Integration of Design of Experiments within a Strong Lean Manufacturing Environment

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Abstract:  
It has been well argued in quality management research that combining and integrating overlapping management practices lead to superior performance. Taguchi methods and lean manufacturing are waste/loss elimination approaches. It is argued that there is a high degree of integration of the Taguchi method within lean manufacturing environment. Surprisingly, there are very few studies that look at how the Taguchi method could be integrated within a lean manufacturing environment. Therefore the key objective of this paper is to address this dearth. The paper is an outline of the PhD research of the first author, shows how the theoretical model explaining how Taguchi philosophy is integrated with lean manufacturing was developed. The paper also shows how the model will be empirically tested using structural equation modelling (SEM) through data collected from world-class lean manufacturing plants.

Authors’ Biographies

Pramila Gamage is a PhD candidate in her first year at the Massey University, New Zealand. She is undertaking her doctoral research in the field of technology. In her research, she deals with Lean manufacturing and Taguchi philosophy in the scope of quality of product and process.

Nihal P. Jayamaha is a lecturer in quality assurance attached to Massey University, New Zealand. Nihal’s research interests include quality/business excellence models, statistical applications in quality and operations management, and healthcare quality.

Nigel Grigg is Associate professor (Quality Systems) at Massey University in New Zealand. His teaching and research area focuses on quality and performance improvement, including statistical thinking, knowledge management, organisational culture and change management.
**Presentation Experience**

Pramila has some experience in presenting ideas (mostly in the form of lectures) in audiences in her home country (Sri Lanka), in English.
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1. Introduction

Rapid globalisation of products and markets in the twenty-first century means that manufacturing competitiveness is increasing in every moment. In the present operational management environment researchers have shown the importance of integrating a mix of different but overlapping manufacturing practices to achieve manufacturing competitiveness (Flynn, Sakakibara, & Schroeder, 1995; Pullana, Bhasib, & Madhuc, 2011).

Toyota Production System (TPS)/Lean Production has received a lot of attention from academia and industry due to the significant achievements of a variety of manufacturing and service organisations within and outside the automobile industry (Hines, Holweg, & Rich, 2004; Holweg, 2007). Lean manufacturing originated in Japan at the Toyota Motor Corporation (TMC), the world’s largest automobile manufacturer, founded by Kiichiro Toyoda in 1937. TPS caught the attention of the western world and the benefits of the TPS became more apparent to the world outside Japan, not so much because of the design or performance of the automobiles that TPS produced but because of the incredible consistency and precision levels TPS achieved in manufacturing (Liker, 2004).

Womack and Jones (1996), the authors of one of the bestselling books ‘Lean Thinking’ have made the terms ‘lean’ and ‘lean production’ popular to the outside world. They define lean as a five-step operational process: “specify value”, “identify the value stream”, “flow”, “pull”, and “perfection” (Womack & Jones, 2003). Shah and Ward, (2007) proposed a definition for lean to capture the many facets of lean production. According to them “the main objective of Lean management is to eliminate waste by concurrently reducing or minimizing supplier, customer and internal variability”. Many of the tools (e.g. Just-In-Time, One-Piece–Flow, 5S, Kaizen etc.) of lean have been derived to minimise waste in eyes of the customer. Lean thinking recognises that manufacturers can make significant progress by squeezing out the large number of non-value-added activities that are inherent in their processes. Toyota defined seven major types of non-value-added activities (waste) which provide huge opportunities to reduce waste, which people normally cannot see without lean thinking (Liker, 2004).

