Design of Experiments (DoE) for non-manufacturing processes: challenges, benefits, case studies and future agenda

Second International Conference on Quality Engineering and Management (ICQEM – July 13-15, 2016) University of Minho, Guimarães, Portugal

Dr Jiju Antony (BE, MSc, PhD, FASQ, FIOM, FRSS, FCQI, FIET, FISSP)
Professor of Quality Management
Director of Corporate Executive Relations
Certified Lean Six Sigma Master Black Belt
Editor, International Journal of Lean Six Sigma
Associate Editor, TQM and Business Excellence
Associate Editor, Quality Assurance in Education (ASQ)
School of Management and Languages
Heriot Watt University, Edinburgh, Scotland, UK
E-mail: J.Antony@hw.ac.uk

Distinctly Ambitious
www.hw.ac.uk

Outline of the Presentation

- An Overview of Design of Experiments (DoE)
- Factors for unsuccessful application of DoE
- DoE in non-manufacturing settings: an overview of benefits
- Challenges in the application of DoE in non-manufacturing settings (literature and viewpoints of experts)
- Case studies of DoE in non-manufacturing settings
- Conclusion and Future Agenda

An overview of DoE

* Design of Experiment (DoE) or Multifactor testing (MFT) is fundamental and crucial to increase the understanding of a product, process or service behaviour (Montgomery, 2003)

* Research has clearly indicated that very few applications of DoE or MFT in a service environment have appeared in the academic literature (Ledolter and Swersey, 2006; Blosch and Antony, 1999 and Kumar et al. 1996)

* Few business leaders in service organisations have a good grasp of its power in tackling problems associated with service process efficiency and effectiveness (Johnson and Bell, 2009)

Factors for unsuccessful application of DoE

- LACK OF MULTI-DISCIPLINARY APPROACH TO EXPERIMENTATION
- EXPECTATION OF INSTANT RESULTS BY TOP MANAGEMENT
- ILL-DEFINED PROBLEM DEFINITION
- WRONG PERCEPTION THAT EXPERIMENTATION IS ALWAYS TIME CONSUMING
- LACK OF UNDERSTANDING OF DOE STRATEGIES (WHAT, WHEN, HOW)
- LACK OF STATISTICAL KNOWLEDGE FOR SERVICE OPERATIONS MANAGERS
- POOR TRAINING OR LACK OF TRAINING
- LACK OF MANAGEMENT SUPPORT AND COMMITMENT

Benefits of DoE in non-manufacturing processes: A review of literature

- Taguchi methods to improve the response-time performance of an information group operation which was responsible for addressing customer complaints concerning a small software export company ***(Kumar et al., 1996)***
- Used computer simulation and DoE to identify the key risk variables within the manpower planning system at the UK's Royal Navy ***(Antony and Blosch, 1999)***
- Used a fractional factorial experiment to increase the subscriptions response rate of Mother Jones magazine from 2% to 25% ***(Ledolter and Swersey ,2006)***
- Illustrated the power of a fractional factorial experiment to understand the effect of advertising and other critical factors on the sales of candy bars ***(Holland and Cravens, 1973)***
- Determined the key attributes of shopping experience in a superstore setting such as Wal-Mart ***(Raajpoot et al. , 2008)***

Benefits of DoE in non-manufacturing settings from case studies

Area	Design	Benefits Achieved
Bill Processing in a Utility Company	16 trial Fractional Factorial design was performed to study 6 factors at 2-levels	• Reduction of 70% in the number of hours taken to process bills without incurring capital cost or increasing any human resource • Savings generated from the project were estimated to be well over $100,000 US per annum
Account receivables	8 trial Fractional Factorial design was performed to study 4 factors at 2-levels	• Improvement in the cash flow in the company • The receivables age can be reduced from the current average of 200 days to 44 days
Retail distributor	DoE aided by Discrete Event Simulation was carried out to understand the factors influence order picking time	The company has reduced order picking time by 20%, evaluated various picking alternatives with minimum risk.

