Received 30 March 2013
Revised 4 July 2013
Accepted 8 July 2013

A Six Sigma and DMAIC application for the reduction of defects in a rubber gloves manufacturing process

Ploytip Jirasukprasert
Warwick Manufacturing Group, The University of Warwick, Coventry, UK
Jose Arturo Garza-Reyes
Centre for Supply Chain Improvement, The University of Derby, Derby, UK
Vikas Kumar
Dublin City University Business School, Dublin City University, Dublin, Republic of Ireland, and
Ming K. Lim
Centre for Supply Chain Improvement, The University of Derby, Derby, UK

Abstract

Purpose – In this era of globalisation, as competition intensifies, providing quality products and services has become a competitive advantage and a need to ensure survival. The Six Sigma's problem-solving methodology DMAIC has been one of the several techniques used by organisations to improve the quality of their products and services. This paper aims to demonstrate the empirical application of Six Sigma and DMAIC to reduce product defects within a rubber gloves manufacturing organisation.

Design/methodology/approach – The paper follows the DMAIC methodology to systematically investigate the root cause of defects and provide a solution to reduce/eliminate them. In particular, the design of experiments, hypothesis testing and two-way analysis of variance techniques were combined to statistically determine whether two key process variables, oven's temperature and conveyor's speed, had an impact on the number of defects produced, as well as to define their optimum values needed to reduce/eliminate the defects.

Findings – The analysis from employing Six Sigma and DMAIC indicated that the oven's temperature and conveyor's speed influenced the amount of defective gloves produced. After optimising these two process variables, a reduction of about 50 per cent in the "leaking" gloves defect was achieved, which helped the organisation studied to reduce its defects per million opportunities from 195,095 to 83,750 and thus improve its sigma level from 2.4 to 2.9.

Practical implications – This paper can be used as a guiding reference for managers and engineers to undertake specific process improvement projects, in their organisations, similar to the one presented in this paper.

Originality/value – This study presents an industrial case which demonstrates how the application of Six Sigma and DMAIC can help manufacturing organisations to achieve quality improvements in their processes and thus contribute to their search for process excellence.

Keywords Six Sigma, DMAIC, Defects reduction, Manufacturing process, Rubber gloves

Paper type Case study

International Journal of Lean Six Sigma
Vol. 5 No. 1, 2014
pp. 2-21

2040-4166
DOI 10.1108/IJLSS-03-2013-0020

1. Introduction

Fierce competition and more complex customer needs and demands have forced entire industries and organisations to continuously improve the quality of their products and services as a mean to gaining a strategic competitive advantage. As well as the rubber gloves manufacturing industry, the organisation studied in this paper itself has to maintain the quality of its products so as to be able to delight customers and thus effectively compete in the market. In general, one of the most vital concerns for the rubber gloves manufacturing industry is the reduction of common quality defects such as holes and stain in gloves. According to Dennis (2002), defects result in rework which consumes more materials, time and energy. Similarly, Slack *et al.* (2010) comment that quality defects increase service, inspection/test, warranty, rework, and scrap costs as well as inventory and processing time. However, although the negative effects resulting from quality problems will invariably affect the operational performance of an organisation, their most important repercussion may be considered to be the loss of customers' satisfaction and trust. Thus, Jugulum and Samuel (2008) state that delivering flawless products is important not only because it generates profits but also because it helps to increase business competitiveness through customers' satisfaction. This was the main driver for a particular Thai gloves manufacturing organisation to improve the quality of its products. This paper presents an empirical case study where some quality issues at this Thai rubber gloves manufacturing company were investigated and improved. Based on the investigation performed, the paper provided a method, evoking the principles and tools of Six Sigma, and a solution to reduce/eliminate the most common defects encountered. Therefore, this paper can be used by managers and engineers in charge of the improvement of processes as a guide to direct the empirical application of Six Sigma and its methods and tools.

Six Sigma may be considered one of the most important developments to quality management and process improvement of the last two decades (Garza-Reyes *et al.*, 2010). It was initiated at Motorola in the 1980s and since then it has gained wide popularity among organisations. For instance, most *Fortune* 500 companies have employed this methodology with the objective of improving their performance (Goh, 2002). Financial evidence suggests that Six Sigma does help firms to achieve significant improvements in performance. For example, some analysts attribute the very survival, and nowadays existence, of Motorola to the adoption of this approach as part of its organisational culture as it helped it to produce $16 billion dollars in savings during the period 1986-2001 (Eckes, 2001; Hendricks and Kelbaugh, 1998). Similarly, other large organisations such as General Electric (GE), 3M and Honeywell also reported significant savings in their operations due to the use of Six Sigma (Arndt, 2004; GE Annual Report, 2002; 3M Annual Report, 2003; Honeywell Annual Report, 2002). According to Garza-Reyes *et al.* (2010), one of the Six Sigma's distinctive and essential approaches to process and quality improvement is define, measure, analyse, improve, control (DMAIC). Under the umbrella of this model, several statistical and quality improvement tools such as cause-and-effect diagram, Pareto chart, design of experiments (DOE) and two-way analysis of variance (ANOVA) were used in the improvement project presented in this paper. As an initial step, this paper reviews some of the relevant theory of Six Sigma and DMAIC, paying particular attention to its philosophy and principles, the benefits and the positive impact on performance that these approaches bring to organisations, and the manufacturing process studied.

