – Possible change strategy for leveraging quality management

Of course, the basic requirement is that the current quality management is able to be part of transformation processes - not only via e.g. quality methods, process understanding, but also in strategic and leadership skills. These skills should be used in combination with the presented strategy and a clear goal of a stronger quality management in the near future.

Quality assessment

In the first step, quality management focuses on its core competencies and mandatory tasks for the management via a quality assessment. Beside the internal analysis, it is necessary, to pay attention to ongoing trends and new possibilities for improving processes by including methods out of the field of trend and innovation management (Brown and Kātz, 2009). These opportunities need to be carefully evaluated. Exemplarily, digitization has the potential for completely automatizing the tracking, tracing, analyzing and predicting of quality data (Chen *et al.*, 2012). It is conceivable that information technology and algorithms will dominate the field of quality assurance. As a result of this analysis, potential fields of action are specified. The collection of possible improvement projects is then prioritized, with focus on necessary changes in combination with a high chance of success as the goal is an increasing positive attention towards quality management. The most attractive project is chosen and enriched by a vision, a strategy and the required resources for the change process.

Convincing the management

In most cases, change processes are only successful with the support of the top management. Therefore, it is necessary to involve the relevant people in the early stages and create a necessary urgency for change, focusing on the chances and risks with regard to upcoming trends. (Kotter, 2015) This is addressed in step two, where the most attractive project including a convincing vision and strategy is presented to the top management. Maybe the top management has not focused on quality management as leading part in the chosen project. Nevertheless, the quality manager can now take the opportunity to convince the management and leave its shadowy existence. This part plays an essential role and needs to be well-prepared. Otherwise there is a high risk to be doomed to failure. After Convincing the management, the change project can be planned in detail and realized.

Successful project realization

In step three, the concrete change project is planned, implemented and continuously improved to sustain the change (Vahs and Weiand, 2013). Here, the communication plays an essential role, as change can only take place, when the involved people realize the necessity and advantages of the project. During the planning phase, short-term goals should be included to keep the motivation. Trainings in accordance with the vision, behavior patterns and skills for using new methods are another aspect to support the employee’s motivation (Kotter, 2015). One potential for quality management in this phase is to be a pioneer in technically improving existing methods to efficiently solve the detected problems within the project. Even supporting methods can be executed in new ways, e.g. for measuring the project progress digitally enhanced surveys or a social media supported stakeholder analysis can be used or the continuous improvement process can be realized by kaizen or six sigma tools, supported by data analytics based on consistent data sets.

Best practices establishment within the whole company

The successful and innovative realization of the change project makes it reasonable to transfer the experiences to other business divisions of the company. Consequently, the visibility and appreciation of quality management increases and quality thinking and (new) methods are strengthened. Now, other fields of action can also be focused in the next step to expand the sphere of influence of quality management.

The goal of this approach is to motivate quality management for a leading role in change processes, regarding the presented megatrends and trends. Of course, an open minded future design of quality management processes can lead to a decrease of traditional quality tasks, as the digitization holds the potential to perform certain quality assurance tasks. In contrary, changes also create new opportunities for quality management activities, as a company only profits of a quality managers in multiple roles (Castiglione, 2011).

CONCLUSIONS

This paper focuses on the future challenges of quality management in the context of designated megatrends. It maps these megatrends to the principles of quality management according to the DIN EN ISO 9000:2015 and describes the expected potentials and challenges within the principles of customer focus, relationship management, leadership, engagement of people, and evidence-based decision-making. Furthermore, an extended quality management understanding is presented and described. The last section identifies the gap between the current and future role of quality management and derives a strategy for a change process to overcome this gap. In conclusion, quality management has to reinvent itself with a focus on strengthening its strategic role, creating synergies with innovation approaches, including new and adapted quality methods and training quality competencies by exploiting the potentials of the designated megatrends.

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World State of Quality 2017: Results of a worldwide approach to measure macroquality

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ABSTRACT

Purpose – This paper aims to present the first results of the World State of Quality project which intends to measure the country macroquality according to different multidimensional quality performance.

Design/methodology/approach – A model encompassing 10 dimensions and 16 indicators was developed aiming to cover the macroquality approach to understand how each country is performing. Different databases were chosen in order to get the data collection. Then, an overall World State of Quality score was computed based on the ranking positions of each country across all indicators.

Findings – The overall World State of Quality allowed the identification of different quality profiles group and each one reflects similar behaviours that the countries of the same group perform. Five groups were created: Leading; Follower; Moderate; Lagging; and Beginning.

Research limitations/implications – Only 110 worldwide countries were used in the 2017 edition of the World State of Quality project due to the lack of compiled information. Besides that the databases were chosen based on those that publish periodic and reliable updates.

Originality/value – Rankings and evaluation of several areas such as innovation, competitiveness, education or health are regularly published and reports are produced to show the results of these areas. The intention of the World State of Quality project is to fill the lack of quality performance assessment across countries in a pioneer approach that was already tested for the European Union countries in 2016.

Keywords: World State of Quality, Macroquality, Quality performance.

Paper type: Research paper.

INTRODUCTION

The World State of Quality project was launched in 2016 in order to assess, analyze and rank countries according to their levels of multidimensional quality performance.

The first edition of this new approach was tested across all the 28 European Union (EU) countries using 21 quality related indicators spread by 10 quality dimensions. For each EU country an overall European Quality Scoreboard score (OEQS) was computed based on the ranking positions of each country for each indicator. The OEQS was determined by a weighted average that was determined using a panel of quality experts. The European Quality Scoreboard (EQS) allowed to the definition of 4 categories of countries, in a simple division of the 28 countries in 4 groups (each one composed by 7 countries): Leading, Follower, Moderate, and Lagging. This first attempt was the pilot test to this approach that intends to understand how each country performs regarding the macroquality, as the aim is to cover the most countries as it is possible (WSQ, 2017; Saraiva *et al.*, 2018).

Thus, the worldwide first attempt was carried out in 2017 and 110 countries were analyzed. This is possible because nowadays it is becoming easier the information access from any place in the world since Internet access exists, mainly due to the repositories of big amounts of data concerning different indicators and areas of interest (Cubo *et al.*, 2017). For this study, several reliable online databases with public access were used.

The objectives of this paper are: explanation of the model used and the changes made compared to the 2016 EQS; presentation of the results of the 2017 WSQ approach; to contribute to better decision making taken for the governments and national institutions regarding new quality policy definition based on the benchmarking that is possible to do with the WSQ.

This paper is structured as follows: presentation of the research methodology, which includes the multidimensional model used and the explanation of the overall score computation method; results of the 2017 World State of Quality approach, the first worldwide one; conclusions and future work to improve this approach.

RESEARCH METODOLOGHY

The WSQ approach deals with a multiscale quality perspective, namely the macroquality (quality at the country or international level). Saraiva & Sampaio (2016) came up with a new look over quality highlighting the necessity and relevance of a new concept, the “Glocal Quality”. In a globalized world it makes even more sense to “think global, and act local”, but also to “think local, and act global", which means the need of combining the "top down" and "bottom up" perspectives concerning quality.

It is easy to understand that when the national agenda for quality of a country has to be defined that it has to take time to really happen, for example, years. In a space time quality has no frontiers and the involvement of national and/or international space is common. This reflects the macroquality level that is where the WSQ approach is focused on.

The 2017 WSQ approach follows the 2016 EQS approach making some adaption of it, as the number of covered countries increased. The model that was used had to be reformulated in order to cover all the dimensions that deal and reflects quality but, at the same time, to cover a larger set of countries. It has been decided to use 16 quality related indicators to assess the macroquality performance level of a country. The WSQ Scoreboard with dimensions and indicators is shown in Figure 10.

The aim of this Scoreboard is to cover several areas that support, develop and promote macroquality performance and each dimension has one or two indicators to characterize the macroquality concept. Some indicators had to be scaled in order to allow comparisons between countries. The corresponding per capita values (actually per 1,000 inhabitants) were used for the indicators related to Organizations, Professionals, and Research dimensions.

The data for each indicator were collected in June 2017 and the latest data available possible to find as of that time was used for each indicator in different databases (see Table 5). Several other reports also use the most recent available data for the reports and rankings (Cornell University *et al.*, 2016; Helliwell *et al.*, 2017).

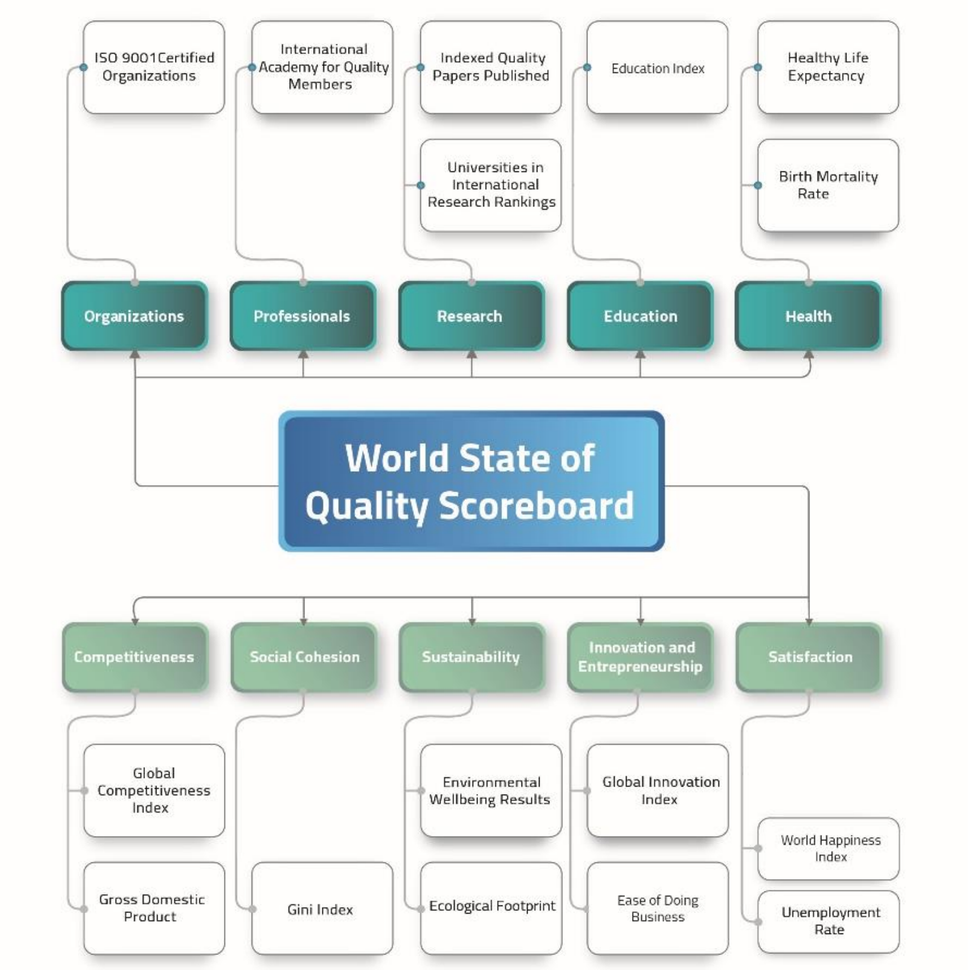

Figure 10 – World State of Quality Scoreboard: dimensions and indicators.

Table 5 – Databases used for each indicator of the WSQ approach

Dimension	Indicator	Database
Organizations	Number of ISO 9001 Certified Organizations	ISO survey
Professionals	Number of International Academy for Quality Members	International Academy for Quality site
Research	Number of Indexed Quality Papers Published	Scopus and ISI Web of Knowledge
	Number of Universities in International Research Rankings	Shanghai Ranking
Education	Education Index	Human Development Reports
Health	Healthy Life Expectancy	World Health Organization
	Birth Mortality Rate	World Bank
Competitiveness	Global Competitiveness Index	World Economic Forum
	Gross Domestic Product	World Bank
Social Cohesion	Gini Index	World Bank
Sustainability	Environmental Wellbeing Results	Sustainable Society Foundation
	Ecological Footprint	Footprint Network
Innovation	Global Innovation Index	Global Innovation Index
	Ease of Doing Business Results	World Bank
Satisfaction	World Happiness Index	World Happiness Report
	Unemployment Rate	World Bank

The WSQ approach comprises data for 16 quality related indicators from 110 worldwide countries. A data matrix (110x16) was built with the raw data, i.e., the latest values available, and a new data matrix was composed replacing the raw data by the scaled data for each indicator of the Organizations, Professionals, and Research dimensions. Then, a new data matrix was computed with the values replaced by the ranking positions, i.e., the relative positions for each indicator ranging from 1 (best performance) to 110 (worst performance) according to the relative ranking position for each country.

The computation of the overall World State of Quality score (OWSQ) was made by using a final weighted average that depends on the weight for each indicator. However the number of indicators was reduced from 21 to 16, so an adaptation had to be made by maintaining the same scoring percentage for each dimension as before (2016 EQS). The average relevance was determined at the first time asking a quality international experts' panel to define the importance of each indicator for the macroquality measurement, using a scale ranging from 1 (very small relevance) to 5 (very high relevance). The new average relevance ranging from 0.048 for the International Academy members indicator to 0.077 for the World Happiness Index indicator.

After the computation of the overall scores, the groups were formed according to the following methodology: 1) the difference between the OWSQ score of the country in the ranking position $i+1$ and the ranking position i was calculated in order to find the major discontinuities; 2) a threshold of 1.75 was defined as the minimum value for the creation of groups; 3) each group had to be a minimum of 5 countries.

RESULTS

The overall score for the 2017 WSQ ranges between 16.074 for Switzerland (in the first ranking position) and 80.254 for Mozambique (in the last ranking position). The overall score allows to understand that no single country outperforms or underperforms the others for all the indicators considered. If we look to Switzerland, an overall score of 16.074 was achieved meaning that Switzerland is positioned close to the 16th position across all the 16 WSQ indicators. The overall score for each country of the 110 worldwide countries under analysis in the 2017 edition of the WSQ project can be seen in Table 6.

Following the methodology previously described in the Research Methodology section, the 2017 WSQ results led to the definition of 5 groups: Leading; Follower; Moderate; Lagging; and Beginning. The larger differences between the overall score of consecutive countries according to their OWSQ was the main reason for the definition of 5 groups of countries.

The first group (Leading – green colored) is composed by 11 countries (Switzerland, Norway, Sweden, Denmark, Netherlands, United Kingdom, Germany, Austria, Finland, Ireland, and Australia) and the OWSQ ranges between 16.074 and 25.855. It is important to point out that Australia assumes the 11th ranking position, which means that the top 10 of the 2017 WSQ results are composed only by European countries, highlighting the focus on quality that there is in this continent. The second group (Follower – yellow colored) is composed by Japan, Czech Republic, Canada, United States, Israel, Slovenia, Belgium, France, Estonia, Italy, Spain, Luxembourg, Portugal, Romania, Hungary, Slovakia, and Poland. The OWSQ of this group of 17 countries ranges from 28.293 to 37.104. The third group (Moderate – orange coloted) has 20 countries and an OWSQ between 39.223 and 50.299 and the countries of this group are: Croatia, Cyprus, Lithuania, Latvia, Malaysia, Thailand, Chile, Greece, Costa Rica, Serbia, Montenegro, Bulgaria, Mexico, China, Moldova, Uruguay, Russia, Mauritius, Panama, and The Former Macedonia.

Table 6 – Overall 2017 WSQ results for the 110 worldwide countries

Country		OWSQ	Group
1	Switzerland	16.074	LEADING
2	Norway	19.168	
3	Sweden	21.426	
4	Denmark	22.303	
5	Netherlands	22.692	
6	United Kingdom	22.736	
7	Germany	23.626	
8	Austria	24.476	
9	Finland	24.631	
10	Ireland	25.623	
11	Australia	25.855	
12	Japan	28.293	FOLLOWER
13	Czech Republic	29.194	
14	Canada	29.916	
15	United States	30.097	
16	Israel	30.587	
17	Slovenia	30.631	
18	Belgium	31.687	
19	France	32.826	
20	Estonia	33.671	
21	Italy	33.823	
22	Spain	33.900	
23	Luxembourg	33.964	
24	Portugal	35.073	
25	Romania	35.667	
26	Hungary	35.875	
27	Slovakia	36.846	
28	Poland	37.104	

	Country	OWSQ	Group
29	Croatia	39.223	MODERATE
30	Cyprus	39.686	
31	Lithuania	40.381	
32	Latvia	40.936	
33	Malaysia	41.357	
34	Thailand	42.764	
35	Chile	43.602	
36	Greece	43.762	
37	Costa Rica	45.307	
38	Serbia	45.377	
39	Montenegro	45.401	
40	Bulgaria	46.101	
41	Mexico	46.529	
42	China	46.669	
43	Moldova	47.676	
44	Uruguay	48.872	
45	Russia	49.400	
46	Mauritius	49.721	
47	Panama	50.197	
48	The Former Macedonia	50.299	
49	Colombia	52.836	LAGGING
50	Argentina	52.844	
51	Turkey	52.950	
52	Georgia	53.097	
53	Viet Nam	53.276	
54	Albania	53.583	
55	Peru	54.652	
56	Sri Lanka	56.039	LAGGING
57	Indonesia	56.939	
58	Philippines	56.947	
59	Brazil	57.003	
60	Ukraine	57.051	
61	Azerbaijan	57.392	
62	Bosnia and Herzegovina	58.036	
63	Jamaica	58.107	
64	Ecuador	58.412	
65	El Salvador	58.456	
66	Armenia	58.483	
67	India	58.712	
68	Guatemala	59.598	
69	Tunisia	60.179	
70	Morocco	60.273	

	Country	OWSQ	Group
71	Iran	62.123	BEGINNING
72	Nepal	62.791	
73	Rwanda	63.383	
74	Mongolia	63.682	
75	South Africa	64.320	
76	Cambodia	64.325	
77	Nicaragua	64.667	
78	Dominican Republic	65.462	
79	Paraguay	65.712	
80	Kyrgyzstan	66.086	
81	Tajikistan	67.104	
82	Venezuela	67.453	
83	Bhutan	67.655	
84	Honduras	67.662	
85	Kenya	68.108	
86	Uganda	68.353	
87	Pakistan	68.747	
88	Bangladesh	69.039	
89	Bolivia	70.280	
90	Tanzania	70.613	
91	Botswana	70.906	
92	Ghana	71.544	
93	Namibia	71.901	
94	Zambia	73.179	
95	Madagascar	73.313	
96	Ethiopia	73.466	
97	Zimbabwe	73.746	
98	Senegal	73.858	
99	Burkina Faso	74.303	
100	Cameroon	74.611	
101	Burundi	74.875	
102	Nigeria	74.930	
103	Benin	75.415	
104	Malawi	76.424	
105	Angola	77.878	
106	Mali	78.876	
107	Côte d'Ivoire	79.170	
108	Lesotho	79.188	
109	Guinea	80.098	
110	Mozambique	80.254	

*OWSQ- Overall World State of Quality score

The fourth group (Lagging – blue colored) ranges from the 49th and 70th ranking position with an OWSQ between 52.836 and 60.273. This group is composed by Colombia, Argentina, Turkey, Georgia, Viet Nam, Albania, Peru, Sri Lanka, Indonesia, Philippines, Brazil, Ukraine, Azerbaijan, Bosnia and Herzegovina, Jamaica, Ecuador, El Salvador, Armenia, India, Guatemala, Tunisia, and Morocco. The fifth and last group (Beginning – red colored) has the remaining 40 countries and an OWSQ ranging from 62.123 and 80.254, making this one the biggest groups in terms of quantity of countries. The countries of this group are: Iran, Nepal, Rwanda, Mongolia, South Africa, Cambodia, Nicaragua, Dominican Republic, Paraguay, Kyrgyzstan, Tajikistan, Venezuela, Bhutan, Honduras, Kenya, Uganda, Pakistan, Bangladesh, Bolivia, Tanzania, Botswana, Ghana, Namibia, Zambia, Madagascar, Ethiopia, Zimbabwe, Senegal, Burkina Faso, Cameroon, Burundi, Nigeria, Benin, Malawi, Angola, Mali, Côte d'Ivoire, Lesotho, Guinea, and Mozambique

An overview of the geographical 2017 WSQ results can be found in Figure 11.

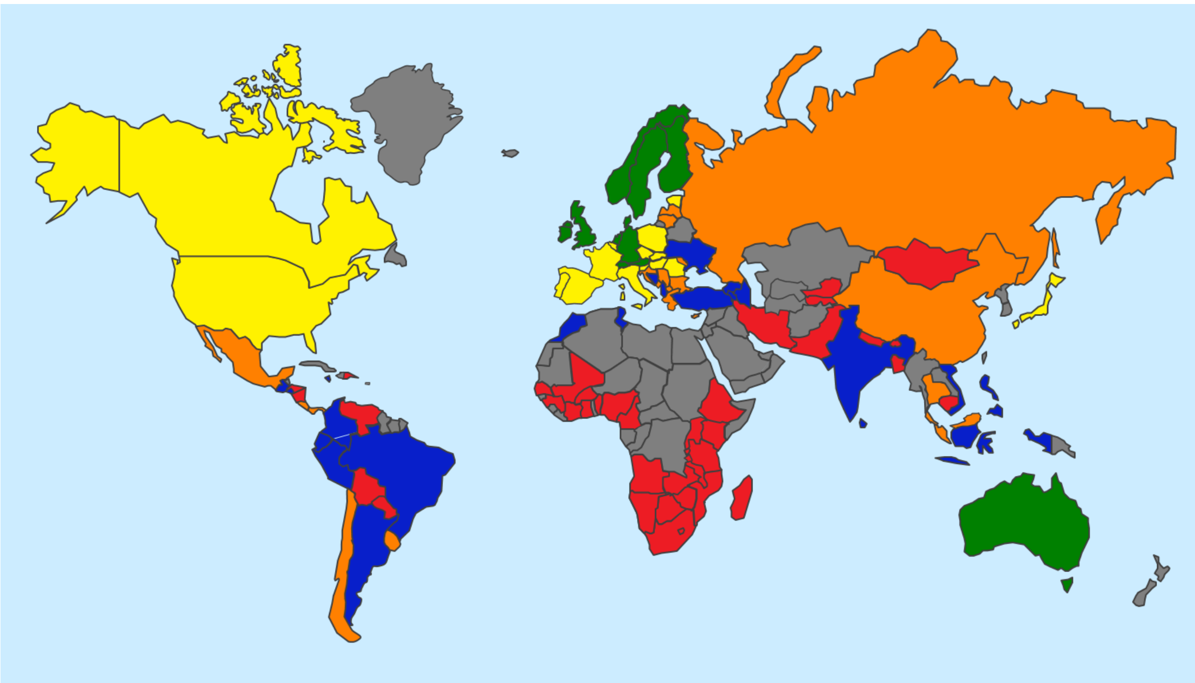

Figure 11 – WSQ geographical overview results (Leading – green; Follower – yellow; Moderate – orange; Lagging – blue; Beginning – red).

It is important to note that although no single country outperforms or underperforms quality across all the 16 considered indicators, some clusters of groups can be found, e.g., almost only European countries in the Leading group.

Quality profiles can also be drawn to a better comprehension of the similar behaviors of country with similar overall scores.

CONCLUSIONS AND FUTURE WORK

There is no single way for interpreting and implementing quality worldwide due to the clear diversity of countries approach, development and importance given to the quality field. The WSQ project intends to cover this gap, as other several areas have already rankings and ways to understand how each country is performing in a given area. In 2016, a first attempt was made by using the European Union countries. Further, in 2017, a more broad geographical area was analyzed and using 16 quality related indicators grouped in 10 dimensions, an overall score was computed for each country under analysis. The results are presented in this paper which intends to be the first worldwide attempt to classify countries according to their macroquality performances. The overall score varies from 16.074 for Switzerland and 80.254 for Mozambique. The OWSQ helped in the confirmation of the diversity of situations regarding the quality approach, similarities and differences between countries. The OWSQ also allowed the proposal of 5 groups composed by different number of countries reflecting the different ways to look and deal with quality. The referred groups are named Leading, Follower, Moderate, Lagging and Beginning.

This work can contribute to help countries to find strengths and weaknesses associated with quality. The definition and revision of strategies, policies and deployments used by different institutions and governments have not only one more input but an important one that deals with the macroquality approach in terms of time and space to improve societal quality levels of a given country.

This work can and should be continued in the future in order to monitor and understand how each country evolves when the same methodology, indicators and countries are under analysis, despite of the dependency of the updating of the chosen databases.

AKNOWLEDGEMENTS

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Service Quality for Retail Banks in the Digital Age

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ABSTRACT

Purpose – The purpose of this paper is to develop a framework for retail banks to leverage their service quality customized to the opportunities and challenges that arise within digitization.

Design/methodology/approach – In this paper the maturity of digitization of retail banks was analyzed and the lack of a holistic approach for digitization for service quality improvement was identified. Subsequently, a service quality framework was developed interrelating state-of-the-art data analytics technologies with service quality management. The framework was then validated in a German retail bank using a single case study with embedded units.

Findings – The findings emphasize that the collection and analysis of data compose an increasingly role for service quality improvement. Therefore data mining can be implemented to process customer data and enable retail banks to predict future customer journeys to provide high service quality which is a prerequisite to strengthen customer relations.

Research limitations/implications – This research is limited to retail banks that offer services through online and offline channels.

Practical implications – Retail banks can apply our framework to improve service quality through customer data and new technologies.

Originality/value – This paper is valuable since it offers guidance to improve service quality on an operational level tailored to the requirements of retail banks. It is the first paper that utilizes data mining in order to proactively provide banking services to customers.

Keywords: Service quality, retail banking, digitization, customer journey

Paper type: Research paper

INTRODUCTION

European retail banks are currently challenged by the low-interest rates established by the European Central Bank and by stricter government regulations (Kotarba, 2016). The legal restrictions limit the retail banks in their scope of actions and reduce their revenues (Sääskilahti, 2018). Simultaneously, retail banks are increasingly losing contact to the customers and struggle to build up effective customer relations. The digitization is a further challenge for conventional banks since traditional business models, products and services compete against new ones offered by new competitors (Corvoisier and Gropp, 2002). The new entrants to the financial market, so called FinTechs, are characterized by disruptive business models that offer new value propositions to customers based upon new technologies. FinTechs have so far gained market share since they exceeded traditional banks in terms of meeting new customer requirements more effectively (Vasiljeva and Lukanova, 2016). They address customers using state-of-the-art technology enabling them to build up individualized customer relations. Accordingly, conventional banks need to change from a product-centric strategy, characterized by standardized products for the mass market, to a customer-orientated strategy, offering customized services as an addition to standardized products. Only by leveraging the potentials of digitization, retail banks can nowadays create customer relations that fit customers' need for individualization as well as convenience and therefore compete with disruptive business ideas. In this research paper an approach for high quality services and high quality customer relations is developed that is especially tailored to retail banks and makes use of new opportunities of digitization.

The subsequent paper is structured as follows. First, the state of the art for service quality and digitization in retail banking is analyzed. We identified the lack of a holistic approach for digitization in retail banking. To close this gap a service quality framework is developed. The framework includes four steps which assist banks to systematically exploit the potentials of new technologies aiming for personalized services for individual customers. After outlining the four steps, the framework is qualitatively validated at a German retail bank by means of a single case study. The results of the case study are presented and finally further research questions are discussed.

SERVICE QUALITY IN RETAIL BANKING

One of the main goals for implementing a quality management system complying with the DIN EN ISO 9001 norm is enhancing the customer satisfaction by providing products and services that meet customer requirements (DIN EN ISO 9001:2015). Accordingly, many researches have proven a significant relationship between service quality and customer satisfaction (Yavas *et al.*, 2004; Sureshchandar *et al.*, 2002; Malik and Oberoi, 2017). Even though the hierarchical relationship between service quality and customer satisfaction, proving which factor is the antecedent, is still controversial, service quality has a great impact on the firms performance (Kumar *et al.*, 2009). From a finance perspective, service quality is defined as “the long-term person-to-person relationship between a financial institution, its distributors and its customer” (Mon Wong and Perry, 1991). It describes the gap between the customers expectation of a service and the actual experience of the service after its delivery process and therefore strongly depends on the customers’ cognitive perception (Parasuraman *et al.*, 1985). Furthermore, service quality is differentiated into technical quality and functional quality (Grönroos, 1984). Technical quality describes the degree in which the provided service meets the customers’ expectation whereas the functional quality refers to the service delivery process itself. Since services are characterized by intangibility, production and consumption interaction, lack of ownership, and transaction ownership (Grönroos, 1978), defining service quality is more difficult compared to product quality. Nevertheless, achieving service quality results in a competitive advantage for retail banks because high service quality is related to cost reduction, the acquisition of new customers as well as retaining existing ones (Goplani, 2017; Julian and Ramaseshan, 1994). Consequently, the provision of high service quality is a precondition for retail banks to survive on the competitive market in the long term.

Taking the current changes in the environment of retail banks into consideration, the definition for service quality is not adequate anymore since retail banking is not only restricted to offline channels that support person-to-person interactions between distributors and customers in physical branches (Seck and Philippe, 2013). In traditional retail banking the customer was often bound to a designated consultant in order to get in contact with the retail bank e.g. for receiving information or making contracts about products and services. The consultant was able to highly influence service quality and was the main success factor for building up relationships with customers (Kotarba, 2016). Nowadays however, there are multiple ways for retail banks to communicate with their customers so that the service delivery process has become more complex. To overcome this challenge many banks have started the digital transformation to meet new customer requirements.

DIGITIZATION IN RETAIL BANKING

In the light of digitization the requirements of customers have changed and their negotiation position have strengthened. Customers can easily research products and services as well as compare offers from various retail banks effortlessly within few clicks. Accordingly, bank customers nowadays own more information about costs as well as prices and are also able to process their bank matters independently (Grewal *et al.*, 2003). Retail banks have realized the urgent necessity to implement new technologies and online channels to fulfil new customer requirements (Sreejesh *et al.*, 2016). However, a holistic approach for the digitization of the service delivery process has not been implemented yet (Payne and Frow, 2005; Durkin and Howcroft, 2003). The digitization in retail banking has been primarily motivated by cost reduction in conjunction with the pressure by new competitors who solely focus on digital services (Campanella *et al.*, 2017). This has lead to the status quo that all efforts by retail banks are unilaterally focused on automating service processes that are associated with customer involvement. Accordingly, many services, e.g. money transaction, conclusion of contract as well as customer consulting, have been digitized by retail banks and are offered through new established online channels, e.g. social media, banking apps and websites (Yavas *et al.*, 2004). These services have become self-services characterized by person-to-machine interactions which not only causes a stronger information asymmetry between the bank and the customer (Larsson and Viitaoja, 2017) but also increases the lack of social interaction during the service delivery (Levy, 2014). As a consequence, retail banks are increasingly loosing knowledge of customers' needs and requirements which hinders them to provide personalized services and to develop individualized customer journeys (Durkin *et al.*, 2015).

For a holistic approach retail banks leave aside that their existing structures should be taken into consideration and can be harmonized with new online structures to optimize their service quality and customer relations management. Retail banks often perceive their branch structure as a burden even though from a service quality perspective branches that involve interpersonal interactions still are a success factor (Xue *et al.*, 2011; Onay and Ozsoz, 2013). Banks do not only need to introduce new channels but have to orchestrate online and offline channels so that they complement each other, which is also referred to as omni-channel (Kotarba, 2016). Mastering an omni-channel strategy through branch structure and online structures helps retail banks to achieve a greater customer understanding enabling them to personalize services across all channels according to customers' needs. This is necessary for a high service quality since offline channels using the branch structure is still a determining factor for building customer relation (Durkin and Howcroft, 2003). Accordingly, retail banks can use both online and offline structures to create unique as well as personalized services that differentiate from services of new competitors.

A DATA-BASED SERVICE QUALITY IMPROVEMENT FRAMEWORK

To overcome the deficit of bringing together online and offline structures as well as the lack of personalization in the process of service delivery, the potential of new technologies and data were insufficiently considered in retail banking. To close this gap, this paper provides a service quality framework which supports retail banks to improve service quality by creating a holistic customer understanding across online and offline channels. Therefore the framework consists of four steps which are classified as *definition of modular customer journey*, *data analysis*, *customer understanding* and *proactive approach* Figure 1.

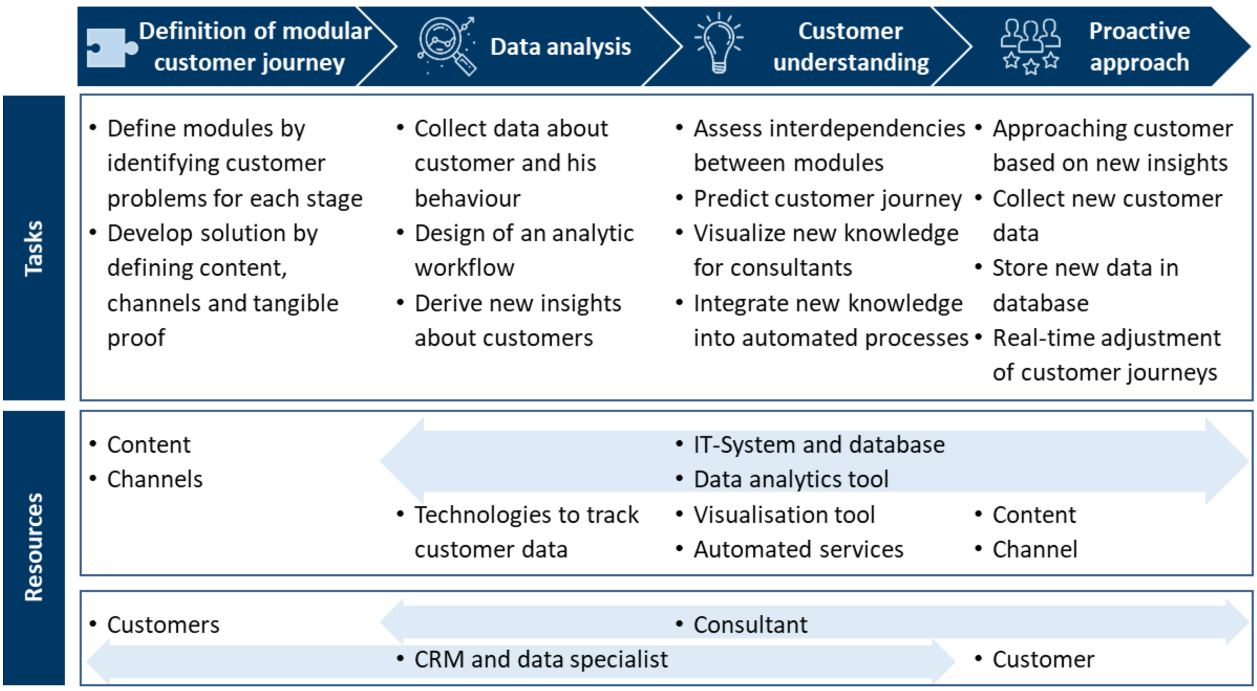

Figure 12 – Service quality framework

The service quality framework compromises a new approach to design customer journeys. Customer journeys are often planned by companies in advance and are taken as an orientation when approaching the customer. But considering the customer variety, which results in many different requirements, there is no one size fits all solution. A rather dynamic customer journey can better support banks expanding their customer understanding. To meet these requirements we created a *modular customer journey* which will be presented first. The following steps of the framework are based on levels suggested in data analytics research (Chen *et al.*, 2012; Gartner, 2016) and have been developed specifically for a data-based service delivery process in retail banking addressing customers. The second step *data analysis* compromises the implementation of data mining aiming for a better apprehension of customer data and subsequently customer journeys. By knowing what services individual customer expects and how they want it to be delivered, retail banks can improve the technical as well as functional quality. Therefore, we outline the required data and prerequisites for data mining customized to the needs of retail banks. In the step *customer understanding* we focus on the integration of results provided by data mining in order to foresee how the customer journey of each customer will develop. Knowing future customer journeys enables retail banks to approach customers proactively, which comprises the last step of the framework. For the step *proactive customer approach,* a newly designed process for service delivery, which supports the modularized customer journey and bases upon data mining, is introduced.

The modular customer journey

The customer journey method helps to guarantee customer orientation by understanding and optimizing all possible points of contact to the customer during the process of service delivery, also touchpoints (Nenonen *et al.*, 2008). Due to the reference to the process of service delivery the modular customer journey is divided into three stages, which are specified as *marketing*, *sales* and *customer service* processes, Figure 2. Moreover, the customer journey is not build up as a whole predefined journey but divided into multiple modules. Modularization is often applied to products in order to decompose an overall problem into sub-systems and to enhance flexibility for the reconfiguration of products by simply changing or adding modules for the purpose of serving a mass market with personalized products (Gu and Sosale, 1999). Also aiming for high flexibility when defining individualized customer journeys, modularization is applied.

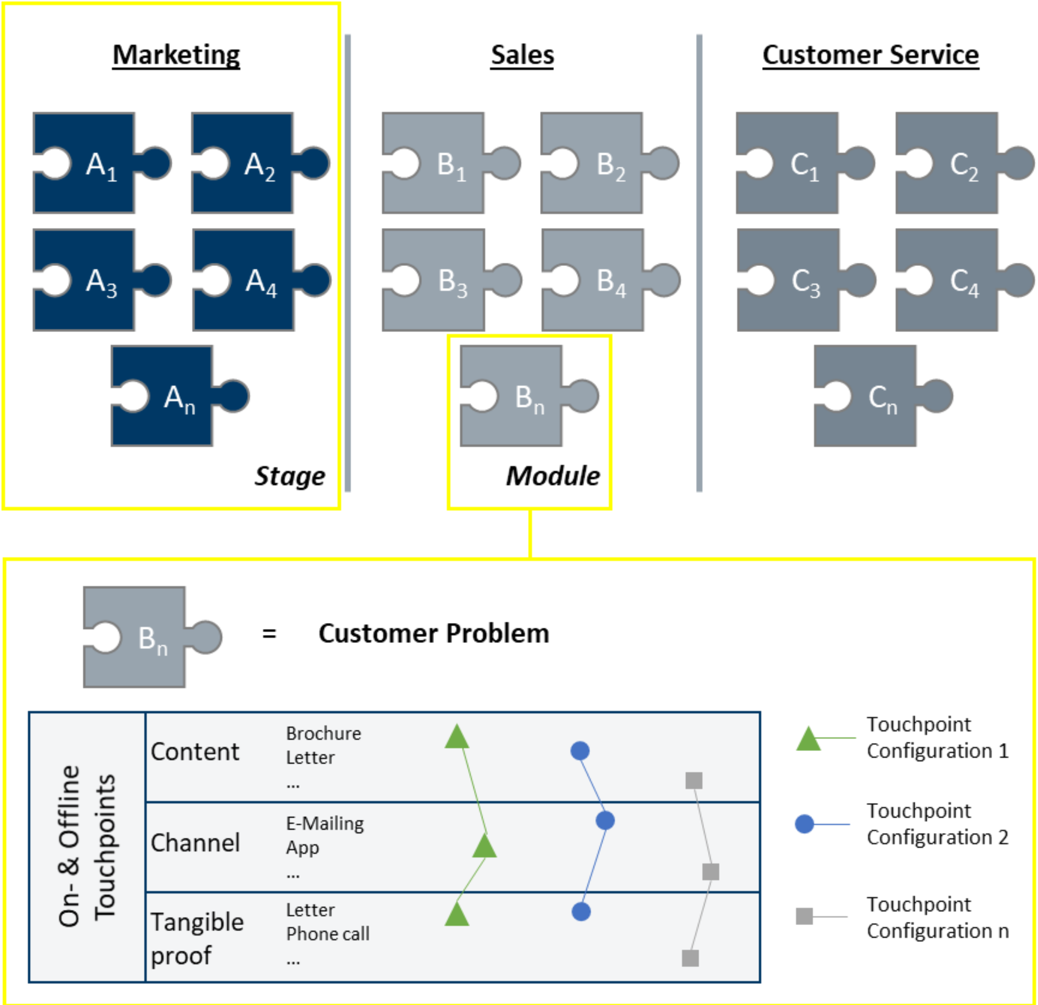

Figure 2 – Structure of the modular customer journey

For each stage any number of modules can be defined. Every module addresses a customer-specific problem that is typical for the associated stage. In the stage of marketing a common problem is e.g. information search or product comparison and in the sales stage e.g. requiring a quote or conclusion of contract. To solve the problems for each module, appropriate content and channels can be defined. Content is especially created to solve a specific customers' problem as competent as possible and channels have to be established aiming for convenience. Only the configuration of the modules by choosing a combination of a content and a channel results in a touchpoint that is assessed as ideal for a specific customer. Each module therefore has multiple configurations depending on the number of content and channels. Unlike other customer journeys, we claim that not only choosing content and channels that fit best to a customer but that also fulfil the functionality of solving customers' problems is vital. After the touchpoint is chosen and the customer is addressed a tangible proof is given to the customer as a reminder of the interaction. A tangible proof is integrated into the customer journey since studies (Siddiqi, 2011; Shanka, 2012) show a significant correlation between tangibility and service quality. Accordingly, customers often look for tangible indicators in the service delivery process to evaluate the service quality even though services are characterized by intangibility. An example for a module is information search as described before. In order to help customers in the process of searching information, appropriate content are e.g. brochures, informative letters or product one pagers that are reasonable to place on channels like e-mail, apps, banners or bank branches. Possible tangible proofs are a letter and a phone call that remind the customer of the interaction by recapping the touchpoint with a time lag. A configuration of the module for information search could be a brochure that is sent via E-Mail with a reminder banner when the customer logs into online banking.

Step one of the framework is the *definition of the modular customer journey* by identifying customers' problems which each represent a module. Once the problems are determined touchpoints should be developed by defining suitable content, channels and tangible proofs. Therefore co-creative methods like questionnaires, feedback channels or workshops ensure the active involvement of customers (Payne *et al.*, 2008) and increase the relevance of the modules as well as touchpoints when implemented operatively. Further resources are customer relations managers who complement the customers' perspective from an internal point of view since they have knowledge about already available touchpoints. In step one it is also possible to come to the conclusion that new touchpoints are required by the customer so that new content and channels have to be established.