Benefits of DoE in service settings from case studies

Area	Design	Benefits Achieved
Billing process	Two level factorial experiment, studied over a dozen factors at 2-levels	• Savings of $ 50k in postage
Hospital	12 trial Taguchi Orthogonal Array experiment was performed to study 11 factors at 2-levels	• Length of Stay (LOS) in Emergency Department has been reduced from 100 minutes to 60 minutes (cost savings approx. $50,000)
Financial Services	16 trial Fractional Factorial design was selected to study 5 factors at 2-levels	• Reduced rework rate due to incomplete information provided by the customer • Increased application completeness from 60% to over 95% • Reduced cycle time for the loan application process by 25%

Challenges in the application of DoE in service settings (literature and viewpoints of experts)

- The performance of a service process is very difficult to measure accurately due to more "noise factors" such as friendliness, politeness etc. (Kumar et al., 1996)
- Lack of awareness, ignorance and misconceptions discourage experimentation in many service organisations (Johnson and Bell, 2009)
- DoE is a 'techy' tool; managers in the service settings may be less likely to have a mathematical/statistical background and be perhaps more likely (than in engineering, say) to be driven by 'experience' and gut feel – (Phil Rowe, Consultant and Six Sigma Master Black Belt, Bourton Group, UK)

Challenges in the application of DoE in service settings (literature and viewpoints of experts)

- The fundamental challenges are that it is not easy to obtain necessary observed data in the service sector, and also it is not easy to provide the same experimental condition for repeated measurement in the service sector (Professor Sung Park, Seoul National University, South Korea)
- Personally, I think the cultural issues are greater. There is rarely a culture of using the scientific method in most service organizations (Roger Hoerl, retired GE MBB, USA)
- Lack of standardized work processes; Lack of improvement mind-set; greater amount of human intervention (Ronald Snee, President of Snee Associates, USA)

DoE in Higher Education: a review of literature

Design of Experiments in Higher Education: some useful literature

- Barone and Lo France (2009) undertook a DoE approach in combination with the SERVQUAL model in an environmental engineering degree program at the University of Palermo. The authors found out that teacher-student interaction is the most influential factor on student satisfaction.
- A case study was carried out to identify the potential factors which influence the teaching performance of academics for postgraduate students (approx. 140) in an Engineering School at one of the Scottish Universities (Antony et al., 2014). The key factors which were influencing the teaching performance from DoE included: presentation content, time of delivery of the class, duration of the class and number of speakers. There was also a strong interaction between the time of delivery and number of speakers.
- Ree at al. (2014) has carried out a Taguchi experimental design approach to improve lecture quality in a higher education setting. Both control and noise factors were considered in the study.

A Case Study on DoE in a Scottish Higher Education Institution

- The case study was carried out in a class room setting at Heriot-Watt University, Scotland, UK.
- MSc students pursuing a course in quality management were used for this study. There were 49 students from over 18 countries in the class room. They were then put in 8 groups.
- The students in each group were asked how they perceive teaching effectiveness of a lecturer who is delivering a course to MSc students.
- A teaching is effective if he or she can accomplish the planned goals and assigned tasks in accordance with school goals (Campbell,2003; Kwan, 2010)
- What factors could potentially influence the teaching effectiveness of a lecturer from students' perspective?

A Case Study on DoE in a Scottish Higher Education Institution

- Initially a total of 20 factors were thought to influence the teaching effectiveness.
- There are a number of sources of evidence of measuring teaching effectiveness: student surveys, student interviews, teaching awards, etc. However this study was primarily focused on the students' perceptions of measuring teaching effectiveness.
- Students were then used a multi-voting system to reduce the number of factors from 20 to 11 (all 8 groups independently voted the most important factors which they thought are of important to teaching effectiveness)
- The students assessed each combination of factors on a scale from 1-10 where 10 is the highest possible score. Table 3 will show the results for each possible combination.

A Case Study on DoE in a Scottish Higher Education Institution

Labels	Factors
A	Content of the course
B	Presentation style of the lecturer
C	Interaction during the delivery of lecture
D	Feedback
E	Background of the instructor
F	Frequency of lectures
G	Professionalism
H	Method of assessment
I	Types of exercise in the classroom
J	Facilities
K	Supporting materials

A Case Study on DoE in a Scottish Higher Education Institution

Runs	A	B	C	D	E	F	G	H	I	J	K
1	+1	-1	+1	-1	-1	-1	+1	+1	+1	-1	+1
2	+1	+1	-1	+1	-1	-1	-1	+1	+1	+1	-1
3	-1	+1	+1	-1	+1	-1	-1	-1	+1	+1	+1
4	+1	-1	+1	+1	-1	+1	-1	-1	-1	+1	+1
5	+1	+1	-1	+1	+1	-1	+1	-1	-1	-1	+1
6	+1	+1	+1	-1	+1	+1	-1	+1	-1	-1	-1
7	-1	+1	+1	+1	-1	+1	+1	-1	+1	-1	-1
8	-1	-1	+1	+1	+1	-1	+1	+1	-1	+1	-1
9	-1	-1	-1	+1	+1	+1	-1	+1	+1	-1	+1
10	+1	-1	-1	-1	+1	+1	+1	-1	+1	+1	-1
11	-1	+1	-1	-1	-1	+1	+1	+1	-1	+1	+1
12	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Plackett – Burman 12 trial experimental layout
Source: Plackett and Burman (1946)