Taguchi methods, articulated by the Japanese engineer Genchi Taguchi, have initiated a new era of thinking about product and process quality. Taguchi methods incorporate a novel philosophical view on quality, which requires some modifications to the traditional design of experiments (DOE) techniques, which are based on the statistical methods developed by Sir Ronald Fisher and his associates in 1919–20 (Antony, 2006; Box & Bisgaard, 1986; Rowlands, Antony, & Knowles, 2000; Roy, 2010). Taguchi’s philosophical view of quality is that any deviation of product or process characteristic or service performance from its target value (target specification) is a loss to the society, particularly to the producer and the end customer (Rowlands, et al., 2000; Taguchi & Clausing, 1990; Unal & Dean, 1991). This view is different from the traditional “goal post” view of quality, which holds that a product (or process) will provide the exact same level of utility (satisfaction) to the customer as long as the value of the product (or process) characteristic under observation stays anywhere between its lower and upper specification limits (Kumar, Motwani, & Otero, 1996; Ross, 1996; Roy, 2010). This basically means that a manufacturing (or service)

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1 The other bestselling book that created great interest about lean is the book titled “The Machine that Changed the World” by Womack, Jones, and Roos (1990).
process is deemed satisfactory as long as the variation of the product (or process) characteristic stays within these limits. Thus the traditional view does not provide any incentive for the manufacturer to make the product (or process) characteristic to stay at or very close to the target value (the target value is usually the midpoint between the lower and upper specification limits).

Taguchi used a quadratic loss function (the loss being proportional to the square of the amount of deviation from the target) to model the losses, which means that the losses rise rapidly as one moves from the target value (D. M. Byrne & Taguchi, 1987; Ross, 1996; Roy, 2010; Sauers, 1999; Taguchi & Clausing, 1990). Taguchi argued that deviation from the target specification occurs as a result of failing to make products and processes robust (invariant) against the variation of actual environmental conditions (for a product the actual use conditions) in which the product or process operates (Myers, Khuri, & Vining, 1992; Taguchi, Chowdhury, & Taguchi, 2000; Taguchi & Clausing, 1990; Wang & Huang, 2007). For example, the performance of an automobile should be robust (invariant) against low/high tire pressure, rough/smooth road, high/low ambient temperature and so on. On the same token, the performance of a domestic appliance (e.g., a TV) should be robust against voltage fluctuations, etc.

Taguchi showed how his philosophical view can be used to achieve high quality levels economically through designing and analysing statistically controlled experiments. Thus Taguchi’s contributions to quality contain both a philosophical element (a new definition of quality) as well as a technical element specifying how an experiment should be designed and analysed (Azadeh, Miri-Nargesi, Goldansaz, & Zoraghi, 2012; Ross, 1996; Roy, 2010; Taguchi, et al., 2000). For this reason, in this paper, the term ‘Taguchi methods’ is used to mean both the philosophical element as well as the technical element.

Both lean and Taguchi methods are based on the premise that waste is undesirable. Lean views waste as a by-product of failing to understand what constitutes “value” to the customer (Shah & Ward, 2007; Womack & Jones, 2003). Taguchi methods (the philosophical element) view waste as a by-product of failing to produce a product (or design a process) that is robust against the variations of the environmental factors (noise). Both methods originated in Japan, a society that does not tolerate waste (Bhasin & Burcher, 2006; Holweg, 2007; Liker, 2004). The logical research question that follows form two philosophies that seem to share a common theme is: can Taguchi methods be successfully integrated within a lean manufacturing environment?

The doctoral research study covered in this paper that of the first author who is nearing her first year of the study, is based on the overall hypothesis that Taguchi methods do complement lean manufacturing. Traditionally, Taguchi methods (or even traditional DOE methods) have not been viewed as a strong component of lean in the literature. Through synthesis of various pieces of literature it is argued in this paper that Taguchi methods do complement lean manufacturing. More importantly, this paper describes how the overall hypothesis will be empirically tested through data collected from world-class lean manufacturing plants (belonging to the same company) that produce intimate apparels to European and US brands. Once completed it is expected that the first author’s doctoral study will make a significant contribution to new knowledge.

1.1 Research Aims and Objectives

The aim of the study is to determine the extent to which Taguchi methods (philosophy as well as tools and techniques) can be integrated within a strong lean manufacturing environment. The specific objectives of the study are as follows:
1.1.1 To develop a theory that predicts and explains manufacturing process outcomes through the concepts ‘lean manufacturing system’, ‘Taguchi’s DOE philosophy’, and ‘continual improvement’.