Tracking and analysis of customer data

Step two is the *data analysis* and consists of tracking as well as processing customer data. When collecting data, retail banks have to differentiate between soft data that requires interpretation to extract information and hard data which is easier to collect as well as clear in terms of interpretation (Pravia *et al.*, 2008). As shown in Figure 3, hard data could be the resting time on an online channel, the movement of individual customers along online channels or the reaction time which can be tracked by means of data collection methods e.g. web logs, java script tagging, sensors and trackers.–Simultaneously, data can arise offline when customers interact with consultants. In this case the availability of data is highly influenced by the cooperation of the consultant since he constitutes an additional interface between data generation and data storage. Accordingly, the consultant has to be trained in order to increase his awareness whether relevant data has been shared by the customer as well as how to correctly digitize the data into the IT-System. User-friendly tools should be implemented that enable front-office consultants to acquire as much information as possible in an error-free manner. In contrast to hard data, soft data are more difficult to obtain but higher in value for personalizing the customer approach (Crié and Micheaux, 2006). Retail banks can extract information online when customer share their opinion, feelings and uncertainties through channels like blogs, social media or online platforms. The attitudinal data can also be collected by the consultant. In this case however, since soft data is qualitative, the perception of the customer by the consultant influences the data quality.

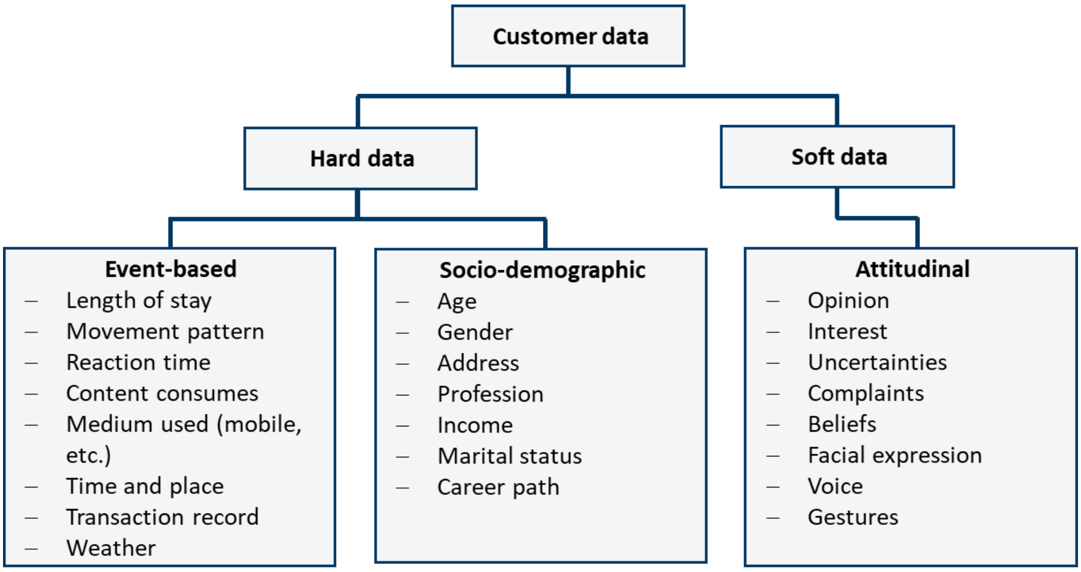

Figure 3 – Overview of customer data

In order to exploit the potentials of the collected data retail banks should implement methods to analyze the data. Accordingly, data mining is the process of transforming input data into novel and valid patterns as the output (Fayyad *et al.*, 1996). Data mining is crucial considering the large data volume that cannot be processed by humans anymore since interrelations between data are hard to discover and the analysis is time-consuming. Retail banks benefit from data mining and its functions like classification, clustering, regression, time series, association analysis and sequence discovery (Köksal *et al.*, 2011). Using these functions retail banks can e.g. segment customers or identify buying patterns in order to understand the cause-effect relations between customer data. Nevertheless, only by using a variety of functions retail banks can gain a comprehensive understanding of customers' behavior and characteristics. To accomplish the presented functions, analytic workflows have to be designed which entails choosing and adapting data mining techniques like neural network, decision tree, association rules and regression (Ngai *et al.*, 2009). The variety of functions and data mining techniques point out that different retail banks facing different problems require customized analytic workflows. Special forms of data mining, e.g. social media mining and text mining, can further support retail banks to extract hard data and to interpret soft data. Overall the step of data analysis requires a database where soft and hard data is stored in a structured format and an analytics software to perform data mining.

Creating a hollistic customer understanding

The following step is classified as *customer understanding*. In this step data mining is executed in order to reveal previously unknown patterns in collected customer data. First the analytics workflow for data mining is applied resulting in hypotheses about interrelations. However, the identified interrelations are derived from data and might be not valid with regard to the service delivery process. As a consequence before implementing the results by data mining a further assessment is mandatory. The hypotheses should be validated by an employee who is a specialist in terms of customer relations management as well as data analytics. If results of data mining are considered as significant, the next step is the development and implementation of predictive models that are appropriate to forecast future outcomes. The specific goal is to predict the sequence of modules resulting in a customer journey that is most probable to occur in the future for an individual customer. Most approaches only result in data describing the future. This model, however, exceeds by defining possible touchpoints based on the modular customer journey. This knowledge about future customer journeys has to be implemented operationally. Results from data mining and predictive models have to be visualized for employees that interact with customers while ensuring comprehensibility as well as use convenience. Retail banks also should implement the findings into automated services which are provided through electronic networks e.g. the internet, automated teller machines, marketing automation and sales force automation. Unlike offline channels, where the integration of the newly created knowledge involve the consultant as a human interface and consequently entails frictional losses, automated services can integrate the results immediately in order to improve the service delivery process.

Proactive customer approach

The last step of the framework is the operational implementation of the customer approach. Utilizing the knowledge about the customer provided from previous steps, retail banks can address the customers proactively. Knowing what the customer will demand enable retail banks to anticipate their needs and offer appropriate services through a process that complies with individual customer requirements. Once the customer is addressed by automated services or front-office employees, new data is collected and stored in the database. The evaluation of new data through data mining leads to the conclusion whether the predicted customer journey has to be adjusted or is still valid for further touchpoints. This iterative process of data analysis ensures that the customer journeys are adjusted dynamically claiming that customers' expectations and chosen touchpoints depend on historic touchpoints and experiences.

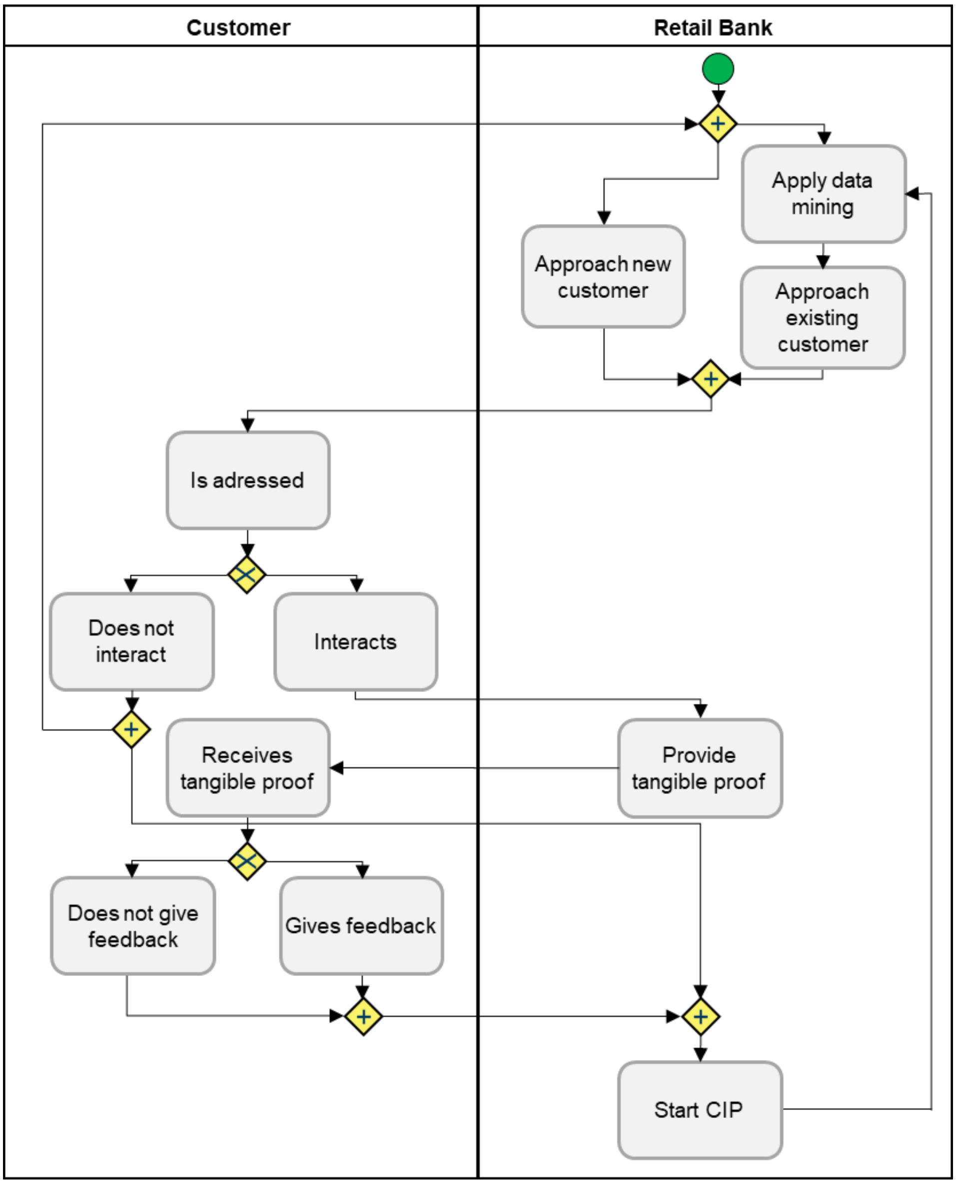

Figure 4 – Process for service delivery

For a successful integration of the results provided by the framework, a service delivery process is designed, as shown by Figure 4. To address the customer, retail banks have to differentiate between existing and new customers. Data mining relies on customer data and therefore unknown customers are approached by mass marketing, sales and service. However, for known customers data mining can be applied as already explained in order to personalize the customer approach. Based on the predicted customer journey and modules, retail banks have knowledge about what problem every single customer faces and which touchpoint, as a combination of content and channel, provides the best solution possible. The customer is addressed with the touchpoint, which was considered ideal, and he can either interact with the bank or not react since the touchpoint is not relevant for him. In case there is no reaction the process of continuous improvement (CIP) is triggered so that data mining techniques automatically improve themselves by incorporating mistakes that have been made. If an interaction occurred, the customers are sent an intangible proof by the retail bank and are offered possibilities to give feedback on the interaction through online and offline channels or designated feedback platforms. Also in this case feedback by customers initiates a process of continuous improvement for data mining or even provokes the need to adapt the modular customer journey.

VALIDATION OF FRAMEWORK AT A GERMAN RETAIL BANK

A systematic case study is performed at a German retail bank for validation purposes of the presented framework. A single case study with embedded cases (Yin, 2016) is chosen since the main focus is on the newly developed framework and its potential is explored considering different inputs within one organization. In this context, the embedded cases are different departments within the organization in order to show similarities or differences between their perception and evaluation of the framework. For collecting data in qualitative, non-numerical form, semi-structured interviews are systematically conducted with experts. Therefore, a well-structured interview guideline is developed and adjusted reasonably to the different cases. The guideline is used as an orientation during the face-to-face interviews but when required the order of questions is changed or further questions are added so that the experts can share their opinions in depth and a natural course of conversation arises. The interview questions are clustered into the five dimensions of SERVQUAL (Parasuraman *et al.*, 1985). The dimensions are *empathy*, *assurance*, *responsiveness*, *reliability* and *tangibility* that altogether influence service quality from a customer perspective. In this context the interviews are conducted to discover the potentials and challenges experts perceive in order to achieve the five dimensions of SERVQUAL by means of the service quality framework. In total 10 interviews are carried out which can be classified into for cases namely management board, department for digitization, marketing and front-office employees. After executing the interviews a transcript that summarizes the interview is written and is sent to the interviewee in order to minimize bias as well as misunderstandings.

All experts agree that collecting more data about the customer and analyzing data according to the framework can improve the dimension of *responsiveness*. The presented bank claims lacking information about the customer across online and offline channels. Most experts state that data is collected in their department but neither analyzed nor shared with other departments. Only the department for digitization reports key performance indicators to other departments. Nevertheless, they struggle to analyze the data in order to derive further actions that enhances the *responsiveness* of the retail bank. One of the main reasons therefore are legal restrictions for data protection and the missing approval from customers for collecting and storing data. A data mining tool is also implemented in the marketing department but only applied to segment customers by predefined socio-demographic data. The marketing expert states the missing know-how to exploit all potentials provided by the data mining tool. In this context, the interviewees agree to the framework and the need to implement a structured process to exploit the potentials provided by already collected data. They also admit that knowing more about the customer gives retail banks the ability to meet and adapt to customers' needs. Due to the lack of customer knowledge especially the front-office employees are demotivated to serve customers on a personalized level and prefer to approach the customer by standardized processes. This emphasizes the need for data tracking and analysis according to the framework to increase the readiness and willingness of front-office employees to assist customers.

The contribution of the service quality framework to reach the dimension of *reliability* is ambivalent. Experts that rather operate back-office, especially the department for digitization, confirm that utilizing data enables retail banks to perform services in a dependable and reliable manner which helps to decrease the gap between the expected service and the final service. In contrast, front-office experts think that reliability highly depends on human interpretation of soft data which cannot be replaced with the aid of new technologies. Simultaneously, these experts admit that they do not have knowledge about the possibilities provided by data mining as well as new technologies. Therefore, it is hard for them to imagine that soft data can be analyzed to its full potential. In terms of *tangibility* all experts agree that especially during online interactions tangibility is missing. Therefore providing a tangible proof after every interaction as suggested in the framework is a good measure to influence the customers' assessment of service quality positively.

The dimensions of *assurance* and *empathy* are evaluated as the most critical. Interviewees agree that a greater knowledge about customer enable retail banks to serving customers proactively and in a more competent manner. The service quality framework supports the retail bank to see service from the customer's point of view which is the prerequisite for *empathy*. However, the experts, especially the management board, claims that achieving *empathy* based on customer data and analytics is contradictory to *assurance*. According to the interviewees approaching customers in a way which clearly displays how much information retail banks own about customers can frighten them and consequently decreases customers' trust. The experts assume that trust and confidence by offering *empathy* and *assurance* can only be increased to a certain level. They cannot foresee how younger generations growing up with new technologies will accept new opportunities provided by new technologies and data. However, in the near future the experts do not think that customers are comfortable with companies obtaining and possessing customer data for banking purposes. Nevertheless, digitization is crucial for improving service quality and therefore the management board is trying to find a fine line where customers consent to automation and data analysis.

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

This paper presents a newly developed service quality framework for retail banks that exploits the potentials of new technologies to improve service quality. The developed framework assists retail banks to deepen their knowledge of customers by defining key tasks and resources to implement data mining for customer data. Furthermore this paper clarifies how the newly created knowledge from data mining can be integrated into the customer approach operatively by offering a newly designed service delivery process. Implementing the framework can lead to higher service quality and consequently helps to strengthen customer relations since the customer approach is personalized as well as relevant for the customer. The limitation of this framework is the reference to only retail banks and customer data for service quality improvement. More data e.g. internal data also represent a valuable input for data mining and can result in new insights about the service delivery process. Furthermore, the implementation of the framework includes front-office employees who are the interface when processing data. Therefore retail banks have to qualify their employees to support new processes which includes new technologies and handling of data. It is crucial to take the employees along the process of digitization by change management systems.

Conducted expert interviews from a systematic case study encourage the service quality framework since the interviewees are aware of the potentials of their collected data that is yet left unused. The interviews reveal that the lack of digitization for service delivery roots in the absence of know-how and the fear of lacking customers' acceptance. The provided framework can help the retail bank to overcome the lacking know how by providing a systematic approach from data collection over data analysis up to delivering the service to the customer. The qualitative validation of the case study is based on different interviewees from a chosen retail bank. Additional cases also from another organizations can contribute further findings about the potential of the service quality framework.

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The EFQM Excellence Model in a Research Centre

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ABSTRACT

Purpose – This paper aims to report the adoption of the European Foundation for Quality Management (EFQM) Excellence Model as a self-assessment tool throughout the organization framework of a Research and Development Centre.

Design/methodology/approach – The level of organizational maturity was ascertained through the elaboration of the management document proposed by the EFQM. This document, with a simple format, adopts the EFQM Excellence Model to describe the main approaches followed by the organization, how they are being implemented and what results have been achieved.

Findings – The document prepared and elaborated made possible the identification of ten organizational improvement activities. A prioritization of the activities to be implemented was carried out using three criteria, and five (out of ten) were chosen to be implemented in the short term. For each one of the five improvements, an improvement plan was elaborated, with a description of the purpose, the execution time, the current state and the alignment with the strategic objectives of the organization. As described in the literature review, it was possible to conclude that the EFQM Excellence Model is not only an effective tool to strategic objectives of the organization, but also a way to check how they are being implemented and reached. In addition, after this work it was possible to verify that some actions described in the strategic plan were not implemented and were thus identified as improvement actions to be carried out.

Originality/value – The application of EFQM Excellence Model in a Research Centre is the main contribution of this work.

Keywords: EFQM Excellence Model, Self-assessment, Continuous Improvement, Research Centre

Paper type: Case Study

INTRODUCTION

The ALGORITMI Research Centre is a Portuguese's research unit with a long and proud history in the Information and Communications Technology & Electronics (ICT&E) domain since 1978. This research unit of the School of Engineering of the University of Minho researches and develops activities in four major fields: (1) information systems, computing technologies; (2) electronics, energy, robotics; (3) computer networks, pervasive computing; and (4) operational research, industrial engineering and management (ALGORITMI, 2014).

Nowadays, the organization has more than one hundred and fifty researchers holding a doctoral (PhD) degree disperse in four educational departments of the School Engineering. The Centre is structured into Research and Development (R&D) lines and groups. This type of structure enables ALGORITMI to have a holistic approach towards the complex task of advancing scientific knowledge within the ICT&E domain. The organization's core activities are the R&D projects with companies and other universities or research centers.

In today´s competitive and globalized world, organizational excellence is one of the preconditions for sustainable success. Therefore, closer attention should be given to the application of organizational excellence, a concept that should not be considered as something that organizations will achieve in the short term, but as a management philosophy and a set of principles that will produce the best overall results in the medium and long term, providing, therefore, support to a sustainable future.

The EFQM Excellence Model is a powerful diagnostic tool providing a learning opportunity for stakeholders to point out strengths and identify improvement opportunities. Historically, this model has been exclusively used in the organizations context (ALGORITMI, 2014). However, the goal of the ALGORITMI Centre is to apply the EFQM Model to promote the excellence in and of the Research Centre.

To achieve this objective, this case of study is structures as follows. A literature review is presented as also a brief review of the application of the EFQM Excellence Model in similar Research Units. Then, the research methodology is explained. Finally, results and some conclusions are described.

LITERATURE REVIEW

The EFQM Excellence Model is an organizational management framework, developed by EFQM and based on the Total Quality Management (TQM) philosophy, which can be applied to any kind of organization, regardless of the sector, size, structure and maturity, with the goal of becoming more competitive, so that, though its principles, it fosters transparency at all levels of an organization (Shergold & Reed, 1996).

According to Coulambidou and Dale (1995), the EFQM model allows to identify opportunities for improvement, providing new motivations for this process, directing and allowing better management of the business. Thus, progress towards excellence can be assessed according to the parameters of this model. Further, it can also be used as a guide to measure total quality practices (Gutiérrez *et al.*, 2010).

For Kim *et al.* (2010), the EFQM Excellence Model is a figurative theory that improves the traditional TQM due to the broader concept of holistic management and as an integrated management system that covers all the management activities of an organization (Kim *et al.*, 2010).

According to some authors, the reasons for adopting the EFQM model are grouped into internal and external motivations. The internal motivations include a desire to improve the organization, quality management, improvement or organizational productivity, product and service quality, quality of planning ant the creation of a global strategic framework (Heras-Saizarbitoria *et al.*, 2011; Heras-Saizarbitoria *et al.*, 2006; Jaeger & Adair , 2016).

Gómez-Lopez *et al.* (2016) classified external motivations into two categories, emphasizing that they can play a significant role in the use of the excellence modes: (1) external market reasons and (2) external requirements. The first one concerns to the improvement of the organization's image and reputation, its competitive position in the market and the way the management practices used by the organization are effective. The second category refers to the requirements imposed by the costumers or by the general competition requirements of the market sector.

Other authors, such as North *et al.* (1998), classified the motivations for the adoption of Quality Management Systems (QMS) in:

1) "Process benefits" related to possible improvements in the organization processes;
2) "Marketing benefits" regarding the possibility or disclosure of the use of the model, as well as the results of the organization QMS to their customers;
3) "External market conditions" alluding to the pressure of costumers and/or competitors.

In addition to the previously described classification, Sternad *et al.* (2017) suggested a new categorization: internal motives are referred to the active organization efforts to improve its performance, such as marketing benefits; and external motives, also called passive motivations which deals to the reaction of an organization through approaches to quality improvement and to external market conditions.

On the other hand, Araújo & Sampaio (2014), through a research project carried out in fifteen Portuguese organizations, tried to understand the motivations behind the use of the EFQM Excellence Model. The results demonstrated that the implementations of this model include: (1) the recognition of a premium and the possibility of benchmarking, characteristics of organizations with a more mature QMS and concerned about excellence; (2) improvement of their organizational QMS; and (3) the perception and adoption of good management practices, which come from the use of the model and the continuous improvement.

Several studies have shown that the adoption of models of excellence, such as the EFQM is related to better commercial results, especially regarding the studies of Hendricks *et al.* (1997) and Kaynak (2003). However, these models cannot be seen as tools for quick solutions, as evidenced by the study of Prajogo & Bown (2006), but rather as sustainable long-term tools, suggesting that their effects are indirectly achieved (Sternad *et al.*, 2017).

Doeleman *et al.* (2014) studied the link between the adoption of a Business Excellence (BE) model and organizational performance, concluding that both provide “a solid basis for continuous improvement to be discussed within an organization”.

From another perspective, the study of Calvo-Mora *et al.* (2015) allowed to come up that the EFQM Excellence Model presents a high predictive power as a framework for the projection and improvement of a Knowledge Management Project (KMP). Thus, as the model advocates a management based on continuous improvement, innovation and learning, this can serve as support to start and later develop a KMP, with the goal of making organizations more competitive in the management and integration of knowledge and new capabilities (Calvo-Mora *et al.*, 2015).

In the case of higher education institutions, self-assessment through the EFQM model enables the creation of a more client-oriented culture, an atypical culture of such organizations (Hides *et al.*, 2004). Para Doeleman *et al.* (2014) the application of this tool significantly improves the results of an organization, enabling its development through a management control cycle. The participatory approach in implementation this model promotes commitment to improvements. The leadership is the driving force for the promotion of improvements, while intrinsic motivation functions is the condition for a successful implementation.

As described in the model, Doeleman *et al.* (2014) concluded, through the analysis of the twenty-four scientific papers published between 2002 and 2012, that the EFQM model provides a solid foundation for engagement and dialogue about continuous improvement within an organization.

According to Suárez *et al.* (2017) the most significant effects of the implementation of the EFQM Excellence Model are: (1) the improvement of the organizational image; (2) the greater satisfaction of customers and employees; (3) the greater commitment of the people; (4) a greater predisposition for innovation; (5) more profits derived from increased exports; (6) an effective knowledge management; and finally (6) an optimization of the utilization of information systems.

A review of the literature by Gómez-López *et al.* (2017) allowed to identify the main barriers to the implementation of the model. Thus, to facilitate the interpretation of the data obtained, the main obstacles encountered in the implementation of the EFQM Excellence Model are presented in Table 1:

Table 9 – Obstacles related to the implementation of the EFQM Excellence Model

Obstacles	**Authors**
-Lack of financial and physical resources.	Mathews *et al.*,2001; Thomas *et al.*, 2003; Soltani *et al.*, 2005; Angell & Corbett, 2009; Heras-Saizarbitoria *et al.*, 2011; Mann *et al.*, 2011; Jaeger *et al.*,2016.
-Lack of time.	Mathews *et al.*,2001; Thomas *et al.*, 2003; Dahlgaard-Park, 2009; Heras-Saizarbitoria *et al.*, 2011; Mann *et al.*, 2011; Jaeger *et al.*,2016.
-Lack of commitment and involvement of top management in the organization's strategic objectives and priorities -Lack of motivation and participation of people in the organization	Mathews *et al.*, 2001; Beer, 2003; Soltani *et al.*, 2005; Angell & Corbett, 2009; Dahlgaard-Park, 2009; Heras-Saizarbitoria *et al.*, 2011; Mann *et al.*, 2011.
-Lack of vertical communication (top-down and bottom-up), which hinders the transparency of feedback on how implementation is being managed and what are the principles key points of improvement	Beer, 2003; Soltani *et al.*, 2005; Angell & Corbett, 2009.
-Complexity of the model, namely, difficulties in the interpretation of the language.	Soltani *et al.*, 2005; Angell & Corbett, 2009; Dahlgaard-Park, 2009; Heras-Saizarbitoria *et al.*, 2011.

In sum, Gómez-López *et al.* (2017) the obstacles and barriers to the implementation in three factors: (1) resource barriers, namely human, physical and financial; (2) the behavioural and cultural barriers, related to the lack of motivation and commitment of the whole organization; and (3) organizational barriers, coupled with the inability of organizations to adopt a system of organizational excellence.

EFQM IN UNIVERSITIES OR RESEARCH CENTRES

In 1988 a group of fourteen leading European Union companies, together with Jacques Delors, signed a "Letter of Intent" to form a foundation dedicated to increasing competitiveness in European enterprises in order to face a decelerating Europe (Conti, 2007).

Thus, in October 1989 the foundation was officially established with the mission of being "the driving force for Europe's sustainable excellence and the vision of a world in which European companies are excellent" (EFQM, 2013).

This model, which was initially designed to help organizations to structure an adequate management system able to improve their operation regardless of their size, sector and structure, started to be used as a diagnostic and self-assessment tool.

Nowadays, EFQM remains committed to support organizations in their process of continuous improvement using the EFQM Excellence Model. This tool, which over the past twenty years incorporated experiences and learning lessons from numerous organizations, has already been used by more than 30,000 organizations throughout Europe (EFQM, 2013).

Thus, the EFQM Excellence Model, intends to promote and recognize the sustained success and is composed by three integrated components (EFQM, 2013).

1) Fundamental concepts of excellence: the eight principles that underpin the sustainability of an excellent organization;

2) EFQM Excellence Model: nine interrelated criteria, divided into "Means" (what the organization conceives and how it conceives it) and "Results" (their achievements in relation to all the interest groups and with reference to general objectives) that help to translate fundamental concepts and logic into practice;

3) RADAR (Results-Approaches-Deploy-Assess-Refine) logic: dynamic evaluation structure.

The fundamental concepts of excellence expressed in the EFQM model are based on a set of European values expressed in the 1953 European Convention on Human Rights and the 1996 European Social Charter (EFQM, 2013).

The eight fundamental concepts outline the essential foundations for any organization to achieve sustained excellence and can be considered as the fundamental attributes of an excellent organizational culture. These were presented following a rigorous process, which included a global benchmarking and considering emerging management trends (APQ, 2017).

The criteria are subdivided into two large groups: the "Enablers" criteria and the "Results" criteria. The former focus on what the organization does, and how it does it, and the latter encompasses what the organization achieves. The arrows in the model, as shown in Figure 1, highlight their dynamic nature, showing that learning, creativity and innovation support the improvement of "Means" which in turn lead to better results (EFQM, 2013).

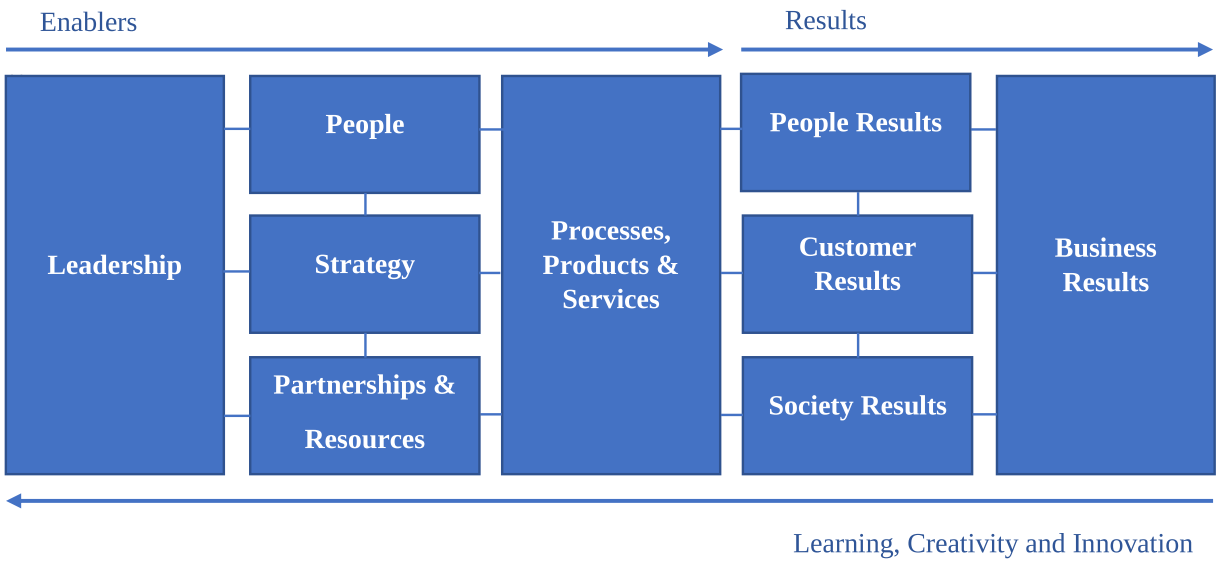

Figure 18 – EFQM Excellence Model.

Each criterion has a generic definition and is composed of several sub criteria, or part of criteria, which are no more than orientation points mostly related to the fundamental concepts of excellence, that is, they do not specify "How", they are holistic and must be interpreted according to the reality of the organization. In the other hand, the "Results" criteria present two groups, in which the first refers to external perceptions and the second to the performance indicators used by the organization.

The EFQM Model also presents in its constitution a tool called RADAR logic, as shown in Figure 2 and shows a concept analogous to the PDCA (Plan-Do-Check-Act) developed by

Walter A. Shewhart. RADAR logic integrates a dynamic assessment framework and is considered as a powerful management tool that provides a structured approach to questioning the organization performance, which at a higher level establishes what the organization needs to do in four steps (EFQM, 2013). In turn, the PDCA cycle is a problem-solving cycle that describes how improvements should be made in an organization, in an analogy tow the RADAR logic but with only four steps.

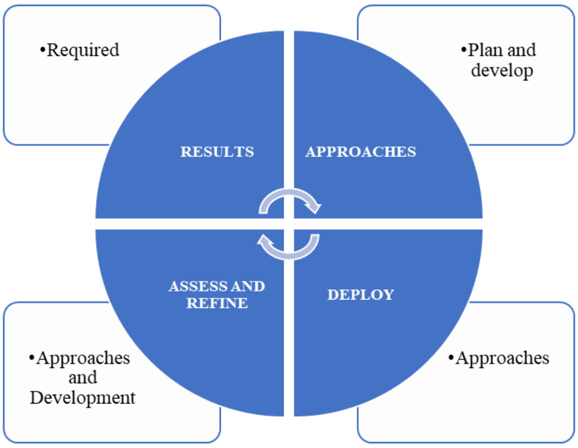

Figure 19 – RADAR Logic.

The evaluation and scoring are performed through the RADAR logic and according to five elements: Approach, Deployment, Assessment & Refinement, Relevance & Usability and Performance. So, RADAR is a rigorous process that has the potential to achieve the desired results, if efforts are continuous and relentless, timely and appropriate measures and learning opportunities are not misaligned. In addition, the application of this tool to the nine criteria of the EFQM Excellence Model is a demanding exercise that requires a careful implementation approach that, in turn, can achieve better results starting with simple steps (Jackson, 2001). The evaluation assumes that some concepts are clearly defined, integrated and used consistently, such as: Mission, Vision, Policy, Strategy, Objectives, and Board of the organization.

To the best of our knowledge no papers were found about the EFQM in Research Centres. Thus, this case study explores the implementation of the EFQM model in an environment different from the hitherto explored.

RESEARCH METODOLOGHY

This work was developed in the ALGORITMI Research Centre to evaluate its position in the path of excellence, understand its strengths and potential, as well as the planned initiatives to integrate with existing ones.

So, for the accomplishment of this work the following steps were defined:

- Review and characterization of the ALGORTIMI Business Excellence project;
- Identification of the current state of the organization against the nine criteria of the model;
- Elaboration of the management document that supports the application for the "Recognised for Excellence" award, based on the model criteria;
- Identification of improvement actions;
- Prioritization and preparation of improvement plans.

The process of self-assessment of ALGORITMI Research Centre, through the EFQM Excellence Model, started with the creation of a working group, entitled "ALGORITMI Business Excellence – Working Group" (ABE-WG). This group is composed by ten researchers of different R&D lines and aims to define and propose improvement initiatives.

Initially the ABE-WG organized a workshop to explain to the people of the Centre the EFQM Model, namely, the components of model, the dynamic structure and the Business Excellence Matrix (BEM).

Subsequently, four working groups were created to fill an input sheet to a set of pre-established criteria within a period of 15 days. Three criteria were then assigned to each group (a criterion of "Enablers", a criterion of "Results" and the criterion of "Leadership"), as can be seen in Table 2.

Table 10 – Division of the criteria working group

Groups	Criteria Group
1	Leadership; Processes, Products & Services; Customer Results
2	Leadership; Strategy; Key Results
3	Leadership; People; People Results
4	Leadership; Partnership & Resources; Society Results

Simultaneously, the ABE-WG identified (with the help of top management) the indicators that are used by the organization to monitor its organizational performance and to perceive the indicators that could be used, considering the areas of activity of the Centre and through the identification of all its stakeholders. The Research Centre stakeholders were divided into three areas: teaching, investigation and development and general stakeholders, as show in Figure 3.

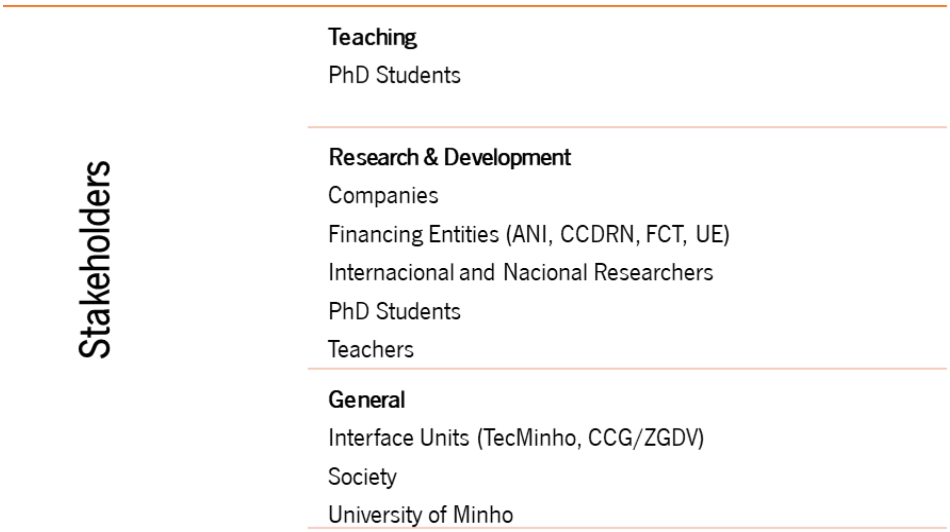

Figure 20 – Stakeholders Mapping.

The management document is presented by EFQM in a simple format to describe how the strategic objectives of an organization are being implemented. This document presents a framework of the EFQM Excellence Model to describe the main approaches taken, how they are being implemented and the results achieved, and is a great benefit in helping the organization execute its strategy effectively. The document can then be used as an integral part of its QMS, maintained with a "living document" or produced annually, regardless of whether the organization applies for external recognition (EFQM, 2013).

The management document elaborated for the Research Centre contains three sections: (1) key information summarizing the operational environment, organizational structure, stakeholders and strategic objectives; (2) Enablers section that describes the main approaches used by the organization in accomplishing its strategic objectives; and (3) the Results section, which provides an overview of the main results achieved by the organization, showing its effectiveness and efficiency in achieving the defined strategic objectives.

After the elaboration of the management document the ABE-WG identified various organizational improvements and selected ten of them. Subsequently through a prioritization process, five improvements were selected to be implemented in the organization.

RESULTS

Following an initial self-assessment of the ALGORITMI Centre (the management document, in the light of the EFQM Excellence Model), improvement actions were identified, and the following steps were followed:

1. Identification of ten improvements;
2. Classification of improvements in relation to the impact and scope of change within the organization;
3. Prioritization of actions using three simple criteria;
4. Selection of the five improvements with the highest score;
5. Description and planning of the previously identified improvements.

As far as the spectre of change and according to the EFQM, the improvements were classified into: (1) "Small Immediate Gains" (SIG), taking into account the low impact and factors of change and the capacity to perform only two or three months, essential for the earnings groups; (2) "Incremental Improvements" (II), when the organization impact and results are significant, "I do it well, but you do a little better"; and (3) "Big Changes" (BC) as the name implies, this improvements have a big impact and a great change within the organization, usually associated with an organizational structure, changes in process, reengineering or the way of work, for example.

Regarding to the prioritization of improvements, three criteria were adopted: (1) the impact of the improvement in the organization; (2) the ease of implementation; and (3) if the improvement is aligned with the strategic objectives defined by the organization. The prioritization of each improvement was performed on each measure according to the following scale: 1 - "low"; 3 - "considerable"; and 6 - "high". The final classification (Total) was computed by the multiplication of the three levels.

Thus, Table 3 shows ten improvements found after the self-assessment process, a classification of improvements according to the change course and an evaluation, according to a scale of each prioritization criterion referred to above.

Table 11 – Improvement prioritization

Improvement Actions	**Type**	**I**	**EI**	**ALP**	**Total I*EI*ALP**
Benchmarking	SIG	3	3	6	54
Setting goals	SG	1	6	3	18
Conduction of satisfaction survey for students of the first year of the doctoral programs of the ALGORITMI Centre	II	3	6	3	54
Environmental policies	II	1	3	1	3
Creation of a physical space ALGORITMI	GC	6	1	3	18
Elaboration of training plans	II	3	6	6	108
Holding an event to disseminate research to local companies	II	6	3	6	108
Develop useful technology to the country's growth	GC	6	1	6	36
Increase lobbying capacity at decision-making centre	II	6	1	6	36
Increase the impact / representativeness of the ALGORITMI Centre in society	II	6	1	6	36

SIG - Small Immediate Gains; II - Incremental Improvements; BC - Big Changes; I – Impact; EI – Ease of Implementation; ALP - Alignment with the strategic plan

The following five priority improvements were selected in the short to medium term, as they got the highest scores:

- Elaboration of training plans (108 points);
- Holding an event to disseminate research to local companies (108 points);
- Benchmarking (54 points);
- Conduction of satisfaction survey for students of the first year of the doctoral programs of the ALGORITMI Centre (54 points);
- Increase lobbying capacity at the decision-making centre (36 points).

In this process, there were three improvements with the same score. In this way, the selection of the fifth improvement was evaluated by which would be the one that would most enhance the organization in the accomplishment of the improvement. The “Increase lobbying capacity at decision-making centre” was selected.

Each improvement was then described, namely its purpose, if it is achievable given the time and resources available, if it is aligned with the strategy, when it is intended to see results and its improvement plan. Considering that the ALGORITMI Centre is an organic subunit unit associated to four departments of the School of Engineering of the University of Minho, some administrative limitations were found in the data collection.

CONCLUSIONS

The accomplishment of the research management document allowed to compile and to describe all the approaches adopted by the ALGORITMI Centre to reach its strategic objectives and to realize that some actions, described in the strategic plan, were not fulfilled and were only identified as actions of improvements. As described in the literature review it was possible to conclude that the EFQM Excellence Model is an effective solution and not an organization position or, how they have to be implemented neither how to use methodologies for results.

In turn, this work allowed to the identification of ten improvement actions, which were prioritized through three simple criteria (impact, ease of implementation and alignment with the organization strategic plan) and subsequent selection of the five improvements with the highest score to start the process of organizational improvement. To facilitate the process of improvement and to encourage organizational commitment, all these improvements were previously defined and should contained at least a "Small Incremental Gain" improvement.

Thus, for each improvement, a possible implementation plan was elaborated and will be carried out when possible, since it was not possible yet. After the implementation of these improvements will be necessary to review the impact of them compared to your established goals.

In addition, it was possible to verify that the current organizational culture of the ALGORITMI Research Centre is not strong enough to support the sustainability of positive organizational results. It is fundamental to understand the profile of each person and to recognize individual competencies, due to the different people, job preferences and skills of the researchers of the Centre.

In this way, it is possible to create an effective team that will channelled their energies to find the root causes of the problems thus allowing all the people to have an active contribution in this process of organizational improvement.

Finally, once all the limitations have been overcome, the Centre will be ready to submit its application for the *Recognised for Excellence Award*, which is the main objective of this paper.