2. Literature review on Six Sigma and DMAIC

The Sigma's name originates from the Greek alphabet and in quality control terms, sigma (σ) has been traditionally used to measure the variation in a process or its output (Omachonu and Ross, 2004). In the Six Sigma's terminology, the "sigma level" is denoted as a company's performance (Pyzdek and Keller, 2010). Particularly, a Six Sigma level refers to 3.4 DPMO (Stamatis, 2004), or in other words, to have a process which only produces 3.4 defects per every one million products produced. The measure of performance and process variability, according to Brue and Howes (2006), is only one of the three meanings of Six Sigma. According to them, besides of being a measure of performance and process variability, Six Sigma is also a management philosophy and strategy that allows organisations to achieve lower cost, as well as a problem solving and improvement methodology that can be applied to every type of process to eliminate the root cause of defects.

Six Sigma focuses on the critical characteristics that are relevant for the customers. Based on these characteristics, Six Sigma identifies and eliminates defects, mistakes or failures that may affect processes or systems. Bailey *et al.* (2001) comments that among the most widely used improvement approaches (i.e. total quality management, business process re-engineering and lean enterprise), Six Sigma has the highest record of effectiveness. Therefore, some authors argue that the main benefits that an organisation can gain from applying Six Sigma are: cost reduction, cycle time improvements, defects elimination, an increase in customer satisfaction and a significant raise in profits (Pyzdek and Keller, 2010; Stamatis, 2004; Dale *et al.*, 2007; Breyfogle III *et al.*, 2001). Markarian (2004) suggests that not only can the process improvement generated by Six Sigma be used in manufacturing operations, as it is the case for the study presented in this paper, but it can also be expanded to improve other functions such as logistics, purchasing, legal and human resources. In addition, Kumar *et al.* (2008) state that although Six Sigma is normally used in defects reduction (i.e. industrial applications), it can also be applied in business processes and to develop new business models. In this context, Garza-Reyes *et al.* (2010) applied the Six Sigma philosophy, and some of its principles, to improve (by reducing errors) the business process employed by an SME to define and produce the specifications and documentation for its customer-made products. Banuelas *et al.* (2005) claim that other benefits such as:

- an increase in process knowledge;
- participation of employees in Six Sigma projects; and
- problem solving by using the concept of statistical thinking can also be gained from the application of Six Sigma.

To illustrate this point, during the utilisation of Six Sigma in this research project, several techniques and tools were employed. Therefore, skills in the use of these techniques and tools were built up within the staff of the Thai organisation studied. As a consequence, people involved in the project enhanced their knowledge and skills. As a reason, not only does an organisation itself gain benefits from implementing Six Sigma in terms of cost savings, productivity enhancement and process improvement, but individuals involved also increase their statistical knowledge and problem-solving skills by conducting a Six Sigma project.

An integral part of Six Sigma is DMAIC. The DMAIC model refers to five interconnected stages that systematically help organisations to solve problems and improve their processes. Dale *et al.* (2007) briefly defines the DMAIC phases as follows:

- *Define*. This stage within the DMAIC process involves defining the team's role; project scope and boundary; customer requirements and expectations; and the goals of selected projects (Gijo *et al.*, 2011).
- *Measure*. This stage includes selecting the measurement factors to be improved (Omachonu and Ross, 2004) and providing a structure to evaluate current performance as well as assessing, comparing and monitoring subsequent improvements and their capability (Stamatis, 2004).
- *Analyse*. This stage centres in determining the root cause of problems (defects) (Omachonu and Ross, 2004), understanding why defects have taken place as well as comparing and prioritising opportunities for advance betterment (Adams *et al.*, 2003).
- *Improve*. This step focuses on the use of experimentation and statistical techniques to generate possible improvements to reduce the amount of quality problems and/or defects (Omachonu and Ross, 2004).
- *Control*. Finally, this last stage within the DMAIC process ensures that the improvements are sustained (Omachonu and Ross, 2004) and that ongoing performance is monitored. Process improvements are also documented and institutionalised (Stamatis, 2004).

DMAIC resembles the Deming's (1993) continuous learning and process improvement model PDCA (plan, do, check, act). Within the Six Sigma's approach, the DMAIC model indicates, step by step, how problems should be addressed, grouping quality tools, while establishing a standardised routine to solve problems (Bezerra *et al.*, 2010). Thus, DMAIC assures the correct and effective process execution by providing a structured method for solving business problems (Hammer and Goding, 2001). This rigorous and disciplined structure, according to Harry *et al.* (2010), is what many authors recognise as the main characteristic which makes this approach very effective. Pyzdek (2003) considers DMAIC as a learning model that although focused on "doing" (i.e. executing improvement activities), also emphasises the collection and analysis of data, previously to the execution of any improvement initiative. This provides the DMAIC's users with a platform to take decisions and courses of action based on real and scientific facts rather than on experience and knowledge, as it is the case in many organisations, especially small and medium side enterprises (SMEs) (Garza-Reyes *et al.*, 2010).

Although many other process improvement and problem-solving methodologies such as QC story (Tadashi and Yoshiaki, 1995), seven steps method (Westcott, 2006), Xerox quality improvement process and problem-solving process (Palermo and Watson, 1993), ADDIE (Islam, 2006), FADE (Schiller *et al.*, 1994), among others, have been developed by organisations to improve their manufacturing and business processes, DMAIC may arguably be considered the most widely used and popular approach. This is because it is an essential element of Six Sigma, which has been extensively implemented in industry (Black and Revere, 2006; Antony, 2004) and lean Six Sigma, which has also received considerable attention from academics, researchers and industrialists (George *et al.*, 2005; Näslund, 2008).

3. Rubber gloves manufacturing process

As concern for hygiene in different industrial sectors such as healthcare and food-handling has increased, the demand for sterilised rubber gloves has also expanded.