A Case Study on DoE in a Scottish Higher Education Institution

- **The most important factors influencing teaching effectiveness were:**
  - **Interaction between the student and lecturer**
  - **Background of the instructor**
  - **Professionalism**
  - **Presentation style and**
  - **Method of assessment**
- **The least important factors influencing teaching effectiveness were:**
  - **Frequency of lectures**
  - **Supporting materials**
  - **Type of exercises**

A Case Study on DoE in a Scottish Higher Education Institution

Limitations of the case study

- The study was carried out for one course with about 49 students pursuing a Masters course in a Scottish University.
- Are the results of the study repeatable?
- Will there be any differences in the prioritization of the factors if the same study is conducted for undergraduate students?
- Moreover, will there be any differences in the importance of factors if the experiment is carried out in two groups – Europeans vs Non-Europeans??

A Case Study on DoE in an invoicing process

- The case study was published in a book entitled “A practical guide to Experimental Design” by Frigon and Mathews (1997).
- A large company was having a problem with receivables. The average age of receivables due was 200 days after delivery of material. The company had $130 million that was 30 days or older after receipt by the customer.
- How can we optimise the process of billing?
- A process flowchart for the billing process was made. It was found that the billing signature and approval cycle was completely manual
- There were several options available that may reduce billing time, however, it was not known to anyone which option is the best to reduce the age of receivables.

A Case Study on DoE in an invoicing process

The four options included:

- **Bill directly on the invoice**
- **Automate the billing and invoicing system**
- **Provide follow-up to the customers by management at 30 to 45 days by telephone or in writing**
- **Contract out the billing department to a professional billing activity**

These options lend themselves to evaluation using a designed experiment.

A Case Study on DoE in an invoicing process

The factors and their levels for the designed experiment are shown below.

- **Factor A – Billing**
  - -1 (low level) – directly on the invoice with the shipment
  - +1 (high level) – billing from the billing department mailed separately from the shipment
- **Factor B – Automation**
  - -1 (low level) – automate the complete billing process with all billing generated automatically on shipment
  - +1 (high level) – maintain the current system in which the generation of billing is automated but the bills and invoices are transmitted and routed in hard copy

A Case Study on DoE in an invoicing process

- Factor C – Follow up
  - -1 (low level) – Follow up by letter at 45 and 60 days
  - +1 (high level) – Follow up by telephone at 45 and 60 days
- Factor D – Contract
  - -1 (low level) – contract out the billing and follow-up
  - +1 (high level) – keep the billing and follow-up in house

The trial took place over a 6-month period.

A $2^{(4-1)}$ fractional factorial experiment was selected.