AKNOWLEDGEMENTS

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Measurement Systems Improvement in a Tire Industry Process

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ABSTRACT

Purpose – Organizations' success strongly depends on their ability to collect, analyze and take swift decisions based upon data. Also, both evaluation of a products' conformance to specifications and process capability studies require measurements, measurements that may lead to wrong conclusions if collected with high-variation systems. Thus, having accurate and precise measures is at the basis of any analysis. This work focuses on the application of measurement systems analysis' techniques in a Portuguese tire factory. The goal is to evaluate the capability of the measurement systems of two critical quality features of the calendered sheet, an intermediate product of the tire that results from the calendering process: weight and thickness.

Methodology and approach – The analysis of historical data, as well as the on-site monitoring of production, exposed problems concerning (1) the handling of the thickness gauge, (2) the ambient conditions (e.g. temperature) at which the measurements are taken and (3) the fact that the current equipment does not allow the computer storage of the registers. First, to assess bias and repeatability effects, a Type 1 study was applied to each measurement system. Subsequently, repeatability and reproducibility (R&R) tests were applied to assess the intrinsic variation of the measurement equipment and the variation resulting from the action of the operators and the measurement method used. Finally, some recommendations are made to improve existing systems, including the suggestion of using alternative equipment.

Findings – The results of the bias and repeatability (Type 1 study) and R&R studies show (i) that the weight measurement system is accurate and precise and (ii) that the thickness measurement system is accurate, but its precision is questionable.

Practical implications – A concrete proposal was made for an alternative thickness measurement system that should reduce the associated variability and allow an effective monitoring of this characteristic. Both the Quality Department and the Production Technical Support Department consider the new system to be appropriate and useful, and its acquisition and implementation should take place in the coming months.

Originality and value – This paper addresses a real and concrete application of measurement systems analysis in a business environment.

Keywords: Measurement Systems Analysis (MSA), Repeatability and Reproducibility (R&R), Quality Improvement.

Paper type: Case study

INTRODUCTION

In a globalized economy, characterized by an ever-increasing market competitiveness and demanding customers, quality management evolved to a paradigm that aims to prevent and anticipate the occurrence of defects, from the moment of the product design and throughout all stages of the production process, involving all the supply chain. To ensure sound financial results, in their daily operations, companies seek to reduce waste, reduce costs of poor quality and increase their productivity through continuous improvement of their processes.

Moreover, organizations' success strongly depends on their ability to collect, analyze and take swift decisions based upon both quantitative and qualitative process data. Also, both evaluation of a products' conformance to specifications and process capability studies require measurements, measurements that may lead to misleading conclusions if collected with high-variation systems or equipment. Thus, having accurate and precise measures is at the basis of any analysis.

The relevance of measurement system analysis is highlighted by Montgomery (2009), which stated "it is very difficult to monitor, control, improve, or effectively manage a process with an inadequate measurement system", establishing a comparison with "navigating a ship through fog without radar - eventually you are going to hit the iceberg".

This paper addresses only a part of a project on quality improvement developed in a Portuguese tire factory (Maia, 2017). The project covered several areas, namely the analysis of the measurement systems of critical-to-quality (CTQ) characteristics – weight and thickness – of the calendered sheet (an intermediate product of the tire that results from the calendering process); and the waste generated in the calendering process. Measurements system analysis (MSA) area is the sole focus of the present paper.

Hence, the goal is to evaluate the capability of the measurement systems of two critical quality features of the calendered sheet, an intermediate product of the tire that results from the calendering process: weight and thickness. To carry out this work, the statistical and analytical methods and acceptance criteria proposed by the standard ISO/TS 16949 and the reference manuals of AIAG were applied. ISO/TS 16949 is one of the automotive industry's most widely used international standards for quality management and it states that "statistical studies shall be conducted to analyze the variation present in the results of each type measurement systems referenced in the control plan".

The remaining part of this paper introduces the criteria to evaluate a measurement system and the formulation of Type 1 and R&R studies in section 2, presents an overview of the tire manufacturing process in section 3, describes the measurement systems of the calendered sheet, by identifying existing problems in each system in section 4, followed by practical results discussion in section 5 and concluding remarks and improvement proposals in section 6.

ASSESSING MEASUREMENT SYSTEM VARIATION

The total variability of a process includes the inherent product variability and gauge variability. Thus, measurements may lead to wrong conclusions if collected with high-variation systems or equipment, a fact that reinforces the need for accurate and precise measurements.

$$\sigma_{\mathrm{Total}}^2 = \sigma_{\mathrm{P}}^2 + \sigma_{\mathrm{gauge}}^2$$

Knowles et al. (2003) defined a set of six criteria to evaluate whether a measurement system is good. A good measurement system should be:

1. linear, i.e. it responds proportionately over the range of equipment;
2. stable, i.e. no special causes of variation present;
3. accurate, i.e. the measurements correspond closely to the true value (known reference standard);
4. precise, having little scatter of individual measurements of the same product;

5. able to support analysis, by generating variable rather than attribute data;
6. robust, i.e. is not sensitive to changes of operator, environmental conditions or other noise factors.

The focus of the present study was the evaluation of the accuracy, the precision and the robustness of a digital scale and a thickness gauge. The goal was to quantify the variability associated with the measurement process and to determine the suitability of the existing systems. The bias and the precision were analyzed using both Type 1 and repeatability and reproducibility (R&R) studies, which suggested that the thickness gauge had a questionable precision, motivating search for alternative devices that will allow the implementation of a more robust system.

The Type 1 study includes (1) a two-tailed t-test (with the null hypothesis stated as "There is no bias" or "The expected value of measurements equals the true value") to assess the bias and (2) a comparison between the sample standard deviation of the collected measurements and the total variability of the process (estimated as one-sixth of the process tolerance) to assess the repeatability effect. The analysis of bias and repeatability effects can also be performed by computing Cg and Cgk capability indices (Andrejiová and Kimáková 2014):

$$C_g = \frac{K \times T}{L \times s}$$

$$C_{gk} = \frac{K/2 \times T - |\bar{x}_g - x_{ref}|}{L \times s}$$

K is, usually, 0.2 (20%);

T corresponds to the tolerance specified for the process;

L is the number of standard deviations (usually, 6 for C_g and 3 for C_{gk});

s is the sample standard deviation;

$\bar{x}_g$ corresponds to the mean of measurements;

x_{ref} is the reference standard (true value).

As stated by Antony et al. (1999), the R&R test allows to distinguish between repeatability effect (observed variation when the same operator uses the same gauge several times to measure an identical characteristic on a single part) and the reproducibility effect (observed variation when several operators use the same gauge to measure an identical characteristic on a single part or when several devices are used by one or more operator to measure an identical characteristic).

The classical approach of R&R test is based on Average and Range Control Chart technology, which separates the measurement system variation into repeatability and reproducibility (Antony et al. 1999). Concerning R&R studies, the precision-to-tolerance ratio (PTR) and the number of distinct categories (NDC) are the most widely used indicators. AIAG (2010) reference manual establishes the criteria for analysis of both indicators.

$$\mathrm{PTR} = \frac{\mathrm{k} \cdot \sigma_{\mathrm{gauge}}}{\mathrm{USL} - \mathrm{LSL}}$$

$$\mathrm{NDC} = 1{,}41 \times {}^{\mathrm{PV}}/_{\sigma_{\mathrm{gauge}}}$$

k is the number of standard deviations (usually, 6);

σ_{gauge} corresponds to the gauge variability;

USL is the upper specification limit;

LSL is the lower specification limit;

PV is the part variation (product variability).

TIRE MANUFACTURING PROCESS

The process adopted by the company to produce a tire is divided in 5 different steps, whose names, inputs and outputs are illustrated in the scheme of Figure 13:

(1) **Mixing** to obtain a homogeneous and palletized layer, known as “final compound”, by combining several materials such as rubber, carbon black and sulfur;

(2) **Preparation** that, by using extrusion or calendering operations to transform the final compound, allows respectively the production of treads, sidewalls and bead elements, and the production of innerliners, metal belts, cap ply, and textile belts;

(3) **Building of the Green Tire**, which results from the sequential action of two types of machines that combine the various elements of the tire;

(4) **Vulcanization** which converts the Green Tire into the final product, using presses and molds that give the tire a consistent shape and define its characteristic pattern;

(5) **Final Inspection**, the step in which the tires are labelled as tires for original equipment (OE), or replacement tires (RT), or even scrap, based on perceived imperfections in the visual tests, uniformity tests and balancing tests performed.

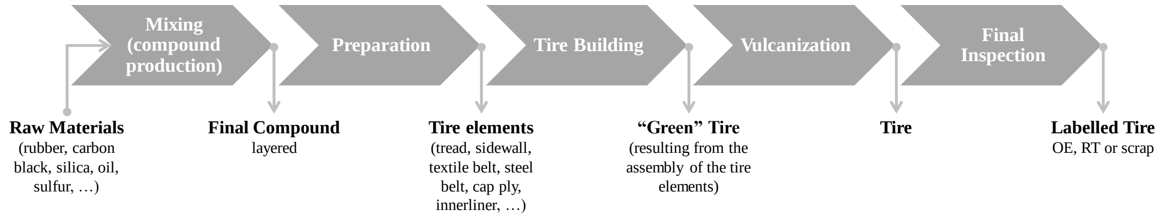

Figure 13 – Steps of the Tire Manufacturing Process

The preparation stage is the most comprehensive, encompassing all the processes that ensure the transformation of the final compound produced in the mixing phase into the elements that, in the construction phase, are combined to form the green tire. Next, the calendering process is explained in more detail, since it is the focus of this project.

Generally, in calendering, a particular material is impregnated in another. In the production of tires, the impregnation of a textile or metallic rubber ply is achieved by using a set of rolls arranged to simultaneously form an upper and a lower layer inside which a screen is impregnated. Therefore, calendering is a process where rubber is pushed through a gap between two rolls (the nip) to form a reinforced rubber sheet with the thickness determined by the size of the nip. Figure 14 shows a representation of a calendering line of metallic material, allowing a better understanding of the connection between equipment and operations in the calendering process.

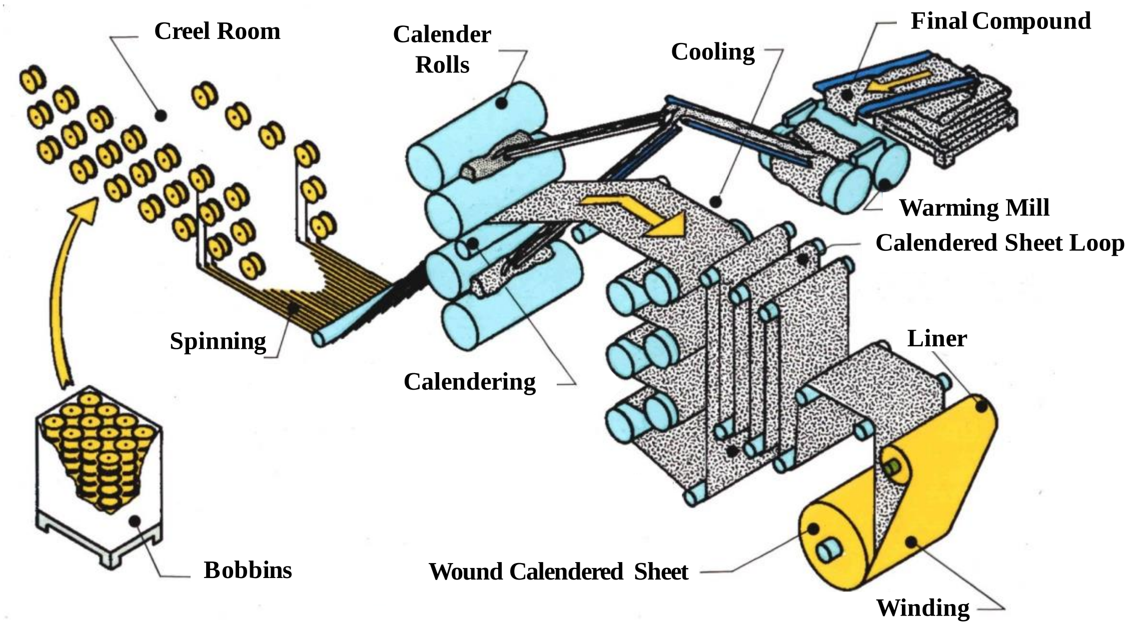

Figure 14 – Calendering line of metallic material

The metal material is supplied in metal rope bobbins, which are stored in a room with controlled temperature and humidity (creel room). After a manual threading process, the metal ropes pass through spinneret, which allow their alignment and the development of a relatively continuous layer of metallic material (metal ply). In the case of the textile material, the raw material is already provided in the form of textile plies, so it does not require a threading process.

A calendering line, regardless of the type of impregnated material, comprises an extruder and two mills, homogenizing mill and feeding/warming mill, which heat the "final compound" produced in the mixing, into which the fabric is impregnated.

The ply, which is also heated prior to impregnation, is then impregnated into the "final compound" by the action of the calender rolls. After impregnation, the calendered sheet is cooled and finally wrapped around a textile material so it doesn't glue. Along the calendering line there are accumulation zones which allow the screen or the calendered sheet to be looped, in order to avoid stopping the machine when changing the setups.

The calendered sheet is then cut in proper machines, resulting in different components of the tire, depending on the material used.

MEASUREMENT SYSTEMS FOR THE CALENDERING PROCESS

The quality of the calendered sheet is evaluated on the basis of four characteristics: the width, the number of ropes per decimeter, the thickness and the weight per square meter. Table 7 summarizes the factors that influence these characteristics.

Table 7 – Factors that influence the characteristics of calendered sheet

Characteristic	**Factor**	**Can machine operators control this factor?**
Width	Position of the calender blades	Yes
Number of ropes per decimeter	Textile ply type	No
	Spinning process	Yes
Thickness	Gap between two rolls (the nip)	Yes
Weight per square meter	Ply thickness	No
	Final Compound characteristics	No
	Extrusion Temperature	Yes
	Temperature of the calender rolls	Yes

The width is relevant only in terms of scrap, since the calendered sheet is subjected to a subsequent cutting process, which depends on the final dimensions (width and length) of steel belts, textile belts and cap ply, so that within the calendering it is only intended that the width of the layer minimizes the waste generated at the time of cutting. On the other hand, the monitoring of weight and thickness should allow for the identification of anomalous situations in terms of the number of ropes. Thus, of the four characteristics mentioned, only the weight and the thickness are considered CTQ (critical-to-quality).

The control plan of the calendering process contemplates the self-control of the four characteristics previously listed. A roll of textile fabric, commonly referred to as green roll, normally produces four rolls of calendered sheet, whereby self-checking must be carried out by sampling one in four rolls of calendered sheet. Thus, it is possible to characterize the resulting production of all rolls in green.

As shown in
Figure 15, in order to perform the sampling procedure for weight and thickness measurement, it is necessary to (1) cut a strip of calendered sheet, (2) obtain three circular samples, each with 1 dm^2, by cutting in three strip locations (near the two ends and in the center), and (3) ensure the correct identification of the samples.

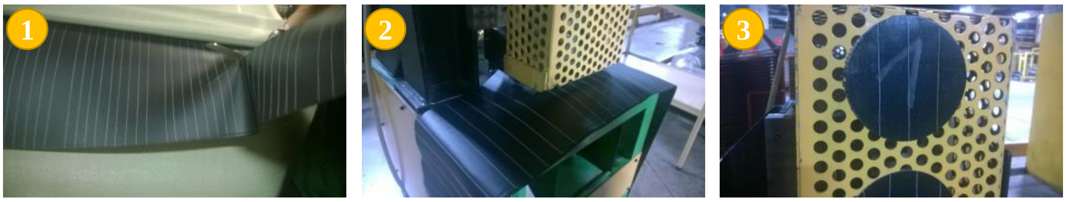

Figure 15 – Procedure to collect samples of calendered sheet

The weight of the samples is obtained using a common digital scale and the thickness is measured through a thickness gauge similar to that shown in
Figure 16. The operator moves the finger lever of the meter, triggering spindle movement. However, according to the statements of a Technical Support Officer (and corroborated by some operators), the lever has a short duration / life, implying that operators start to move the spindle directly through their wrist / cape.

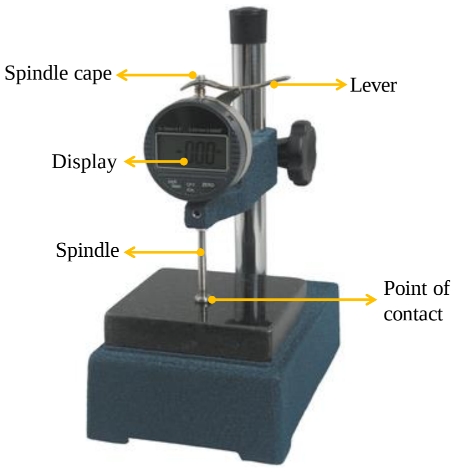

Figure 16 – Thickness Gauge

The values of the characteristics monitored in the self-monitoring are recorded on paper. By month, more than 400 rolls can be controlled, which implies measuring more than 1200 values of thickness and 1200 values of weight. Although this self-monitoring has no relevant production implications as it is carried out by the machine master (which can interrupt control whenever problems occur which require their intervention) and that each calender has two winding modules at the time of cutting of the calendered strip the layer winding is already taking place on another roll), the recording of those measurements in the computer system, which is carried out by the process inspectors at the end of each month, may take more than 2 hours. Although it is a necessary task for the subsequent evaluation of process capacity, it is not an activity that adds value, and the associated resource consumption led to the decision to only record the values of the weight in the computer system.

The problems concerning the handling of the thickness gauge, the ambient conditions (e.g. temperature) at which the measurements are taken and the fact that the current equipment does not allow the computer storage of the registers led to an analysis of the systems for measuring the thickness and weight of the meter. The results and conclusions are presented below.

STUDY OF THE MEASUREMENT SYSTEMS: RESULTS

The analysis of the calendered sheet measurement systems (scale and thickness gauge) was firstly based on Type 1 gage studies and, secondly, on repeatability and reproducibility (R&R) studies.

Type 1 studies

To assess bias and repeatability effects, a Type 1 study was applied to each measurement system.

Scale

The weight of the samples depends on the impregnated material and can range from 6 g (e.g. nylon) to slightly more than 20 g (e.g. metal). Considering the range of values specified for the different types of calendered material and given the available reference standards, the Type 1 study included collecting 50 measurements of a 10 g standard. Figure 17 was generated using Minitab software and shows the results of this study.

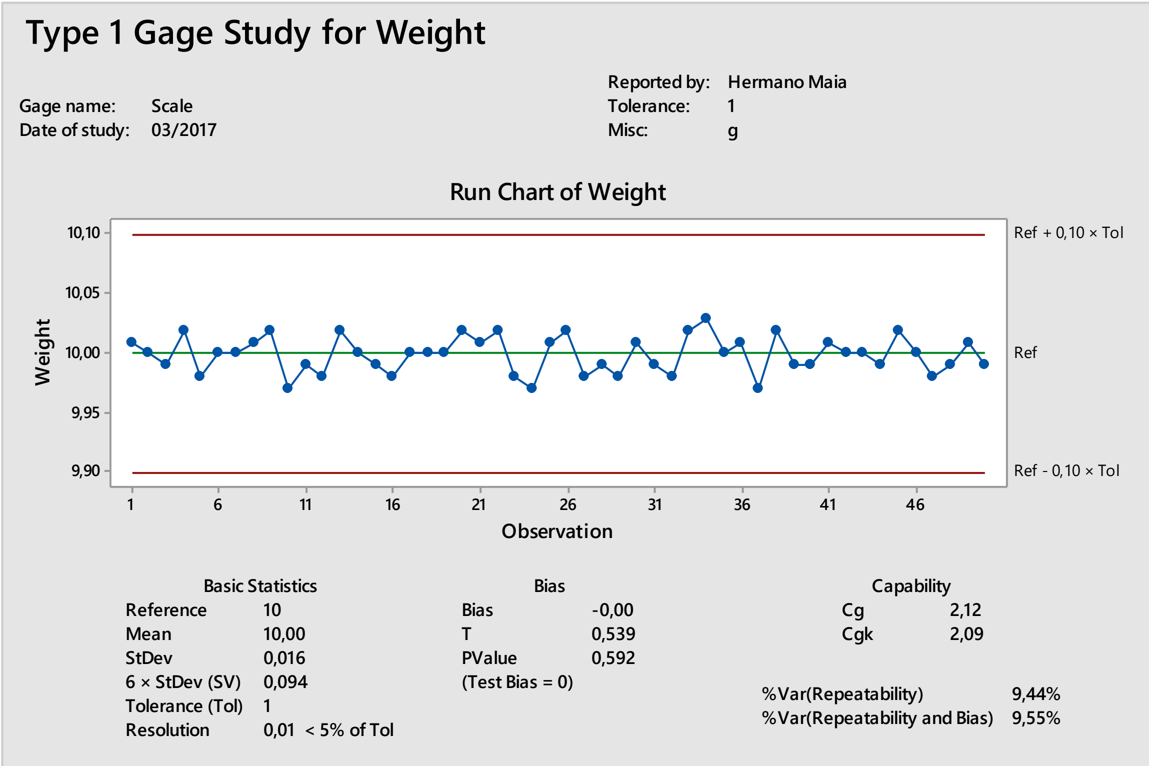

Figure 17 – Type 1 study for weight

The mean of the 50 collected measurements was 10.00 g and the standard deviation was 0.016 g. The individual observations range between 9.97 g and 10.03 g, as shown in Figure 17.

The proximity between the mean value of the measurements and the true value of the standard (reference mass) suggests that the scale does not generate bias, which is corroborated by the t-test. The p-value obtained in the t-test was 59,2%, that is, higher than the significance level adopted (5%), thus concluding that the scale is accurate.

The variability of the measurement attributable to the repeatability effect corresponds to 9,44% of the total variability, which Minitab software estimates to be one-sixth of the specified process tolerance. Considering the recommendation of AIAG (2010), and since this value is less than 10%, it is concluded that the scale is acceptable in terms of the repeatability effect. This conclusion is reinforced by analyzing the capacity index Cg, which value (2.12) is higher than the reference value (1.33). Finally, the Cgk index, which combines the effects of repeatability and bias, is analyzed. The value of this index, 2.09, is higher than the reference of 1.33 and only slightly lower than the value of the Cg index; so, the bias is not significant. Thus, it is concluded that the digital scale is capable, generating accurate (no bias) and precise (repeatable) measurements.

Thickness gauge

Although less pronounced than weight, the thickness of the calendered sheet depends on the impregnated material. As in average the specification is 1.00 ± 0.10 mm, the Type 1 study of the thickness gauge consisted in obtaining 50 measurements of a standard of 1 mm. The measurements have been collected with the thickness gauge placed on a granite plane (i.e., a granitic block with adequately assured flatness conditions) in order to prevent them from being influenced by level oscillations. Figure 18 was generated using Minitab software and presents the results of the study.

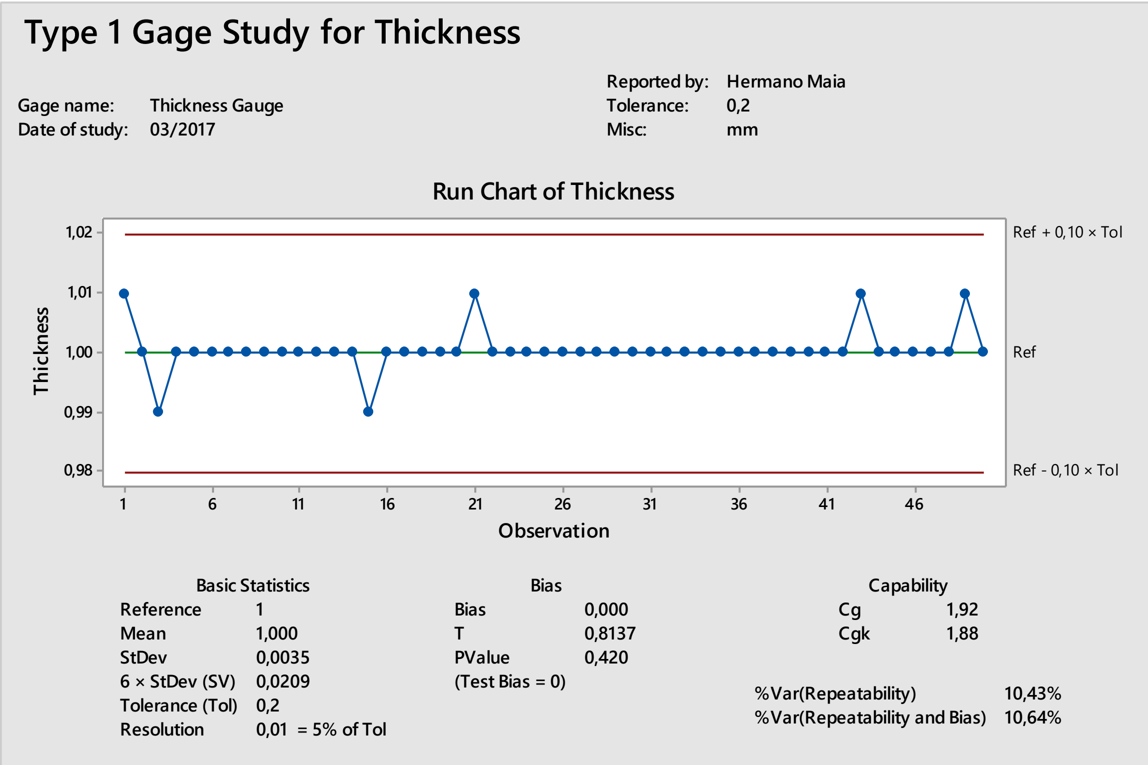

Figure 18 – Type 1 study for thickness

As shown in Figure 18, the measurements range from 0.99 mm to 1.01 mm, presenting a mean of approximately 1.00 mm and a standard deviation of 0.0035 mm.

Therefore, the mean value of the measurements is close to the true value of the standard, which suggests that the thickness gauge does not generate bias. On the other hand, the result of t-test, which presented a p-value of 42.0%, that is, a value above the significance level adopted (5%), reinforces the conclusion that the thickness gauge is accurate.

The variability of the measurements attributable to the repeatability effect corresponds to 10.43% of the total variability. Considering the recommendations formulated by AIAG (2010), since the value is greater than 10% and less than 30%, the thickness gauge may be acceptable, but it must be analyzed according to the importance of the process and the relevance of monitoring of the characteristic under study. However, if the decision is based on the analysis of the capacity index Cg, which value is 1.92, i.e. higher than the reference of 1.33, it is concluded that the thickness gauge is capable in terms of repeatability effect.

Finally, the Cgk index is compared with the Cg index, in order to reinforce the previous conclusion that there is no bias. As the value of the Cgk index, 1.88, is very close to the value of the Cg index, remaining above the reference 1.33, it is concluded that the bias is very small. The Type 1 study applied to the thickness gauge suggests, briefly, that this equipment is capable and that it generates accurate measurements. An additional analysis to its precision must be carried out.

R&R studies

In section 0, the results of the Type 1 measurement studies were presented, concluding, on the one hand, that the balance analyzed is accurate and precise and, on the other hand, that the thickness gauge is accurate, but its precision is questionable.

The assessment of the accuracy in the context of a Type 1 study, i.e. the repeatability effect, is limited by the fact that the analysis concerns a single sample (a standard with a known true value). It is then necessary to analyze the repeatability in the real context of the process, that is, by measuring several samples of the calendered sheet. R&R tests, which assess the intrinsic variability of the measuring equipment (repeatability) and the operator variability (reproducibility), can be used for this purpose.

It should be noted, however, that if Type 1 studies had suggested that any of the measurement systems were not capable of generating measurements close to the true value of the sample - which is not the case - it would not be appropriate to analyze the performance of that system in the real context of the process through an R&R test. In these circumstances, it would be necessary to calibrate the measuring equipment, and, subsequently, to repeat the Type 1 test.

Scale

The scale under analysis is digital and the operator only needs to place the sample on its base waiting for the value displayed in the monitor to stabilize. So, it has been determined, a priori, that for this measuring system only the effect of repeatability would be analyzed, which reduced the number of measurements and samples to be collected compared to a typical R&R test.

To carry out the test, 10 samples of calendered sheet were collected. Then, the weight of each sample was measured 5 times by a single operator.

After applying the test (Table 8), it was found that the variability attributable to the repeatability effect corresponds to 8.77% of the total variability (the total variability considered corresponds to one-sixth of the process tolerance). This value is close to the one obtained when the Type 1 measurement study (9.44%) was carried out. Thus, the conclusion that the scale is precise and suitable for measuring the characteristic under study, still holds.

Table 8 – Results of repeatability test applied to the scale

	Measurements (g)						
Part ID	1	2	3	4	5	Mean	Range
1	11,64	11,63	11,65	11,64	11,65	11,64	0,02
2	11,45	11,42	11,45	11,44	11,44	11,44	0,03
3	11,64	11,62	11,60	11,59	11,59	11,61	0,05
4	15,56	15,55	15,57	15,59	15,56	15,57	0,04
5	12,64	12,62	12,65	12,62	12,66	12,64	0,04
6	19,61	19,63	19,65	19,66	19,65	19,64	0,05
7	12,94	12,96	12,95	12,95	12,95	12,95	0,02
8	11,65	11,66	11,65	11,65	11,64	11,65	0,02
9	8,69	8,65	8,66	8,67	8,69	8,67	0,04
10	11,65	11,64	11,65	11,64	11,62	11,64	0,03
						$\bar{R}$ =	0,034
	Equipment Variation (EV) = 0,0146						
	Tolerance = 1,0						
	%EV = 8,77%						

Thickness gauge

To carry out an R&R study of the thickness gauge, 10 samples of calendered sheet were collected and 3 operators were selected. Then, each operator measured 3 times each sample, which resulted in a total of 90 measurements. Operators were randomly selected from those who routinely control the width, weight and thickness of the calendered sheet. No specific instructions were given to operators, in order to avoid any influence in their natural behavior. The Figure 19 summarizes the procedure adopted to apply the R&R test, which was based on Li and Al-Refaie (2008) method.

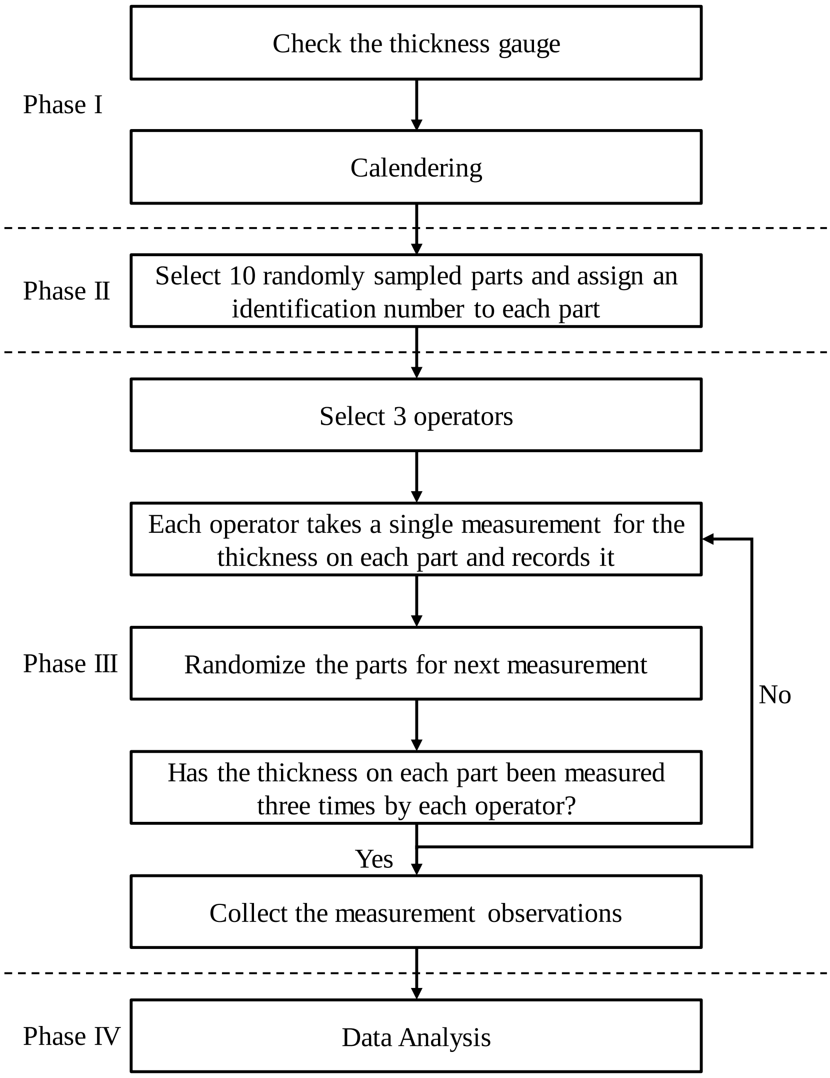

Figure 19 – Procedure of the R&R test applied to the thickness gauge

The results of the R&R test, according to the classical approach, are summarized in Table 9. The Precision-to-tolerance Ratio (PTR) for the individual effects of repeatability and reproducibility is 13.00% and 8.03%, respectively, suggesting that the variation observed in the collected measurements is influenced more significantly by the equipment factor than by the operator factor.

The combined effect of repeatability and reproducibility presents a PTR of 15.28%, which, according to AIAG (2010), does not allow the immediate acceptance of the measuring equipment, being necessary an additional analysis. On the other hand, the number of distinct categories (NDC) obtained is greater than 1 and less than 5, which suggests that the data provided by the thickness gauge only allows a rough estimation of parameters and indices, producing little reactive control charts (AIAG 2010).

Table 9 – Results of the R&R test according the classical approach

Source	VarComp	%Contribution (of VarComp)	StdDev (SD)	Study Var (6 x SD)	%Study Var (%SV)	PTR (%)	NDC
Total Gage R&R	2,59E-05	10,30	0,00509	0,03055	32,09	15,28	4
Repeatability	1,88E-05	7,46	0,00433	0,02600	27,30	13,00	
Reproducibility	7,16E-06	2,84	0,00268	0,01605	16,86	8,03	
Part-To-Part	2,26E-04	89,70	0,01503	0,09017	94,71	45,09	
Total Gage R&R	2,52E-04	100,00	0,01587	0,09521	100,00	47,60	

When the interaction between sample and operator factors is statistically significant, the ANOVA version of the R&R test allows a more reliable estimation of reproducibility (Antony *et al.* 1999). Thus, to verify if this interaction is significant, a two-way ANOVA test was performed (Table 10).

Table 10 – ANOVA test for the R&R test

Source	DF	SS	MS	F	p-value
Part	9	1,64E-02	1,82E-03	43,22	0,000
Operator	2	4,62E-04	2,31E-04	5,47	0,014
Part * Operator	18	7,60E-04	4,22E-05	1,52	0,115
Repeatability	60	1,67E-03	2,78E-05		
Total	89	1,93E-02			

The ANOVA test suggests that the interaction between the sample and the operator is not significant (p-value of 11.5%), so the analysis of repeatability and reproducibility according to the ANOVA approach was not continued. The analysis of Figure 20 (generated by Minitab software), especially the lower right-hand graph, does not allow to detect an interaction between sample and operator, reinforcing the previous conclusion.

It should be noted that the control charts presented in Figure 20 – based on subgroups of dimension 3, since this was the number of times each sample was measured by the same operator – especially in the control chart for means, present several points outside the control limits. In fact, in the context of R&R tests, it is desirable that to have in the x-bar chart most points (representing the means of each subgroup) outside the control limits, because this suggests that the measuring equipment is able to distinguish between the different samples. The AIAG (2010) recommends that at least 50% of the total number of points should appear outside the control limits. In the control chart for means under analysis, 17 of the 30 points represented (57%) are outside the control limits, thus according to AIAG recommendations.

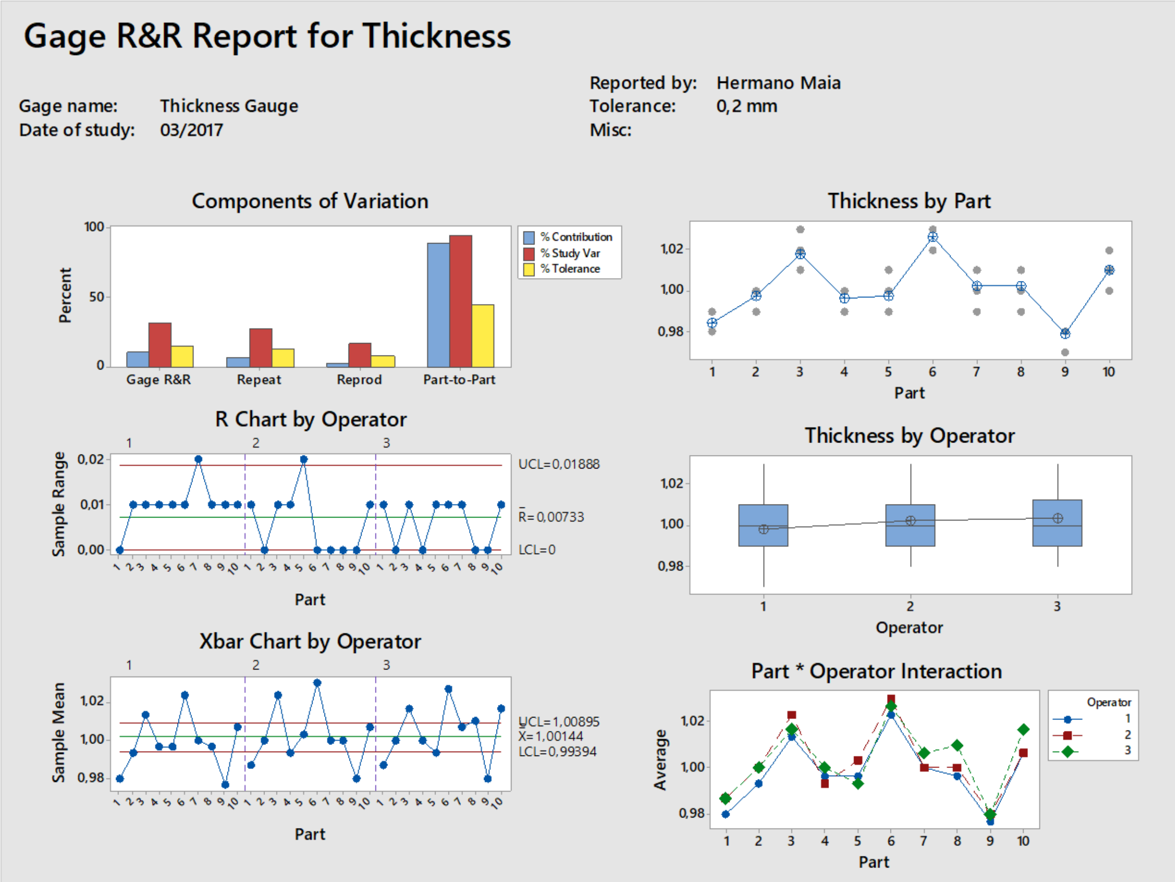

Figure 20 – R&R test applied to the thickness gauge

REFLECTION ON RESULTS AND IMPROVEMENT PROPOSALS

As stated in section 0, the analysis of the measurement systems for the CTQ characteristics of the calendered sheet (weight and thickness) was motivated by problems concerning the handling of the thickness gauge, the environmental conditions in which the measurements are carried out and the fact that the current equipment does not allow an electronic storage of records.

This analysis studied the bias, the repeatability and the reproducibility of the measurement systems. If a system results in measurements without bias, then the system is considered accurate. On the other hand, a system where the measurements for the same sample are close to each other (repeatable), even when obtained by different operators (reproducible), is a precise system.

The results of the bias and repeatability (Type 1 study) and R&R studies, presented in the previous sections, show (i) that the weight measurement system is accurate and precise and (ii) that the thickness measurement system is accurate, but its precision, based on the recommendations of the AIAG (2010), is questionable. In fact, the R&R test resulted in a

PTR greater than 10% and a NDC of less than 5. The R&R test also suggests that the variability associated with the repeatability effect is greater than the one relative to the reproducibility effect, which suggests that the factors behind variability are intrinsic to the measuring equipment and/or shared by all operators.

The thickness gauge analyzed in the R&R test no longer had a lever, and the three operators moved the spindle by pulling the respective cape. In fact, one of the operators mentioned that, even if there was a lever, he would still prefer to use the spindle. During the study, all three operators gave a few strokes to the spindle several times before recording the measurements. Although the adopted method specifies that each sample should be measured at three points, with the respective thickness corresponding to the average of the three values obtained, the operators sometimes did not perform the three measurements. In addition, for each sample, operators only took note of the mean value of the measurements, which they mentally calculated, using two decimal places (that corresponds to the number of decimal places displayed on the thickness gauge reader).

Considering the goal of reducing the variability of the measurement process and in order to solve the problems identified or confirmed during the R&R study, a system should be defined in which thickness measurements are less influenced by inappropriate behavior of the operators, as it is the case if a more robust measuring equipment is used. A search for existing solutions in the market was then carried out, to identify equipment capable of overcoming these problems and recording and storing measurements in such a way that allows the data to be directly exported to spreadsheets.

This research was conducted by consulting the several catalogs (namely, Mitutoyo (2016), Qualitest (2017) and EGITRON (2017)) and, although there is equipment using more advanced technologies (e.g. pneumatic solutions for spindle movement), the identification of simple equipment, similar to the current ones, but with functionalities that allow to suppress the existing problems was the main focus. Based on the research, it is proposed to acquire:

- a new digital thickness gauge, visually similar to the one currently in production, prepared for the storage and exportation of measurement data;
- a spindle lifting cable compatible with the new gauge: this cable is a substitute to the lever, allowing to control the position of the spindle, without physically contacting the thickness gauge;

- an acrylic box to protect the thickness gauge and its support stand 1, with an opening through which the samples can be introduced into the base of the stand and holes for the cables: this box isolates the thickness gauge, preventing operators from acting directly on the spindle of the equipment;
- equipment required to register, store and export data of measurements: this equipment should be able to replace the handwritten record of thickness measurements, avoiding the time consumed inserting the data in the computer system. Furthermore, it should allow the individual storage of the three measurements that must be performed on each sample and ensure that the average of these measurements is calculated without errors.