For example, the President of the Malaysian Rubber Glove Manufacturers Association (Margma), Lee Kim Meow, stated in Ching (2010) that the rubber gloves industry is expected to continue growing due to the increasing healthcare awareness in emerging markets, especially in Latin American countries, China and India. As a result, it is of paramount importance for organisations in this industry to improve their manufacturing processes and achieve a level of quality that not only satisfies but also exceeds the expectation of their customers. Rubber gloves manufacturing processes, and particularly the process studied and investigated in this paper, are generally comprised of seven steps, namely:

(1) raw material testing;
(2) compounding;
(3) dipping;
(4) leaching and vulcanising;
(5) stripping and tumbling;
(6) quality control; and
(7) packing.

The precise details of the rubber gloves manufacturing process featuring in this case study are proprietary information though it can be summarised in the seven steps described below:

- *Step 1: raw material testing*. According to Hirsch (2008), raw material testing is important as it prevents the production of out-of-specification products, from which unnecessary expenses can be created. In the case of the Thai gloves manufacturing company studied, the assessment and analysis of raw materials are performed in the factory's laboratory, where they are subjected to different detailed and stringent quality tests (i.e. chemical properties testing) before they proceed to the compounding process.
- *Step 2: compounding*. This stage of the process consists of dispersion. This method is prepared by a ball mill technique which is used for blending the chemical substances together with proper monitoring of time and other important aspects. An approved dispersion from the company's laboratory is mixed with latex based on its specified formulation. The compound latex is then measured and tested to confirm that it meets the specification requirements, before it is fed to the production line.
- *Step 3: dipping*. In order to form the gloves by using gloves moulds, a dipping process is required. The moulds are cleaned with diluted HCL acid, NaOH and water so as to remove dust and contaminants, and are then dried and dipped into the coagulant tank, which contains a processed chemical. After having become sufficiently dried, the gloves begin to shape and the moulds are dipped into the compound latex. Both coagulant and compound latex tanks are properly checked for their properties and conditions such as total solid content, temperature, and levelled to ensure that they contain the appropriate components.
- *Step 4: leaching and vulcanising*. Vulcanisation is a process which is fulfilled with sulfur. It includes a combination of rubber, sulfur and other ingredients heated

up and behold until rubber has formed into a tough and firm material (Kumar and Nijasure, 1997). In the case of the rubber gloves manufacturing process performed by the organisation studied, proper latex gel on moulds are beaded, further dried, and then leached into the pre-leach tank before they are vulcanised to ensure the best physical properties and reduce moisture content. All the gloves are then moved through the pre-leaching and post-leaching processes into treated hot water at around 80-90°C with an overflow system. The post-leaching is used to ensure the minimum latex protein level and to remove the extractable water soluble materials, chemical residue and non-rubber particles. Cyclone tumbling is the final step in the leaching and vulcanising process. In this step, the gloves are tumbled, with temperature and time critically controlled to reduce powder content and moisture to a minimum level.

- *Step 5: stripping and tumbling*. After the leached gloves are dipped into a closely controlled wet slurry tank to build up bacterial and protein content, the gloves are finally stripped from the formers with auto-stripping lines.
- *Step 6: quality control*. The quality control process is performed by random sampling after all products have been finished. The products are inspected by several methods. The first method is called airtight inspection. In this method, air blowers are used to investigate whether the air is coming out from the gloves by looking for pin holes which might appear on the glove's surface, if so, these gloves are rejected. In this type of inspection, the air stays in the gloves for approximately one hour. The second quality control method to which gloves are subjected is watertight test. This method is fundamentally similar to airtight inspection but in this case water is poured inside the gloves instead of the air. The third quality control method consists of a visual inspection to check for stain marks on the gloves and/or misshaped gloves. Defective gloves are rejected. Lastly, size, thickness and aesthetic appeal are also inspected to ensure that the form of the gloves is in accordance with specifications.
- *Step 7: packing*. The gloves packing area is under a tight controlled dust free environment by using a hygienic filtered air system. Packing operators perform, as part of their packing operation, one last visual inspection and remove defective products before packing the gloves. A hundred pieces of a specific size are first weighed and such weight is made up for packing per box. Finally, the boxes are loaded into cardboard boxes to be ready to be delivered to customers.

4. Six Sigma and DMAIC application – a case study

This section presents the practical application of Six Sigma, and DMAIC, in the rubber gloves manufacturing process of the organisation studied. Thus, this section is sub-divided based on the sequential stages that must be systematically undertaken, according to the DMAIC model, for process improvement and problem-solving. In terms of the research methodology followed, a single detailed case study, like the one presented in this paper, can be considered a valid research approach (Cameron and Price, 2009) to demonstrate the application of Six Sigma, DMAIC, and some of its concepts and tools so as to be replicated, or used as guide, by managers and engineers in their quest for the improvement of manufacturing processes.

4.1 Define

The first stage of the Six Sigma and DMAIC's methodology is "define". This stage aims at defining the project's scope and boundary, identifying the voice of the customer (VOC) (i.e. customer requirements) and goals of the project (Gijo *et al.*, 2011). However, before defining these elements within the project, the Six Sigma team has to be set up. In the case of this improvement project, the team was comprised of three people, which included a production manager, an experienced operator from the shop-floor, and the improvement project leader.

Stating the project's scope was the next step within the "define" stage of DMAIC. Nonthaleerak and Henry (2008) suggest that a Six Sigma project should be selected based on company issues related to not achieving customers' expectations. The chosen projects should be focused on having a significant and positive impact on customers as well as obtaining monetary savings (Nonthaleerak and Henry, 2008; Murugappan and Kenny, 2000; Banuelas and Antony, 2002). Regarding to these suggestions, the problem selected to be tackled through this project was to reduce/eliminate quality defects (i.e. holes/stains) on gloves, which clearly comprise both an impact on customers' expectations and important savings for the organisation studied. In addition, according to Pande *et al.* (2000) listening to customers is critical for a business to be successful. Therefore, the VOC concept, which means identifying what the customers want and serving priorities to their needs (Griffin and Hauser, 1993) was used in this project to define, based on customer requirements, the selected project's objective.