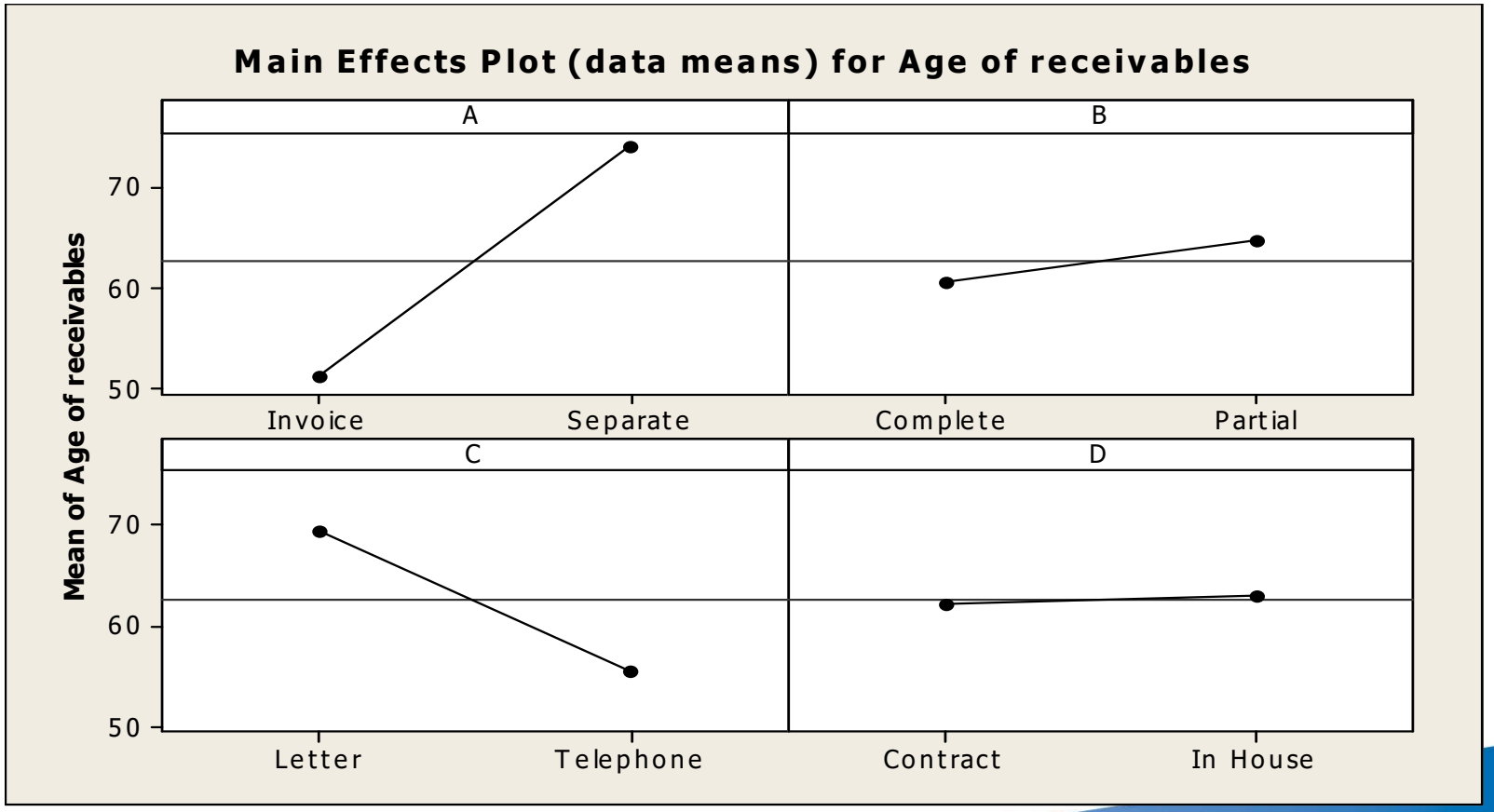
A Case Study on DoE in an invoicing process

Trial	Billing (A)	Automation (B)	Follow-up (C)	Contract (D)
1	Invoice	Complete	Letter	Contract
2	Separate	Complete	Letter	In House
3	Invoice	Partial	Letter	In House
4	Separate	Partial	Letter	Contract
5	Invoice	Complete	Telephone	In House
6	Separate	Complete	Telephone	Contract
7	Invoice	Partial	Telephone	Contract
8	Separate	Partial	Telephone	In House