Both the Quality Department and the Production Technical Support Department consider the new system to be appropriate and useful, and its acquisition and implementation should take place in the coming months.

Summing up, if process capability analysis answers the critical question of how proficient I am at making good parts, measurement system analysis tells us about the not least important question of how good I am at correctly measuring those parts.

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Identification of inefficiencies in a complaints handling process

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ABSTRACT

Purpose – This paper aims to identify inefficiencies in the complaints handling process of a world leader company in the production of components for the food packaging sector, and propose some improvement actions to overcome them.

Methodology – The first step was to examine the complaints management process with the organizational agents, and model it using Business Process Modelling Notation. The data resulting from the organization process were later studied. From the combination of these two analyses, some elations about the process and its inefficiencies were draw.

Findings – The main conclusions were that (i) there is a need to standardize the activities in order to control the resources that are used; (ii) it is essential to increase the actors' awareness to the importance of the process improvement; and (iii) digital platforms should be implemented in order to facilitate interactions.

Practical implications – This article reiterates the need to improve business processes as a source of competitive advantages and may help organizations with similar processes and needs to implement improvements in their own processes.

Originality – This paper combines two approaches – process modelling and statistical process analysis – which are not usually employed together in the process improvement context.

Keywords: Complaint handling process, Process improvement, Business Process Modelling, BPMN.

Paper type: Case study

INTRODUCTION

Despite all the efforts made by organizations to increase market share and attract new customers, it is of utmost importance, for organizations, to provide a satisfactory service to those who have relied on them. So, an after-sales service must be provided so consumers won't be dissatisfied with the product or service, which would cause changes in their future behaviour and could reduce the attractiveness of the company with regard to other potential buyers who would be adversely affected. Customer retention capacity is therefore important, not only for profitability, but also for the image and sustainability of organizations (Filip, 2013).

As much as organizations try to provide customers with the best product and service, it is sometimes impossible to avoid a delayed flight, a damaged packaging or a failed delivery. Errors are sometimes inevitable, but customer satisfaction is not. Although they cannot foresee all the problems, organizations must have the ability to recover from them. A good recovery service can turn the customer's dissatisfaction into loyalty, in fact it can even create a better relation than if everything had gone as planned (Christopher et al., 1990).

The value of retaining customers over time for an organization is greater than the value of the products they complain about so, the concern with identifying, analysing, and solving customer problems is beneficial to organizations because it avoids their occurrence in the future, while satisfying and retaining current customers (Fornell and Westbrook, 1984).

Therefore, any opportunity that organizations have to receive feedback from customers must be leveraged, not only to satisfy those who need help, but essentially to anticipate the needs of others and adapt the product or service to market requirements. In this perspective, customer complaints arise as an extremely valuable opportunity for companies, and they should encourage the customer to do so, since it is a unique opportunity to realize what the customer wants (Filip, 2013).

Hence, the department responsible for managing customer complaints should be responsible for integrating the departments involved in the problems that were the source of such complaints, and also contribute to improve their processes, by identifying and reformulating the organizational activities related to those problems. The tasks of the department responsible for complaints management are then twofold, addressing client dissatisfaction adequately, compensating them, and finding internal means for removing the roots of discontent and their future recurrence (Fornell and Westbrook, 1984).

To fulfil the first function, manage customer dissatisfaction, according to the study of the determinant factors of management complaints in the context of Business to Business, done by Brock et al.(2013), the speedy treatment of the complaint process and the resulting fair compensation is clearly the most important thing, and the relation that employees have with the clients during this process is relegated to the background, contrary to what is often argued about the importance that is given to the interpersonal relationship. Industrial customers appear to act more rationally and more impersonally than consumers and, as a result, even with all the empathy of the employees and their customer orientation, this may not be enough if a weak compensation is given or an ineffective recovery process is implemented.

The second function is to find a way to reduce the causes of the problems. It can only be achieved if the organization has a structured system for evaluation and problem solving, following a specific set of procedures, to give real answers to the target consumers and eliminate the causes of their dissatisfaction. For this to happen, it is necessary to design a fully integrated complaint management system so that weaknesses are reduced, performance improved and similar experiences avoided in the future, establishing a relationship of trust, loyalty and commitment with the client (Filip, 2013).

Both of these aspects are critical to adequately satisfy customers requirements, which is the main issue within the scope of Quality.

The objective of the work presented in this paper is to improve the quality of the product and the service provided by an industrial company that supplies the food packaging industry – in a business to business context – by analysing their current process of complaints' handling and recommending improvement actions to overcome the problems found. It should be noted that since the organization belongs to the food sector, some of the identified issues can be critical, namely those related to contamination which can have harmful consequences for consumers.

RESEARCH METODOLOGHY

To understand how the organization manages its complaints, the first step was to examine the business process associated with complaints' handling. This phase was performed through the analysis of several complaints' processes, treated in the past by the organization, and was duly validated by the organizational agents.

Since many business processes are not easily understood in all their complexity many users, aware of the necessity to properly manage them, began to describe the processes in different graphic forms as a way of understanding them and identifying the most susceptible points of action (Chinosi and Trombetta, 2012). Thus, the concept of Business Process Modelling (BPM) has emerged as a key element in the development of processes oriented organizations, since the existence of documentation, and a standardization of the processes in the form of graphic models, allow for an easy understanding by all the agents (Gabryelczyk and Jurczuk, 2017). It was then decided to develop the proper modelling of the studied process, using the concept of BPM, in order to do a more objective analysis. BPM helps to improve the efficiency and effectiveness as its functional representation encourages the use of other continuous improvement methodologies and aspects of total quality management (TQM) (Schmiedel et al., 2014).

The modelling language chosen for this purpose was the Business Process Modelling Notation (BPMN) since it fulfils all the requirements and it is the standard in the field of modelling languages. It is chosen by most of the experts, since it has the advantage of developing graphical models in an intuitive way, being also able to handle the complexity of business processes (Arevalo et al., 2016). BPMN uses only four categories of objects to represent the whole process, namely Flow Objects, Connecting Objects, Swimlanes and Artefacts. The Flow Objects with the objective of representing all actions that take place within the process (Events, Activities and Gateways); the Connecting Objects to present different ways of relating these Objects (Sequence Flow, Message Flow and Association); the Swimlanes to locate the elements within the space (Pools and Lanes); and, finally, the Artefacts to provide additional information about the process not contemplated in the flow (Data Object, Text Annotation and Group) (Chinosi and Trombetta, 2012).

Once the process has been duly mapped and explained, the next phase was to analyse all the available data regarding it. The data resulting from all the complaints received by the organization in the year 2017 were then analysed, specifically their occurrence, and also the time it took the organization to close them, comparing the different motives, in an attempt to associate them with the performance of the process.

At a final stage, the identification of inefficiencies in the organization's current process was done, by analysing the model and by interpreting the data processing results. It was taken into account that a business process always begins with a market need and ends when that need is met, so the process should add value to the customer and should not include activities and resources that are not needed or valuable. Ideally, the well-established business process creates value for the costumer while minimizing the organizational costs associated with its activities (Singh, 2012).

RESULTS AND DISCUSSION

This section is divided in two subsections. The first one describes the result of the process modelling and, in the second part, the statistical analyses of the data regarding the complaints are presented.

Process Modelling

All the details of the complaint handling process are presented in Table 1. There is an explanation of the main components of the process, as well as the respective sequence of events, their activities and the related actors and objects. The process mapping, developed using BPMN, is presented in Figure 1.

Table 1 – Complaints handling process' details.

Event Sequence	Activity	Actor	Object
1	Complaint requests are submitted by clients in the organization specific software and the product manager receives a notification via email, whenever a request is submitted, marking the beginning of the complaint handling process.	Client	Complaint request on software
2	A pre-analysis of the complaint request is made, to confirm if it really corresponds to a complaint. If it does not correspond to the criteria the request is cancelled. If it corresponds, it is determined if the information necessary for the handling of the complaint is complete. In case the information is incomplete, all necessary information is requested to the client, and the process only continues when all the information needed is gathered.	Product Manager	
3	Once the information is available, the product manager opens the complaint on the system, that is, assumes the request as valid and all the data related to the complaint are inserted in a software to support its resolution (the complaints database).	Product Manager	Insert complaint on complaints' database
4	If a deeper analysis is required, depending on the motive of the complaint, an internal analysis is carried out in the department responsible for the type of problem claimed. This analysis is performed by the product manager and results in a technical report issued by the department in question, where it gives its technical opinion on the complaint.	Product Manager Responsible Department	Technical report

5	A proposal for the final resolution of the complaint based on the information presented in the technical report, together with the requirements presented by the client, is then prepared by the product manager. This proposal, due to the impact it can cause in the organization, may have to be validated by the administration, a communication that is promoted by the product manager. If the administration does not validate it, the proposal must be reformulated by the product manager, and only when it obtains administrative validation, the process proceeds.	Product Manager Administration	Final resolution proposal
6	After the final resolution proposal is prepared and, if needed, duly validated, it may be necessary to promote a negotiation with the client. If the client does not agree with the proposal, different terms are negotiated until a consensual proposal is reached.	Product Manager Client	
7	Finally, the product manager closes the complaint in the software, where it was initially opened, and an answer with the summarization of the whole process is sent to the client. The data related to the complaint resolution process is updated in the complaints database, so it can be properly stored.	Product Manager	Complaint closed on software Update complaints' database

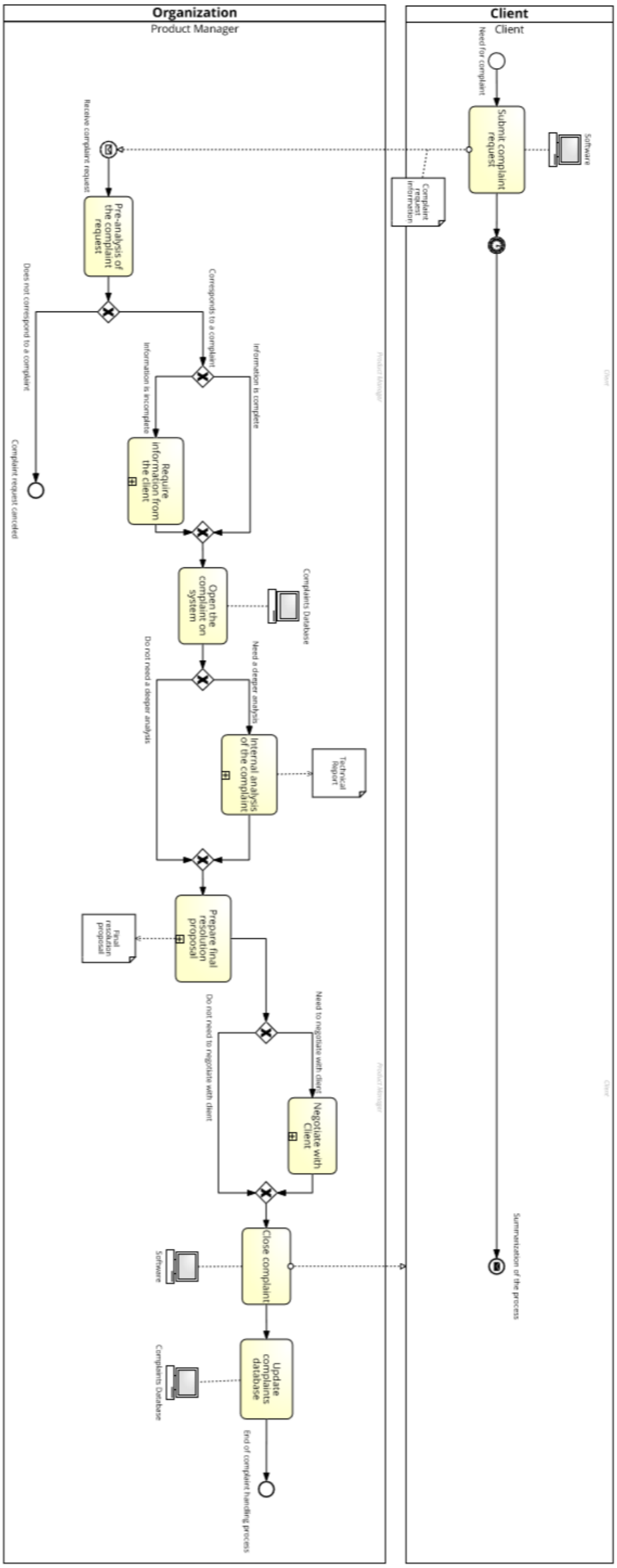

Figure 21 – Mapping of the complaint handling process with BPMN.

Analysing the model of the process in BPMN it is possible to verify that documents are generated in 3 moments, the complaint request information, the technical report, and the proposed resolution, but in practice, and with the unfolding of the process, more versions of these documents, as they are being updated and reformulated, are generated. At the moment, documents are sent by email between the actors, and this diversity of information is not beneficial for the efficiency of the process. In an ideal situation, the documents should be managed on a platform with document management functionalities and where it would be possible to make changes and submit updates, avoiding the redundancy of information and its inherent wastes.

It is also possible to verify that the client does not interact with the process. The client submits the complaint request, but only is informed of the process when it is closed. Promoting a more frequent communication with clients and keeping them up-to-date of the state of the process can be a good policy, increasing the satisfaction of those who complain and, in some cases, assisting with the resolution of the complaints.

Since the complaints are submitted by the clients in a specific software for the purpose, it is very time consuming for the product manager to evaluate if the request corresponds to a complaint and ask clients for additional information if needed. Although these activities cannot be completely eliminated, it is possible to incorporate part of them in the software as an automatism that requires that clients insert all the necessary information according to the motive of their complaint. Additionally, it should make a first filter of the request, verifying if it corresponds to a complaint or not. If this happens, much of the current process's activities would disappear, and that would be an important step to make the process simpler and more efficient.

Complaints Data Analyses

In this subsection, some results about the complaints and their resolution time are presented. This indicator was chosen by the company because it is considered crucial within the context of the relationship with the customers.

Data from the four classes of complaints used within the company are compared. Those classes were defined taking into consideration the department that is responsible for the problem claimed, and are: product in general (Motive 1), sensory characteristics (Motive 2), product classification (Motive 3) and service associated with the transaction (Motive 4).

In 2017, there were a total of 1214 closed complaints, with resolution times that varied from less than 1 day to 1 year (there was only one complaint that took more than 1 year to close). Figure 2 shows the resolution time distribution for all of the 1214 complaints and Table 2 presents the average and the standard deviation of the referred time.

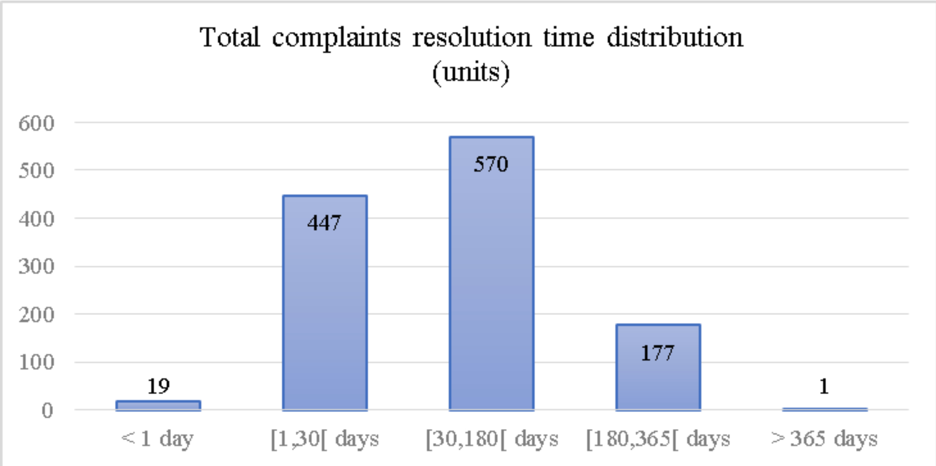

Figure 2 – Total complaints resolution time distribution, in units.

Table 2 – Average and standard deviation time of the total complaints closed, in 2017.

$\bar{x}$	80 days
s	86 days

The complaints are divided in classes, according to their motives. The four different classes of motives, as mentioned previously, are related to the organizational department where the deepest analysis is made, if necessary. In this exploratory study, it is assumed that the complexity of the complaints' analyses and their temporal extension are similar for all classes. Table 3 presents the number of complaints closed in 2017, for each of those classes.

Table 3 – Number of complaints closed in 2017 by type of motives.

Motive 1	Motive 2	Motive 3	Motive 4	Total
310	398	395	111	1214

It can be noticed that the number of complaints is quite similar for Motives 1, 2 and 3, while Motive 4 has a smaller frequency of occurrence.

Figure 3 presents the resolution time for each of the motives, and Table 4 shows the average and standard deviation of those times' distribution.

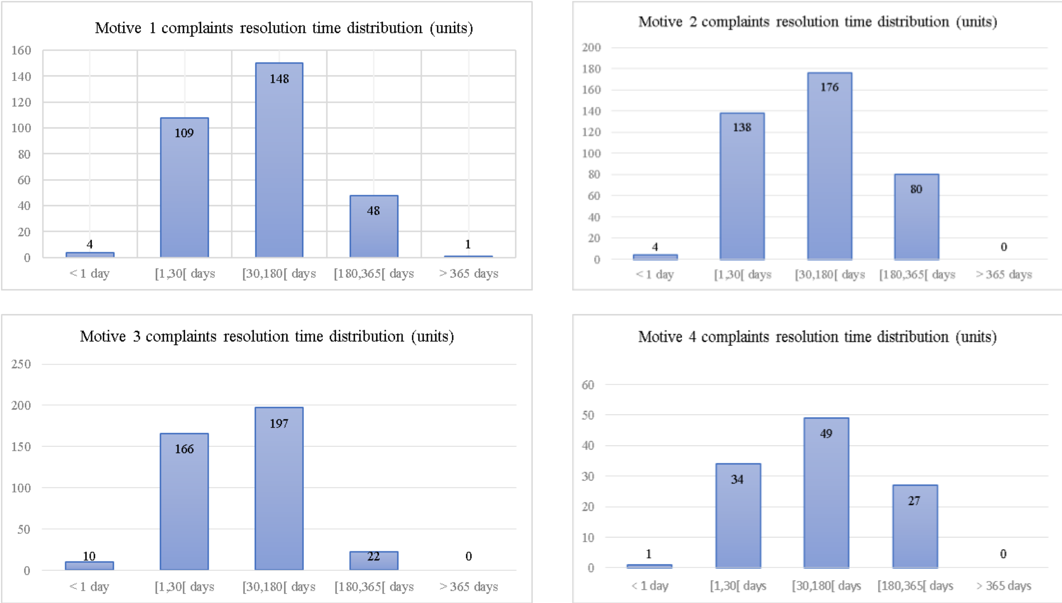

Figure 3 – Resolution time distribution, in units, per motive.

Table 4 – Average and standard deviation time of the complaints closed, in 2017, per motive.

	Motive 1	Motive 2	Motive 3	Motive 4
$\bar{x}$	91 days	87 days	56 days	102 days
s	97 days	85 days	66 days	96 days

It is interesting to visualize the discrepancies in the resolution time of different motives. Motive 4 presents a mean resolution time and a standard deviation with high values, with most of the processes solved between 1 and 6 months. As this is the motive with the least associated complaints, and, consequently, the organizational department should spend less time solving them, is interesting to verify that it does it less quickly than the others. On the contrary, Motive 3 has shorter resolution durations, despite being one of the motives with more associated complaints. It follows that the internal complaint handling process can be improved, and guidelines should be created to standardized the way different departments analyse complaints.

The standard deviation values can be considered high (86 days, for the total), which shows that there is potential for the implementation of improvement actions.

The high variability of each of the four processes and between them, can show that the control over the resources involved is not adequate. It is vital for the organization to have a clear sense of all the resources it needs to resolve a complaint, for each motive, and how much time they are spending on this activity, only then they will have the ability to monitor and improve it in the future.

Based on the results presented and taking into consideration the inputs obtained from different agents involved in the process, it is assumed that the activities that have a higher impact on the duration of the process are those where it ceases to depend solely on the product manager, either because validation of the administration is required or because a negotiation with the client is needed. Whenever one of these activities occurs, the process becomes discontinuous and, since communication is done indirectly, and there are no stipulated deadlines to complete each activity, complaints' treatment is postponed by the other departments, that give priority to other functions. It is considered then that most of the complaints that were closed on the same day or that had a duration of less than one month were mostly those that were treated continuously and where the product manager did not depend on others to proceed with the resolution.

Finally, it is considered that there is the need to carry out an in-depth study of each activity of the process and create deadlines for the different activities, establishing a standard on how complaints should be handled, ensuring not only a better performance in terms of response time, but also facilitating the internal control of the process and promoting its continuous improvement.

CONCLUSIONS

In this study, the complaints handling process of a company that belongs to the food packaging sector was analysed using two approaches, namely process mapping and statistical analyses.

Organizations must have a structured system of complaints evaluation and problem solving, following a specific set of procedures, in order to answer customers adequately, and to eliminate the causes of their dissatisfaction. It is then necessary to design a fully integrated complaint management system so that weaknesses are reduced and performance is improved.

The study of the process in question revealed that there are many inefficiencies in the organization's current complaints handling. This work highlighted some of those, namely: (i) the high duration of the process; (ii) the variability of the resolution durations; (iii) the lack of contact with the clients; (iv) the discontinuity of the process in certain activities; (v) the excess of documents generated; (vi) a poor process control; and (vii) the lack of standards.

In order to fill these gaps, a number of possible solutions have been outlined. The adaptation of computer systems, so that they are able to manage the information generated and automate some of the activities should be implemented. The processes should also be standardized in order to: provide the actors with instructions of what they should do, allow the monitoring of the activities duration, assign responsibilities and thus enabling the organization to manage its resources and optimize their use. These proposals are considered important but to become viable and effective should be explored in a greater detail.

Although the graphic modelling in BPMN and the data analysis performed were effective and useful, it is worth mentioning that the use of a different approach to study this process, whether by using an alternative mapping method, or by studying additional data, could lead to the identification of other inefficiencies and findings.

As such, as future work, it is intended to continue this study, making more statistical analyses that should support the implementation of some of the suggestions and enable the emergence of more process improvement proposals. The cost/benefit relationship of the proposed actions should be performed and those that prove to be advantageous for the company should be implemented.

AKNOWLEDGEMENTS

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Contributions towards the improvement of the IMS-MM©: A Delphi method study

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ABSTRACT

Purpose– This paper aims at reporting the results collected throughout a research study focused on the assessment of the relative importance of potential indicators/metrics that may be suitable to evaluate the efficiency of Integrated Management Systems (IMSs) by further incorporating them into the existing back-office component of the IMS-MM©. In addition, this novel semi-quantitative approach will hopefully overcome one of the shortcomings ascribed to the first version of the Integrated Management Systems- Maturity Model (IMS-MM©).

Design/methodology/approach– Potential indicators/metrics suitable for adoption to monitor the performance of IMSs were identified and selected based on a thorough and extensive revision of literature and on two case studies conducted in industries. These indicators/metrics were assessed (rated according a 5-point importance Likert scale) by a Delphi panel (encompassing 30 academic, industry and business experts) throughout 3 rounds (iterations). Supported on the statistical summarized results collected throughout the 3 rounds they were subsequently organized and prioritized (1st: Importance degree- Median; 2nd: Round at which the consensus criterion was fulfilled; 3rd: Evolution of the Median score throughout the three iterations; 4th: Evolution of the opinions of the experts (throughout the three rounds) according to its potential importance to assess the performance of IMSs.

Findings– At the end of the last round all of the proposed indicators/metrics fulfilled the consensus criterion previously established (Interquartile range (IQR)<1). The indicators/metrics can be clustered throughout 11 levels. On one hand, it should be highlighted that indicators/metrics such as the “Existence of integrated policy”, “Existence of integrated indicators", "Existence of integrated objectives" and "Existence of integrated procedures" were rated as the most important. Conversely, the indicator "Number of guidelines, frameworks or standards adopted to integrate the management subsystems" was ranked at the 11th cluster.

Research limitations/ implications– The research limitations of the current study relate with those inherent to the research method adopted (Delphi study), *i.e.*, reliability issues and drop-outs of experts throughout the successive rounds (iterations).

Practical implications– These results will be adopted to develop a second version, *i.e.*, an improved, more reliable, less biased and semi-quantitative version of the IMS-MM©. This work will impact both on academia (the proposal of a novel framework to assess IMSs) and on companies (the assessment of their own IMSs).

Originality/value– As of today scarce are the instruments/tools that enable the overall assessment of IMSs (effectiveness and efficiency). The reported results will support the development of an updated version of the IMS-MM© that, ultimately, will point out to companies an optimized path in order to reach a higher maturity level.

Keywords: Integrated Management Systems, Delphi Panel, efficiency, Maturity, Performance Indicators/metrics

Paper type: Research paper

INTRODUCTION

The increasing globalization of markets and the economy growing more competitive drive organizations to look at the implementation of an IMS as a great opportunity and consequently as a differential against competitiveness. This fact enables a high level of product and processes quality developed by the companies (Abad *et al.*, 2016; Almeida *et al.*, 2012; Nunhes *et al.*, 2016, 2017; Simon *et al.*, 2014). A great deal of studies and relevant contributions were published in the last years addressing the benefits, motivations and obstacles that revolve around the integration phenomenon and the shortcomings of managing various sub-systems apart (Sampaio *et al.*, 2012; Bernardo *et al.*, 2015; Mustapha *et al.*, 2017; Moumen and El Aoufir, 2017). Other scientific contributions in this domain focused on the potential integration levels attained, models, strategies and guidelines to proceed with a proper and suitable integration (Gianni *et al.*, 2017; Kania and Spilka, 2016; Rebelo *et al.*, 2017). The crucial role that an IMS may play in the improvement of the company performance in terms of quality, environmental and occupational health and safety involving a holistic, logical and systematic approach (Olaru *et al.*, 2014) has been discussed by authors throughout the last years. In addition, the standards usually adopted to implement the MSs are often dissected in order to seek for potential improvement opportunities and to propose strategies aiming at its alignment and harmonization. Furthermore, some authors systematically address a critical and relevant topic- the audit function- suggesting how to select the audit team and pointing out which strategies should be implemented in order to optimize the available resources (Rivera *et al.*, 2017). In previous years some contributions were published in order to reduce the divergence of opinions concerning the implementation of an IMS. Regarding to the efficiency of IMSs, at the moment, there is not any proposal to evaluate it, although three models and one instrument had emerged to assess the maturity of IMSs. This paper aims at reporting the results from a Delphi panel conducted to assess the importance of various proposed indicators/metrics. Ultimately, it is expected that these indicators/metrics will encompass and improve the existing IMS-MM© and, thus, minimize the shortcomings pointed out and ascribed to it (Domingues *et al.*, 2017). Although some of the proposed indicators/metrics do not address explicitly the efficiency assessment of an IMS it is believed that, when incorporated in the model, they will be able to provide information regarding this issue notably through the back-office component of this hybrid maturity model (Domingues *et al.*, 2016). This paper is structured as follows: section two presents the revision of literature carried out, namely, a revision of the latest studies that addressed various topics within the IMSs domain and a revision of literature of the existing maturity models/instruments aimed at the assessment of IMSs. The following section ("Research Method") describes the procedure adopted to select the experts that encompass the panel, those procedures adopted throughout the Delphi study and the criteria to define the consensus and the consensus zone. The "Results and Discussion" and the "Conclusions" sections present the results collected, discuss some of their potential applications and shortcomings and point out the soundest conclusions.

LITERATURE REVIEW

Integrated Management Systems

Throughout the last years an increasing concern with the certification process became notorious among a great deal of companies. The set of available standards with the potential to be implemented and certified seek at the application and uniformization of best practices. The similarities between the structure of the ISO 9001 standard (Quality Management System- QMS), the ISO 14001 standard (Environmental Management System- EMS) and the OHSAS 18001 (Occupational Health and Safety Management System- OHSMS) suggest that an integrated management system (certifiable and that addresses simultaneously to different stakeholders' requirements and expectations) is aligned with the best and recommended management practices and approaches (Nunhes *et al.*, 2017; Paranitharan, 2017). These three MSs encompass the same basic principles and a generic common structure. All of them require the definition of roles and responsibilities, the training of personnel, the organization of procedures and the monitoring of processes (Bernardo *et al.*, 2009; Santos *et al.*, 2011; Mustapha *et al.*, 2017). Moreover, this latter revision of the ISO meta-standards enhanced the compatibility and alignment between a great deal of the requirements notably those encompassing the high level structure (HLS) depicted in the Annex SL (Fonseca and Domingues, 2017).

Maturity models in the domain of IMSs

As of today, and to the authors' knowledge, four models/instruments were proposed to assess IMSs and/or maturity although some recent efforts and contributions were reported in other similar domains such as supply chain management (Fernandes *et al.*, 2017). Domingues *et al.* (2016) proposed the IMS-MM© a (1+5)-level maturity model, supported on three axes and encompassing two components, Dragomir *et al.* (2017) proposed an instrument (encompassing an innovative visualization approach) that take into account the information collected in process audits, Poltronieri *et al.* (2016) developed a tool supported on the sustainability pillars and Moumen and El Aoufir (2018) proposed a model in line with the process approach that support the ISO 9001 standard. The shortcomings of the IMS-MM© were evidenced when conducting case studies in several companies (Domingues *et al.*, 2017). The qualitative nature of the information required to populate the IMS-MM© (Figure 1) and the fact that the model do not consider some relevant external dimensions other than those considered by the standardized MSs were identified as the major limitations of the IMS-MM©. Concerning the instrument proposed by Dragomir *et al.* (2017) it should be pointed out that it is designed to assess an IMS that comprises three subsystems maximum and, in the version proposed, relies on information from the audit reports and do not take into account other dimensions or peculiarities than those reflected by the requirements of the standards that are being audited (similarly to the IMS-MM©). Regarding the IMS-MM© (Domingues *et al.*,

2016) it should be emphasized that it is supported on three axes: the key process agents (KPAs), the externalities and the principles of quality management. It is intended, due to the abovementioned shortcomings of the current version, to introduce changes (enabling the incorporation of quantitative information) in the three axes to be assessed. The information collected from the present study will be incorporated in the axis “KPAs” in order to decrease the bias of the supporting information (in the current version through a structured questionnaire). Additionally, some changes are planned to occur in the two other axes that encompass the model and ongoing research studies are being carried out in order to proceed with those updates.

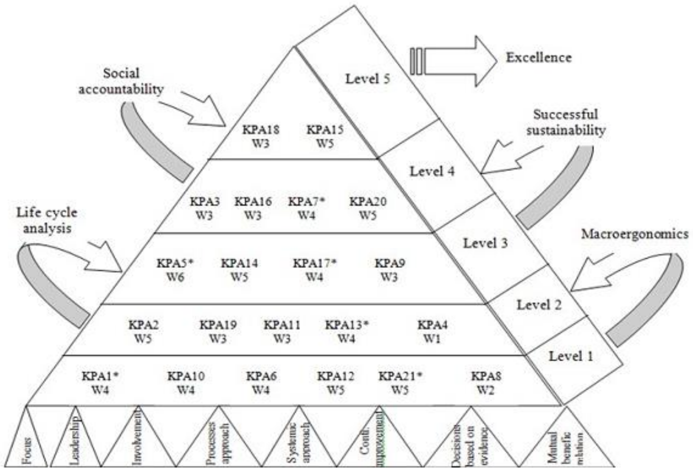

Figure 1 – The front office component of the IMS-MM©.

RESEARCH METODOLOGHY

The review of the literature focusing IMSs and the Delphi method pointed out that a great deal of the published studies are supported by surveys in order to collect valid information about different subjects. Afterwards collected data is analysed by the means of statistical techniques. According to the literature, a completely reliable specific technique is absent, *i.e.*, all of the existing research techniques and methods are ascribed with pros and cons depending on the context in which they are adopted being the most important feature the adaptation of the method to each specific goal.

For this study, in particular, a survey was carried out in order to validate the information collected during a previous and thorough revision of the literature, *i.e.*, the most common research methods were adopted. However, solely the collection of data does not provide information regarding the agreement between those indicators/metrics that are more or less important. For the conception of the methodology proposed, the following elements were taken into account: (1) Existence of a set of several performance indicators/metrics related to IMSs by reviewing the literature; (2) Present all the indicators to a group of experts with special knowledge in the field by using an online survey; (3) Questionnaire application in order to obtain concordant results among the experts - consensus building and finally, (4) Statistical analysis of the data collected. The Delphi method, defined as a systematic and interactive research technique aimed at obtaining the judgement of an experts' panel on a specific domain, was the research approach adopted. This method was developed during the 1950s by workers at the RAND Corporation to carry out a scientific study based on experts' opinions about military projects in the United States of America (USA) (Buckley, 1994; Grisham, 2008; Habibi *et al.*, 2014). The term "Delphi" has its origin in Apolos' divine inspirations ant it refers to the sacred oracle site in Greece. This method is supported by a research technique that gathers opinions in order to generate consensus through the application of a questionnaire where, usually, two or three successive rounds are conducted (Landeta, 2006). All the information collected in each round is analysed and will be considered in the following rounds (Keeney *et al.*, 2001; Grisham, 2008). It is expected an increased consensus round after round till the last iteration.

Delphi Method

The Delphi method is usually adopted to validate some research relevant topics and is hugely dependent on a thorough and objective selection of experts' panellists (Avella, 2016). The experts encompassing a Delphi study are usually professionals or researchers with a special knowledge/ experience evidenced by several specific requirements such as working appointments, professional qualifications, working experience, and/or relevant publications (Donohoe, 2011). This method is supported by four main characteristics: anonymity, iteration, controlled feedback and the summarized statistical analysis of the collected information (Rowe and Wright 2001; Skulmoski *et al.*, 2007; Landeta *et al.*, 2011). In the current study the selection of the experts (32 total) that comprised the panel took into account their experience in the IMSs domain (both academic and industrial- at least 5 years), the dimension of the companies that they usually deal with, the activity sector, the MS standard which they are more familiar with and the geographical context where the research activities are usually carried out (to assure a diversified sample)- Figure 2. Experts from Portugal, Spain, Brazil, Sweden, Romania, Italy, UK, Greece, Denmark, Poland, Pakistan, Trinidad and Tobago and Netherlands encompassed the Delphi panel.

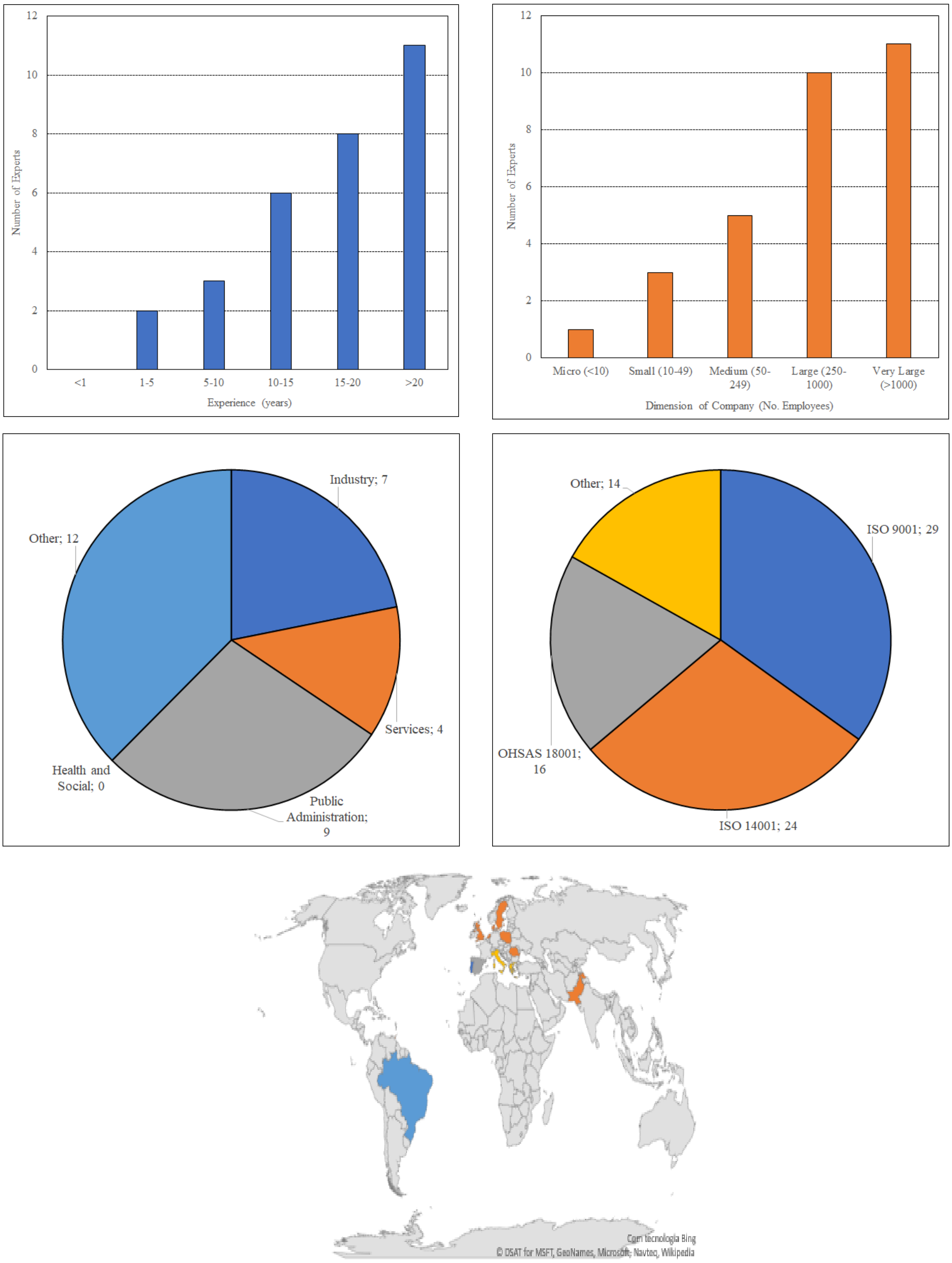

Figure 2 – Characterization of the Delphi panellists.

The identification of the 29 indicators/metrics (Table 1) assessed by each expert was carried out through a comprehensive revision of the mainstream and available literature and in two case studies previously conducted.

Table 1 – Indicators/ metrics to be assessed by the Delphi panel.

Dimension	ID_{Ind}	Indicator
Costs	ID 20	Total costs ascribed to the IMS.
	ID 21	Cost reduction achieved with the implementation of the IMS.
Audits	ID 24	% of non-conformities detected and ascribed, simultaneously, to the various MSs.
	ID 3	% of audits conducted adopting an integrated approach.
	ID 23	Average time to close corrective actions derived from external and internal audits.
Stakeholders/ Suppliers	ID 1	Nº of complaints from the stakeholders.
	ID 2	Nº of suppliers holding more than one certification.
	ID 18	% of integrated requirements demanded to suppliers.
	ID 19	Nº of suppliers assessed in the dimensions of quality, environment and OHS.
Employees	ID 10	Nº of improvement proposals originated from the employees.
	ID 14	Nº of meetings conducted to provide employees with information concerning the IMS.
	ID 16	% of employees informed about the relevance of the IMS.
	ID 17	% of employees who attended training courses about the IMS.
	ID 22	Nº of training hours addressing the topic “Integration of MSs”.
	ID 12	% of training courses addressing the IMS.
Standardized Organizational Structure	ID 13	% of IMS procedures improved due to corrective actions.
	ID 8	Existence of integrated procedures.
	ID 5	Nº of policy references to all stakeholders.
	ID 4	Existence of an integrated policy.
	ID 9	Nº of meetings, addressing IMS issues, with the participation of Top Management.
	ID 11	Existence of organizational functions with responsibilities and duties in the IMS.
Monitoring	ID 15	Nº of integrated goals established.
	ID 6	Existence of integrated indicators.
	ID 7	Existence of integrated objectives.
	ID 25	Effectiveness rate of preventive actions.
	ID 26	Effectiveness rate of corrective actions.
	ID 27	Effectiveness rate of training sessions.
Integration Process	ID 28	Nº of guidelines, frameworks or standards adopted throughout the integration process.
	ID 29	Nº of integrating concepts adopted during the integration process.

A 5-point Likert scale was adopted to assess the importance of each indicator/metric by the means of an online survey. This assessment procedure was carried out throughout 3 iterations (or till the consensus criterion was fulfilled for each indicator/metric). After each iteration statistical treatment of the information took place to check if the consensus criterion was fulfilled or to define the consensus zone and identify the median of the results of each indicator/metric (next section). Furthermore, all the indicators/metrics assessed were clustered (Figure 3) in several dimensions following the guidelines established in the development of an affinity diagram (one of the novel 7 quality tools).