In order to ensure that the research is in-control and focuses on the project problem explicitly, the boundary of the project had to also be defined and clearly indicated. This research was set to experiment solely with the gloves of "medium" (M) size. The improvement team and organisation decided to initially focus on this particular product not only due to this size had historically had the highest number of rejected products but also the largest orders from customers.

Montgomery (2001) indicates that the improvement of processes is not possible unless there is strong support and commitment from top management and other functions within the organisation. Therefore, alongside the creation of the improvement team and definition of the project's scope, boundary and objectives, gaining support from top management was a key activity. The objective of this was to legitimate the improvement project, make the reduction of quality defects a goal for the organisation, and ensure that resources were assigned to it. The Juran's concept of "cost of quality" was employed as a strategy to obtain top management's commitment. In this context, the overall cost that the organisation was incurring on due to the production of defective gloves was calculated. The fundamental principle of the "cost of quality" concept is that any cost that would not have been expended if quality were perfect is a cost of quality (Ishikawa, 1982). After being calculated, the resulting figures were presented to the organisation's top management. This assured their commitment towards the project as it demonstrated that a reduction in defective gloves would directly produce a significant cost saving for the company.

Finally, a project charter, which is a tool used to document the objectives of the project and other parameters at the outset (Pande *et al.*, 2000), was employed to state and present the project's information structure. The project charter, in other words, summarised the project's scope, boundary, VOC, objective and the team's role in this improvement project. The project charter is presented in Table I.

Project title	Defects reduction in rubber gloves
Background and reasons for selecting the project	A large amount of rubber gloves has been rejected by customers due to they were defective. This problem causes several types of losses to the company, for example, time, materials, capital as well as it creates customers' dissatisfaction, which negatively affects the organisation's image
Project objective	To reduce the defects by 50 per cent after applying Six Sigma into the gloves manufacturing process
Voice of the customer (VOC)	Product's quality
Project boundary	Focusing the gloves solely on "medium" (M) size
Team members	Production manager, an experience shop-floor operator and the improvement project leader
Expected financial benefits	A considerable cost saving due to defects reduction
Expected customer benefits	Receiving the product with the expected quality

Table I. Project charter

4.2 Measure

The "measure" phase of the DMAIC problem-solving methodology consists of establishing reliable metrics to help monitoring progress towards the goal(s) (Pyzdek, 2003), which in this project consisted of reducing the number of quality defects in the rubber gloves manufacturing process. Particularly, in this project the "measure" phase meant the definition and selection of effective metrics in order to clarify the major defects which needed to be reduced (Omachonu and Ross, 2004). One of the metrics defined was simply number of defects per type. In addition, two other metrics were used to compare the "before and after" states of the gloves manufacturing process when conducting the Six Sigma's project. These factors were quality level, which was measured through DPMO, and the sigma level of the process.

After defining the total number of defects, the DPMO and sigma level of the gloves manufacturing process were calculated. According to the company's records, there were two major types of defects which had contributed to the gloves to be rejected by the customers. These two major defects were leaking and dirty gloves. In addition, other less frequent defects were grouped and categorised as "miscellaneous". For this particular research, the leak defect was defined as those gloves that had one or more holes and thus presented a water/air leak when subjected to quality testing. In the case of the dirty gloves defect, it was defined as the gloves not being clean (i.e. having one or more stain marks). Finally, the miscellaneous category consisted of other types of defects such as misshaped, sticky gloves, etc. Defects data was collected for twenty days. The results are summarised in Table II.

As a next step, a Pareto analysis (Slack *et al.*, 2010; Ishikawa, 1982) was carried out to identify the utmost occurring defects and prioritise the most critical problem

Type of defects	Number of defects	Percentage of defects
Leaking	4,495	19.51
Miscellaneous	1,686	7.32
Dirty	788	3.42
Total	6,969	30.25

Table II. Defects summary (before the Six Sigma improvement project) which was required to be tackled. The collected data was generated in the form of a Pareto chart, which is shown in Figure 1.

The Pareto chart shown in Figure 1 indicated that the highest rate of defects was caused by leaking gloves. In particular, this type of defect contributed to over 60 per cent of the overall amount of defects. Therefore, the improvement team and organisation decided to initially focus on the reduction of the leaking gloves defect. The leaking gloves defect rate was then translated into the quality and sigma levels as "Quality level – 195,095 DPMO" and "sigma level – 2.4 sigma". With this amount of defects and sigma level, and according to the classification of organisational performance proposed by Harry (1998) and Lucas (2002) in relation to the DPMO and sigma level measures, the organisation studied could be categorised as "non-competitive". This reinforced the importance that this improvement project had for the organisation. The calculation of the DPMO and sigma metrics allowed the improvement team and organisation to have a more detail and operational definition of the current state of the gloves manufacturing process as well as the Six Sigma's objective in terms of the gloves process improvement. These are shown in Table III. The next stage in the Six Sigma project, and following the