1.1.2 To develop operational definitions (through a survey questionnaire) of lean manufacturing system, Taguchi’s DOE philosophy, continual improvement, and manufacturing process outcomes.

1.1.3 To test the theory referred to in 1.1.1 empirically.

1.1.4 To identify issues those arise when implementing Taguchi methods in lean apparel organisations.

The remainder of this paper has been structured as follows. Section 2 explains the development of theoretical model based on extensive literature review. Section 3 describes the methodology which will be used to address the research questions. Section 4 and 5 cover the expected outcomes and concluding remarks respectively.

2. Literature review and model development

Lean manufacturing is a set of manufacturing practices (as well as a philosophy) that have been brought forth through application of tools and techniques such as Just-In-Time, Kaizen, One-Piece-Flow, Jidoka, Heijunka, Shingo-Shingo/Single Minute Exchange of Die (SMED) system etc. that were developed under the leadership of the late Taichi Ohno, the inventor of the TPS (Hines, et al., 2004; Liker, 2004) at the TMC. The vision of Ohno was mainly to develop an alternative to mass production which did not suit the Japanese manufacturing environment at the time (soon after the Second World War due to scarcity of resources). TPS is based on the premise that a traditional production process (mass production in the case of automobiles) do result in some activities that do not add any value to the customer. Therefore the main objective of Lean philosophy is to create customer value (Womack & Jones, 2003). In business, the term customer value is defined as “the difference between the values the customer gains from owning and using a product and the costs of obtaining the product” (Armstrong & Kotler, 2000). Therfore customer value can be created by either increasing the worthiness (value) of the product or service (as perceived by the customer) or by reducing the cost. Lean obviously achieves both value enhancement and cost reduction (Hines, et al., 2004). The practitioner interest on ‘lean manufacturing’ is mainly manifested as a method aimed at reducing waste (Pavnaskar, Gershenson, & Jambekar, 2003; Womack & Jones, 2003) while the academia interest (like in other research topic) has evolved around a range of aspects that are current at the time of publication (e.g. the early research evolved around understanding Just-in-Time manufacturing).

Figure 1 shows an initial theoretical model that has been developed within this research, representing hypothesised relationships between lean manufacturing system, Taguchi’s DOE philosophy, continual improvement and manufacturing process outcomes. This model will be empirically tested within this research. The following sections discuss each of the hypothesised relationships in turn.
According to the literature (e.g., Karlsson & Åhlström, 1996; Motwani, 2003; Shah & Ward, 2003; White, Pearson, & Wilson, 1999), the ultimate goal of implementing lean production in an operation is to increase productivity, enhance quality, shorten lead times, reduce cost—all of which will result in creating customer value. This leads to the first research hypotheses:

**H1: Lean manufacturing system has a positive effect on manufacturing process outcomes.**

The next step is to search for any mediating variable/s that affects (mediates) the relationship between lean production and process outcomes. These process outcomes are happening through a system of continual improvement (continuous improvement and innovation). According to Womack and Jones (2003) identifying the value stream is the second step in lean thinking. A value stream analysis always shows three type of activities: value-added activities, non-value-added activities that can be eliminated immediately, and non-value-added but needed activities (which are unavoidable with the current technology)(Womack & Jones, 2003). The non-value-added activities (those that can be eliminated based on current technology) need to be avoided continuously through small step improvement (kaizen). However, big step improvements (innovation) will be needed ultimately for reducing non-value added but needed activities and for the survival of the organisation, in a competitive manufacturing environment. Therefore both small-step improvement (kaizen) as well as big-step improvement (innovation), which are collectively referred to as continual improvement in this paper are thought to be an outcome (effect) that results from a lean manufacturing system (cause). Thus the second hypothesis is:

**H2: Lean manufacturing system has a positive effect on continual improvement.**

While Taguchi methods adopt a different philosophical view on quality compared to the traditional view of quality upon which the traditional DOE methods are based, both DOE approaches use