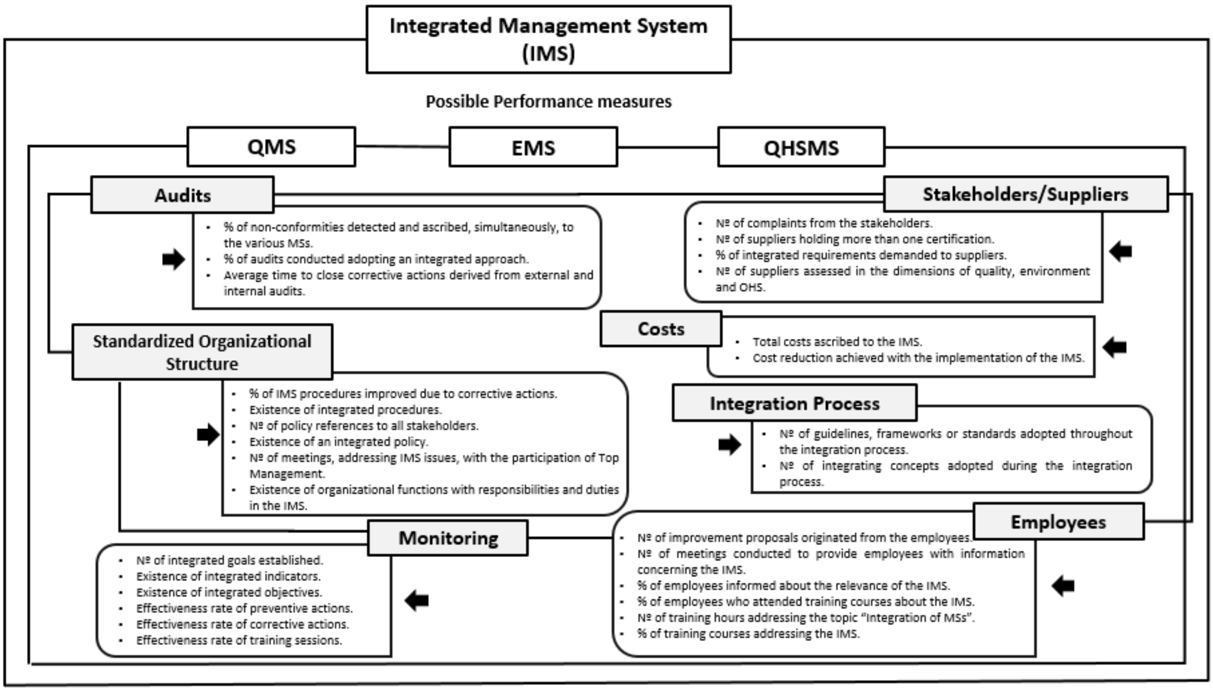

Figure 3 – Afinity diagram.

Establishment of the consensus zone and the consensus criterion

The establishment of the consensus zone and the consensus criterion were based on those guidelines reported in previous studies (Ramos, 2013). Although the existence of several definitions of consensus zone and different reported consensus criteria the option relied on those established in a study with similar goals of the current one. The consensus criterion was established considering the difference between the 1st and 3rd quartile, *i.e.*, the interquartile range (IQR)≤1. The indicator(s)/metric(s) that fulfilled the consensus criterion were not considered for assessment in the following Delphi iterations. Those indicators/metrics that did not attained consensus according to the abovementioned criterion were assessed in the following iterations. In this case, both the median and the consensus zone of the results collected were reported to the experts in the 2nd and 3rd iterations. The consensus zone was established considering the items in the 5-point scale that encompassed, at least, 50% of the responses from the experts.

Hierarchical cluster analysis

The hierarchical cluster exploratory analysis was adopted aiming at the identification of structures within the data, *i.e.*, aiming at the identification of homogenous groups of cases. IBM SPSS v. 24 was adopted to carry out the cluster analysis. The grouping/classification of the subjects was carried out by hierarchical cluster analysis adopting the between groups linkage as the cluster method and the squared Euclidian distance as the dissimilarity measure between subjects. The R^2 (providing the solution that ascribed the least number of clusters considering 80% of the total variance) was the decision criterion adopted concerning the number of clusters to take into consideration. Both the resulting dendrogram and the dissimilarity matrix were considered for analysis.

RESULTS AND DISCUSSION

The Delphi study was carried out throughout 3 iterations (rounds). A total of 32 experts agreed to encompass the Delphi panel and, at the end of the first iteration, 30 responses were collected. In the following iterations (2^{nd} and 3^{rd}) 29 and 28 responses were collected, respectively. The successive abandonment of experts during the Delphi study is a well reported shortcoming of this research method but, it is our belief, do not invalidate the results attained (3.3% abandonment rate). A total of 29 indicators/metrics were proposed to the experts in the first round to be assessed according to a 5-point importance scale (1- Without any importance; 2- Little importance; 3- Important; 4- Very important; 5- Extremely important). Figure 4 presents the evolution of the number of indicators/metrics that attained consensus throughout the successive rounds according to the criterion previously established.

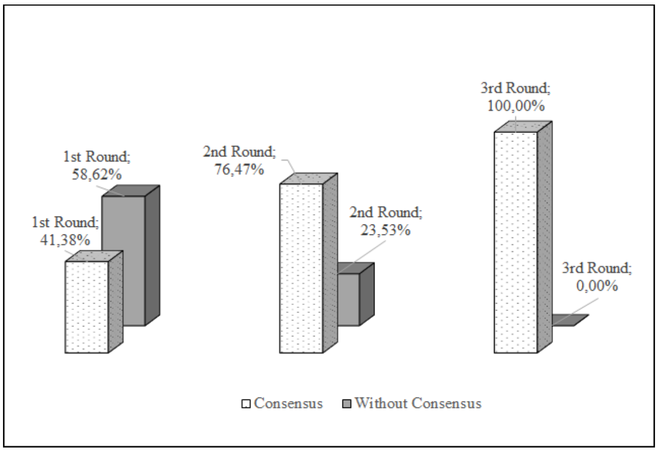

Figure 4 – Evolution of the indicators/metrics that attained consensus.

Results obtained throughout rounds- 1st, 2nd and 3rd rounds

The statistical analysis of the collected data was carried out by IBM SPSS V. 24 software. Figure 5 presents the box-plot diagrams of the results of the successive rounds. Positions corresponding to the median of each indicator are represented by black line (in the middle of bar) as well the outliers' positions (o) and severe outliers (*). The procedure adopted to analyse the results obtained in the second and third rounds was similar.

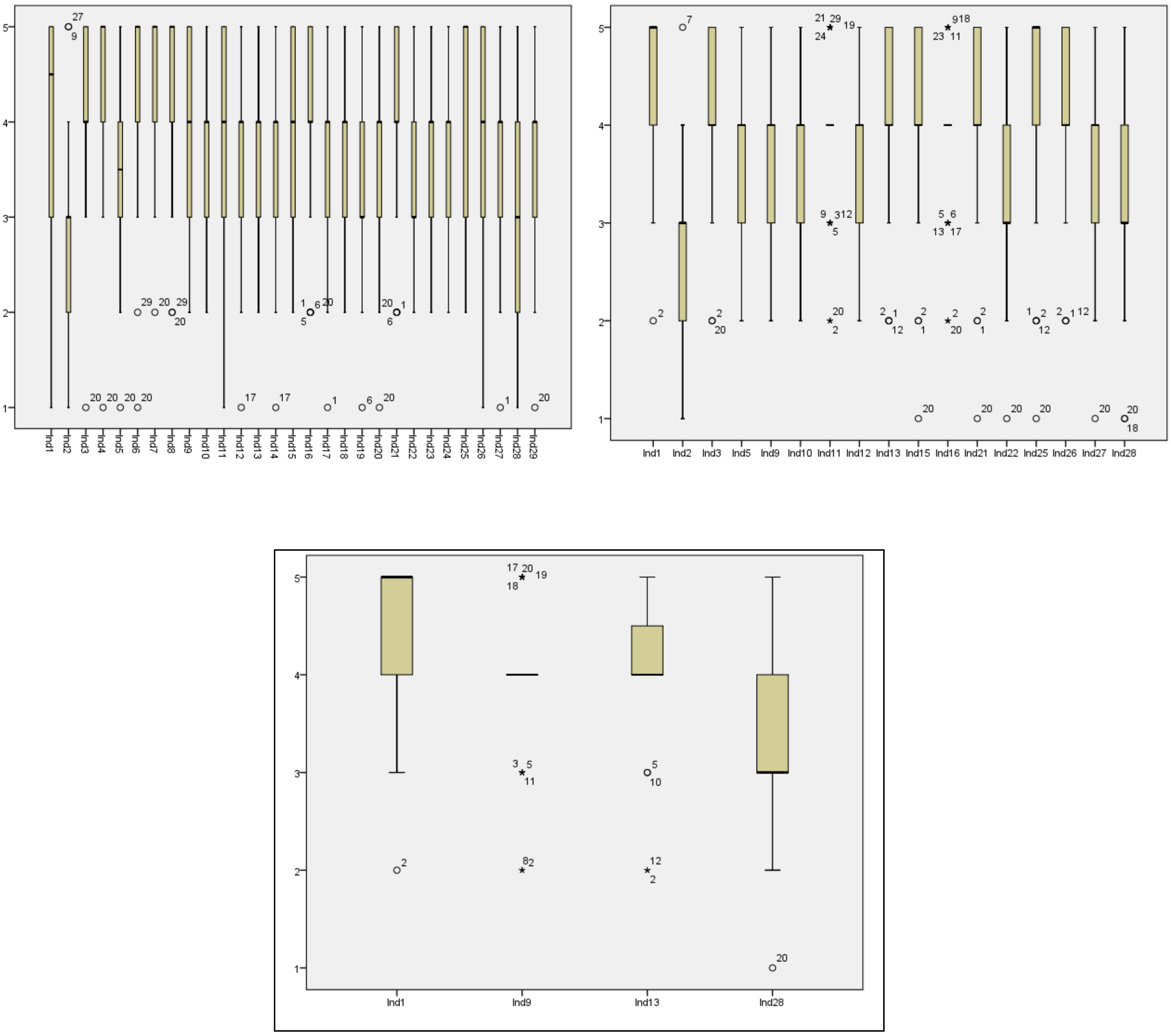

Figure 5 – Box-Plot diagrams of the successive rounds.

Cluster analysis

Figure 6 and Table 2 present the dendrogram and the dissimilarity matrix (1st round) of the hierarchical cluster analysis carried out. The results suggest, considering a cut-off value of 8, the existence of three distinctive clusters of experts and two outliers (Exp. 17 and Exp. 20).

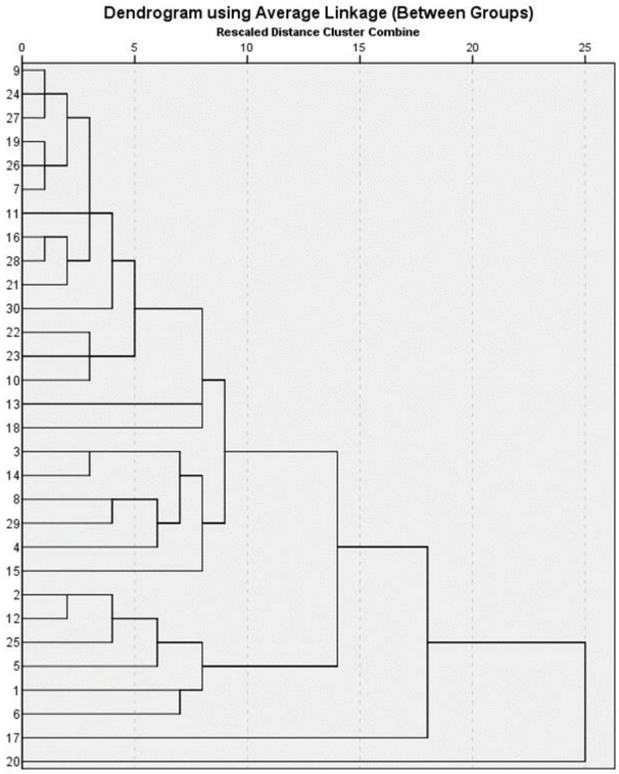

Figure 6 – Dendrogram.

Table 2 – Dissimilarity Matrix.

	Squared Euclidian Distance																													
Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	44	65	46	46	39	63	67	102	69	89	39	79	66	53	68	91	83	85	124	83	84	63	88	35	102	116	90	75	93
2		0	57	42	32	45	55	35	90	61	85	15	65	50	43	60	81	77	87	52	65	76	51	86	29	96	96	76	39	87
3			0	57	83	70	36	34	73	54	42	54	54	21	42	43	80	48	56	109	56	55	32	57	32	67	67	51	52	68
4				0	56	37	21	35	44	31	47	47	35	32	45	36	77	65	35	118	29	48	25	34	27	40	52	30	33	39
5					0	37	83	55	136	95	127	25	83	84	65	108	77	113	135	104	101	120	77	130	43	138	152	114	63	117
6						0	58	52	99	74	82	48	54	51	68	69	82	80	80	93	70	85	62	85	42	81	105	75	62	78
7							0	28	15	18	16	60	32	15	36	21	74	42	14	125	20	25	16	13	26	15	17	19	42	28
8								0	63	50	42	44	52	23	32	57	56	50	50	95	42	51	32	53	28	51	61	53	28	54
9									0	21	29	95	51	42	71	24	123	57	17	162	27	26	29	10	53	22	12	24	75	31
10										0	40	54	40	39	36	25	108	52	28	149	28	21	22	25	32	37	33	33	62	34
11											0	94	46	23	58	29	86	26	18	135	34	31	30	15	46	21	17	21	60	28
12												0	70	61	38	67	86	82	100	93	74	77	44	93	24	113	113	83	50	94
13													0	37	60	37	116	50	46	99	44	45	32	45	44	45	49	43	42	42
14														0	47	26	73	41	27	98	27	36	23	28	31	26	34	24	47	39
15															0	65	78	66	62	121	60	57	40	67	38	69	79	73	56	66
16																0	101	35	17	118	21	22	21	18	31	34	24	14	55	31
17																	0	102	100	185	92	101	76	101	82	95	121	89	68	100
18																		0	38	119	58	27	40	49	48	59	47	43	72	38
19																			0	153	24	23	30	11	50	13	13	19	62	26
20																				0	123	158	131	154	99	158	148	138	97	143
21																					0	39	36	17	38	21	25	17	52	24
22																						0	21	30	47	34	32	28	71	27
23																							0	25	22	41	41	21	36	30
24																								0	45	14	12	12	59	21
25																									0	65	59	41	38	54
26																										0	16	24	67	27
27																											0	24	77	35
28																												0	53	17
29																													0	62
30																														0

Guidelines adopted to prioritize the assessed indicators

As previously pointed out (Figure 3) all the indicators/metrics attained consensus among the experts that encompassed the panel concerning their importance to be adopted in IMSs. After the analysis of all the results, is time to prioritize the assessed indicators/metrics according to their increasing importance. It is expected that at the end of this study, the proposed indicators can be applied in order to measure the efficiency of IMSs, involving a stage and levels process. Thus, in order to prioritize the assessed indicators/metrics according to their importance the following guidelines and decision vectors were adopted cumulatively:

- 1st- Importance Level (Median).
- 2nd- Iteration (round) at which the consensus criterion was fulfilled and/or IQR score (the lowest the IQR the better the definition of consensus level).
- 3rd- Evolution of the Median score throughout the successive rounds (for those indicators/metrics without consensus).
- 4th- Analysis of the opinion of the experts' round after round.

Considering these guidelines, the following 11 clusters of indicators/metrics were identified (Table 2) and grouped according to the importance level ascribed by the experts that comprised the Delphi panel. In addition, Table 3 presents the main justification (according to the abovementioned guidelines and decision vectors) to cluster the indicators/metrics in each Level.

Table 3 – Indicators/metrics clustered according their importance.

Level	**Line-up**	**ID_{Ind}**	**Comments**
1	1st	ID 4	Indicators/metrics that scored 5 (Median) and fulfilled the consensus criterion in the 1st iteration (round). All of them scored IQR=1.
	2nd	ID 6	
	3rd	ID 7	
	4th	ID 8	
2	5th	ID 25	Indicator/metric that scored 5 (Median) and fulfilled the consensus criterion in the 2nd iteration (round).
3	6th	ID 1	Indicator/metric that scored 5 (Median) and fulfilled the consensus criterion in the 3rd iteration (round).

4	7th	ID 9	Indicator/metric that scored 4 (Median) and fulfilled the consensus criterion in the 3rd iteration (round) with IQR=0. The score of the Median kept unchanged throughout all the iterations of the Delphi study.
5	8th	ID 16	Indicator/metric that scored 4 (Median) and fulfilled the consensus criterion in the 2nd iteration (round) with IQR=0.5. The score of the Median kept unchanged throughout all the iterations of the Delphi study.
6	9th	ID 13	Indicator/metric that scored 4 (Median) and fulfilled the consensus criterion in the 3rd iteration (round) with IQR=0.75. The score of the Median kept unchanged throughout all the iterations of the Delphi study.
7	10th	ID 14	Indicators/metrics that scored 4 (Median) and fulfilled the consensus criterion in the 1st iteration (round) with IQR=1.
	11th	ID 17	
	12th	ID 18	
	13th	ID 20	
	14th	ID 23	
	15th	ID 24	
	16th	ID 29	
8	17th	ID 3	Indicators/metrics that scored 4 (Median) and fulfilled the consensus criterion in the 2nd iteration (round) with IQR=1.
	18th	ID 5	
	19th	ID 10	
	20th	ID 11	
	21st	ID 12	
	22nd	ID 15	
	23rd	ID 21	
	24th	ID 26	
	25th	ID 27	

9	26th	ID 19	Indicator/metric that scored 3 (Median) and fulfilled the consensus criterion in the 1st iteration (round).
10	27th	ID 2	Indicators/metrics that scored 3 (Median) and fulfilled the consensus criterion in the 2nd iteration (round). IQR=1
	28th	ID 22	
11	29th	ID 28	Indicator/metric that scored 3 (Median) and fulfilled the consensus criterion in the 3rd iteration (round).

CONCLUSIONS

A Delphi study was conducted aiming at the assessment of potential indicators/metrics suitable to be adopted to monitor IMSs performance. Further work will be carried out (confirmatory analysis through non-hierarchical cluster methods) in order to corroborate the existence of the three cluster of experts identified by the hierarchical method. At the end of the last round all of the proposed indicators/metrics fulfilled the consensus criterion previously established (Interquartile range (IQR)<1). The indicators/metrics can be clustered throughout 11 levels. On one hand, it should be highlighted that indicators/metrics such as the “Existence of integrated policy”, “Existence of integrated indicators”, “Existence of integrated objectives” and “Existence of integrated procedures” were rated as the most important. Conversely, the indicator “Number of guidelines, frameworks or standards adopted to integrate the management subsystems” was ranked at the 11th cluster. These results will be adopted to develop a second version, *i.e.*, an improved, more reliable, less biased and semi-quantitative version of the IMS-MM©. This work will impact both on academia (the proposal of a novel framework to assess IMSs) and on companies (the assessment of their own IMSs).

AKNOWLEDGEMENTS

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Strategic Quality Management for Airports

The Case of the Libyan Airports

Investigations with a focus on the operational processes

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ABSTRACT

Purpose – This paper aims to gain a deeper understanding of and insight into Strategic Quality Management (SQM) through developing a new framework of SQM for airports, as well as identifying the most important factors influencing the improvement of passengers and cargo services operations.

Design/methodology/approach – An extensive search and review of the relevant literature was conducted. An empirical study employing a survey was carried out to identify the most important factors affecting the integration of quality management concepts and strategic planning.

Findings – The study results indicated that most of the stages of strategic quality management according to this framework contained the concept of leadership, which is important because of its vital role in achieving better performance, increasing competitiveness and continuous improvement. The results also showed the importance of using modern equipment in the stages of security inspection and registration. In addition, the use of IT in various stages of passenger service. The study showed that Libyan airports have little experience in cargo services as well as effect of the human elements on all the airport operations.

Originality/value – This is a first attempt to develop an SQM framework of for Libyan airports. The most important contribution of this study is to combine quality management concepts with strategic planning stages in an integrated framework for airports.

Keywords: Strategy, Quality, Airport, Integration

INTRODUCTION

Many firms which practice independently sound management methods to implement higher quality fail because these methods are either not aligned with strategy or because these methods are not properly co-ordinated with each other. Therefore, effective quality management cannot be practiced in isolation from other initiatives and from the overall strategy of the firm. SQM was developed to address the gap though the formulation and deployment of quality management within the overall framework of strategic planning (Srinidhi, 1998). According to (Juran, 1999), SQM is a systematic approach to setting and achieving quality objectives throughout the company. The BSI Standards (1992) define it as a management philosophy and company practices that aim to harness the human and material resources of an organization in the most effective way to achieve the objectives of the organization. Successful implementation of SQM is not an easy task as (Deming, 1982) stated, “Everyone doing his best is not the answer. It is necessary that people know what to do. Drastic changes are required". Practically speaking, companies with defined business processes are better able to assess their strengths and weaknesses and identify opportunities for improvement. They can improve the quality of their products and services and deliver more consistently to their customers, increasing customer satisfaction and loyalty. They are better able to cope with the unknown and react swiftly to changes in the competitive landscape. In short, process companies know when they are doing things right. The development of air transport activity worldwide has increased the demand for airport services and the need for more efficient processes of servicing aircraft, passengers or luggage. According to the Airports Council International (ACI), today’s air travelers have the opportunity to choose between several airports, hence there is the increasing need for airports to compete and to distinguish themselves among their competitors by providing their performance advantages,(Pabedinskaite and Akstinaite,2014).

This paper aims to gain a deeper understanding and insight of that subject, as well as to develop a new framework of SQM for Libyan airports with a focus on passengers and cargo service processes.

LITERATURE REVIEW

Strategic Quality Management (SQM)

The term SQM was first introduced by Garvin in the nineteen eighties of the last century, even though he did not define it. (Srinidhi, 1998) defines SQM as the formulation and deployment of quality management within the overall framework of strategic planning. According to (Aravindan et al., 1996) SQM is the process by which quality management activities focus towards the long range direction and progress of quality enhancement. (Juran, 1999), on the other hand, defined SQM as a systematic approach for setting and meeting quality goals throughout the company. The BSI Standards(1992) define it as a management philosophy and company practices that aim to harness the human and material resources of an organization in the most effective way to achieve the objectives of the organization. Organizations pass through different stages of strategy-quality integration, each one associated with unique quality management practices and strategy process characteristics. Figure 1 presents the evolution of SQM which summarizes the characteristics of each model as specified by its authors.

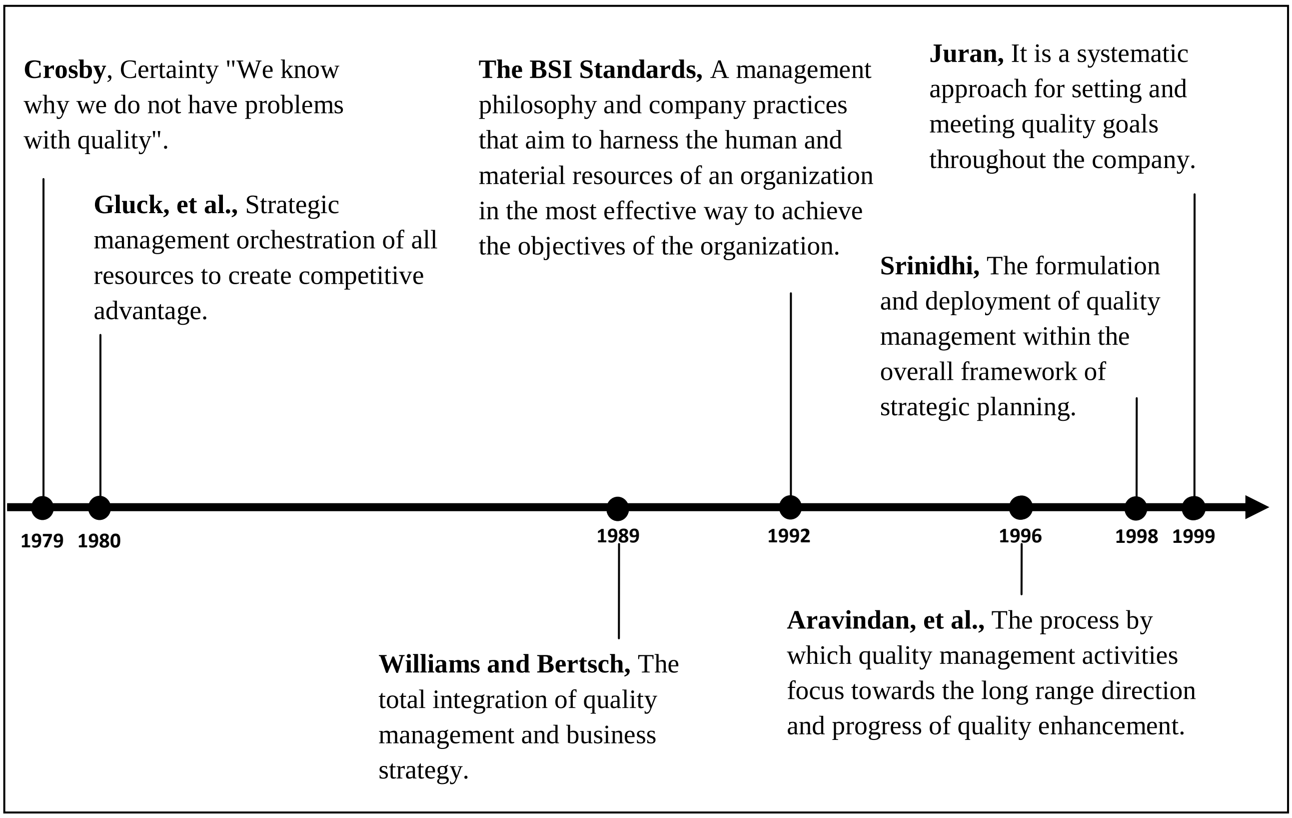

Figure 1 – The evolution of SQM

The evolution of SQM and the forces shaping that evolution make it amply clear that SQM should achieve congruence between the offerings of the firm and the expectations of the firm's customers. The natural tendency of various management methodologies used in its deployment to grow incongruent with each other requires an explicit framework to continuously monitor the congruence between them. The core concepts of SQM were identified and promoted by the quality gurus in one form or another in managing quality within seven concepts as follows: customer focus (CF), leadership (LDR), continuous improvement (CI), strategic quality planning (SQP), design quality, speed and prevention (DQSP), people participation and partnership (PP&P), and fact-based management (FBM)" (Tummala &Tang , 1994). These seven concepts have been chosen as the basis of establishing the proposed framework of SQM. In order to develop an excellent model of SQM, organizations should determine what steps are best to follow to achieve this goal. According to (David, 2009), The approach of strategic management lists what steps managers should take to create a complete strategy and how to implement that strategy successfully in the company. It might comprise from 6 to nearly 30 steps and tends to be more formal in well-established organizations.

The way that strategies are created and realized differ. Thus, there are many different models of the process. The models vary between companies depending upon:

- Organization's culture.
- Leadership style.
- The experience the firm has in creating successful strategies.

(David, 2009) provides an excellent model of strategic management that is characterized by its emphasis on the most important component of management systems, namely the development of the vision of the organization as well as the logical sequence of the other steps of strategic management. This model includes six steps as follows:

1. Develop vision and mission
2. External and internal environment analysis
3. Establish long-term objectives
4. Generate, evaluate and choose strategies
5. Implement strategies
6. Measure and evaluate performance

Airport management

Airports are not just places where airplanes land and take-off but they are also natural interfaces between ground transport modes and air transport (Classen et. al, 2016). Airports are complex organizations whose efficiency depends on the coordination of operations such as taxiway, gate departures and arrivals. Airport efficiency hinges on elements that airport management is more likely to control (i.e., the choice of runway configuration) than others (i.e., weather), (Diana, 2010). Modern airport management requires a more holistic approach to the whole travel chain and aims at a better situational awareness of airport landside processes and an improved resource management, (Classen and Rudolph, 2015). An analysis of literature shows that assessments of the quality of airport services are performed most frequently by conducting passenger surveys. However insufficient attention is devoted to yet another important participant in this industry, namely, airlines, which are highly important customers. In the light of increasing competition, airports need to focus more on strategic planning in terms of quality concepts, not only for competition purposes but also for survival. This can only be achieved by adopting an integrated system of strategic planning and quality management with emphasis on improving service operations, especially in the seam points between the customer and the service provider. The aim is to redesign or improve the service to achieve continuous improvement and gain high levels of performance. One of the most distinctive characteristics of services is their process nature (Shostack, 1987). There are many service delivery systems for measuring customer experience. (Shahin, 2010) describes it using a special kind of flow-chart called Service Blueprint, which also includes the line of visibility, between customers and service provider. In other words, in Service Blueprint, the line of visibility separates activities of the front office, where customers obtain tangible evidence of the service, from those of the back office, which is out of the customers' view. The high and low contact parts of the service delivery process are kept physically separate, but they remain linked by communications. Service Blueprint helps the organization to see the key operational, human resources, and marketing issues offering the service experience for the customer, easily (Bitner et al., 2007). According to (Mascio, 2007) Service Blueprinting is the process of creating the delivering service standard that shows the personnel and equipment required. In this research, Service Blueprint is used to determine fail points and waiting times within service process system, it helps decision makers to figure out critical points in their service.

METHODOLOGY

Research methodology is a way to systematically solve the research problem. It may be understood as a science of studying how research is done scientifically (Kothari, 2004). According to (Burgess, 2001), research methodology is the process by which the researcher obtains research respondents and collects information from them. In this study, the researcher has adopted survey approach to develop a deeper understanding of the different views of the study sample towards the development of a new framework of SQM for Libyan airports. The research question is: How can the application of practices of SQM be developed to assist airport managers in further developing Libyan airports? In order to answer the research question the study has been divided into three stages which include;(1) reviewing previous studies,(2) carrying out a survey to develop a deeper understanding of the different views of the study sample towards the integration of strategic planning stages and quality management concepts, and (3) developing a new SQM framework for Libyan airports based on the two stages above. Four levels of managers were asked to complete the survey. They were Chairman, security officer, strategy director and head of section.

DATA COLLECTION

A survey was designed and distributed to identify the views of managers at Libyan airports about how to integrate strategic planning and concepts of quality management and its relationship to operational processes. The survey was divided into five sections, the first section contained the respondents demographic data. The second section included the factors affecting the integration of strategic planning and quality management concepts. Section three was concerned with the respondents' views on how to include strategic quality concepts in strategic planning stages. Section four dealt with the respondents' views on the factors affecting passenger operations. The final section included factors affecting air cargo operations. Five-point Likert scales from 1 = strongly disagree to 5 = strongly agree were used in the survey.

This survey was designed to be completed by people working in leadership positions at Libyan airports. It was sent to 30 managers who work in Libyan airport authorities and some main airports. A total of 23 usable replies were received. The survey is included as an appendix.

DEMOGRAPHIC CHARACTERISTICS OF THE SAMPLE

Demographic questions collect data about the characteristics of the sample population(age, position, education and experience). Figure 2 illustrates respondents to the questions by the demographic.

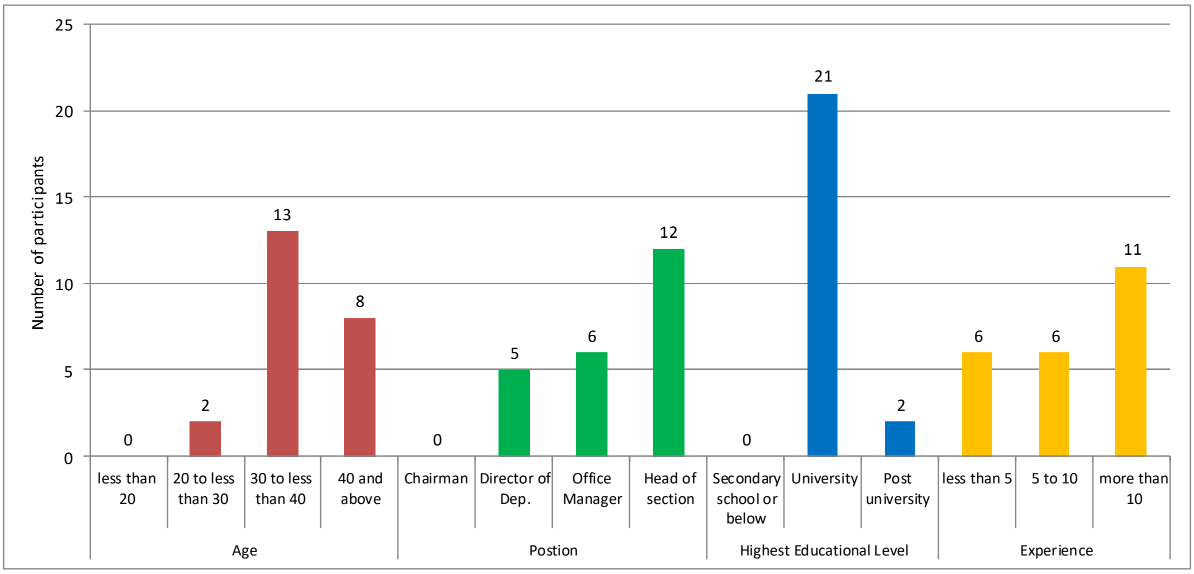

Figure 2 – The sample demographic

It can be seen that the large number of respondents (13) fell between the ages of 30 to less than 40 years old. Regarding position in organization, 12 out of 23 respondents worked as a head of section. The chart also presents the highest educational level of respondents, most of them had graduated with a college degree(21). Finally, experience in current position category shows that 11 respondents have more than 10 years in their current position.

PASSENGER SERVICE PROCESSES

The operations of the passenger service represent the main core of the operations in an airport. Focusing on them in the early stages, especially in the strategic planning phase of the airport, contributes greatly to improving the quality of services and avoiding failure and delay. This also leads to increased consumer satisfaction. Most airports rely primarily on providing services to travelers only, while other airports offer service to both passengers and air cargo. In this research the researcher utilized the Service Blueprint tool to analyze passenger service operations as well as air freight. As a result of the Service Blueprint analysis and the distribution of the survey the researcher was able to develop a preliminary vision of the most important elements that must be taken into account in order to redesign those services to achieve better performance. Figure 3 illustrates respondents perspectives about the components of passengers service processes.

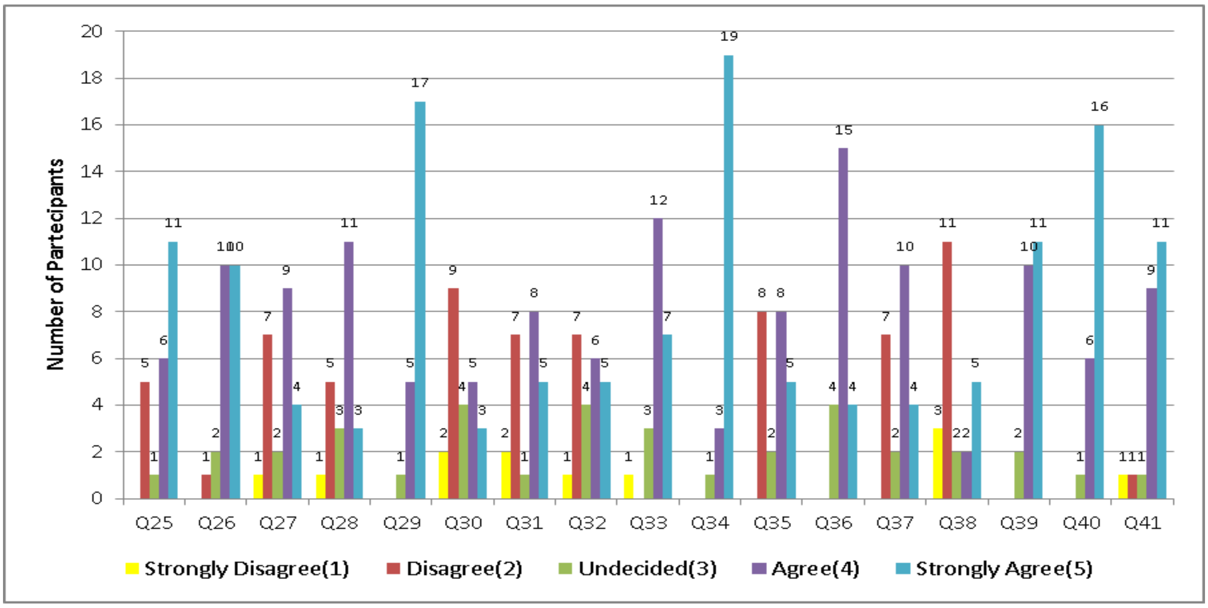

Figure 3 – The respondents perspectives about the components of passengers service processes

It can be seen that the larger number of respondents strongly agreed with question 34, which refers to " To what extent do you agree that the use of modern equipment and IT in the check-in stage contributes to improve quality of services for travelers?". Questions 29 which refers to "To what extent do you agree that the use of modern security inspection devices and their diversity contribute to improving the quality of airport security procedures?" and question 40 which refers to "To what extent do you agree that backstage services and support systems have an impact on improving the quality of services within the airport?" followed with 17 and 16, respectively. The figure also shows that 15 respondents agreed with question 36 which refers to "To what extent do you agree that registration officer has an important role in the registration process?". In contrast, about 50% of the respondents answered that they disagree with question 37, which refers to "To what extent do you agree that passport control procedures contribute significantly to the creation of queues and the delay of flights?". nine respondents answered that they disagreed with the question 30, which refers to "To what extent do you agree that strict security inspection procedures contribute to increased passenger satisfaction?".

Overall, it can be seen that most of the respondents answered either "strongly agree" or "agree" to most of the questions, and this indicates that they support the suggestions of the researcher on the factors that positively affect passengers service processes.

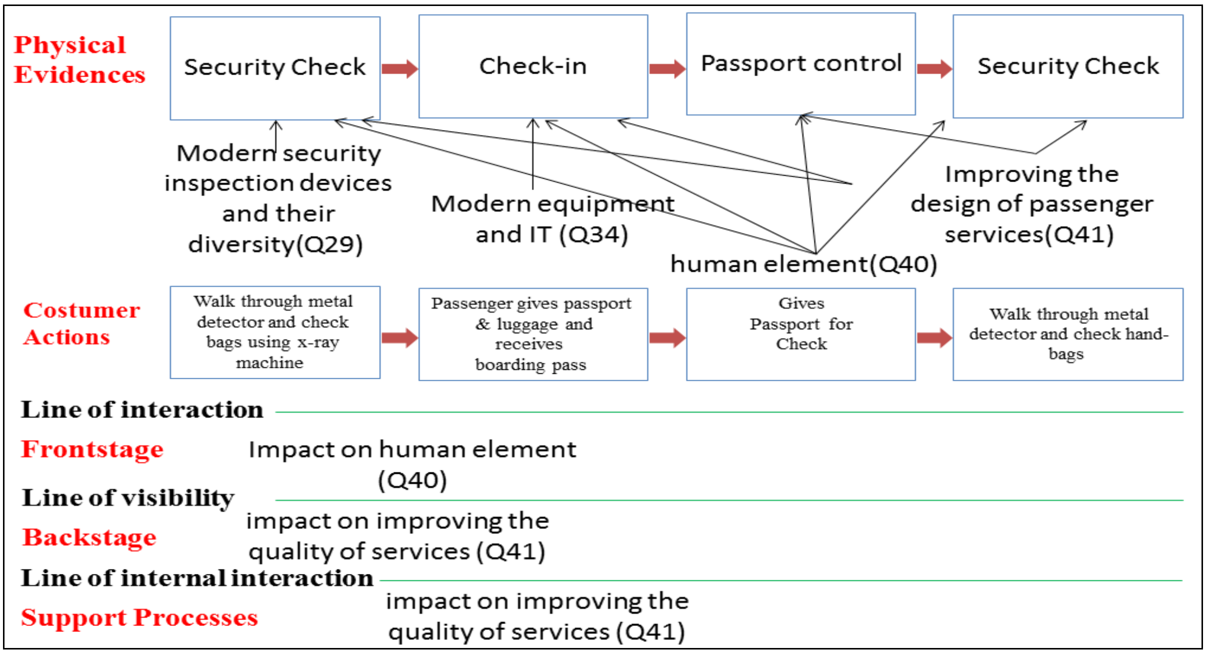

Figure 4 – Service Blueprint for passengers processes

Figure 4 shows the actual steps of service which are provided to passengers through Libyan airports, using the Service Blueprint tool. It can be seen that a number of suggestions have been added to support the passenger service process. These suggestions were based on the responses of the respondents during the implementation of the survey.

In general, we note that the most important proposal focused on the researcher as well as the respondents (directors working in the authority of the Libyan airport) are the need to keep up with the use of modern equipment both in the security inspection stage and the registration stage, in addition to the use of modern devices, there is a need to develop the human element in all stages of service and redesigning services to achieve the highest level of performance.

CARGO SERVICE

Air freight has recently increased significantly across international airports. Many airports around the world have developed within their plans to provide air cargo services and try to compete in this field. This service requires the provision of appropriate infrastructure such as airstrips and large aircraft stations as well as additional investments. This study focused on identifying the most important factors affecting the success of providing air freight service at

Libyan airports by asking a number of related questions in the survey. Figure 5 illustrates the answers of respondents for cargo service processes factors.