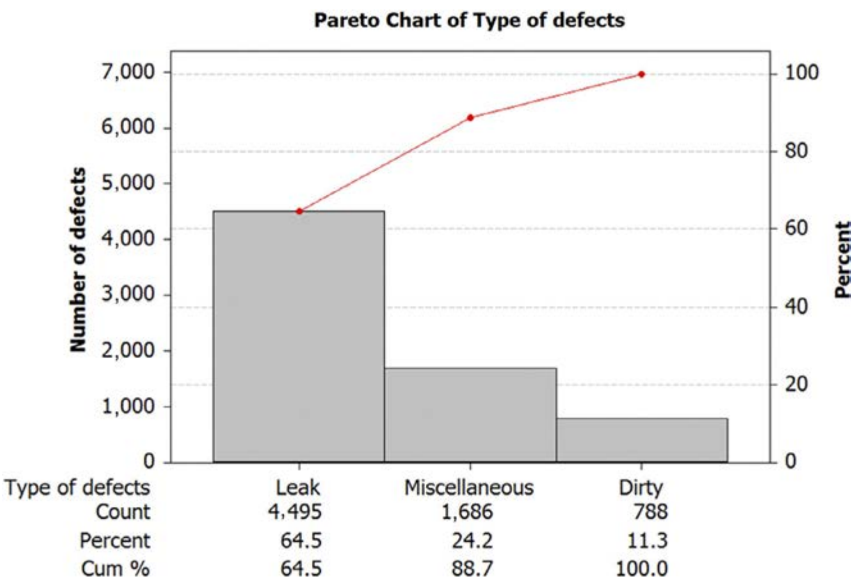


Figure 1.
Gloves defects Pareto chart

Table III.
Gloves manufacturing process – current and expected states

Major type of defects	Number of the major defect (units) C*	E*	Quality levels (DPMO) C*	E*	Sigma levels C*	E*	Loss ($) C*	E*
Leaking gloves	4,495	2,248	195,095	97,569	2.4	2.8	$16,000	–

Notes: C* – current process performance; E* – expected process performance after the completion of the Six Sigma project

DMAIC methodology, consisted in analysing the root causes of this particular problem, as well as identifying an appropriate solution.

4.3 Analyse

This phase in the DMAIC improvement model involves the analysis of the system, in this case the manufacturing process that produces the rubber gloves, in order to identify ways to reduce the gap between the current performance and the desired objectives(s) (Garza-Reyes *et al.*, 2010). To do this, an analysis of the data is performed in this phase, followed by an investigation to determine and understand the root cause of the problem (defects) (Breyfogle III *et al.*, 2001). Identifying and prioritising improvement opportunities are then conducted (Omachonu and Ross, 2004). Garza-Reyes *et al.* (2010) comment that the activities carried out during the analyse stage can be performed through the use of specific approaches and techniques traditionally employed in this stage of DMAIC. The approaches and techniques normally used in the analysis stage include: process mapping, brainstorming, cause-and-effect diagrams, DOE, hypothesis testing, statistical process control (SPC) charts and simulation (Pyzdek, 2003). According to Pyzdek (2003), the nature of the project and the way in which it is conducted will normally dictate the selection of the most effective approaches.

In order to gain an enhanced comprehension and understanding of the gloves production process, which according to Aguilar-Saven (2003) is a main requirement for improvement, the analysis phase of this project started from illustrating the manufacturing process using a flowchart (Figure 2). Flowchart is a basic graphical tool used for displaying processes' flow sequentially (Pyzdek and Keller, 2010) in order to gain a full comprehension and understanding of the process. Figure 2 shows a detail picture of the different stages of the gloves manufacturing process.

Once that the inputs, outputs and sequence of the process were understood with the help of the flowchart, an analysis was carried out to identify the root cause(s) of the leaking gloves quality defect. Several brainstorming sessions were conducted to identify, based on the improvement team members' experience, possible causes as

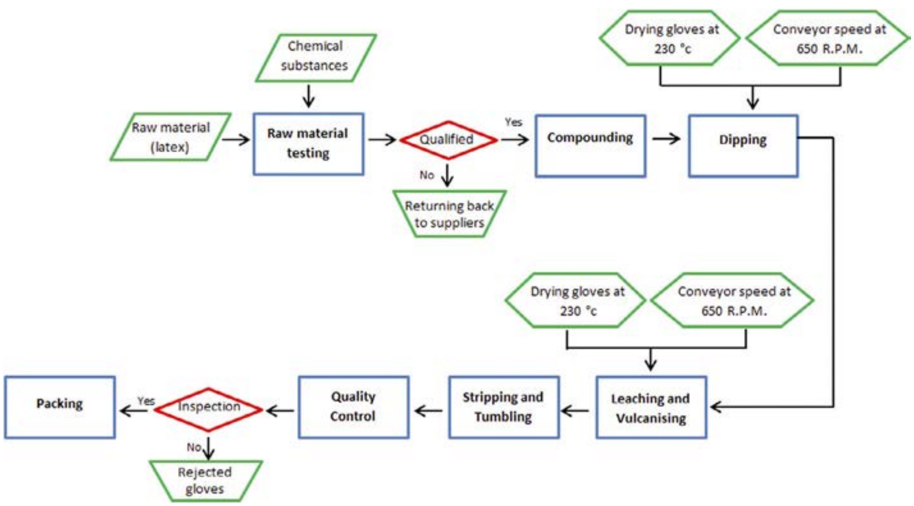


Figure 2.
Gloves manufacturing process flowchart

to why the leaking problem in gloves occurred. All members of the improvement team participated in the brainstorming sessions, where they were allowed to think and participate freely. Ishikawa (1982) comments that the identification and solution of root causes of quality problems is driven out by freedom thinking and participation. In order to illustrate and categorised the possible causes of the problem, a cause-and-effect diagram was constructed. The cause-and-effect diagram, also known as Ishikawa or fishbone diagram, is a systematic questioning technique for seeking root causes of problems (Slack *et al.*, 2010) by providing a relationship between an effect and all possible causes of such effect (Omachonu and Ross, 2004). Once completed, the diagram helps to uncover the root causes and provide ideas for further improvement (Dale *et al.*, 2007). There are five main categories normally used in a cause-and-effect diagram, namely: machinery, manpower, method, material and measurement (5 M) (Dale *et al.*, 2007) plus an additional parameter: environment. The possible root causes brainstormed are illustrated in the cause-and-effect diagram shown in Figure 3.