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2 Since eliminating (or minimising) waste is an on-going activity in a factory setting (Liker, 2004), lean relies heavily on small-step improvement (Pavnaskar, et al., 2003).
statistically designed experiments to minimise variation to improve quality. Thus minimising variation is at the very heart of continual improvement (Bañuelas & Antony, 2003). Given that Taguchi’s DOE philosophy is embedded in Taguchi methods and in fact Taguchi’s DOE philosophy serves as the foundation on which Taguchi methods are developed, the third research hypothesis is:

\[ H_3: \text{Taguchi’s DOE philosophy has a positive effect on continual improvement.} \]

For the benefit of the reader it is important to distinguish Taguchi methods from the traditional DOE approaches. In the traditional approaches (e.g. fractional factorial designs, full factorial designs, central composite designs) knowledge is gained through conducting a series of simple experiments in a sequential fashion honouring the “keep it simple and sequential” (KISS) principle, making few inquiries at a time (Montgomery, 2005). In Taguchi methods variation reduction is accomplished through a single larger (in terms of number of runs) experiment. However, Taguchi method has been viewed as simple, and less costly, although it has not been proliferated into the wider industry. Taguchi methods seem to be extremely popular in some industries (automotive, metal fabrication, electronics and semiconductors) but not in other industries (e.g. the fashion industry, service-based processes). This also is an important issue worth exploring.

There are number of companies and industries that have not got real benefits through Taguchi’s method mainly due to two reasons. Firstly in these companies/industries experiments are threatened in isolation by not integrating the experiments into the continuous improvement strategy (Rowlands, et al., 2000). Secondly, Taguchi methods aim to minimise variation in product and process performance by setting the process parameters right at the very outset, which is usually not the way manufacturers achieve optimisation: trial and error (Mileham, Culley, Owen, & McIntosh, 1999; Razfar, Zinati, & Haghshenas, 2010; Yusoff, Mohamed, Hamid, Harun, & Ramly, 2004).

According to the Taguchi ‘quality has to be “designed in” to achieve high system quality levels (Gunter, 1987). Therefore the Taguchi’s quality control approaches mainly focus on offline quality control. The Taguchi methods have intensive applications in various manufacturing companies such as plastic, automotive, electronic, service based process (Kumar, et al., 1996) etc. to optimise scrap and rework rate, to increase process yield, to increase product performance such as strength, durability, taste etc. and to optimise service performance through lesser number of experiment or runs. Therefore, Taguchi’s DOE philosophy seems to have a direct effect on process outcomes. Therefore the fourth hypothesis is:

\[ H_4: \text{Taguchi’s DOE philosophy has a positive effect on manufacturing process outcomes.} \]

In 2005 Womack and Jones crystallised a new principle of lean taking into account the frustration and disappointment a customer suffers when using (consuming) a product: low reliability, durability, poor performance etc. (Womack & Jones, 2005). In articulating loss to the society through the loss function, Taguchi too was thinking about losses to the customer (as well as losses to the producer). Womack and Jones (2005) assert that systematic attack on waste is also a systematic attack on the factors underlying poor quality and fundamental management problems (Monden, 1997). Basically, reduction of process variability means improvement of process outcomes while reducing waste that is similar to zero variability equates to zero waste and zero defects in ideal situation if the target is correct (Nicholas, 1998). According to the above cited authors, Taguchi method and lean manufacturing are waste elimination approaches having some parallels with each other. Therefore it is logical to hypothesise some degree of correlation between
Taguchi’s DOE philosophy and the lean manufacturing philosophy. This gives rise to the fifth hypothesis:

**H5: Taguchi’s DOE philosophy is positively related to lean manufacturing system.**

Surprisingly, there are very few studies that look at how the Taguchi method could be integrated within a lean manufacturing environment. A small electrical manufacturing company in Midwestern, United States used DOE methods to reduce the waiting time and defects in the plasma cutting machine. The lean six sigma team which solved the problem also used the ‘5 whys’ method to clear one of the major bottlenecks that keep company away from the moving towards the future state (Chen, Li, & Shady, 2010). One of the leading forging companies in Eastern India, used Taguchi methods (parameter design) to successfully map in lean environment to minimise forging defects produced due to imperfect operating conditions, which were identified through the present and future states of value stream maps (Sahoo, Singh, Shankar, & Tiwari, 2007).