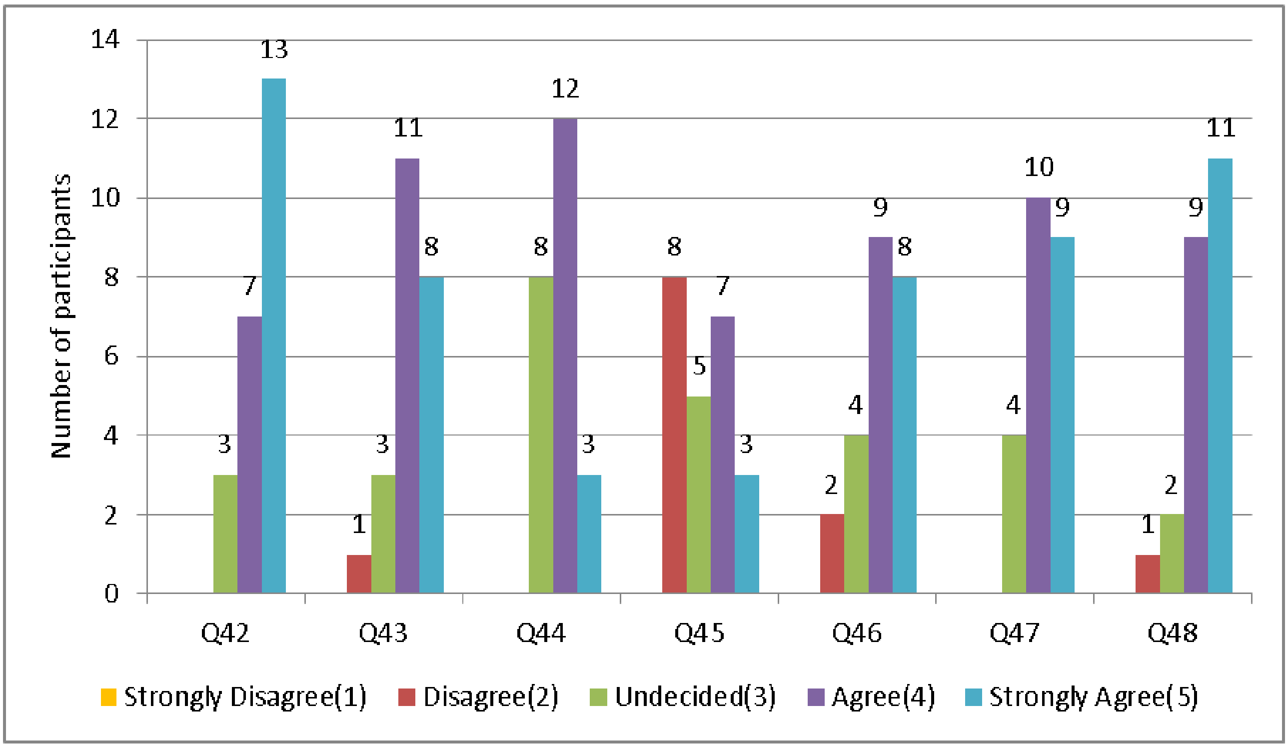

Figure 5 – The answers of respondents for Cargo service processes factors

It can be seen that a larger number of respondents 13 strongly agreed with question 42, which refers to "To what extent do you agree that airport capabilities such as airstrip and aircraft stations have a significant impact on freight operations?". Questions 48, which reads "To what extent do you agree that laws and regulations have a direct impact on the encouragement or reluctance of many companies to work at the airport in the field of air cargo?" followed with 11 respondents. The figure also shows that 12 and 11 respondents have agreed with questions 44, which refers to "To what extent do you agree that the tax rate has a significant role to increase or decrease the volume of freight during the airport?" and question 43, which indicates to "To what extent do you agree that the most important shipping operations are security inspection and customs?" respectively. In contrast, question 45, which refers to "To what extent do you agree that the management of the airport bears the greatest responsibility for the success of cargo operations than shipping companies?" recorded the lowest support from the respondents.

Overall, it can be seen that about 50% of the respondents preferred to answer most of the questions with "agree" except question 42, which refers to "To what extent do you agree that airport capabilities such as airstrip and aircraft stations have a significant impact on freight operations?". The figure also shows that no respondents answered "strongly disagree" with the questions asked.

STRATEGIC QUALITY MANAGEMENT FACTORS

Figure 6 illustrates the respondents answers to questions related to factors of SQM.

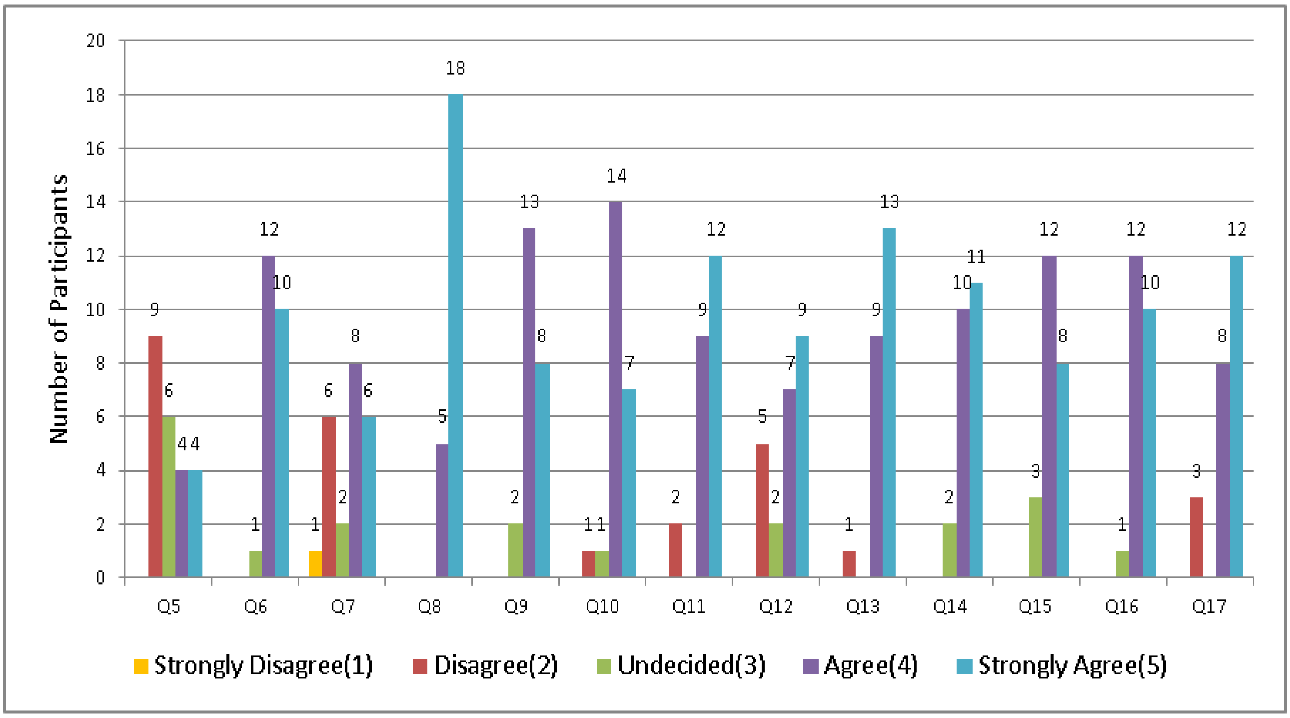

Figure 6 – The survey questions for factors of SQM

It can be seen that question 8 recorded the highest score with 18 respondents who answered "strongly agree". This question refers to the quality improvement is the responsibility of everybody working at all levels in the airport space (see Appendix).

In contrast, the majority of respondents answered either strongly disagree or disagree with question 5, which refers to "the majority of the senior managers at the airport understand well the importance of integrating quality management and strategic planning and its role in achieving high standards of quality and performance in service organizations".

Overall, it can be seen that most of the respondents answered either "strongly agree" or "agree" to most of the questions except question 5. This indicates that they support the view of the researcher on the factors that positively effect strategic quality management in the Libyan airport environment.

THE FRAMEWORK DEVELOPMENT

The main aim of this study was to develop a new framework for strategic quality management applicable to the Libyan airport environment. This part of the survey was concerned with a number of questions related to two dimensions. The first is the stages of strategic planning and the second is the concepts of quality management. These questions are intended to determine the respondents' opinions about which of the principles of quality management must be involved in one or some or all stages of strategic planning. Table 1 shows the perspective of respondents on how quality management concepts can be integrated into strategic planning stages in an airport environment.

Table 1 – The perspectives of respondents about integrating quality management and strategic planning stages for airport environment.

Strategic planning stages / Quality management concepts	Developing Vision		Environment analysis		Establish Objectives		Choose strategies		Implement Strategies		Evaluate strategies	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Leadership (LDR)	17	74	6	26	11	48	8	35	10	43	9	39
Strategic Quality Planning(SQP)	9	39	9	39	6	26	10	43	5	22	3	13
Design Quality, Speed and Prevention (DQSP)	6	26	7	30	6	26	6	26	6	26	6	26
People Participation and Partnership (PP&P)	8	35	9	39	8	35	9	39	11	48	5	22
Fact-Based Management(FBM)	6	26	8	35	6	26	12	52	5	22	7	30
Continuous Improvement (CI)	8	35	7	30	10	43	9	39	10	43	10	43
Customer Focus (CF)	16	70	5	22	6	26	6	26	8	35	6	26

* No. = No. of respondents.

Figure 7 illustrates the answers of respondents on how quality management concepts can be integrated into strategic planning stages in airport environment.

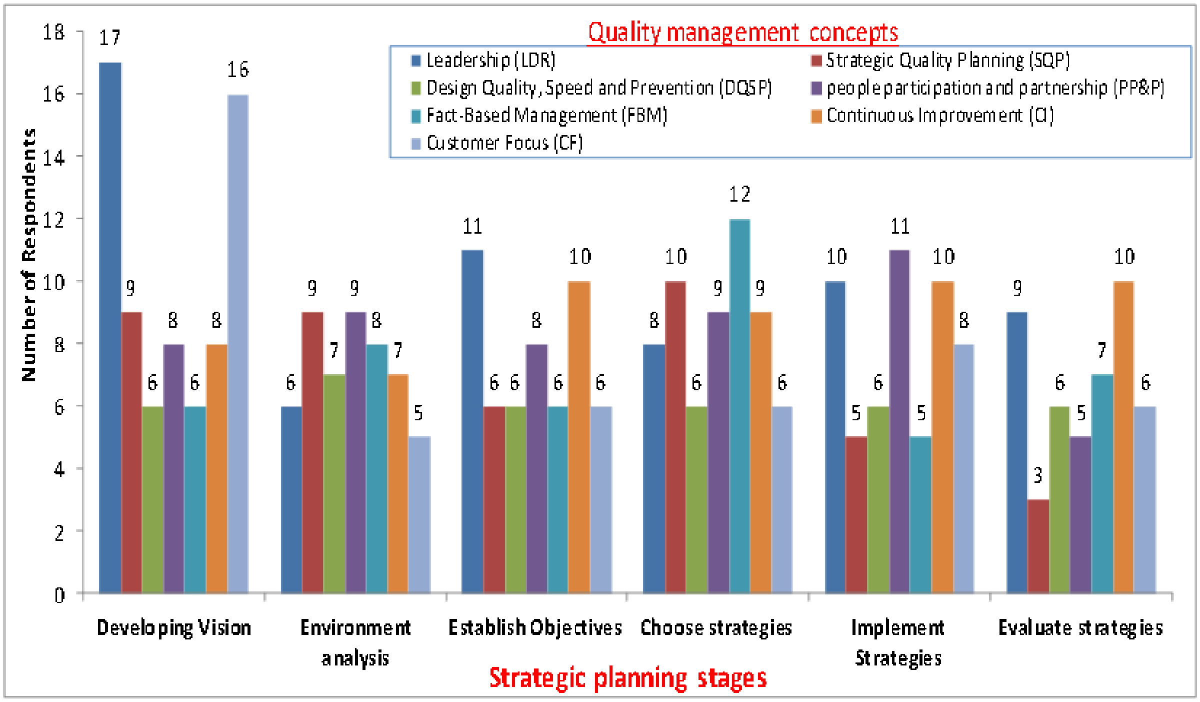

Figure 7 – The perspectives of respondents about integrating quality management and strategic planning stages for airport environment

It can be seen that the highest recommendation was most noticeable in developing vision, where 17 respondents answered that leadership(LDR) has an important role in the stage of developing vision. In addition, 16 respondents responded that Customer Focus(CF) should be taken in account during the developing vision stage. In the stage of environment analysis, strategic planning and employee participation ranked highest among the respondents' responses; 9 for each one. Regarding the establishing objectives stage, Leadership and Continuous Improvement recorded the highest number of respondents with 11 and 10, respectively. In the stage of choosing strategies, Fact-Based Management and Strategic Planning reported a large number of respondents with 12 and 10 respectively. It can be seen also that 11 respondents answered that People Participation and Partnership should be included in the stage of implementing strategies. Leadership and Continuous Improvement should also be included at the stage of implementing strategies with 10 respondents for each. Finally, in the stage of evaluating strategies, the highest number of respondents was for Continuous Improvement with 10 responses. It was also recommended that Leadership should be included at this stage. The views of the respondents obtained in this section of the survey as presented in Figure 7 were used to complete the construction of the framework for SQM, as shown in Figure 8. This form includes two basic dimensions: the stages of strategic planning and the concepts of quality management.

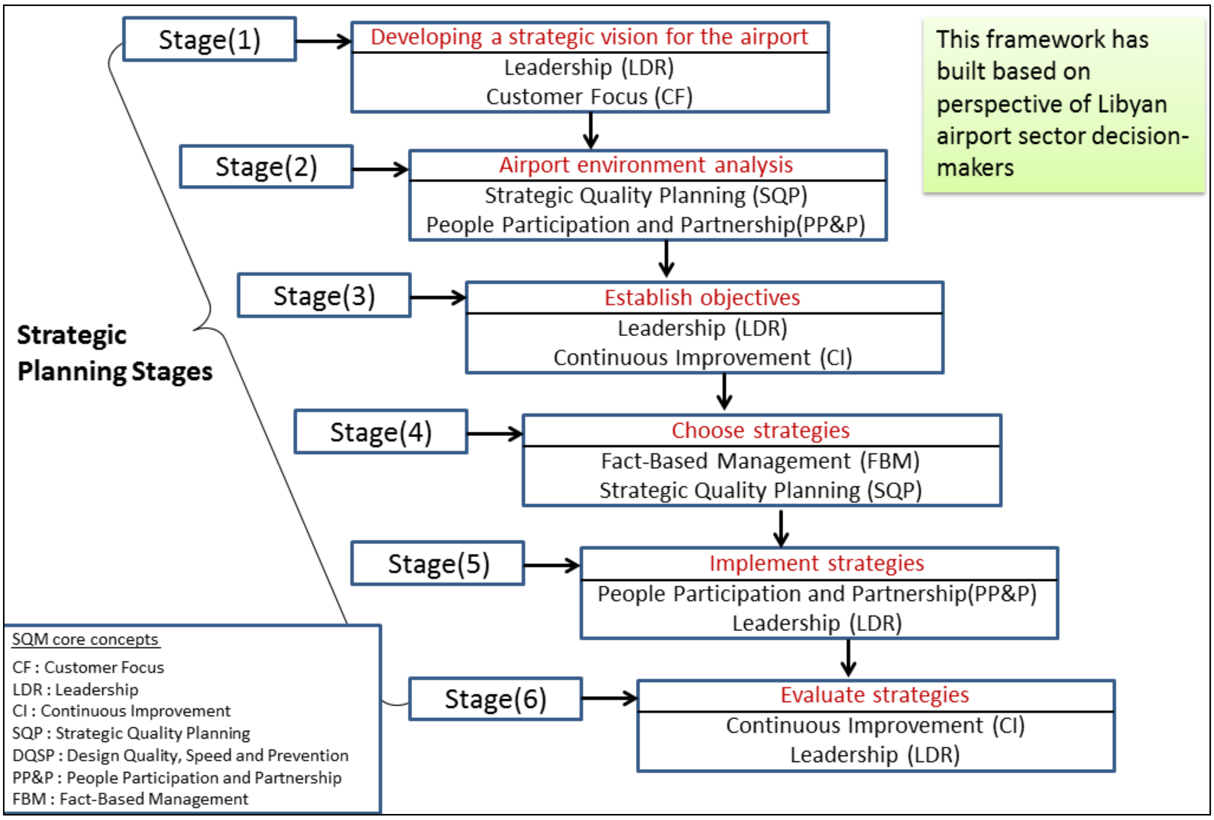

Figure 8 – The SQM framework

Figure 8 shows the proposed framework, which consists of the interaction of two basic dimensions: the stages of strategic planning and the concepts of quality management. In addition, which of the concepts of quality management should be involved in one, some or all stages of strategic planning.

It is clear that Leadership (LD) has a vital role in most of the strategic quality management phases of this model. The figure also shows that the focus on the customer came at the first stage, which refers to the development of the vision of the institution, on the other hand, Continuous Improvement (CI) was included at the last stage, which is the stage of evaluating the strategies.

CONCLUSION

This paper focuses upon the factors effecting the integration between strategic planning and quality management concepts in the airport environment in Libya.

This paper examines to what extent these factors are affected by passenger and air cargo operations and vice versa. The results of the study showed that the respondents (managers working at Libyan airports) strongly recommend using modern equipment, especially in the stages of security inspection and registration, in addition to the use of information technology in various stages of passenger service. The study showed that Libyan airports have little experience in air cargo services as well as effect of the human elements on the all the processes of the airport.

The main objective of this study was to develop a new framework for strategic quality management to be applied to Libyan airports. Although there have been attempts to develop a model for strategic quality management. These attempts differ from the goal of this study. The previous models did not attempt to include quality management concepts within the framework of specific stages of strategic management. In addition, previous studies did not refer to any research related to the airport environment. The development of the framework in this research was based mainly on the basic operations exam, such as passengers and air cargo, as well as identifying the most important factors affecting the integration of the phases of strategic planning and quality management concepts, through the survey of the views of those concerned, especially decision makers at Libyan airports.

The results of the study also show that most of the stages of strategic quality management according to this model contained the concept of leadership, which shows their importance in most of these stages because of their vital role in achieving better performance, increasing competitiveness and continuous improvement.

Finally, the aim of developing this framework is to answer the research question, which is " How can the application of practices of SQM be developed to assist airport managers in further developing Libyan airports?". In order to enable airports to establish strategic goals that would contribute to continuous improvement and to restructure inefficient processes, increase customer satisfaction and deliver high performance.

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APPENDIX

The survey

Factors influencing the integration of quality management

and strategic planning in the airport sector

Dear participant (managers)

This survey aims to identify the most important factors influencing the integration of strategic planning and quality management in the airport sector, and its role in the development of a new framework which will seek to continuously improve and contribute to the long-term competitiveness of the airport. I appreciate your cooperation in completing this survey, and it will only take a few minutes to do so. All information provided will be handled with confidentiality and will be used for the purpose of scientific research only.

The researcher

Q1) Please indicate your age:

- Under 20 ☐
- 20 to less than 30 ☐
- 30 to less than 40 ☐
- 40 and above ☐

Q2) Please indicate your current position :

- Chairman of Board ☐
- Director of Department ☐
- Office Manager ☐
- Head of section ☐

Q3) Please indicate your highest level of education:

- Secondary school or below ☐
- University ☐
- Post-university (Graduate studies) level ☐

Q4) Please indicate your experience in the airport sector :

- Less than 5 years ☐
- 5 to 10 years ☐
- More than 10 years ☐

A) Factors influencing the integration of quality management and strategic planning

Based on your opinion as staff member at airport, please indicate your assessment (by ticking the correct answer). According to a 5-point Likert scale (1 = Strongly disagree to 5 = Strongly agree)

No.	Questions	1	2	3	4	5
Q5	To what extent do you agree that most of the senior managers at the airport understand well the importance of integrating quality management and strategic planning and its role in achieving high standards of quality and performance in service organizations					
Q6	To what extent do you agree that to achieve the correct application of strategic planning that quality concepts should be integrated with the strategic planning of the airport					
Q7	To what extent do you agree that the development of a vision precedes the analysis of the internal and external environments of the airport					
Q8	Quality improvement is the responsibility of everybody working at					

No.	Questions	1	2	3	4	5
	all levels in the airport					
Q9	To what extent do you agree that quality should be integrated into the airport's business strategy					
Q10	To what extent do you agree that If the airport is to stay competitive, the only way to do so is to formulate strategies to meet the environmental changes and challenges					
Q11	To what extent do you agree that engaging employees should be embedded in the stage of establishing goals and selecting strategies					
Q12	To what extent do you agree that the first priority objective of the airport should be focused on customer satisfaction rather than profitability					
Q13	To what extent do you agree that service design with built-in quality considerations effectively prevent the occurrence of defects					
Q14	To what extent do you agree that continuous improvement (CI) should be embedded in all stages of strategic quality management implementation.					
Q15	To what extent do you agree that feedback is very important for improvement and should preferably be implemented within the proposed strategic quality management framework					
Q16	To what extent do you agree that one of the most important factors influencing the integration of quality and strategic planning is the improvement of operational processes by analyzing failures and delays.					
Q17	To what extent do you agree that improving passenger service operations is the most important part of all airport services					

B) Building a new framework of strategic quality management for airport sector

The table below consists two dimensions, strategic planning stages and quality core concepts, in your opinion which quality core concepts should be involved in one, some or all strategic planning stages. Please tick appropriate boxes.(note: it is possible to tick more than one box in the same row).

SQM matrix			Strategic planning stages					
			Stage I Developing Vision	Stage II Environmen analysis	Stage III Establish Objective	Stage IV Choose strategies	Stage V Implemen Strategies	Stage VI Evaluate strategies
Quality core concepts	Q18	Leadership (LDR)	☐	☐	☐	☐	☐	☐
	Q19	Strategic quality planning (SQP)	☐	☐	☐	☐	☐	☐
	Q20	design quality, speed and prevention (DQSP)	☐	☐	☐	☐	☐	☐
	Q21	people participation and partnership (PP&P)	☐	☐	☐	☐	☐	☐
	Q22	fact-based management (FBM)	☐	☐	☐	☐	☐	☐
	Q23	continuous improvement (CI)	☐	☐	☐	☐	☐	☐
	Q24	customer focus (CF)	☐	☐	☐	☐	☐	☐

C) Passenger Service Processes (Service Blueprint)

Based on your opinion as staff member at airport, please indicate your assessment (by ticking the correct answer). According to a 5-point Likert scale (1 = Strongly disagree to 5 = Strongly agree)

No.	Items	1	2	3	4	5
Q25	To what extent do you agree that the basic procedures for dealing with passengers at the airport are: security check, check-in and passport control?					
Q26	To what extent do you agree that there are procedures for travelers in all airports around the world that should be universal?					
Q27	To what extent do you agree that the multiplicity of security checkpoints at the airport enhances the security situation of passengers, airports and aircraft?					
Q28	To what extent do you agree that the various procedures of service from one airport to the other may contribute to causing problems .					
Q29	To what extent do you agree that the use of modern security inspection devices and their diversity contribute to improving the quality of airport security procedures?					
Q30	To what extent do you agree that strict security inspection procedures contribute to increase passenger satisfaction?					
Q31	To what extent do you agree that the security inspection procedures contribute to the creation of queues and the delay of flights?					
Q32	To what extent do you agree that there should be a security inspection for the arrivals?					
Q33	To what extent do you agree that the sequence of check-in procedures for passengers depend primarily on airlines?					
Q34	To what extent do you agree that the use of modern equipment and IT in the check-in stage contributes to improving the quality of services					

No.	Items	1	2	3	4	5
	for travelers?					
Q35	To what extent do you agree that check-in procedures contribute significantly to the creation of queues and the delay of flights?					
Q36	To what extent do you agree that registration officer has an important role in the registration process?					
Q37	To what extent do you agree that passport control procedures contribute significantly to the creation of queues and the delay of flights?					
Q38	To what extent do you agree that passport control procedures are more important when arriving than when departing?					
Q39	To what extent do you agree that the human element is the most important component of the passenger service process?					
Q40	To what extent do you agree that backstage services and support systems have an impact on improving the quality of services within the airport?					
Q41	To what extent do you agree that improving the design of passenger services, for example: security inspection, registration process and passport control should be taken into account while airport strategic planning and focusing on high quality standards?					

D) Cargo Services

Based on your opinion as staff member at airport, please indicate your assessment (by ticking the correct answer). According to a 5-point Likert scale (1 = Strongly disagree to 5 = Strongly agree)

No.	Items	1	2	3	4	5
Q42	To what extent do you agree that airport capabilities such as airstrip and aircraft stations have a significant impact on freight operations?					

No.	Items	1	2	3	4	5
Q43	To what extent do you agree that the most important shipping operations are security inspection and customs?					
Q44	To what extent do you agree that the tax rate has a significant role to increase or decrease the volume of freight during the airport?					
Q45	To what extent do you agree that the management of the airport bears the greatest responsibility for the success of cargo operations than shipping companies?					
Q46	To what extent do you agree that owning an appropriate number of hangers contributes to encouraging many shipping companies to work at the airport?					
Q47	To what extent do you agree that good strategic planning should ensure future plans for the development of the airport shipping sector?					
Q48	To what extent do you agree that laws and regulations have a direct impact on the encouragement or reluctance of many companies to work at the airport in the field of air cargo					

If you have any comments you would like to make regarding the outlook for passenger procedures, please provide them in the space below .

……………………………………………………………………………………………………
……………………………………………………………

Thank you for your co-operation.

Public Works in Brazil: Contracting, Execution and Inspection

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ABSTRACT

Purpose – To analyze the main practices currently adopted in Brazil regarding public works, so that the nonconformities involved in the process are identified and suggested solutions are proposed.

Design/methodology/approach – This study was developed through a bibliographical survey conducted in official documents of the Brazilian government, books and academic papers on the subject.

Findings – Presentation of the most relevant factors involved in the contracting, execution and inspection of public works in Brazil, with special emphasis on the positive and negative aspects involved in each step, as well as their consequences for the conformity of these works. Presentation of a comparative analysis involving the practices adopted in public and private sector works. Proposition of actions that aim to improve the result of the public works in Brazil in terms of quality, time, cost and performance after delivery.

Social implications - It is hoped that through the study of the analysis performed and the proposed actions, the financial resources invested in public works carried out in Brazil will serve the population in a very effective way, either in the improvement of the country's infrastructure or in the construction of popular housing with acceptable standards of quality.

Originality/value - Although legislation related to the contracting, execution and inspection of public works is old, there are few studies that establish an approach focused on the identification and treatment of nonconformities.

Paper type: Technical paper

Keywords: Public works, Contracting, Execution, Inspection

INTRODUCTION

Concept: Public work in Brazil is considered all construction, renovation, manufacture, recovery or expansion of public good, whose contractor is an organ of the public power (TCU, 2013). The works may have direct execution, when the work is done by the public administration itself, or indirect execution, when the work is contracted with third parties. In the case of indirect execution, because it is an action of interest to the population, from where the financial resources to be employed come from, hirings can only be made through the bidding process (Queiroz, 2001).

Main Features: The execution of public works must comply with the principles of legality, efficiency and economics enrolled in the Federal Constitution of Brazil. A public administrator must submit to the laws and procedures that guarantee the quality of the work, and that the best offer was obtained from the market (TCEES, 2010). Can be cited as typical characteristics of public works in Brazil: high costs when compared to private sector works, frequent contracting of works poorly planned technically and financially, beginning without forecasting of all the necessary resources, excess change in relation to the initial agreement, exaggerated increase of anticipated quantities, high number of unfinished and abandoned works (Coelho, 2009).

Importance to the Market and the Country: Public works are fundamental to society, through the dynamization of the economy and the provision of infrastructure for the development of the country, besides having an important social value. The population may or may not directly benefit from public works, but invariably benefits from its result, explicity (schools, hospitals, roads) or implicity (works for the purpose of improving public security, construction of historical monuments) (Gomes, 2007).

Quality, Cost and Deadline: The quality of public works as a whole is essential for the adequate investment of public resources aimed at meeting the social, political and strategic demands (Gomes, 2007). As for the cost, the Brazilian government needs the support of laws, decrees and jurisprudence to be able to release the commitment of the budget and realize the investment. For this commitment to be released and be at the disposal for use, there needs to be a budget, and that this budget is based on the Basic Project (Vasconcelos, 2011). As regards the deadline, public works contracts in Brazil must be faithfully followed between the parties, and this includes their schedule. Its correct compliance provides efficiency of the processes and economy of both parties. Although it is very common to have delays in the execution and delivery of these enterprises, the correct thing is that they do not exist, and the legal forecast for this type of exceptional situation is very restricted (Farias, 2016).

RESEARCH METODOLOGHY

This study was developed through a bibliographical survey conducted in official documents of the Brazilian government, books and academic papers on the subject.

Contracting of Public Works

Initial Considerations: The contracting of public works in Brazil, for indirect execution, is a process that involves three steps: Preliminary Bidding Phase, Internal Bidding Phase and External Bidding Phase.

Bidding: Procedure to which the Public Administration is obliged to submit to public knowledge all acts of contracting works, services, purchases, disposals, concessions, permissions and leases of the Public Administration. Only special cases, whose hypotheses are provided for in the law itself, constitute an exception to the rule (Law nº 8.666/1993). The objectives of the bidding are: to guarantee isonomy, to select the most advantageous proposal for Public Administration, and to promote sustainable national development, following the basic principles of legality, impersonality, morality, equality, publicity, administrative probity, binding to the instrument call and objective judgment (Lobato, 2015). To start bidding for a work, it is imperative to correctly define the object to be tendered. By characterizing the work through a complete project, while complying with legal requirements, it ensures the efficient and economical execution of the expected product (Farias, 2016).

Preliminary Bidding Phase: The stages included in the Preliminary Bidding Phase are of fundamental importance for the bidding decision making, since they have the objective of identify needs, estimate resources and choose the best alternative for meeting the aspirations of society (TCU, 2013). Compose the Preliminary Bidding Phase: elaboration of the program of needs of the Municipality, choice of terrain, viability study and preparation of draft (TCEPR, 2015). The utility of the preliminary phase is linked to the cost factor. Initial studies, although less precise, have significantly lower costs than later ones. Insofar as stages evolve, the greater the capital contribution. In this way, to avoid wasting resources in later phases, it is essential that the economic suitability of each investment be assessed in advance by means of preliminary studies (Altounian, 2016). Moving to the other phases of a bidding without positive sign of the feasibility of the project, obtained in the preliminary stage, may result in the waste of public resources due to the impossibility of carrying out the work, due to difficulties in its conclusion or effective future use (TCU, 2013).

Internal Bidding Phase: Once the enterprise has been defined, it is necessary to begin the preparation for contracting, which should usually occur through bidding. The preparatory stages for the publication of the bidding notice constitute the Internal Bidding Phase. It is at this stage that the object to be contracted is specified, through the elaboration of the Basic Project, and the requirements for the receipt of proposals from those interested in contracting with the Public Administration are defined, considering rules that allow maximum competitiveness among participants, with the purpose of obtaining the most advantageous proposal for the government. Compose the Internal Bidding Phase: the Basic Project, the environmental licensing and the preparation of the bidding notice or invitation (TCU, 2013). The main product to be materialized in the internal bidding phase is the bidding notice. Law nº 8.666/1993 establishes that the bidding notice must be properly structured and contain a set of mandatory information, in order to provide bidders with the perfect understanding of the entire bidding process. The principle of binding on the convening instrument establishes the impossibility of submitting proposals in disagreement with the parameters set, as well as the change of the main rules established during the process. The bidding notice must define rules that will avoid the restriction of the number of competitors, and also that will remove companies without technical or financial conditions to execute the enterprise. This balance will enable the most favorable hiring for the Public Administration. It is the responsibility of the Administration’s representatives to define the requirements that will be included in the bidding notice or invitation, which should not contradict the norms and principles established by Law nº 8.666/1993. Issues related to the Basic Project, reference prices, price acceptance criteria, qualification requirements, among others, must be perfectly studied and justified in the documents related to the bidding. The Internal Bidding Phase is of extreme relevance, because it is from this phase that the perfect specification of what will be contracted is born, with technical and cost parameters, and the definition of requirements for those wishing to submit a proposal. For this reason, all care should be taken in order to avoid future problems (Altounian, 2016).

External Bidding Phase: The External Bidding Phase begins with the publication of the bidding notice and ends with the signing of the contract for the execution of the work. The Bidding Committee aims to promote the bidding process in all its phases, preparing, publishing and publicizing the bidding document, providing clarification to bidders, receiving and analyzing the proposals. This committee may be permanent or special, but must consist of at least three members, with at least two qualified servants belonging to the permanent staff of the Public Administration (TCU, 2013). The Bidding Committee shall verify, through objective criteria, the compliance of the proposals with the requirements established in the bidding notice or invitation. This usually involves two stages: the qualification of the proposals and the analysis of price proposals (Altounian, 2016). The qualification of the proposals consists in the evaluation of the observance of the requirements of the bidding notice by the bidders, proposals that do not meet the bidding conditions must be declassified. In the analysis of price proposals, the total price and unit prices offered by the bidders must be evaluated. Proposals with an overall value higher than the established limit, with a total price that is manifestly unenforceable, or with unit prices of services higher than those defined in the criterion of acceptability of maximum unit prices stated in the bidding notice, should be declassified (TCU, 2013). Finally, the classification of the proposals is carried out for subsequent deliberation by the competent authorities regarding the approval of the bidding process and award of the object of bidding (Altounian, 2016).

Bidding Modalities: Law nº 8.666/1993 defines the possible modalities of bidding: Competition, Price-Making, Invitation, Tender, Auction and Trading Session. Competition: bidding modality among any interested parties who, at the initial stage of preliminary qualification, prove to possess the minimum qualification requirements for the execution of its object. Price-Making: bidding modality among interested parties duly registered. Invitation: bidding modality between interested parties, registered or not, chosen and invited in a minimum of three by the administrative unit. Tender: bidding modality among any interested parties for the choice of technical, scientific or artistic work, through the institution of prizes or remuneration to the winners. Auction: bidding modality between any interested parties for the sale of useless property to the Administration, of products legally seized or pawned, to whom offer the highest bid, equal to or greater than the value of the valuation. Trading Session: bidding modality for the acquisition of common goods and services by the Public Administration, whatever the estimated value for hiring, in which the supply dispute is made through proposals and bids in public session, having its main innovation in authorizing the inversion of the bidding phases. The proposals are analyzed first, and the approval of the winner is verified later. The choice of the bidding modality should include the economic aspect (value of the project) and the technical aspect (complexity of the object and the need to impose technical qualification requirements).

Types of Bidding: The Bidding Law establishes the types of possible bids to be made for contracting public works: “Lower Price”(should be used as a rule, it will have as winner the bidder who submitted the proposal according to the specifications of the bidding notice or invitation, and offer the lowest price); “Best Technique”(it will be used only for services of a predominantly intellectual nature, such as preparation of preliminary technical studies, Basic Project and Executive Project); and “Technique and Price”(it selects the proposals under the criteria of technique and price, being the bidding notice responsible for assigning weight to both criteria).

Execution Modalities: According to Law nº 8.666/1993, there are four execution modalities for public works in Brazil: Contracting by Global Price, Contracting by Unit Price, Task and Integral Contract. Contracting by Global Price: contracting of works for a certain price, adopted when the Administration can perfectly define the characteristics of the work in a quantitative and qualitative way, remunerating pre-defined stages of a project, being indicated for works in which there is a project with reduced uncertainly. Contracting by Unit Price: It is that in which the work is paid per unit, where the Administration establishes standard unit of measure, since the project does not allow to define with precision the necessary quantitative. Task: Execution modality in which labor is contracted for small jobs at a certain price, with or without supply of materials. Integral Contract: Execution modality in which the entire enterprise is contracted, comprising all stages of the works, services and facilities required, under the entire responsibility of the hired until delivery to the contractor in conditions of entry into operation.

Inspection of Public Works: Inspection is the activity that must be carried out in a systematic way by the contractor and his agents for the purpose of verifying compliance with the contractual, technical and administrative provisions in all their aspects.

Inspection by the Public Administration: The contractor will maintain, from the beginning of the services until the final receipt, professional or inspection team consisting of qualified professionals, who must have technical experience necessary to monitor and control the services related to the type of work being performed (TCU, 2013). The role of inspection in a public work is basically to verify that the contractual requirements are being met, as well as to certify the services for measurement and payment purposes. This activity involves qualitative and quantitative monitoring of services, in a systematic and constant way, with reference to the project and its components, such as the budget, schedule and technical specifications. The inspection activity is carried out by the contract manager and the public works supervisor (Farias, 2016).

Inspection by the Contracted Company: The contracted company must maintain a representative at the site of the work or service to respond for the enterprise to the Administration, and ensure that the technical officer indicated at the time of the bid follows the evolution of the enterprise effectively. The company representative must be present continuously in the enterprise to meet any request of the Administration (Altounian, 2016). The company must facilitate, by all means within its reach, the inspection action, allowing broad access to the services in execution and promptly responding to the requests addressed to it (TCU, 2013).

Obligations of the Contracted Company: The total or partial non-performance of the contract leads to its termination, with the contractual consequences and those provided by law or regulation. The contracted company is liable for damages caused directly to the Administration or to third parties, resulting from his guilt or deceit in the performance of the contract, not excluding or reducing the responsibility of the inspection by the public administration (Bidding Law).

Cost Control: One of the main activities of the inspection is related to the measurements of the services performed and to attest to the quality of these services (Altounian, 2016). The measurement of services and works will be based on periodic reports prepared by the contracted company, where the surveys, calculations and graphs required for discrimination and determination of the quantities of services are recorded. Only services and works actually performed by the contracted company and approved by the public administration inspection may be considered for measurement and payment purposes, respecting the strict correspondence with the project and modifications expressly and previously approved by the Administration (TCU, 2013). The measurement record, which contains the calculation memory and identification of who was responsible for the services performed, must be prepared and archived in order to preserve traceability (Coelho, 2009).

Deadline Control: The maintenance of the deadlines agreed for the delivery of the work is one of the great challenges to all those involved in its execution: managers, supervisors and contractors (Queiroz, 2001). Any extension of time must be justified in writing and previously authorized by the competent authority. If this legal command is neglected, the inspectors can be held responsible for the delay of the work, even if they have complied with verbal determinations of hierarchical superiors (Farias, 2016). Extensions not foreseen in the execution period of the work may lead to an increase in administrative expenses, which will be passed on to the final value of the contract, while reductions of estimated periods usually generate decreases in these expenses (Altounian, 2016).

Quality Control: The quality control of services performed is of vital importance to the Administration, and must be done in all phases of the project: initial services, foundations, reinforced concrete structure, masonry and roofing.

Comparative Analysis of Practices Adopted in Public and Private Works in Brazil

Management: Public management needs to adapt in practically everything to the current government policies and projects. This means that its budget, allocation of funds and theme of action must be perfectly aligned with that the government intends. In addition, there will also be political pressure, which strongly influences the decisions of works to be carried out. Private management is more professional, and always aims at the best possible result. It does not suffer interference from politicians, and does not take into account government projects and plans (Ribeiro, 2013).

Budget: The preparation of a budget for a public work in Brazil requires the use of official tables, cost compositions from official sources, and market research with at least three quotations of each service or input. With these actions, the government seeks to ensure that the costs included in the budget are the most fair for the company contracted, as well as for the Public Administration. The values made available in the bidding process are considered the highest that can be paid by the public company for the budgeted service, that is, the company that will compete in the bidding will not be able to offer a higher amount that the one published in the bidding notice, except in special cases (Vasconcelos, 2011). In case of private works, the methodology of budgeting changes. The sources of price surveys and cost compositions are not strict or governed by law. The prices of almost all services and inputs are collected in the local consumer market, giving greater veracity to the budget elaborated. For these reasons, the budget for private works is generally more faithful to the reality of the market than the budget prepared for public works. In summary, it can be said that the reliability of the budget depends on who prepares, supervises and contracts it (Vasconcelos, 2011).

Contracting: The public works have a special rite for their contracting, and there must be: needs assessment, inclusion in the multiannual plan and legislative approval through budget law. Only then must bidding, contracting, execution, inspection and delivery take place. The public entity, when ordering a work, is actually enforcing the budget law. Therefore, their expenses are linked to administrative acts (Gomes, 2007). Private works are contracted freely, according to the interests conveniences and needs of the contractor and contracted company. The contracting of private works is marked by the ample freedom and informality of negotiation, selection and contracting. A private work may be contracted and executed as the private entity wants, provided that within its own financial limitations, and in accordance with general positions imposed on the community (Queiroz, 2001).

Quality Management: There is some resistance to the dissemination of quality management in the public sector. Both the federal government and the vast majority of Brazilian states and municipalities do not yet require the adhesion of private companies to quality control programs for the execution of public works, which can allow a negative differentiation between the standard practiced in works destined to the public entities of the one destined to the private sector. It can be said that the costs of investments in the area of quality on private works are financed by the end customer, through the final price paid (Gomes, 2007).

Workmanship: In general, the workmanship problems presented in the public works segment are the same as those presented in private works: high turnover, low level of education, lower wages than other industries, among others. The pressure of the lowest price imposed by the bidding often means that the wages paid to workers in public works correspond to the floor of the syndicate, which encourages the turnover, as they will be attentive to opportunities in private ventures aimed at high-income clients. Often, public works sites installations are worse than private ones, as well as not complying with minimum safety standards defined by law, resulting in problems of storage of materials and damage to occupational health, among others. All these factors favor a lower productivity of workmanship in public works, in relation to private works (Gomes, 2007).

RESULTS

Contracting of Public Works

Positive Aspects: The current process of contracting public works is composed of several procedures which aim at constitutional principles, in order to provide the Administration with the acquisition, sale or provision of services in an advantageous manner, that is, less costly and with the best possible quality.

Negative Aspects: Unnecessary requirements of restrictive nature in the bidding notice; incompatible bidding modality; inadequate type of bidding; exemption from bidding without justification or with incompatible justification; non-compliance of the winning bid with the requirements of the bidding notice (TCU, 2013).

Inspection of Public Works

Positive aspects: The management and inspection of public works, when done strictly within the established in law, are essential for obtaining the expected result: the faithful execution of the work regarding the deadline, cost and quality determined in contract (Gallardo, 2014).

Negative Aspects: Payment of services not carried out fully and effectively; payment of services executed, but not approved by the inspection; payment of supervisory contract services, although the work is paralyzed; lack of verification by the supervision of the services performed; divergences between attested measurements and values actually paid; measurements and payments executed with criteria different from those stipulated in the bidding notice or contract; inconsistencies in inspection reports; overbilling.