After considering all possibilities, it was found that some stages and operations (i.e. dipping, leaching and vulcanising) within the gloves manufacturing process had an impact on causing the leaking gloves. In particular, it was determined that two process factors (i.e. oven's temperature and conveyor's speed) had a direct effect on the number of leaking gloves produced. Interestingly, these parameters had a relationship between each other as the gloves have to be dried by using oven's heat at the same time as they are conveyed by the rollers. As a consequence, the relationship between oven's temperature and conveyor's speed and their impact on the number of leaking gloves produced was investigated in the following DMAIC's improve phase.

4.4 Improve

After the root cause(s) has/have been determined, the DMAIC's improve stage aims at identifying solutions to reduce and tackle them (Omachonu and Ross, 2004). Stamatis (2004) suggests the use of DOE, which is defined as a statistical technique to investigate effects of multiple factors (Roy, 2001; Antony and Kaye, 2000), in the improve phase. According to Montgomery (2009), benefits of DOE can be seen as enhancing process yields, decreasing variability and lowering the overall expenses. Therefore, although experience and common sense dictated the existence of a correlation between oven's

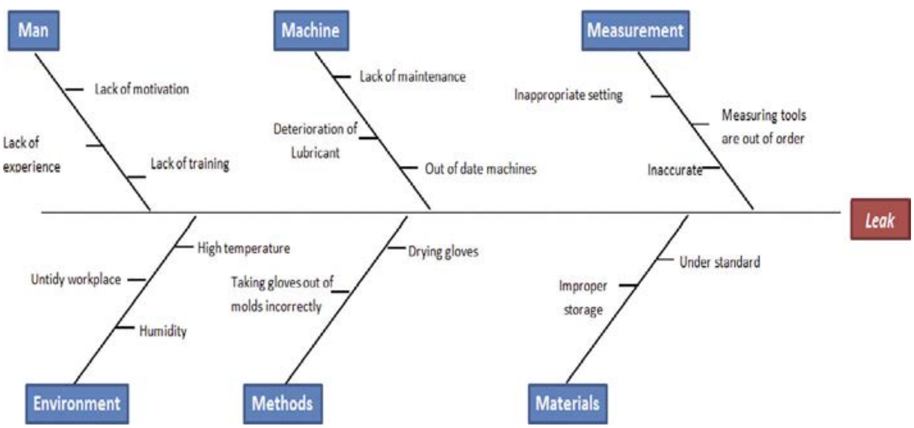


Figure 3.
Cause-and-effect diagram related to the leaking gloves quality problem

temperature and conveyor's speed with the number of leaking gloves, the DOE technique was used to investigate whether the assumed correlation was statistically significant. In particular, an experiment was designed to investigate whether the combination of the factors oven's temperature and conveyor's speed had a negative effect on the process, causing leaking gloves. Specifically, the experiment consisted in manipulating these factors by modifying them into different parameters (i.e. other values for oven's temperature and conveyor's speed) and analysing their impact on the process output. To do this and in order to analyse the experiment's results, two-way analysis of variance (ANOVA) was used. ANOVA is a statistical model for comparing differences among means of more than two populations (Moore *et al.*, 2009). However, if there are two sources of data, like in this case, which need to be investigated, two-way ANOVA, which is a statistical methodology for analysing the effect of two factors, is required (Moore *et al.*, 2009). The two factors which were mentioned earlier (i.e. oven's temperature and conveyor's speed) were investigated with four different parameters of temperatures; 220°C, 225°C, 230°C and 235°C and four distinct speeds; 600, 650, 700 and 750 revolutions per minute (RPM). These parameters were defined based on the process knowledge and experience of the improvement team members, specifically the production manager and shop-floor operator. From this point, the experiment was conducted with two factors (i.e. temperature and speed) at four levels each. Since performing a large number of experiment trials can be expensive, time consuming (Montgomery, 2009) and disrupt normal production, the improvement team determined, based on production capacity, that the experiment could be replicated four times for each combination of factors, where 1,280 units (i.e. gloves) where collected for every replication. This resulted in a total of 64 replications. Pyzdek and Keller (2010) suggest the two-way ANOVA with replication as the most effective tool to be used for this type of analysis. Table IV presents the experiment's structure and the results obtained, in terms of leaking defects, from the experiment trials. For example, Table IV indicates that at an oven's temperature of 220°C and a conveyor's speed of 600 RPM, 278 leaking gloves

		Conveyors speed (RPM)				
Temperature (°C)	Order	600	650	700	750	Number of defects (units)
220	1	278	189	156	147	2,682
	2	244	154	193	108	
	3	253	173	129	83	
	4	214	147	101	113	
225	1	212	120	101	78	1,780
	2	152	85	62	28	
	3	200	71	94	71	
	4	166	106	83	152	
230	1	189	41	78	232	2,105
	2	150	60	127	173	
	3	168	74	133	193	
	4	147	44	94	202	
235	1	78	97	242	299	2,742
	2	127	85	205	292	
	3	87	147	170	219	
	4	94	99	223	278	
Number of defects (units)		2,758	1,691	2,192	2,668	18,616

Table IV. Experiment design structure (out of the 1,280 units inspected) were found in replication one, whereas in replication two, 244 leaking gloves were identified, and so on.

As the statistical test aimed at investigating whether the two factors (i.e. oven's temperature and conveyor's speed) resulted in defective gloves, null and alternative hypotheses that suggested whether a variation in the number of defects would occur if the oven's temperature and conveyor's speed were varied were formulated. These hypotheses are presented below:

H_0 α. There is no interaction between the temperature and the number of defects (leaking) ($\alpha_{220°C} = \alpha_{225°C} = \alpha_{230°C} = \alpha_{235°C}$).