In recent years several types of organisations/industries have employed the continuous improvement approaches as a new management paradigm (Bessant, Caffyn, & Gallagher, 2001; Caffyn, 1999; Singh & Singh, 2012). There are several definitions given for continuous improvement in academia as well as in industry. Every organisation needs to be continually improved to compete in the continuously changing environment such as rapidly to new demands to remain in manufacturing competitiveness (Singh & Singh, 2012). Bessant et al. (1994) asserted that “continuous improvement is increasingly being seen as an important complement to more radical, step-change forms of innovation”. The continuous improvement concept underlying the Deming management method was exemplified as “the propensity of the organisation to pursue incremental and innovative improvements of its processes, product, and services” (Anderson, Rungtusanatham, & Schroeder, 1994). Therefore the generic meaning of one of the constructs of theoretical model is titled as continual improvement to mean both incremental/small-step improvement (kaizen) as well as non-incremental/big-step improvement (innovation).

There is overwhelming support in the literature (Bhuiyan & Baghel, 2005; Caffyn, 1999; Singh & Singh, 2012) to suggest that continual improvement has direct effect on process outcomes. This gives rise to the final (sixth) hypothesis:

**H6: Continual improvement has a positive effect on manufacturing process outcomes.**

### 3. Research Methodology

Having developed a theoretical model explaining how the Taguchi philosophy is integrated with lean manufacturing (section 2), the next step is to collect data to test the model using structural equation modelling (SEM). For this purpose a questionnaire has been developed (currently at the content review stage by eight content experts) to capture the four constructs in the theoretical model. Due to space constrains the questionnaire (as well as the literature used to develop the questionnaire) is not enclosed in this paper.

The questionnaire consists of two parts. Part A covers general information about the person who answered the questionnaire. Part B consists of 41 items in the form of 41 statements. These are used to capture the four (4) constructs of the proposed theoretical model. A seven-point Likert scale is used in each of the 41 statements.
After completion of the content review, including incorporation of emendations to the questionnaire (end of November 2012), the questionnaire will be further tested through a sub sample (n = 15) of the relevant population (i.e. pilot testing) for improving the clarity of the questionnaire and to identify any issues associated with the questionnaire.

Upon completion of the pilot testing (February 2013), the questionnaire will be administered on a stratified sample representing managers (senior, middle and junior level) employed in 31 manufacturing plants in 31 locations in Sri Lanka. The questionnaires will be posted to approximately 1000 respondents with the hope that there will be at least a 20% response rate. This will result in about 200 responses, which would be sufficient to obtain the 80% statistical power required for the RMSEA goodness-of-fit test used in SEM (MacCallum, Browne, & Sugawara, 1996). Blue collar workers have been excluded from the study because of all blue collar workers may not have the ability (e.g. literacy skills) to respond to all the questionnaire items in the questionnaire reliably.

The study reported in this paper will also involve two subsequent waves (second and third waves) of data collection from a narrower group of respondents (about 10 to 15) located at a specific plant in which a Taguchi DOE will be carried out by the first author to address the fourth research objective mentioned earlier (section 1.1.4). The second wave corresponds to quantitative data collected from the Taguchi DOE, which addresses a specific product/process problem at the plant (the problem is yet to be identified). The major steps that will possibly be involved in the second wave of data collection and data analysis are briefly described below.

An initial fact-finding inquiry will be conducted with higher-level managers and operators to unearth operational problems (at a selected manufacturing plant of the company) that impact product quality. Examination of SPC charts such as year-to-date quality related Pareto chart, control charts, histograms etc. can also be used to identify processes that need improvement. Of the problems identified, one will be chosen for solving (using Taguchi methods), based on the (negative) impact a problem has in achieving the future state shown in the value-stream map. After that, the problem and the objectives to be achieved will be defined in qualitative terms. Then the next stage will be followed by a brainstorming session to identify potential factors (potential causes) that have an effect on the defined problem using a tool/s such as cause and effect diagram, ‘5 whys’ etc.. The potential factors will be further assessed and reduced to few key signal and noise factors. In the next step, the levels for the key factors as well as interactions between the factors will be identified to fit them into an appropriate orthogonal array. The signal and noise factors will then be manipulated as per the orthogonal array and the values of the response will be recorded. The data will then be analysed (using procedures prescribed by Taguchi) to determine the factor-settings (levels) that achieve the desired outcome by solving the problem. Finally, a verification test will be carried out on the new settings to validate the findings (i.e. to validate that the desired outcome is actually achieved at the chosen factor settings).