Proposed Actions for Improvements

a) In current legislation, public works can be tendered only with the Basic Project, or even just with the Draft, without sufficient definitions, resulting in delay and cost increase. For a change in this scenario, there should be a change in legislation that would require the creation of a complete project for all public works, including the Executive Project. The development of a complete quality project represents 5% to 10% of the total cost of the work, and values the quality of public equipments. The higher the quality of the work, the lower the cost of maintenance and conservation, the greater the government control over what happens in the work, and smaller the possibility for the companies in charge of construction to request additives of cost and deadline.

b) One way to improve the contracting, execution and inspection of public works is the creation and strengthening of specialized careers in the areas of government management, engineering and infrastructure. The Public Administration urgently needs trained professionals to manage public affairs.

c) Thinking in terms of governance, adopting practices that lead to the real attention of the various segments interested in public action.

d) Always consider the citizen as the final customer in the process of construction of public works.

CONCLUSIONS

This study sought to show and exemplify the practices currently adopted in Brazil regarding the contracting, execution and inspection of public works, and its consequences for the conformity of these works with regard to quality, cost, deadline and performance in post delivery. The main finding regarding public works in Brazil is negligence and disregard for the applicable legislation in the bidding of works and services, as well as the technical norms and knowledge of engineering, both by the Public administration and the private sector. The result of this finding is: failure in public works, waste of public money, works of poor quality and unfinished, and devaluation of the engineering professional.

Most problems in the execution of public works in Brazil are related to governance and management. These are principles and tools that increase the probability of success in the execution of a public work. The construction of efficient systems that address these two issues is the challenge of all public bodies and entities to definitively solve the problem of recurrent irregularities, delays and unfinished or unserviceable works. A public work that does not meet the real needs of the population does not serve its public purpose, and should be reformulated.

Public works must be planned and executed not as an end in themselves, but as a means to achieve a public purpose, within the principles of isonomy, transparency and economicity, as the legislation preaches. As an example, we can mention the construction of schools, bridges and hospitals. Such works should be considered, respectively, as: part of the offer of educational services, part of a transport/mobility system, and as a means of reducing mortality. Therefore, unfinished works must be associated to: a lower number of literate children, higher transportation costs or higher population mortality. In the view of all the information presented, it can be concluded that good management and governance in the process of contracting, executing and supervising public works are of fundamental importance.

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Digital Transformation of Quality Management

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ABSTRACT

Purpose –Digital transformation planned, underway or even a reality for many businesses. Quality management, as an organizational activity or function, should be also transformed and quality managers should be aware of the new possibilities.

Design/methodology/approach – The paper is completely exploratory and focused on presenting the scenario and make a list of suggestions to be discussed.

Findings – A set of seven general proposals in the form of advices to quality managers looking at the digital transformation.

Practical implications - This paper is structured around a series of propositions for quality managers to take advantage of the new technological possibilities that could heavily impact their areas in the new coming years.

Originality/value – The intention is to provoke debate and call to reflection and action to quality managers on how to transform their activities.

Paper type: Viewpoint

Keywords: Digital transformation, quality management

INTRODUCTION

The huge impact of digital technologies in most areas of human activity is broadly recognized, even obvious, especially along the last decades. The use of such technologies has caused, and it is still fueling, a tremendous evolution on a process that has come to be called digitalization.

Even when there is not a consensus definition of digitalization, it can be stated as the process of adopt the use of digital means to manage information. In other words, digitalization is the process of transition from using analogical means to rely on the use of digital means.

To continue simplifying, one could say that digitalization is propelled by the big amount of advantages of digital means, whose list could be long, but at the end, one can synthesize in allowing things to be done faster, better and cheaper. The digitalization process has made a log way so far, and still continues having a long way to go.

But something profoundly conservative is embedded into this conception of digitalization, and this is the fact that what it involves is just a change in the means, and not so much in its core or in the essence of what is being done.

Digital transformation

In contrast with the former, it has been coined the concept of "digital transformation" (Matt et al., 2015; World Economic Forum, 2015) referring to the use of digital technology, not just to make things more effective or efficient, but to transform and implement new ways of doing, by taking advantage of the brand new possibilities and adapting them to the new emerging digital world.

In brief, just to cite some of them, some of these new technological possibilities could be: mobility, big data, Internet of things (IoT), new artificial intelligence (IA) techniques like deep learning, or just the pervasiveness of internet. This list could be very much longer and it could be also always growing, so take these just as examples.

But the key here is not to focus on specific technologies but to state how the digital transformation is coming to change the way of doing for a digital world. It is not just about improving the ways things were done in the old analogic world. Just to underline it, obviously, the keyword here is transformation.

One could say that digital transformation is to digitalization what disruptive innovation is to incremental innovation. There is a thin line between them and, frequently, it is difficult to say when it is crossed but, conceptually, the terms do not refer to the same. Both have sense and obvious benefits but the former involves a paradigm shift.

There are many business companies nowadays that are taking more or less risky steps in the digital transformation direction. Like other innovations, failing in doing so could lead those who ignore this transformation to run out of business. Of course, it depends on the sector and on the competitors but, it is clear that, digital transformation strategies are being put on set, not only by innovative companies in the technological sector, but, by all those companies of all sectors which are conscient of how the world is changing, how the customers are changing too and also of the huge amount of new possibilities appearing.

It is relevant to say, from now, that the key of digital transformation does not lean mainly on the new revolutionary technologies adopted, but on the capacity of thinking out of the box and the ability of taking advantage from those new technologies in very innovative ways, otherwise we would just be talking about a new wave of digitalization.

QUALITY MANAGEMENT FROM DIGITALIZATION TO TRANSFORMATION

Like most other human activities, and even more on those related to the creation of value through the products and services, quality management has gone a long way into the digitalization process. The quality management has broadly benefited from the use of digital tools and it is still having a lot of opportunities for improvement by following this path.

It is not too long time ago that quality management practices involved high amounts of hand or typewriter written paper records that were handed from one desk to another and finally handily summarized into more paper reports. The days when stickers were used for quality assurance tracking and chalk blackboards or cardboard panels were used to support kanban dashboards with daily work orders.

Just to establish a time reference, one could remember how the considered as the first non-military purpose computer ever, the UNIVAC, was bought by the USA government in 1951 to tabulate part of the 1950 census and the 1954 economic census (Eckert, Jr. et al., 1951), still not 70 years ago from now. Absolutely all before was done by manual or mechanical means.

From then, the digitalization process has included, as could not be otherwise, the quality management related activities. Quality records have become digital records into digital files and databases and the same has happened to work orders, logged data or even documents which are created and maintained digitally, sometimes even no being never printed in paper. This is just to cite some examples among millions.

It is not an objective of this paper to describe, and even less, to determine, which are the quality management practices and neither the extent of their digitalization. On the other hand, there is no reason to think that quality management could have a more or less degree of digitalization than other activities in the same organizations. This is, the degree of digitalization could seem to vary more depending on the specific organization or on the sector of the organization than on the different activities inside the organization, being the quality management to what we are referring here.

QUALITY MANAGEMENT DIGITAL TRANSFORMATION

As quality management is an activity or set of activities inserted into organizations, one can divide the way to digital transformation into two mainly different scenarios: the transformation of quality management in those organizations where main digital transformations is under their way or practically done and the transformation of quality management of those organizations that do not have a general digital transformation plan or view.

It will be easier, of course, for those quality managers in digital transformed companies to address the job of design their own digital transformation path. With a company leading or even pulling, the energy to transform the whole organization should be there, and of course, the pressure to do so too.

On the other hand, the lack of leadership or intention to address this subject at a company level should be not an excuse to realize that quality management will be, more sooner than later, dragged by this wave and that probably it is better to take advantage of it before it is too late.

That is where this paper is trying to make a contribution, by helping quality managers to realize or being more conscious that, as says the famous Bob Dylan’s song: “the times they are changing” and any quality manager who cares should be aware of, and eventually embrace, the transformation that has already started and is underway.

As has been said, digital transformation is not about taking isolated initiatives, but to transform with a new viewpoint. Anyway, quality managers must be aware of the new opportunities and consider them. This is why the following section of this paper takes the form of several advices. This is, of course, a license taken and those advices are not intended to be followed to the letter or as exact and compulsory statements or, even less, as a show of arrogance from the author. Next section advices are just calls of attention among several specific topics in order to be considered by quality managers and, eventually, be incorporated into their agendas. Even more, anyone could reasonably disagree with any or all of the points proposed, but it could be worth if they serve as a starting point of reflection or discussion.

Register and analyze all

Sampling is the common way to avoid the hard, expensive, or even impossible, work of measuring and register everything. After sampling, one frequently makes decisions based on the samples, taking the necessary precautions due to the lack of complete data. But today, in a lot of cases, measuring is becoming easier and cheaper as increasingly cheaper is storing and processing those measures.

Phenomena like Internet of Things and ubiquitous sensing has opened the door to a full of new data sources from sensors placed everywhere (Kortuem et al., 2010). On the other hand, big data has come to analyze all this ‘huge, complex and growing data sets from multiple autonomous sources’ (Xindong Wu et al., 2014) and to extract unexpected and valuable information (John Walker, 2014; Provost and Fawcett, 2013).

Moreover, today new kinds of data have become sources of valuable information. The use of non-structured data that can be interpreted by IA is a new resource that should exploited. Right now, a simple and inexpensive camera leaning on the IA capabilities can monitor a lot of things and extract tons of useful information for quality management.

Image recognition technology has been used into industrial quality assurance embedded in production chains for a long time, for example detecting defective parts to be removed before entering production, but new applications are emerging by taking advantage of IA.

Have you realized that facial recognition is already an everyday technology, able to recognize people on your personal photos in Internet or even unblock your mobile phone? Or that digital home assistants can heard and answer you in a proper manner? If they can recognize your photos or listen to your voice, what in ‘your process’ could be not recognized?

Let’s suppose, for example, that you are working on customer satisfaction on retail stores. Should you continue asking one in every ten customers about their satisfaction, just to be fooled or just used as a scape valve to show their fury. Nowadays, it is possible to just read the faces of every single of your clients and deduct their real feelings. And even react to their lack of satisfaction in the very moment?

Adopt blockchain to register evidences

Records and traces have been stored as proves of processes performance for long, but proving that the traces are not fake usually rely on the own the robustness of the process of logging itself. That way, frequently, when audited, managers need to prove how data is got, stored and processed. A few have implemented digital signatures as a mean of establish trustfulness, but it still relies on the prestige and security of the signature chain.

The blockchain technology, popularized by their use to support cryptocurrencies like bitcoin, allows to have secure, decentralized and fully trustful “record-book” (Marc Pilkington, 2016; Tapscott and Tapscott, n.d.). As what happens with other tools, quality managers probably don’t need to know much about the insides of every specific technology, but just take advantage of them.

By using blockchain to register one can solve the question of trustily register evidences, which is useful specially if you are subject of audits. It is also very tolerant to disasters, given its distributed nature. This, among other characteristics, makes blockchain a technology that will be in the background for the future coming, like today is digital signature, wireless or GPS technology, which were very innovative at their time but now are just the invisible building blocks supporting our digital world.

Use IA to monitor and control processes

Monitor and decide if a process is under control is something that has been being done sometimes by pure intuition, other by using statistical methods, more or less under human supervision, and lately by capturing huge amounts of data and the use of complex computerized techniques, like, for example event correlation or big data.

The advancement of IA has been focused on solving this particular problem for decades, allowing very complex processes to be controlled by tools like neural networks with success. With the arrival of deep learning and the easy to deploy by using prepacked IA service the time for popularization of it. There is a broad kind of situations where IA learning machine can do this job.

Activities like, for example, prioritization or raising exceptions in common processes are tasks that a IA system with a little training can do much better than humans, in general terms, of course. Moreover, today anyone can take advantage of this, not by writing complex code, but by training generic IA services, using graphical interfaces, available from third party providers in well and conveniently packaged services.

Use IA to route your procedures

Procedure design, since now, has been about stablishing activities and define paths between them. For not so simple procedures, some conditions embedded in the procedure are used to make the decision when it comes to choose the path or route to take between several possibilities.

Even when this routing decisions can contain parameters, this hard-coded routing design has to be made at design time, resulting in procedures that lack of flexibility and unable to respond to not predesigned situations.

But IA can make the job in a more adaptable way. A central IA dispatcher can decide when and what task should come next in your flow, probably, in a more clever, flexible and informed manner. The more complex is the procedure and the more exceptions are possible, the more value can add a central and clever dispatcher.

In fact, there is a fewer need to stablish all possible paths in complex procedures when an IA dispatcher is in charge. Just define the “happy path” supposing everything is going to be right and raise exceptions when it is not. Then IA could help to solve those infrequent situations.

Don’t write process workflows, write requirements

Quality managers have been in charge of defining, or control the definition of, how things where supposed to happen by conscientiously reviewing processes, procedures and so on. Those have served as exact guidelines on what was supposed to happen and what was the next step. This detailed specification works very well in much cases but it is difficult to scale to complex and uncertain scenarios.

But as the times advances, the complexity and also the need of agility in making business is reducing timeframes and pushing aside a lot of good but conservative practices. In fact, agility and quality seems to have an unsolved tension. Many times, design decisions are pushed to production faster than before and quality considerations and controls frequently makes late.

This way, one approach to address this apparent contradiction could be to move from defining everything to stablish lists of requirements, that at the same level and the same syntax as other business requirements, like those functionals, from marketing or legal, could be taken into account when products and services are designed and made.

Those requirements should not only be driven to assure the quality of new products and services but to integrate quality management control measures into everyday activities. This could help to put in place a “quality by design” way of doing, that could last during the, each time, more frequent product/service changes.

Apply human touch wisely and augment humans

One should not confuse digital transformation with the relegation of every human activity. It is clear that most successful services rely on the “human touch”. The question here is how to redesign processes and procedure in a way that both, human beings and digital devices, could contribute with their best.

Even more, today and more in the future, humans can multiply its capacities if they are helped by technology. This is not new, but it’s being revolutionized. In the past, machines have helped humans to multiply their own capacities, like force or visual acuity. Now the new possibilities are expanding the human capacities to unsuspected levels and also gaining brand new ones. Examples the technologies that help people to add new capabilities could be: automatic translation, augmented reality or brain control machines. This way, processes should be reviewed to take advantage of this powered human capacities.

Take advantage of benchmarking

Benchmarking has been a recommended quality management practice for a long time now (Zairi, 1998), but today, digital technologies facilitate the sharing of online anonymous information. This creates new opportunities to more easily stablish benchmarking to compare your activities against other doing similar, just near you, in other sites, other countries or even on your competitors.

In fact, platform and third-party providers are seeing their mediating position and the information they own as valuable resources that can be sold among their clients.

Wherever it is, inside the own company or not, benchmarking allows to know you how well are performing you or your processes. Outside the company walls one could rely on good-intention agreements with the companies, but it will be probably easier to lean on the use of third parties that serve you and your competitors. They have data from both, if not a good piece of your sector, and they can share them, aggregated and anonymously. An open attitude about this will probably make a benefit to those taking a step forward in this direction.

CONCLUSIONS

With a world changing so fast, those on quality management are pushed to do so at the same speed. This is why quality managers should be aware that the digital transformation is on most business agenda, f not underway, and that they probably should incorporate to their own.

This transformation should take the form of a new view over quality management by taking advantage and exploit the new technological opportunities.

Several proposals, in the form of advices, have been presented in this paper. They are briefly exposed with the aim of contribute to an eventual open debate on the directions and how the quality management is going to evolve in the few next coming years.

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The Market Concentration on Education and the Effects on Quality

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ABSTRACT

Purpose – The management models adopted by educational institutions undergo changes, much due to the mergers and acquisitions of large conglomerates. Thus, the article aims to analyze the effects of mergers and acquisitions in the Brazilian private higher education sector from 2008 to 2014, considering the courses that presented the highest number of enrollments, as well as academic performance and quality measures.

Design/methodology/approach – The methodology is divided into two stages; first the propensity score matching (PSM) was calculated to obtain the common support and later the estimation by the differences-in-differences method.

Findings – The results indicate a greater proportion of professors with Ph.D. in Business Administration and Pedagogy and a greater proportion of professors with a Master's degree in the Business Administration course. The indices evaluated here pointed to a non-significant change in the quality of the students.

Research limitations/implications – The limitations are related to the possibility of including different courses, besides those that were evaluated as well as the period of collection.

Practical implications – The implications address the application of the data from institutions, in terms of management and quality assessments, both from collaborators and clients/students.

Social implications – The social implications highlight the quality of intellectual capital that is offered by the institutions to the Brazilian labor market.

Paper type: Research paper

Keywords: Higher Education, Mergers and Acquisitions, Service Quality.

INTRODUCTION

The concentration of private higher education has motivated researchers to analyze the internalization of application offerings, showing that the concentration of courses offered has decreased in response to the mergers and acquisitions operations. In the line of market concentration because of the process of mergers and acquisitions, Chaves (2010) points out that, since 2007, there is an increase of market power of higher education institutions (HEI) participating in these operations, thus major educational groups were born. For the author, the four largest educational groups: Kroton Educacional, Anhanguera Educacional, Estácio Participações, and Ser Educacional represent 25% of the total number of enrollments in private higher education and 20% in higher education in Brazil. Carvalho Júnior (2006) highlights the advantages that large private education groups had because of public policies aimed at increasing the total number of students, that is, the process of oligopolization the market has suffered.

The literature about the academic performance in the Brazilian higher education focuses on the system of evaluations, such as Enade and CPC, the way they are applied and their results, usually involving some course and specific year, but without relating them to acquisitions that occurred in the market. The study that most closely matches the present work is of Garcia (2014), in which the author investigates if being part of an educational network through mergers and acquisitions from 2007 to 2012 leads to changes in the quality of the undergraduate courses offered by the HEI acquired. However, in the proposed period, none course had more than two evaluations and the results do not show the effect per course, but only in general.

Once there is this gap, the present study aims to analyze the effects of mergers and acquisitions in the Brazilian private higher education sector from 2008 to 2014, considering the following courses: Business Administration, Law, and Pedagogy, given the highest number of enrollments (INEP, 2015).

The analysis of effects addresses the academic performance and quality measures to identify and analyze if the acquisitions change the quality of the courses offered by an HEI acquired, thus contributing to the market concentration studies empirically, where there are major discussions on the economic effects of mergers and less about the effects in terms of quality.

The period chosen is justified due to the large number of mergers and acquisitions among private for-profit institutions, according to Hoper (2014), the portal of BM&F Bovespa (2014), and the reports of the Administrative Council for Economic Defense (CADE). This period also has a greater availability of data about the performance of the courses, which were released by the Instituto Nacional de Pesquisas Educacionais Anísio Teixeira (INEP) in full since 2008.

LITERATURE REVIEW

Performance and Quality in Higher Education

For Mazzarotto (2007), the quality of higher education goes through five determining factors: generation of high-quality research, production of high-quality education, generation of applied research, interaction between researchers, and selection of the best students to perpetuate the system.

In Brazil, however, the generation of research is mandatory only for Universities, according to INEP (2015), as it is not mandatory for University Centers and Faculties. Academic research and the need to adapt to the system of evaluation imposed on HEI are relevant factors for the quality of higher education, in addition to other important factors, such as the Institutional Development Plan (in Portuguese, PDI), where are defined the objectives, HEI's goal targets, academic management policies, policies on research, teaching, extension and academic organization (Mazzarotto, 2007).

Evaluating and classifying the quality of higher education is not a precise activity needs, for Freitas et al. (2009). The authors argue that the HEI should go through a multi-criteria evaluation so that a larger number of intangible variables are considered in the evaluation.

A comparative study of the evaluations of higher education in the United States, United Kingdom, Australia and Canada was carried out by Dill and Soo (2005). The research showed that there is no consensus among the countries on which are the best indicators to evaluate the HEI. According to the authors, there is no convergence in the rankings of universities and faculties, since some of them emphasize the quality of the professors, others emphasize the quality of the students, while others emphasize the infrastructure.

However, according to Green (2014), there are categories of understanding about quality. For the author, the traditional concept of quality is linked to the status of belonging to a great and renowned HEI, while evaluating institutions better than others given their performance history. The category related to quality and customer satisfaction addresses the student, the Government, and the employers would evaluate the outcomes of education. Thus, Curth (2012) stresses the importance of the perceived quality by the student, enabling results and consequent loyalty.

Therefore, national and international studies on assessment in higher education suggest a multi-criteria evaluation system, that is, quantitative and qualitative criteria, where the parties involved should be considered to evaluate HEI or the education system.

Mergers and Acquisitions and impacts on quality

In Brazil, the literature on the effects of the market concentration of market in the education sector is minimal. Some authors had analyzed the structure of the Brazilian higher education market, but without quantifying the concentration or relating it to the academic performance, according to Marques (2013). The author highlights the process of market concentration through which the for-profit higher education went, due to the merger operations and acquisitions disclosed. Sarfati and Shwartzbaum (2012) examines why the firms in the education sector have increased the number of students through acquisitions rather than organic growth. The hypotheses referred to by the author are the sector-specific synergy gains, resulting in higher returns to shareholders; however, it does not refer to the issue of education quality. Chaves (2010) draws attention to the process of concentration of HEI starting from 2007, citing industry mergers and the interest of private equity funds in exploring the market of higher education in Brazil.

With the premise that it is up to the Federal Government incentives the higher education, Leher (2004) demonstrates that the idea of tax waiver by the government in exchange for unfilled places (slots) in private HEI ends up by encouraging the formation of large educational groups. In 2009, according to a study of the National Association of Directors of Higher Education Federal Institutions (ANDIFES), with R$ 1 billion it would be possible to create 400,000 new places (slots) in the Federal Institutes of Higher Education.

Carvalho Júnior (2006) questions the expansion of the number of places (slots) for students in higher education. According to the author, the for-profit institutions do not invest in infrastructure and teaching qualifications, thus aiming to capitalize their shareholders. In the same vein, Chaves (2010) claims that the academic performance of Law graduates in large educational groups is below the national average, since less than 10% of the graduates are able to pass the Bar exam.

Finally, one study that stands out when measuring quality in the Brazilian higher education and relating it to the movement of mergers and acquisitions was the study by Garcia (2014), in which being part of an educational network of higher education would be a form of concentration in this market. The author estimated results based on the differences-in-differences methods and differences-in-differences matching by finding a positive correlation between the Institutions of Higher Education that were acquired and CPC, the percentage of professors with Ph.D., and the percentage of teachers working full-time or part-time.

In short, there are many empirical studies analyzing the impacts of mergers and acquisitions in various sectors on the prices and quantities, but there is a greater difficulty in the literature regarding the impact on the quality of product or service.

Brazilian Higher Education Market: characteristics, evolution, and concentration

According to Oliveira (2009), mergers and acquisitions, the public listing on the stock exchange (IPO), and the entry of investment funds in the private higher education sector (Private Equity) contributed to the large-scale privatization of higher education institutions. The penetration of 4 multinational companies in the sector reinforced the expectation of great profits for the economic agents, contrary to the educational principles as a public good.

Private equity funds operate through share participation in firms, by focusing on sectors with high profitability and growth, according to Brealey et al. (2008), providing support with organized management structures and focus on profitability and sustainability, and bringing greater efficiencies and gains in the markets where they operate. The main funds operating in the Brazilian private higher education market are Pátria Investimentos (participating in Anhanguera Educacional), GP Investments Fund (participating in Estácio), and Advent International (participating in the Kroton Educacional group), according to Hoper (2014). In addition to the entrance of investment funds in the sector, the largest educational networks went through the process of opening the capital of the São Paulo stock exchange, according to Hoper (2014).

The IPO's processes were launched to the market when investments in the capital market were attractive given the positive expectations generated in the Brazilian economy in the years 2005 to 2012 and were successful in terms of capitalization. According to Sécca and Leal

(2009), the private higher education market was even more attractive to investment funds due to the increase in the number of graduates from high school, as there was a restrained demand for students who could not afford the high tuitions of private institutions (which were reduced until then) and had no access to public institutions.

For Schwartzman and Schwartzman (2002), another line of educational researchers in Brazil condemns the expansion of private for-profit HEI, as the maximization of wealth as the main objective of managers would not be compatible with the quest for quality education. According to the authors, with the increased participation of private HEI, the State would play only a supporting role in educational policies, that is, it would leave the executive role in the hands of the coordinator, thus going against the Law of Guidelines and Bases of Education (Brasil, 1996).

RESEARCH METHODOLOGY

Data Basis

For the objectives of the study, the data of the Censo da Educação Superior (in Portuguese, Census of Higher Education) and quality indicators of higher education had been used, as measured by the Ministry of Education by means of INEP (2015). Considering the databases available, the effects of mergers and acquisitions on academic performance were analyzed comparatively between 2008 and 2014, during which 106 mergers or acquisitions occurred in the Brazilian private higher education market.

In order to organize the databases, the grades of the Institutions of Higher Education on the General Index for Programs (in Portuguese, Índice Geral de Cursos Avaliados da Instituição (IGC)), Higher Education Census Data, the grades obtained in the three courses from Enade 5, and socio-economic data of municipalities where the courses are offered. Regarding the courses, they are evaluated once per triennium. Considering the period 2008 to 2014, the Pedagogy course was evaluated in 2008, 2011 and 2014, and the Administration and Law courses were evaluated in 2009 and 2012.

The databases used in this study for quality indicators of the courses are those used by INEP to calculate the grades in CPC: percentage of professors with Ph.D., percentage of professors with a Master's degree, average number of students on the specific training test and the general training test (Enade) Furthermore, it was necessary to add the databases on IGC, Census, and Enade and, finally, to identify the HEI based on the courses offered and relate them to their IGC. Finally, it was used socio-economic and demographic information from the municipalities where the courses are offered, which are available by IBGE, as the total population of the municipality, population aged 15 to 24 years, and GDP per capita.

Propensity Score Matching - PSM

The matching estimator searches for the individuals in the nearest control group in terms of the observable variables and uses the result of these individuals to obtain the product of the individuals in the treatment group in case it was not treated and was a counterfactual, in this case. What differentiates the estimators by matching is the metric used to define the HEI that are nearest to the estimators treated in terms of observable characteristics in the control group.

Therefore, the estimator by matching requires comparable HEI between the two groups in relation to the observable characteristics, a condition called a common support, in which the hypothesis that the likelihood of a unit not receiving the treatment for a given characteristic vector is always greater than zero (Wooldridge, 2007).

$$P(= 0 \mid) > 0 \quad (1)$$

Where is an indicator equal to 1 for the HEI acquired and 0 for those that were not acquired and P (propensity score). The propensity score matching will also depend on a pre-determined metrics, which will define the proximity of the propensity score of the HEI treated in this study with the propensity score of the HEI not treated here.

Therefore, a pairing estimator of the nearest neighbor with the function nearest neighbor matching (NN), which uses the results of the HEI in the non-treated group that have propensity scores nearest to the HEI propensity score *i* to estimate which the result of the HEI would be *i* in case it does not receive treatment, according to Wooldridge (2007).

In this study, each treated HEI is paired with ten nearest non-treated HEI in terms of the propensity score. It is assigned zero weight to the HEI of the control group that were not paired to any treated HEI. The average treatment effect on treated (average treatment effect on treated - ATT), i.e., the parameter of interest, can be estimated by:

$$\hat{\tau}^{ATT}_{Matching} = \frac{1}{n_1} \sum_{i \in Se|d_i=1)} \left[y_i^1 - \sum_{i \in Se|d_i=0} \omega(i,j) y_j^0 \right] \quad (2)$$

Where ω(i, j) is a function that assigns different weights to the HEI of control groups to generate a counterfactual, as this would have happened to the unit handled if this had not received treatment, according to Wooldridge (2007) and Garcia (2014). The notation used refers to the first term as estimators' influence to be reconsidered, which would be obtained by using real values of the regression functions and the propensity score.

Differences in differences

The differences-in-differences method is used when the interest variable is observed by two groups in two distinct periods, but only one group is exposed to the treatment between the two periods, according to Fogel (2012) and Garcia (2014). Therefore, in the context of the present study, they were divided into four groups: the control group before the acquisition, the control group after the acquisition, the treatment group before the acquisition, and the treatment group after the acquisition.

The differences-in-differences method has some drawbacks, such as not being able to deal with temporal changes of an unobservable characteristic affecting the decision to participate in the treatment; the impact on the treatment can only be estimated after the acquisition of the HEI, thus not allowing the tool to be predictive; and if the treatment group and control group do not have a close tendency for the resulting variable, the method tends to estimate biased results.

RESULTS

Descriptive Statistics

Using the database in the previous section, one can trace a profile of the HEI acquired compared to those that were not acquired. Of the 1292 HEI offering the Business Administration, Law, or Pedagogy, 264 of them had no data available for the continuous IGC for the period under examination, and so they were excluded from the analysis. The HEI acquired and other HEI from 2008 to 2014 add up to 934 and 94, respectively.

It is noted that the acquired HEI present a greater number of students allowed per year, with an average of 821 compared to 510 students in other HEI. When it comes to the market share, the acquired HEI present, on average, a participation of 29% in relation to the total market compared to the non-acquired HEI that present a participation of 42% on average. Regarding the number of HEI in the municipality, considering the group of HEI acquired, in the municipalities where these institutions are present, there is on average 17.76 HEI.

The group with non-acquired HEI works in municipalities where there are, on average, fewer HEI, which is equivalent to 14.81, thus possibly confirming a smaller market share of the acquired HEI. With respect to the mean of cities where each HEI is, both the treatment and the control group presented similar results: 1.26 municipalities on average for the acquired HEI, and 1.22 municipalities on average for the non-acquired HEI. The population in the municipality, the percentile of the population aged between 15 and 24, and GDP per capita are also on average larger than the acquired HEI.

Propensity score matching: results

Once the Probit model for each course is estimated, were calculated the propensity scores needed for pairing the HEI acquired and the others per course analyzed, as shown in Table 1.

Related to the HEI offering the Business Administration, the variable Market share presented a positive and significant coefficient. Therefore, one can say that the greater the market share of the HEI in the municipality is, the greater the likelihood of the institution to be acquired is.

However, the non-linear term included in the model must be evaluated before analyzing the marginal effect of the variable Market share. The Market share^2 variable presented a negative and significant coefficient.

Therefore, a greater market share for the HEI in the city increases the likelihood of the institution to be acquired; however, this increase occurs in smaller rates. There is also a higher likelihood of acquisition if the municipality has an HEI as the coefficient was positive and significant. Because the HEI are located in a metropolitan region, their likelihood to be acquired is increased. The coefficient was positive and significant for the variable GDP per capita, that is, the higher the GDP per capita in the municipality is, the higher the likelihood of the HEI to be acquired is.

The fact that the HEI in the Business Administration course is private increases its probability of being acquired, therefore the referring coefficient for this variable was positive and significant. The variable faculty presented a negative and significant coefficient, that is, the fact of being accredited as a faculty decreases the likelihood of an HEI to be acquired.

Table 1 – Probit: Determinants of the probability of acquisition.

Course	**Administration**		**Law**		**Pedagogy**	
Variable	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Places/Slots	0.0000	0.0001	-0.0001	0.0001	-0.0001	0.0001
Market Share	1.5901*	0.9448	1.3935	1.2830	1.3935	1.2830
Market Share²	-1.8752**	0.8381	-1.5076	1.1177	-1.5076	1.1177
Municipalities	-0.0709	0.0620	-0.0294	0.0665	-0.0294	0.0665
HEI Courses	0.0353	0.0296	0.0230	0.0326	0.0230	0.0326
University center	-0.3245	0.2909	-0.2350	0.3070	-0.2350	0.3070
Faculty	-0.5225**	0.2665	-0.5743*	0.3015	-0.5743*	0.3015
Private HEI	0.9987***	0.2297	1.2649 ***	0.3020	1.2649 ***	0.3020
Public HEI	0.2862*	0.1644	0.1583	0.2274	0.1583	0.2274
HEI in the municipality	-0.0057	0.0041	0.0008	0.0055	0.0008	0.0055
Metropolitan Area	0.2539*	0.1477	0.3689*	0.1962	0.3689	0.1962
Population aged 15-24	-0.0070	0.0494	0.0018	0.0651	0.0018	0.0651
GDP Per capita	0.0107**	0.0045	0.0085	0.0061	0.0085***	0.0061
Constant	-2.1018**	0.9305	-2.4657**	1.2525	-2.4657*	1.2525
Observations	848		463		440	
Prob > chi2	0.0000		0.0001		0.0001	
Pseudo R2	0.1067		0.1235		0.1485	

Source: Elaborated by the author.
*** Significant at 1%; ** Significant at 5%; * Significant at 10%

Considering the HEI offering the Law course, the likelihood of being acquired is greater when they are private, since the coefficient for this variable was positive and significant. The fact that HEI are located in metropolitan regions also increases the likelihood for them to be acquired, since the coefficient for the metropolitan region variable was positive and significant, just as in the Business Administration course, the fact that the HEI are accredited as faculties also decreases the likelihood of acquisition in the Law course, while showing a negative and significant coefficient.

Finally, the HEI offering the Pedagogy course are more likely to be acquired when are private because the variable Private HEI presented positive and significant coefficient once again. The coefficient was positive and significant for the GDP per capita, that is, the HEI is more likely to be acquired if it is located in municipalities with higher GDP per capita. The likelihood of acquisition decreases when the HEI is accredited as a faculty, with a negative and significant coefficient, as for the HEI that offer Business Administration and Law courses.

With regard to the HEI group offering the Business Administration course, for the explanatory variables Places (Slots), Market Share, Market Share², HEI Courses, Private HEI, Public HEI, Metropolitan Region, and GDP per capita, the means of the groups before matching were statistically different and only stopped being different after matching, as shown in Table 2. With regard to the HEI group offering the Law course, for the variables Market Share, Market Share², HEI Courses, Private HEI, Public HEI, HEI in the municipality, Metropolitan Region, and GDP per capita, the means of the groups before matching were statistically different and also stopped being different after matching.

Finally, with regards to the HEI group offering the Pedagogy course, for the variables Market Share, Market Share², Private HEI, Public HEI, and GDP per capita, the means of the groups before matching were statistically different and stopped being different after matching.

Mean effect of Acquisition

For the HEI offering the Business Administration course, as shown in Table 3, considering the effects of the acquisition about the variable IGC 2014-2008 (difference of 2012 compared to 2008), the impact was negative and non-significant.

Regarding the variable IGC 2014-2008, the impact was also negative and not significant, which is similar to the variable Mean SK 2012-2009 (difference of Mean SK 2012 compared to Mean SK 2009) whose effect of the treatment was negative and non-significant. However, before matching the effect of the acquisition on this variable was negative and significant. In the variable Mean GT 2012-2009, the effect showed to be positive, but not significant. In the same line, CPC 2012-2009 presented a positive coefficient for the impact of the acquisitions, but not a significant one. The variable Master's degree 2012-2009, the effect was positive and significant. The average effect of the acquisition on the percentage of professors with Master’s degree in a course was an increase of 9.8% compared to the percentage of professors with Master’s degree of the course.

Considering the difference of the percentage of professors with Ph.D. in 2012 vs 2009, the effect of the acquisitions was also positive and statistically significant, being responsible for a 14.2% increase in the course. Both Master’s degree and Ph.D. degree also presented positive and significant coefficients before matching; however, for Master’s degree, the difference increased and, for Ph.D. degree, it decreased, as shown in Table 3.

For the HEI offering Law courses, the only statistically significant variables were IGC 2014-2008 and Master's degree 2012-2009, but both with negative estimated coefficients, as shown in Table 4.

Table 2 – Tests of differences of means of the explanatory variables between the control and treatment groups

Variable	Before or after *matching*	Administration Course			Law Course			Pedagogy Course		
		Treatment group	Control group		Treatment group	Control group		Treatment group	Control group	
		Mean/Grades	Mean/Grades	t Statistics	Mean/Grades	Mean/Grades	t Statistics	Mean/Grades	Mean/Grades	t Statistics
Places/Slots	Before	880	571	2.57**	1072	770	1,55	912	669	1,09
	After	880	831	0,22	1072	1029	0,18	912	871	0,18
Market Share	Before	0,312	0,446	-3.02***	0,304	0,450	-2.82***	0,320	0,467	-2.29**
	After	0,312	0,331	-0,40	0,304	0,302	0,03	0,320	0,351	-0,44
Market Share²	Before	0,191	0,355	-3.49***	0,180	0,339	-2.88***	0,193	0,378	-2.70***
	After	0,191	0,212	-0,42	0,180	0,176	0,08	0,193	0,232	-0,53
Municipalities	Before	1,271	1,254	0,11	1,436	1,431	0,02	1,561	1,394	0,63
	After	1,271	1,213	0,25	1,436	1,191	0,85	1,561	1,373	0,43
HEI Courses	Before	3,12	2,43	2.49**	3,71	2,95	1.71*	3,46	2,83	1,26
	After	3,12	2,75	0,85	3,71	3,25	0,69	3,46	3,54	-0,08
University center	Before	0,129	0,121	0,24	0,218	0,194	0,43	0,146	0,153	-0,11
	After	0,129	0,134	-0,09	0,218	0,231	-0,16	0,146	0,168	-0,27
Faculty	Before	0,741	0,788	-0,99	0,582	0,642	-0,87	0,610	0,687	-1.00
	After	0,741	0,747	-0,09	0,582	0,573	0.10	0,610	0,617	-0,07
Private HEI	Before	0,941	0,744	4.09***	0,945	0,694	3.98***	0,902	0,669	3.10***
	After	0,941	0,928	0.34	0,945	0,918	0,56	0,902	0,910	-0,11
Public HEI	Before	0,753	0,565	3.35***	0,800	0,647	2.26**	0,732	0,516	2.65***
	After	0,753	0,721	0,47	0,800	0,773	0,35	0,732	0,729	0,02
HEI in the municipality	Before	17,13	14,70	0,89	21,18	14,06	2.21**	17,32	15,15	0,51
	After	17,13	14,33	0,79	21,18	19,54	0,31	17,32	15,13	0,43
Metropolitan Area	Before	0,529	0,389	2.50**	0,618	0,400	3.10***	0,488	0,376	1.40
	After	0,529	0,522	0,09	0,618	0,615	0,04	0,488	0,485	0,02
Population aged 15-24	Before	17,65	17,60	0,26	17,62	17,69	-0,35	17,47	17,48	-0,04
	After	17,65	17,73	-0,36	17,62	17,68	-0.20	17,47	17,60	-0,36
GDP *per capita*	Before	23.021	20.022	1.97*	23.054	19.856	1.68*	26.398	19.781	3.05***
	After	23.021	25.361	-0,93	23.054	25.473	-0,78	26.398	26.087	0,09

Source: Created by the authors.
*** Significant at 1%; ** Significant at 5%; * Significant at 10%

For the variable IGC 2014-2008, the effect was - 0.196 points in the composition of the index. Regarding the variable Master's degree 2012-2009, the effect was a worsening of 7.76% of professors with Master's degree of the course. In the variable IGC 2012-2008, the estimated coefficient was negative and non-significant, the same relation can be made with Mean SK 2012- 2009, where the impact generated from the acquisition was negative, but not significant. As for the CPC 2012-2009, when related to the course, also presented a negative and non-significant effect. The percentage of professors with Ph.D. of the course also had a negative effect with the acquisitions, but not statistically significant, as shown in Table 4.

Table 3 – Mean Acquisition Effect on the interest variables in the Business Administration Course

Variable	**Sample**	**Treatment group**	**Control group**	**Difference**	**Standard Error**	**t *Statistics***
IGC 2012-2008	Before *matching*	0.301	0.275	0.026	0.062	0.42
	ATT	0.301	0.387	-0.085	0.087	-0.98
IGC 2014-2008	Before *matching*	0.274	0.311	-0.037	0.061	-0.61
	ATT	0.274	0.395	-0.121	0.080	-1.51
Mean GT 2012-2009	Before *matching*	-0.439	-0.392	-0.046	0.930	-0.05
	ATT	-0.439	-1.281	0.843	1.302	0.65
Mean SK 2012-2009	Before *matching*	-5.508	-4.464	-1.044	0.614	-1.7*
	ATT	-5.508	-4.298	-1.211	0.876	-1.38
CPC 2012-2009	Before *matching*	0.507	0.348	0.160	0.072	2.2**
	ATT	0.507	0.350	0.157	0.100	1.57
Master's degree 2012-2009	Before *matching*	72,454	64,034	8.420	2.507	3.36***
	ATT	72,454	62,655	9.799	3,333	2.94***
Ph.D. degree 2012-2009	Before *matching*	32,298	16,522	15,776	1.911	8.26***
	ATT	32,298	18,179	14,119	3.393	4.16***
Obs.		80	703			

Source: Created by the authors.
*** Significant at 1%; ** Significant at 5%; * Significant at 10%

For the HEI offering the Pedagogy course, it had a three-year term more than to be evaluated at Enade, thus generating one more sequence of course-related indicators for each year, as Mean GT, Mean SK, Master's and Ph.D. degrees, as shown in Table 5.

For the Pedagogy course, the variable IGC 2012-2008 presented estimated negative and non-significant coefficients, similar to the IGC 2014-2008. The variable Mean GT 2011-2008 was also negative and non-significant regarding the acquisition effect, and in the same line, the variable Mean GT 2014-2008 followed. The variable Master's degree 2011-2008 had an estimated positive coefficient, but not statistically significant, similar to the Master's degree

2014-2008. For the variable Ph.D. degree 2011-2008, the coefficient was positive, but non-significant in statistical terms. As for the CPC 2014-2008, the coefficient was also positive and not significant.