H_0 β. There is no interaction between the speed and the number of defects (leaking) ($\beta_{600} = \beta_{650} = \beta_{700} = \beta_{750}$).

$H_{1.}$ There is interaction between the temperature and speed.

Note: α_i – variance derived from the temperature, β_j – variance derived from the conveyors speed.

Once formulated, the hypotheses were tested through the two-way ANOVA analysis with replication shown in Table V.

Hypotheses are evaluated based on the p-value and the F-statistic values (Moore *et al.*, 2009). In case of the F-statistic, Devore and Peck (1993) cite that when F-value is higher than F critical, H_0 is rejected. On the other hand, the p-value represents the H_0 rejection when the p-value is less than a significance value (Moore *et al.*, 2009). In the case of this improvement project, a comparison of F and F critical was used to test the hypotheses. This resulted in $H_0\alpha$ to be rejected ($F\alpha = 16.73373 > F\alpha$ critical 2.798061), $H_0\beta$ to be rejected ($F\beta = 18.77653 > F\beta$ critical $= 2.798061$), and H_0 to be rejected ($F\alpha\beta = 21.47981 > F\alpha\beta$ critical $= 2.08173$). Therefore, the two-way ANOVA analysis indicated that there was a correlation between the oven's temperature and conveyor's speed at a significance level $= 0.05$ (Iversen and Gergen, 1997). As a result, the analysis helped to statistically conclude that both temperature and speed influenced the amount of leaking gloves.

After it was statistically proven that the temperature and speed had a correlation with the number of leaking gloves, the next step was to determine the optimum temperature and speed that would result in the lowest amount of defects. The number of defects from the experiment replications are summarised in the line and Boxplot charts shown in Figure 4(a) and (b). These figures denoted that a 230°C temperature and conveyor speed of 650 RPM provided the lowest amount of leaking gloves.

After the optimum parameters were defined, a trial was performed in order to test whether the optimum parameters (i.e. 230°C and 650 RPM) defined by the experiment were the best options to provide an improvement for the gloves manufacturing process

Table V. Results of the two-way ANOVA analysis with replication

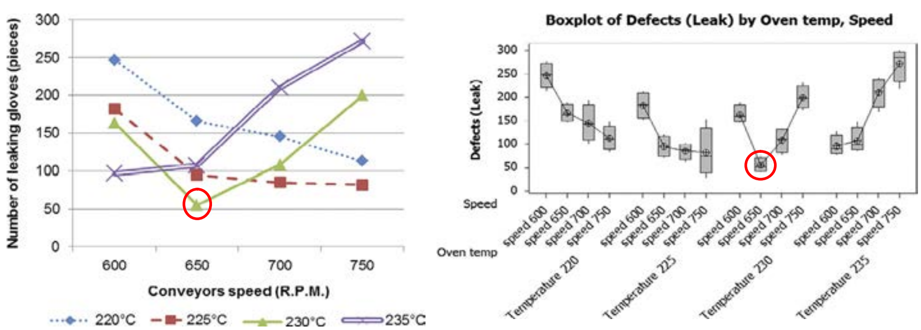
Source of variation	SS	df	MS	F	*P*-value	*F* critical
Sample (temp)	40,392.04	3	13,464.01	16.73373	1.41×10^{-07}	2.798061
Columns (speed)	45,322.98	3	15,107.66	18.77653	3.39×10^{-08}	2.798061
Interaction	155,544.6	9	17,282.73	21.47981	5.57×10^{-14}	2.08173
Within (errors)	38,620.97	48	804.6035			
Total	279,880.6	63				

and reduce defects. In order to avoid disrupting production and taking into consideration that the previous experiment had already determined the optimum oven's temperature and conveyor's speed, a sample size of only 12,800 units was taken as a base for the investigation. Table VI presents the results of the trial and a comparison between the "before and after" setting the new parameters. The results indicate that the optimum parameters identified in the experiment improved the gloves manufacturing process by reducing the amount of leaking gloves by about 50 per cent. This resulted in a reduction of DPMO from 195,095 to 83,750 and a sigma level improvement from 2.4 to 2.9. Consequently, the initial targets set for DPMO and sigma level, see Table III, were exceeded.

It can be concluded that, by setting up the oven's temperate at 230°C and conveyor's speed at 650 RPM, not only did the amount of leaking gloves defect declined but also the other types of defects. The improvement also demonstrated that the utilisation of Six Sigma and DMAIC problem-solving methodology was effective and efficient to minimise the number of defects and thus enhance productivity. A comparison between the "before and after" the Six Sigma improvement project presented in this paper is shown in Figure 5, whereas Table VII summarises and compares the improvement project's results with the objectives.

4.5 Control

The aim of the control phase is to sustain the gains from processes which have been improved (Omachonu and Ross, 2004) by institutionalising process or product improvements and controlling ongoing operations (Stamatis, 2004). Design controls can then be used to monitor the processes and ensure that the improved processes have



(a) (b)

Notes: (a) Line chart and (b) boxplot chart representations

Figure 4. Number of leaking gloves defects correlation with oven's temperature and conveyor's speed

Type of defects	Percentage of defects before the improvement	Percentage of defects after the improvement
Leak	19.51	8.38
Miscellaneous	7.32	3.88
Dirty	3.42	2.44
Total	30.25	14.70