The second wave of data collection will be immediately followed by a third wave of (qualitative) data collection based on the experiences the respondents have had in conducting the Taguchi DOE with the first author. It is hoped that this exercise will result in context-rich information related to issues surrounding using Taguchi methods in lean apparel companies.

3.1 A Brief Overview of the Case Study Organisation
The research project will be carried out in collaboration with a multimillion dollar Sri Lankan lean apparel organisation, which has branches in ten other countries (India, China, Mexico, Indonesia, Bangladesh, Vietnam, UK etc.). There are many parallels with the Toyota Production System and the operating system of the Sri Lankan organisation (fibre2fashon, 2007). This organisation exports garments for US and European markets under brand names such as Victoria’s Secret, NIKE, GAP, BHS, Pink, Banana Republic and Speedo. Thus case study organisation does its share in contributing to Sri Lanka’s GDP (the annual turnover of the case study organisation is over US$ 800 million approximately). Given that quality is what sets apart world class apparel brands from the others it is hoped that this study may also benefit the case study organisation also, for example by being able to learn how a new tool (Taguchi methods) can be added to their lean tool box to achieve their operational goals.

4. Expected Outcomes

Without the actual data and the results, it is difficult to predict whether or not all of the six hypotheses covered in this paper would be supported by the data collected in the first wave of data collection.

Obviously failing to accept a few hypotheses shown in the structural model (Error! Reference source not found.) does not invalidate the position that Taguchi methods can be integrated within a lean manufacturing environment, if the theoretical model shown in Error! Reference source not found. becomes a good fit to the data, within a SEM framework (Blunch, 2008; B. M. Byrne, 2009). It is hoped that the data will support the theoretical model (an acceptable fit to the data) and consequently, most of the hypotheses will be supported.

It is also hoped that the second and third waves of data collection will also result in useful outcomes such as demonstrating the benefits of the Taguchi methods to the lean practitioner in the apparel industry and identifying any issues in introducing Taguchi methods in the apparel industry. Therefore it is hoped that the study proposed in this paper will result in significant new knowledge.

5. Concluding Remarks

At this stage, in the absence of data and results, as mentioned earlier, no definitive conclusions can be given on final outcomes of the study.

It was argued that both Taguchi methods (philosophical element) and Lean manufacturing do focus on waste minimisation. A theoretical model was proposed to support this argument and the proposed method of testing the model (data collection and statistical techniques that will be used) was described. Each of the four constructs used in the theoretical model—lean manufacturing system, continual improvement, Taguchi’s DOE philosophy, and manufacturing process outcomes—are very important constructs in their own right. Given the fact that the study reported in the study covers how these constructs are measured and are causally related, not to mention the potential benefits of other components of field work (e.g. conducting an actual Taguchi DOE in a lean environment), means that the study has the potential to become very useful to both the academia and the lean practitioner.

There are a few limitations in the research. The findings may be specific to the particular industry (apparel) of which the data will be collected. Therefore one should be extremely cautious in generalising the results beyond the apparel industry. The other limitation could possibly be in
difficulties in getting highly representative random samples from the population (the entire case study organisation). Even though the questionnaire will be sent to respondents picked through a stratified random sampling process, there is no guarantee that the results will not be affected by nonresponse bias (some groups of people may have a greater chance of not responding to the questionnaire than the others). Taguchi prescribed a wide variety of statistical designs and in this study examines only Taguchi’s parameter design approach in the second wave of data collection and analysis by addressing the fourth research objective (section 1.1.4). This study does not explore the possibility of using other designs prescribed by Taguchi in a lean environment.

References