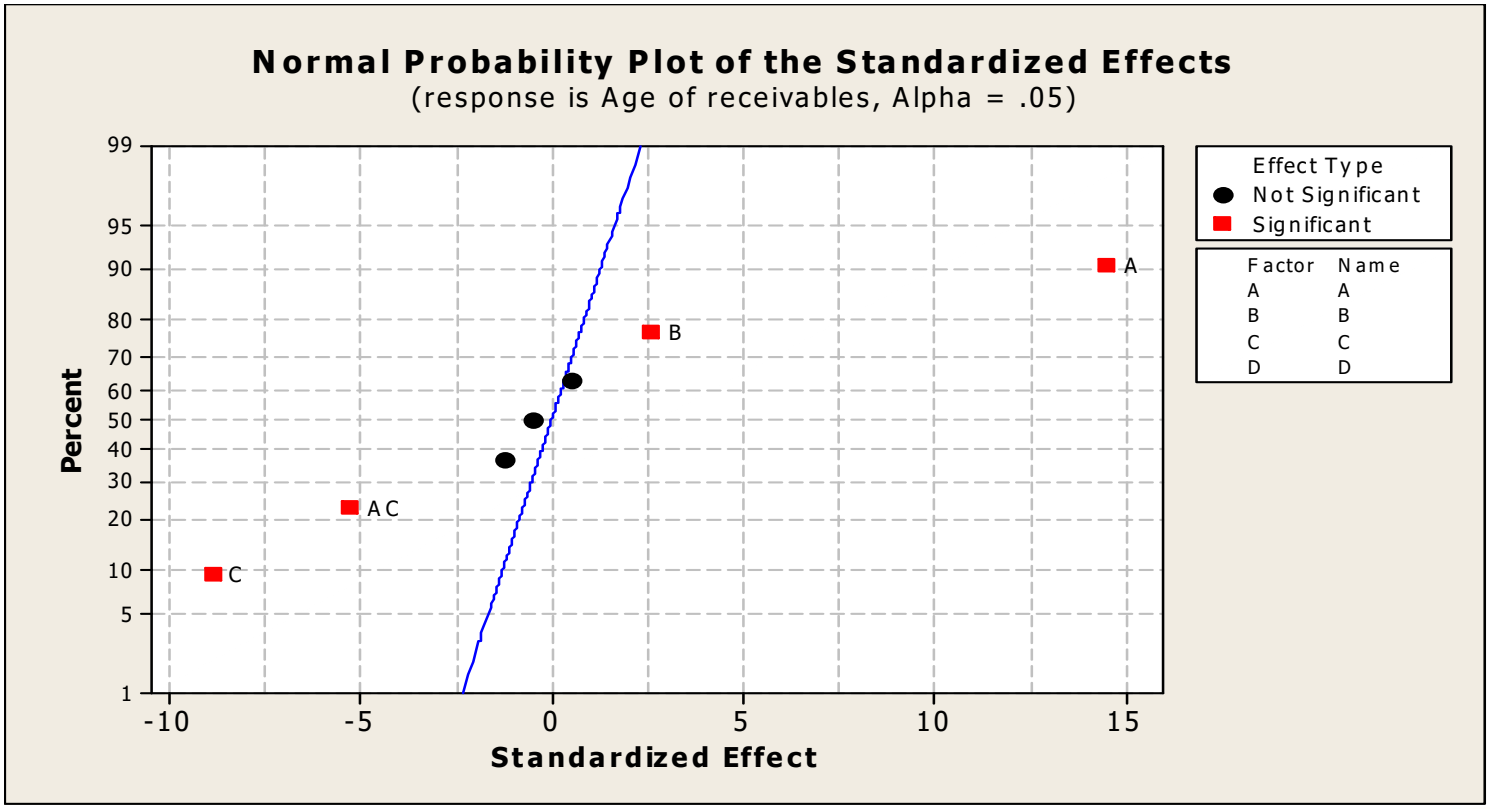
A Case Study on DoE in an invoicing process

Run	A	B	C	D	y – bar (average age of receivables in days)
1	-1	-1	-1	-1	**50**
2	1	-1	-1	1	**84**
3	-1	1	-1	1	**58**
4	1	1	-1	-1	**86**
5	-1	-1	1	1	**46**
6	1	-1	1	-1	**62**
7	-1	1	1	-1	**51**
8	1	1	1	1	**64**