Table 4 – Mean Acquisition Effect on the interest variables in the Law Course

Variable	Sample	Treatment group	Control group	Difference	Standard Error	t *Statistics*
IGC 2012-2008	Before *matching*	0.273	0.313	-0.040	0.074	-0.54
	ATT	0.273	0.374	-0.101	0.097	-1.04
IGC 2014-2008	Before *matching*	0.271	0.352	-0.081	0.074	-1.10
	ATT	0.271	0.463	-0.191	0.098	-1.95**
Mean GT 2012-2009	Before *matching*	-0.323	-1.823	1.500	1.213	1.24
	ATT	-0.323	-2.022	1.700	1.673	1.02
Mean SK 2012-2009	Before *matching*	-12.922	-12.669	-0.252	0.696	-0.36
	ATT	-12.922	-12.239	-0.682	1.036	-0.66
CPC 2012-2009	Before *matching*	0.393	0.404	-0.010	0.088	-0.12
	ATT	0.393	0.407	-0.013	0.137	-0.10
Master's degree 2012-2009	Before *matching*	64.544	68.122	-3.579	3.072	-1.16
	ATT	64.544	72.304	-7.761	4.039	-1.92*
Ph.D. degree 2012-2009	Before *matching*	19.828	20.335	-0.507	2.096	-0.24
	ATT	19.828	21.650	-1.822	2.867	-0.64
Obs.		54	385			

Source: Elaborated by the author.
*** Significant at 1%; ** Significant at 5%; * Significant at 10%

In the case of variable Mean SK 2011-2008, the estimated coefficient was negative and significant, whose effect was a worsening of 3.643 points in the grades of the graduating students in the specific knowledge test of Enade in 2011 for Pedagogy course. Regarding Mean SK 2014-2008, the coefficient was also negative and significant, with the mean acquisition effect being negatively impacted in 3.112 points in the grades of the graduating students in the specific knowledge test of Enade in 2014. The only variable with estimated significant and positive coefficient was Ph.D. degree 2014-2008, with an effect of 0.11, that is, the acquisition is linked to an average increase of 11% of professors with Ph.D. teaching in a course, as shown in Table 5.

Table 5 – Mean Acquisition Effect on the interest variables in the Pedagogy Course

Variable	Sample	Treatment group	Control group	Difference	Standard Error	t *Statistics*
IGC 2012-2008	Before *matching*	0.330	0.266	0.063	0.082	0.78
	ATT	0.330	0.409	-0.079	0.102	-0.78
IGC 2014-2008	Before *matching*	0.341	0.324	0.017	0.086	0.20
	ATT	0.341	0.412	-0.071	0.104	-0.68
Mean GT 2011-2008	Before *matching*	1.619	1.484	0.135	1.064	0.13
	ATT	1.619	3.596	-1.977	1.396	-1.42
Mean SK 2011-2008	Before *matching*	-1.186	-0.336	-0.850	1.006	-0.85
	ATT	-1.186	2.456	-3.643	1.397	-2.61***
CPC 2011-2008	Before *matching*	0.415	0.263	0.152	0.102	1.49
	ATT	0.415	0.625	-0.210	0.144	-1.46
Master's degree 2011-2008	Before *matching*	0.162	0.061	0.101	0.033	3.10***
	ATT	0.162	0.118	0.043	0.050	0.87
Ph.D. degree 2011-2008	Before *matching*	0.234	0.066	0.168	0.028	6.11***
	ATT	0.234	0.158	0.075	0.051	1.48
Mean GT 2014-2008	Before *matching*	0.225	0.796	-0.571	1.017	-0.56
	ATT	0.225	2.311	-2.086	1.468	-1.42
Mean SK 2014-2008	Before *matching*	-4.221	-2.115	-2.106	1.131	-1.86*
	ATT	-4.221	-1.108	-3.112	1.531	-2.03**
CPC 2014-2008	Before *matching*	0.482	0.326	0.155	0.108	1.44
	ATT	0.482	0.475	0.006	0.138	0.04
Master's degree 2014-2008	Before *matching*	0.211	0.141	0.070	0.038	1.84*
	ATT	0.211	0.130	0.081	0.051	1.60
Ph.D. degree 2014-2008	Before matching	0.314	0.133	0.182	0.030	6.14**
	ATT	0.314	0.205	0.110	0.035	3.14***
Obs.		34	308			

Source: Elaborated by the author.
*** Significant at 1%; ** Significant at 5%; * Significant at 10%

CONCLUSIONS

The profile of the acquired HEI in 2008 presents some characteristics that are different from the not acquired HEI, as having the largest number of places (slots) approved by the Ministry of Education (MEC), smaller market share, higher concentration of HEI in the municipality in which it operates, the greater proportion of population aged between 15 and 24 years with respect to the total population in the municipality, largest GDP per capita in the municipality, and higher General Courses Index (IGC) .

These results converge for the search for financial income on the part of the purchasers, because the profile of acquired HEI allows the expansion and consolidation in their markets, as the largest number of authorized places (slots), young population, and higher GDP per capita. With respect to the HEI offering the Business Administration course, the likelihood of being acquired is greater following the market share and the GDP per capita of the municipality where the institution is. The facts that the HEI are located in the metropolitan region, having a public HEI in the municipality and being private also increase the likelihood of being acquired. However, the accreditation of HEI as a faculty decreases the probability of an acquisition.

Regarding the likelihood of an HEI offering Law courses to be acquired, it increases when it is private and/or situated in the metropolitan region. As in the Business Administration course, the likelihood decreases if the HEI is accredited as a faculty. The likelihood of an HEI to be acquired if it offers the Pedagogy course increases when it is a private institution as well as when there is a higher municipal GDP per capita.

The results, in this case, show a trend of acquisitions of HEI located in large urban centers and preference for HEI consolidated in their regions, such as University Centers and Universities. Regarding the effects of the acquisition on the interest variables, the results show a higher proportion of professors with Ph.D. in the HEI offering Business Administration and Pedagogy courses, but in the latter, the coefficient was significant only for 2014.

The proportion of professors with Ph.D. had no significant effect in the Pedagogy course in 2011 and in the Law course. The Business Administration course was the only one that had a positive and significant effect on the increase of the proportion of professors with Master's degree. CPC did not show significant effects in any of the three courses, as well as the grades of the students in general training (Mean GT) and specific knowledge (Mean SK) tests.

Thus, it can be concluded in part that the acquisitions in private higher education in Brazil did not reflect an effect on the quality and academic performance to date, except for short-term measures, such as hiring people with Ph.D. and Master degree, although it is an isolated fact in one or another course.

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Development of a methodical Approach for Requirements Management in Cross-Company Networks (ReMAiN)

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ABSTRACT

Purpose – Global competition and reduced development time of complex products are forcing companies to face constantly increasing challenges. In order to face these challenges and also to ensure the market position, several companies are merging to a corporate network or a cross-company network. This leads to new problems regarding the communication between the companies within this network as well as the holistic registration of requirements. The main objective of this paper is to present an approach for requirements management in cross-company networks, which is built on the model-based concept of System Engineering.

Design/methodology/approach – The system-theoretical approach for requirements management in cross-company networks has to assure that requirements of the different Stakeholder are collected, structured, weighted systemically and distributed to the right co-partner. Furthermore, the tracking and updating of the requirements have to be realized.

Findings – In order to develop the innovative approach, first the present publications will be performed with a substantiated analysis and evaluation of requirements management approaches that already exist and are scientifically and practically in use.

Originality/value - The innovative concept is based on extensive international literature analysis and the results of international studies. The new approach establishes an innovative concept for requirements management for cross-company network, which combined concept stages of requirements management with Model Based Systems Engineering.

Keywords: Requirements Management, Cross-Company, Model Based Systems Engineering, Complexity.

Paper type: Research paper.

INTRODUCTION

The cooperative relations with other companies in a corporate network provide through the flexible specialization many advantages for a stand-alone company. For example with a solution-oriented approach and a just in time reaction they will be able to match the rapid development or increasing innovation pressure in the market (Storper et al., 1987, Piore et al., 1984). As a part of a corporate network, an individual company has the opportunity to respond to rapid market changes. Although the trend to cross-company network is continually rising in the last years, research for this form of organisation has been neglected, especially concerning the traceability of requirements. Current approaches of requirements management are insufficient to realise the traceability of the requirements and the managing of product and service complexity in cross-company networks (Glückler et al., S.6., Stadlbauer 2007, S. 13). Ncube et al. (Ncube et al. 2013), (Lewis et al. 2009), (Hallerstede 2012) and (Meyers 2006). In this paper a cross-company network is defined as a socio-technical system that consists of three or more companies with common objectives. In order to accomplish that, resources and core competences of each company need to be combined in a goal-oriented way. Only if core competencies of various companies from different disciplines are bundled best performances in the manufacturing of mechatronic products can be realized. Certainly, the interaction of various disciplines could cause issues due to the fact that every discipline has their own individual, intern processes, technical jargon and models to handle complexity (Willing, 2015). Those divergences, as well as the complex interactions of various companies in a cross-company network create issues regard to requirements management, which are discussed in this article:

- How can be ensured that contradictory requirements of customers from different countries are recorded and verified?
- How is it possible not only to collect data of the requirements in a corporate network, but also to realize them in a structured, validated and systemically way?

In the context of this paper, requirements are defined as the expectations and needs of stakeholder, which are in usually assumed or obligatory (Winzer 2012). In order to realize a sustainable and effective organisation of a corporate network, requirements need to be defined specifically, collected systematically, structured and analysed. If requirements have been incorrectly defined and incompletely implemented, the success of the products and services can no longer be guaranteed (Ponn 2011). In a corporate network, as a complex organisation, the incorrect definition of a requirement due to an insufficient allocation between service providers and customers can be a major problem. In addition, a lack of knowledge can result from the application of different and specific corporate languages. (Nicklas et al. 2012, Killich 2007). Which steps have to be taken to ensure that the requirements are clearly defined and implemented with a common language between the network companies? One possible solution for this problem is a methodical approach to handle requirements in a corporate network. This methodical approach could be a solution to create a uniform language within corporate network in order to define correctly the requirements and to assure their holistic implementation.

The new approach is based on a comprehensive literature analysis of requirements management procedures, which points out the absence of a standardized procedure (Nicklas 2016). For this reason, systems engineering is used to control the mentioned complex problems. Using current concepts from requirements engineering and management combined with systems engineering must be possible to ensure that the requirements of different stakeholders are collected, structured, weighted systemically. Furthermore, the tracking and updating of the requirements have to be realized. This can only be done through a complexity-dominating system engineering approach, which describes system elements and subsystems with their relationships (Dohms 2001). For this system approach, an interdisciplinary system model for cross-company networks and their products has to be created. This system is supposed to interact iteratively with a general and standardized procedure from requirements engineering, so that topicality of requirements and information flows can be controlled and managed. For this purpose, first the current approaches of requirements engineering and management from science and practice will be analysed in the next chapter. Based on the strengths and weaknesses of the approaches, a concept for the requirements management in company networks will be worked out and presented. After that, the applicability of the new approach will be verified in the field of public transport in the penultimate chapter. Afterward the results and conclusions will be discussed.

REQUIREMENT MANAGEMENT APPROACHES

Table 1 shows the different approaches of requirements engineering and management, which are classified into general, software and electronics development as well as product development approaches (c.f. Table 1).

Table 1 – Proposed phases of requirements management (Based on Nicklas 2016)

Literature	Proposed management of the phases					
General approaches						
(Hull 2005)	Coordination	Analyze and model	Deduce and qualify	Coordinate		
(Lewis 2009)	Definition of the system	Analyzation of the system	Analyzation of the interactions	Capability analysis	Analyzation of the gab	
(Schulze 2016)	Collect	Analyze	Validate	Allocation	Verification of the design	
(Lou 05)	Elicitation	Negotiation	Specification	Validation		
(Parviainen 2005)	Collect	Analyzation	Negotiation and prioritization	Documentation		
Software and electronics development						
(Broy 2007)	Acquire	Analyze	Filter	Classify	Modelling	
(Ebert 2014)	Acquire	Specification	Validate	Analyze	Stipulation	Manage
(Hood 2008)	Elicitation	Specification	Analyzation	Review		
(Partsch 2010)	Acquire	Describe	Analyze (Verify and validate)			
Product development						
(Jiao 2009)	Elicitation	Analyzation	Specification			
(Lindemann 2009)	Determine	Structure & weight	Documentation			
(Ponn/ Lindemann 2011)	Determine	Structure	Analyze and prioritization	Maintain and integration		
(Stadlbauer 2007)	Determine	Analyze	Documentation	Verify and validate		
(Lindemann; Ponn 2011, S.39)	Determine	Structure	Analyze and structure	Maintain and integration		
(Bender et all. 2016)	Elicitation	Analyze	Documentation	Release and communicate		

Most approaches begin with the phase of elicitation-, acquire- or collect of requirements. In this phase it is important to know and to document the sources (stakeholder) of the requirements, so that information about service providers, customers or suppliers cannot be lost (Winzer 2012). After the first phase, the requirements are structured, analysed or described in the next phase. The final phase is defined as validate, maintenance or documentation. All approaches from Table 1 focus on individual companies and not on a cross-company network. None of the approaches captures and examines the inconsistency requirements of customers from different countries or collect data about the requirements in a cross-company network. Moreover, none of the approaches ensure that the requirements in a corporate network will be implemented in a structured, validated and systematic procedure. Furthermore, none of the approaches realise the transparent traceability of the requirements. Hence, requirements cannot be assigned to their source (stakeholder) or to the person, which is responsible for implementing of the requirements. The results of the analysis show that there is a scientific and practical gap concerning an approach for requirements management in cross-company networks. In order to fill this gap, a new methodical approach has to be developed, which has to fulfil the following demands:

- Ensure that inconsistency requirements of the customers from different countries can be recorded and checked.
- Collect data of the requirements in a corporate network and realize it in a structured, validated and systemically way.
- Realise a transparent traceability of the requirements. A possible solution to fulfil the demands above will be shown in the next chapter.

DEVELOPMENT OF AN INNOVATIVE METHODICAL APPROACH FOR REQUIREMENTS MANAGEMENT IN CROSS-COMPANY NETWORKS

As shown above, a new methodical and systematically approach needs to be developed for requirements management in cross-company. For this purpose, a model-based concept of systems engineering (Model-based engineering) has been used to describe a corporate network as a system model. It shall show the implicit relationship between the companies in a corporate network transparently and offer a better management of the complexity of the whole system. Model-based engineering (MBE) "is an approach for engineering that uses models as an integral part of the technical baseline that includes the requirements, analysis, design, implementation, and verification of the capability of a system, and/or product throughout the acquisition life cycle" (Model-based Engineering Subcommittee, 2011). It includes an interdisciplinary procedure, which is combined with a system model for handling complexity (Sage, 2009, Weilkiens, 2006). This procedure starts with the definition of the system with its aim in order to solve a problem. In the following, a problem solution in form of a procedural concept is worked out to solve the problem in a systematic and structured way.

In order to develop a system model, in the first step a system modeling method must be selected. In practice and science are numerous different procedures for system modelling, such as the Axiomatic Design (Suh, 2001), Consens (Gausemeier et al. 2012) or the structural complexity management (Maurer 2007). Those procedures were created to describe a technical system in the product development phase.

Nevertheless, none of these procedures are suitable for application in a cross-company network. They only focus on the product, but the new approach also needs to consider the organisation structure of the companies. For that reason, a method was selected, which is called eDeCoDe (enhanced Demand Compliant Design), developed by the Research Group Safety and Quality Engineering. The method contributes creating a standardized model by using a basis of data, information and knowledge. Based on eDeCoDe methods five standardized views (requirements, functions, processes, components and persons) are interlinked in order to create a standardized system model, which can describe a real product or a cross-company network. Furthermore, the interaction of the system elements within the whole system will be considered (Winzer, 2013). The method contains a “social” view (persons) specifically developed for socio-technical system by Nicklas in his doctor thesis. With the help of the fifth view a standardized depiction of collaborative networks in context of requirements management is possible. The linking of the system elements has been realized with a matrix, which is called eDeCoDe - main matrix (cf. Figure 1).

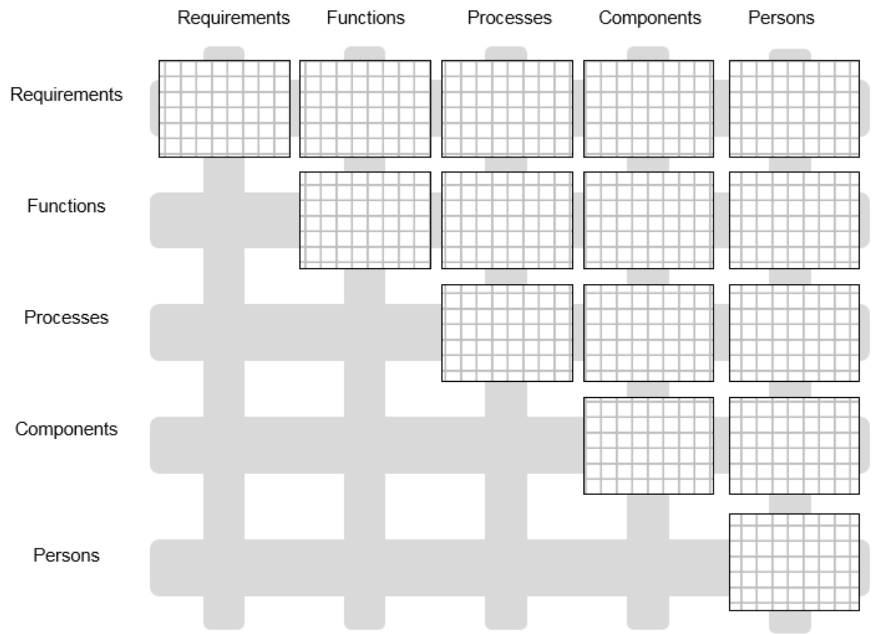

Figure 1 – eDeCoDe- main matrix as a tool for the implementation of DeCoDe (Sitte, 2011, Nicklas 2016)

The five views, which stand opposite to each other, are connected systematically and purposefully. Each matrix represents the dependence, interdependency and interaction of the system elements. The requirements in the eDeCoDe-based system model are described as the expectations of the stakeholders. Those requirements are fulfilled by functions, which are realized by processes and components. Persons use and realize components as well as processes and generate input. In consequence, they realize functions, which correspond to the requirements (Winzer, 2013, Nicklas, 2016). All five element-classes are in relation with each other with matrices to describe the (socio-) technical system. For example, the "requirements-person" matrix (top right in the Figure 1) can contribute to ensure the traceability of for example between stakeholder (source) and requirements. In this way, requirements can be assigned to the source (stakeholder) or to a person, which is responsible for the implementation of the requirements. Another benefit of the eDeCoDe method is that it can be combined with other methods or approaches, e.g. methods for requirements elicitation, structuring, weighting and validation. Thus, it can be used for modelling a cross-company network and to collect, structured and validated requirements in a systematically way. In the next step a standardized procedure from requirements engineering has to be develop and combine with eDeCoDe in order to realize a requirements management for cross-company network. Based on the analysis of requirements management and engineering approaches, Nicklas pointed out the following possible standardized procedure (c.f. Nicklas, 2016). For the adaptation, the phase “system definition” was implemented in the new approach. In addition, the steps “structure” and “analyze” were compiled. Each of the four phases interact with the uniform network model. The points of time (t) represents the versions of the system model or uniform network model (c.f. Figure 2).

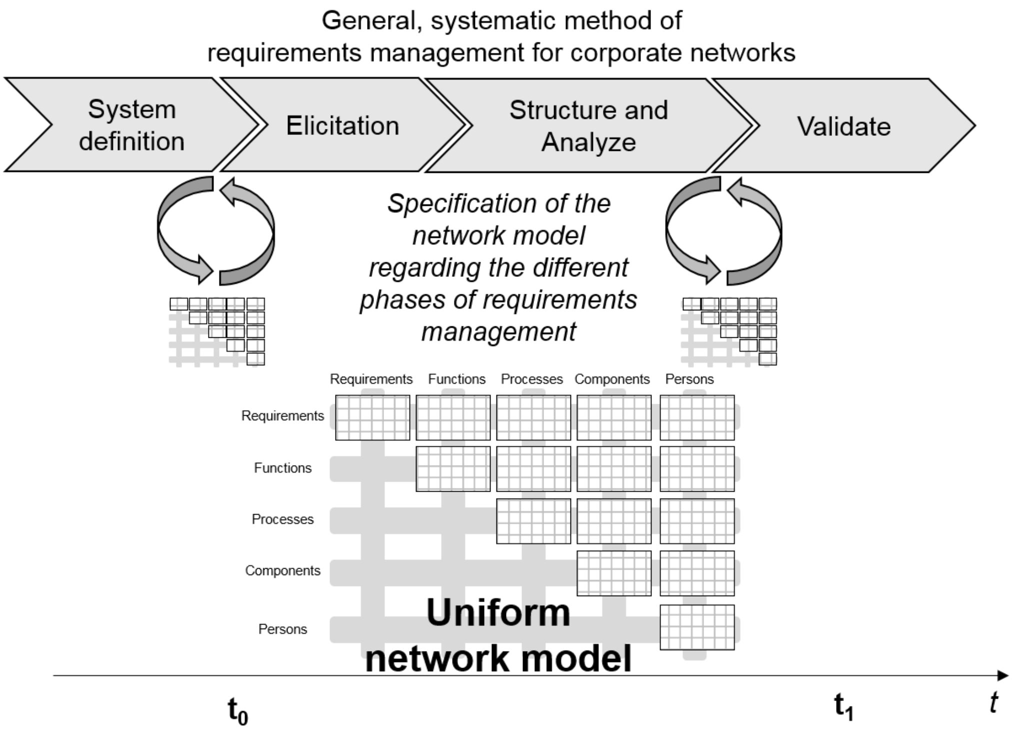

Figure 2 - Methodical approach for requirements management in cross-company networks.

For a better understanding, a practical application of the methodical approach will be shown in the next section.

PRACTICAL APPLICATION OF THE METHODICAL APPROACH FOR REQUIREMENTS MANAGEMENT IN CROSS-COMPANY NETWORKS

The application of the methodical approach was implemented within the project aim4it, which has been done by the Research Group Safety and Quality Engineering. The project „Accessible and inclusive mobility for everyone with individual travel assistance" (aim4it) concentrates on a public transport system, which is suitable for all groups of the society. The unrestricted use of a fully integrated cross-modal-public-transportation along the complete mobility chain allows handicapped persons to use the public transport without any barriers (e.g. no elevator for wheel-chair users in station buildings). Especially passengers with special mobility demands have to be informed early about their departure or transfer time at the station. The information should be current and understandable. Furthermore relevant information need to be presented in an optical, acoustical, tactile way to the passengers or as a combination of two perception modes. In the project aim4it expertise of a multidisciplinary project team has been combined to develop a new, individual travel assistance. In order to consider the requirements of passengers (user groups) from planning to implementation, the methodical approach for requirements management in cross-company networks from Figure 2 was used.

The following four steps of the approach are:

- System definition
- Elicitation
- Structuring and analysis and
- Validation

1) *System definition*

In the first step the system and its stakeholders have to be defined. Because aim4it focuses on a barrier-free public transportation system, special needs of passengers with disabilities besides to normal passengers, are concentrated on:

- Deaf passengers,
- Wheelchair users and
- Blind passengers.

Next, the passengers, operators, legislator and developer must be implemented into the progress of requirements development. With the principles of systems engineering the black-box approach are used to isolate the system from its environment (Haberfellner et al., 2012, Winzer, 2013).

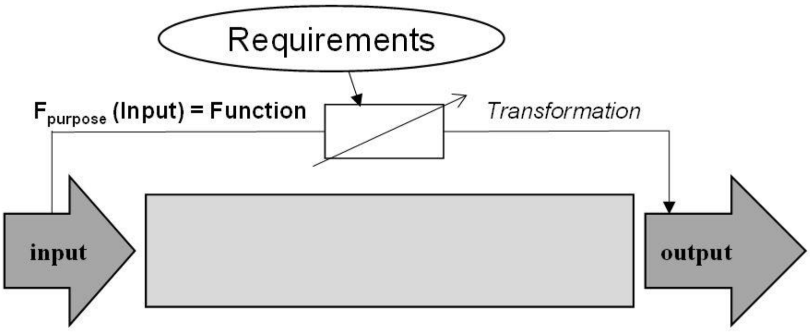

Figure 3 - Black-box approach

According to the black-box approach the inputs and outputs of the system are defined. Thus, the system focus can be realized in a more detailed and precise way. Generally, the system is defined as a set of related elements with mutual interactions and interdependences (Patzak, 1982). In addition the boundary of the complex system can be realized by decomposing the system into a set of subsystems by using the black-box approach from Figure 3 (Visser, 2007, Ashby, 1957). Because of the variety of stakeholders, the most important stakeholders have to be identified. First, passengers of the public transport are considered as the most important stakeholder-group of the new travel assistance system. After this, requirements have to be gathered and documented in a systematic way (c.f. next step 2 Elicitation).

Figure 4 shows the aim4it mobility concept with its connected parts (infrastructure, public transportation - provider, backend system) and the stakeholders (source of requirements). To get a first overview of the aim4it system as a uniform network model, the system elements from Figure 4 have to be integrated into the system model.

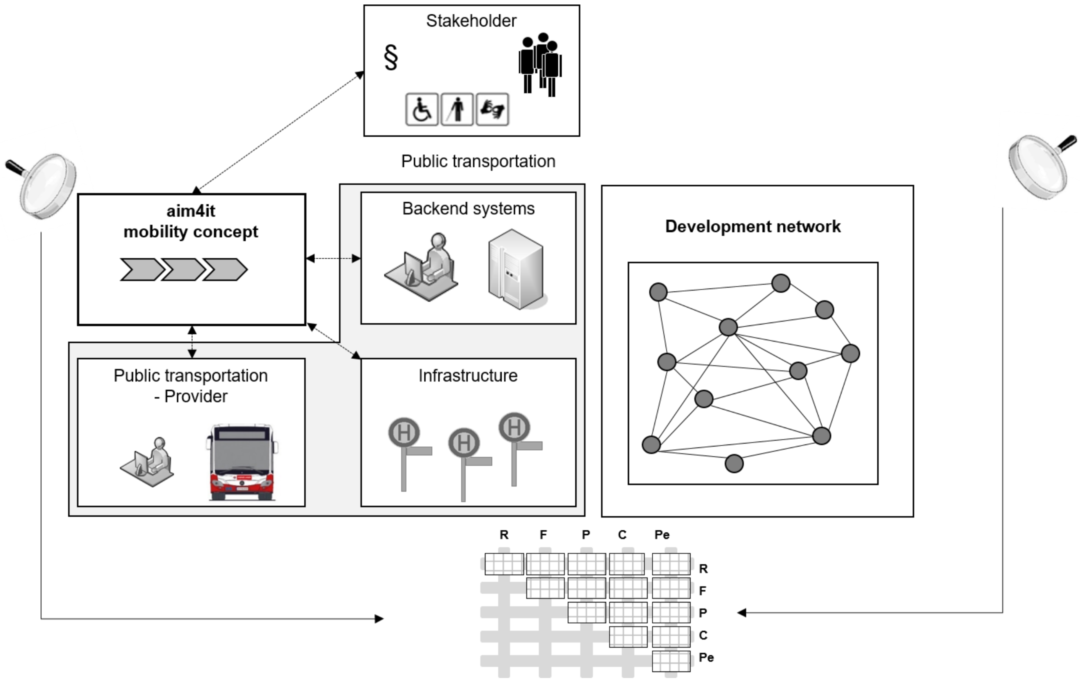

Figure 4 – System boundaries (cf. Nicklas, 2016)

2) Elicitation

Generally the elicitation is the main challenge especially in collaborative networks (Marchlewitz et al., 2013, Meyers et al., 2006, Nicklas, 2013, Savio et al., 2011). The reasons for this are as follows:

- The variety of stakeholders.
- Stakeholders who cannot articulate their requirements regarding systems that are too complex
- The dynamic behavior of the system and its environment.
- Different partners, products and customers in network structures.
- Ambiguous structures, contact points and responsibilities.

There are many methods for elicitation in literature, e.g. questionnaires, monitoring, different interview types (single interviews or focus groups), workshops, market studies, use-cases etc. (c.f. Ehrlenspiel/Meerkamm, 2013, Ponn/Lindemann, 2011, Yu et al., 2011). However, a general approach for requirements elicitation described by Hickey/Davis can be used to elicit and formalized the requirements in a systematic way based on the problem- and solution domain (c.f. Figure 5).

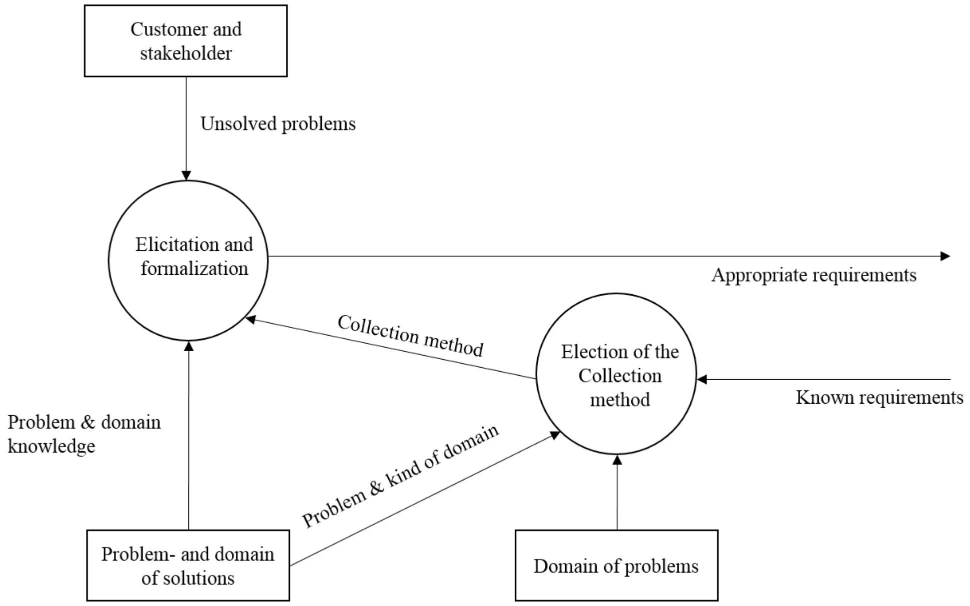

Figure 5 - Approach for requirements elicitation (Hickey et al., 2004)

Furthermore, a combination of requirements elicitation methods has been used: questionnaires, workshops and single interviews. The results are documented and considered for the development of the system model. After that, the requirements are gathered and formalized by use-cases (Nicklas et al., 2015). Figure 6 shows the combination between procedures for requirements elicitation with the system model. Input data from the first version of the system model was used from the use-case participants and responsible persons. Use case activity diagram and customer survey provide input data for a more detailed system model (c.f. Figure 6).

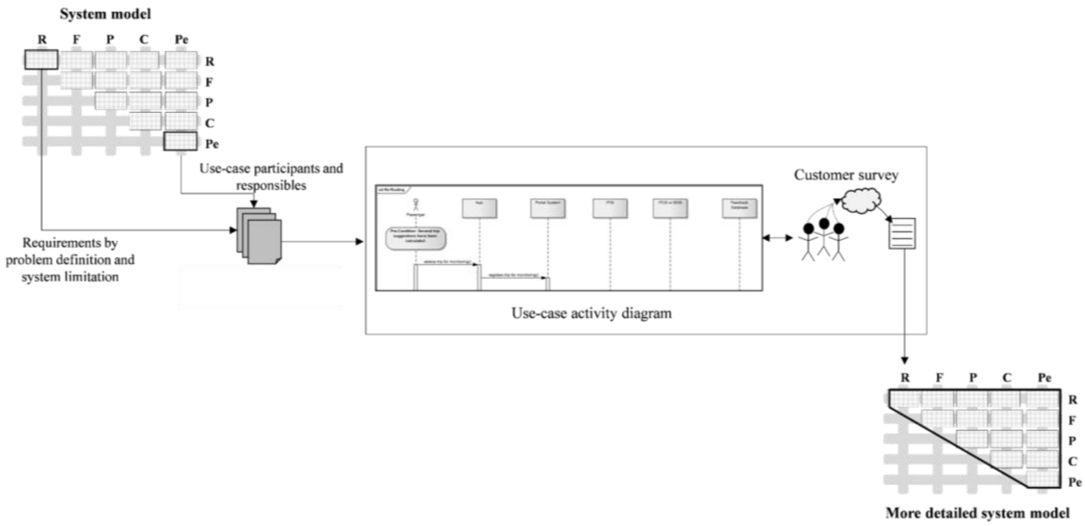

Figure 6 - Combined procedure for requirements elicitation with the help of the system model (cf. Nicklas, 2016)

The use-cases are based on SysML and UML (system modeling language, unified modeling language) with the focus on the interaction between system model (Use-case activity) and stakeholder (customer survey) (c.f. Figure 6). In addition to that, a consistent combination of the technical requirements (UML-flowcharts) and the user requirements (requirements lists, storylines) are realized to develop the system model with more details.

3) Structuring and Analysis

For a systematic system development the requirements have to be structured. To insert structural input into the system model, a use case cluster was used (c. f. Figure 7). The structure of the hierarchy is built in a logical way and starts with the goal, which is divided into different use-cases. Requirements of the application were derived from individual use-cases and further classified into detailed requirements. After that, the requirements can be prioritized through use of corresponding methods.

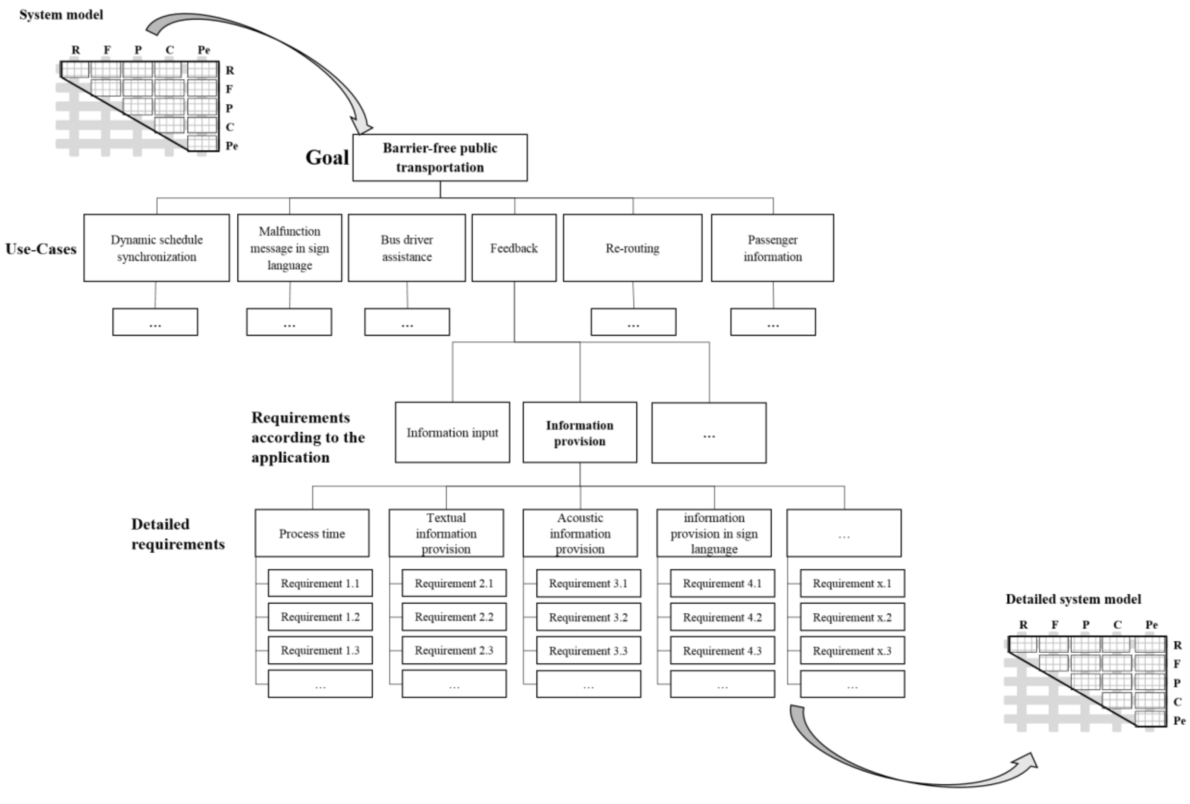

Figure 7 - Requirements structuring and analysis

There are many different methods (pairwise comparisons, ranking-methods etc.), which can be used for the prioritization of the requirements (Nicklas, 2016). The working group has chosen the analytical hierarchy process (AHP), because the experience has shown that this is the most suitable method to prioritize the requirements systematically (Nicklas, 2016).

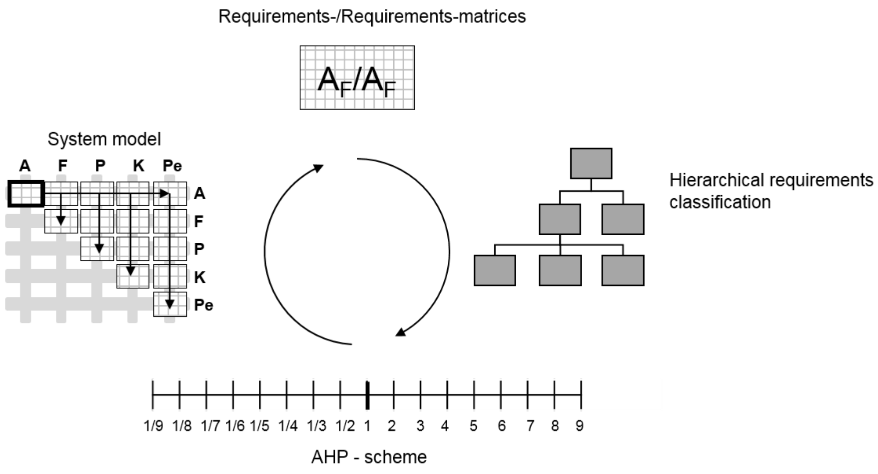

Figure 8 - Requirements analysis by the usage of the AHP

The use and update of the system model by utilizing the AHP is an important step for a systematic and consistent system development.

4) Validation

Validation means in this case to verify the degree of the implementation of the requirements. To validate the system, users were tested based on the prototypical phone use-case. After that, measurements have been made to determine the satisfaction of the users. The purpose of those measurements was to compare the user's or customer's satisfaction data with the requirements, which have been defined in the second phase (Elicitation).

The results of the satisfaction measurements (customer data) are integrated and interlinked as new requirements in the system model (t_{n+1}). Figure 10 shows the comparison between the defined requirements (system model t_n) and the new requirements form the customer data (t_{n+1}).

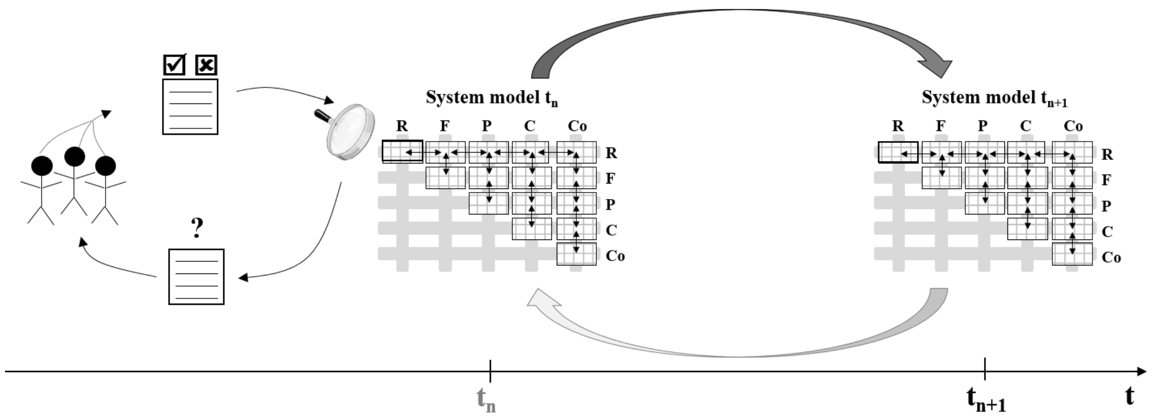

Figure 9 - Requirements validation

The system model can also be used at a later point of time, e.g. for integration of new customer satisfaction data or new use-cases and systems to realize a consistent system model (over time). In this way, requirements will be continually updated.

RESULTS AND CONCLUSION

The focus of this paper was to present new methodical approach which shows how to ensure that the requirements of the customers can be recorded, checked, structured and validated systematically.

For the development of the approach was necessary to analyze approaches and methods of requirements engineering from science and practice. A suitable approach was chosen and adapted so that it was possible to combine it whit a system model. The system model for the Cross-Company Networks was established on the principles of systems engineering using eDeCoDe method, a standardized procedure from the model-based engineering sector. Each of the four steps of the approach interact with the uniform network model in order to generate and update the system. The usability of the new methodical approach has been tested by a corporate network in the field of public transport. In the second section, requirements concerning the new approach have been derived from the results of this analysis of the approaches and methods of requirements engineering.

Hereinafter will be examined, if the requirements concerning the new approach have been fulfilled.

• Ensure, that inconsistency requirements of the customers from different countries can be recorded and checked.

In the first phase of project aim4it requirements of users or customers from three different countries (Austria, Germany and Poland) have been identified. In the phase of validation it was be possible to check and identify inconsistency requirement by comparison between system model t_n and system model t_{n+1} (c.f. Figure 9, subchapter validation).

• Collect data of the requirements in a corporate network and realize it in a structured, validated and systemically way.

Based on the black-box approach, a system model could be created and the through the use of an approach for requirements elicitation from Hickes (Hickey et al., 2004) first requirements could be determined. Based on the use case method respectively use case diagrams a detailed description of requirements could be realized. The input for those use cases were the defined requirements from the system model (c.f. subchapters system definition and elicitation). By using the analytical hierarchy process (AHP) the requirements of the aim4it system was classified and structured in a systemically way (c.f. subchapter structuring and analysis). Furthermore, a prioritization helps to identify the most important requirements.

• Realise a transparent traceability of the requirements.

It can be assumed that with the help of the eDeCoDe main matrix tool a transparent traceability of requirements could be realised. However, a traceability of requirements is very dependent on data, information and knowledge, which are available in the system model. For further research, the presented approach has to be evaluated in more scenarios and with more examples. For that reason is planed a further application at companies from different countries.

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