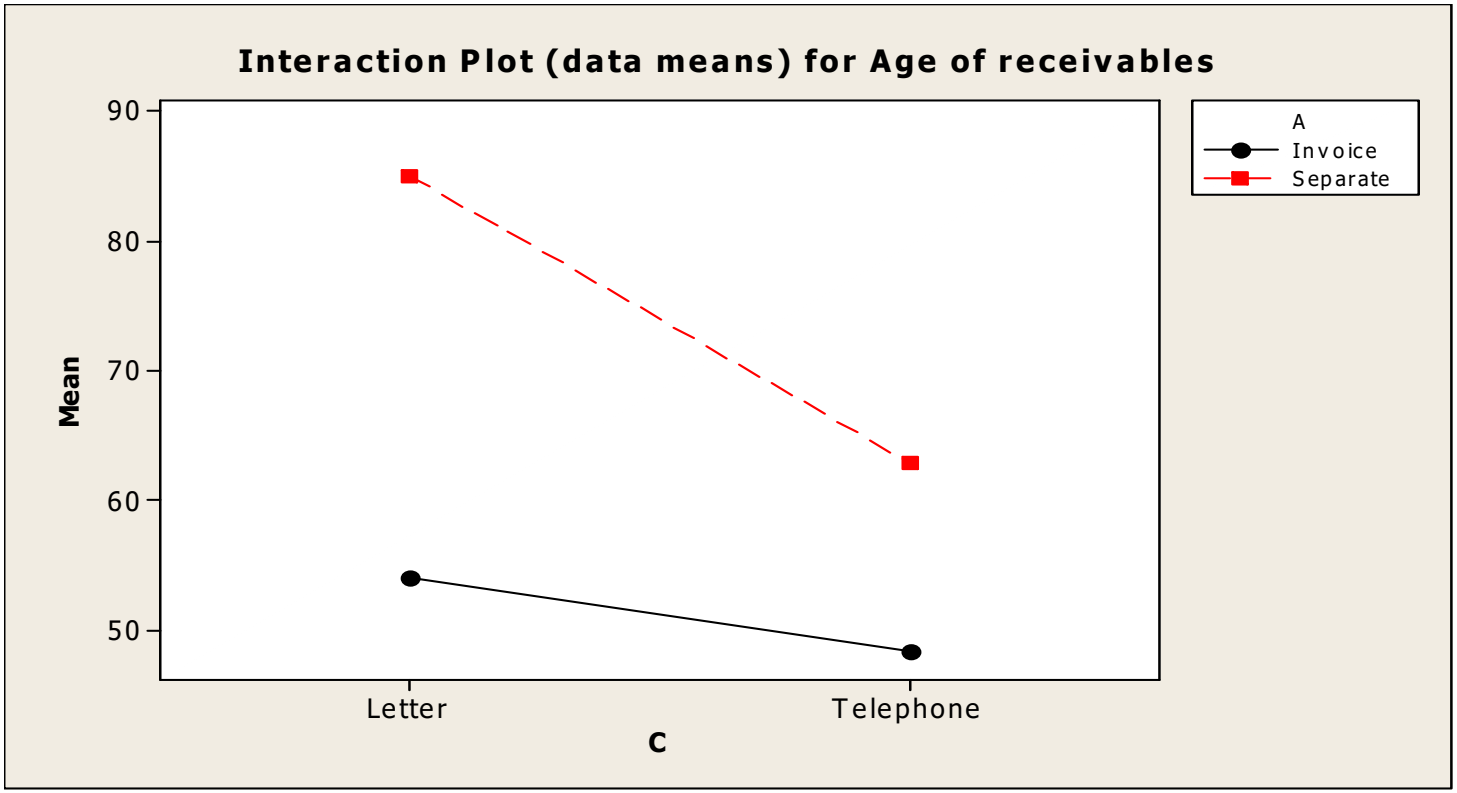
A Case Study on DoE in an invoicing process



A Case Study on DoE in an invoicing process



A Case Study on DoE in an invoicing process



DoE for non-manufacturing processes

❑ Conclusion and Future Agenda

- ❑ Research has indicated that very little attention has been given to the application of DoE in the context of non-manufacturing processes due to various challenges.
- ❑ More research projects on teaching effectiveness and training effectiveness in the delivery of CPD courses are on the agenda in the forthcoming years
- ❑ We also expect to see more applications of DoE in non-manufacturing processes in the next 5 to 10 years or so because of the increased use of Six Sigma methodologies in non-manufacturing settings.

DoE for non-manufacturing processes

❑ Key References

- *Antony, J., Design of Experiments for Engineers and Scientists (second edition), Elsevier, 2014, USA*
- *Antony, J., Coleman, S. Montgomery, D.C., Anderson, M.J., and Silvestrini, R.J. Design of experiments for non-manufacturing processes: benefits, challenges and some examples, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, November 2011; vol. 225, 11: pp. 2078-2087*
- *Ledolter, J. and Swersey, A.J. ,Testing 1-2-3 : Experimental Design with applications in Marketing and Service Operations, Stanford University Press, Stanford, USA, 2007.*
- *Frigon, N.L. and Mathews,D. (1997), Practical Guide to Experimental Design, John Wiley and Sons, USA*
- *Antony, J., Laxman, S. and Gijo, E.V.(2014), Design of Experiments in a Higher Education setting, International Journal of Productivity and Performance Management, Vol.63, No.4, pp. 513-521.*
- *Ree, S., Park,Y.H. and Yoo, H. (2014), A study on Education Quality using the Taguchi Method, Total Quality Management and Business Excellence, Vol. 25,No.8,pp. 935-943.*

Thank you !!!

Any Questions??