Table VI. Percentage of defects between before and after the improvement

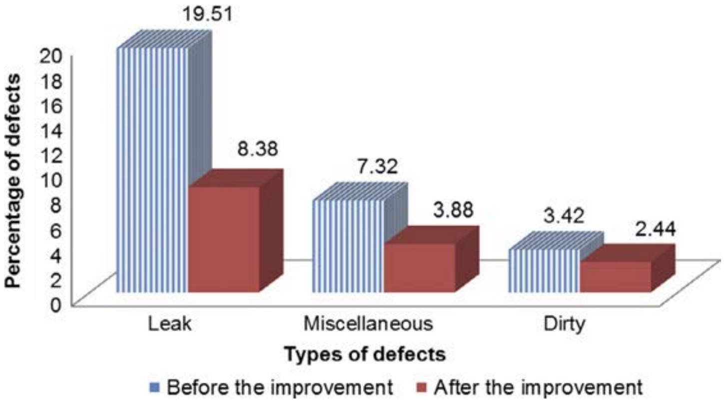


Figure 5.
"Before and after" states of conducting the Six Sigma project in the gloves manufacturing process

Table VII.
Final results summary

Major types of defects	Quality levels (DPMO) Before the improvement	Expected	After the improvement	Sigma level (sigma) Before the improvement	Expected	After the improvement
Leaking gloves	195,095	97,569	83,750	2.4	2.8	2.9

remained in-control (Omachonu and Ross, 2004). In the case of this improvement project, the organisation studied institutionalised the improvements made by including the optimum parameters for the oven's temperature and conveyor's speed in the process sheets used during the calibration of the oven and conveyor. In addition, control charts were also implemented to detect abnormalities in the process so appropriate actions can then be taken to eliminate them. Control charts are a statistical tool for monitoring a process to identify whether there are special causes of variation affecting it (Grant and Leavenworth, 2000). Control charts are commonly used in the control phase of DMAIC. In particular, *p* and *np* charts were implemented to monitor the performance of the rubber gloves production process. *P* and *np* charts are employed when the process monitoring is performed through the analysis of attribute data, or in other words, data that is not able to be illustrated by the negative integers (Pyzdek and Keller, 2010), and through the analysis of defective units (i.e. number of rejections). This has allowed the organisation studied to sustain the improvements achieved.

5. Results, discussion and conclusions

This paper presented a successful case study of defects reduction in a rubber gloves manufacturing process by applying Six Sigma principles and the DMAIC problem-solving methodology. Therefore, the paper can be used as a reference for managers to guide specific process improvement projects, in their organisations, similar to the one presented in this paper.

After the analysis carried out in the analyse and improve phases of DMAIC, the improvement project presented in this paper found that the oven's temperature and conveyor's speed had a statistically significat impact on the production of leaking gloves. By considering this, a reduction in the amount of defects was obtained by determining the optimum oven's temperature and conveyor's speed, which were defined as 230°C and 650 RPM, respectively. In terms of the Six Sigma level, the concept literally refers to reaching a sigma level of six, or in other words, 3.4 DPMO. In the case of this study, the improvement project presented in this paper has not been able to take the organisation studied to achieve a Six Sigma level. However, moving from one sigma level to another does take times (Harry and Schroeder, 2000). In addition, this study was considered a pilot project that was conducted in order to empirically demonstrate the Thai organisation studied that Six Sigma and the DMAIC problem-solving methodology are effective approaches capable of improving its gloves manufacturing process by reducing the amount of defects. This demonstrates that as long as the organisation continues embracing Six Sigma within its continuous improvement culture and applies its concepts and principles to systematically solve quality problems, it is believed that benefits such as cost savings, increase in products' quality and customer satisfactions will be achieved.

References

Adams, C.W., Gupta, P. and Wilson, C.E. Jr (2003), *Six Sigma Deployment*, Elsevier Science, Burlington, MA.

Aguilar-Saven, R. (2003), "Business process modelling: review and framework", *International Journal of Production Economics*, Vol. 20 No. 2, pp. 129-149.

Antony, J. (2004), "Some pros and cons of Six Sigma: an academic perspective", *The TQM Magazine*, Vol. 16 No. 4, pp. 303-306.

Antony, J. and Kaye, M. (2000), *Experimental Quality: A Strategic Approach to Achieve and Improve Quality*, Kluwer Academic Publishers, Norwell, MA.

Arndt, M. (2004), "'3M's rising star", *Business Week*, 12 April, pp. 62-74.

Bailey, S.P., Mitchell, R.H., Vining, G. and Zinkgraf, S. (2001), "Six Sigma: a breakthrough strategy or just another fad?", *Annual Quality Congress Proceedings*, pp. 1-3.

Banuelas, R. and Antony, J. (2002), "Critical success factors for the successful implementation of Six Sigma projects in organizations", *The TQM Magazine*, Vol. 14 No. 2, pp. 92-99.

Banuelas, R., Antony, J. and Brace, M. (2005), "An application of Six Sigma to reduce waste", *Quality and Reliability Engineering International*, Vol. 21 No. 6, pp. 553-570.

Bezerra, C.I.M., Adriano, A.B.A., Placido, L.S. and Goncalves, M.G.S. (2010), "MiniDMAIC: an approach to causal analysis and resolution in software development projects", *Quality Management and Six Sigma*, August.

Black, K. and Revere, L. (2006), "Six Sigma arises from the ashes of TQM with a twist", *International Journal of Health Care Quality Assurance*, Vol. 19 No. 3, pp. 259-266.

Breyfogle, F.W. III, Cupello, J.M. and Meadows, B. (2001), *Managing Six Sigma*, Wiley, New York, NY.

Brue, G. and Howes, R. (2006), *Six Sigma: The McGraw-Hill 36 Hours Course*, McGraw-Hill, New York, NY.

Cameron, S. and Price, D. (2009), *Business Research Methods: A Practical Approach*, Chartered Institute of Personal and Development, London.

Ching, O.T. (2010), "Glove lovely growth: rubber glove exports are due to grow 23 per cent to RM8.8 billion this year", available at: http://myinvestingnotes.blogspot.co.uk/2010/12/glove-lovely-growth-rubber-glove.html (accessed 7 November 2012).

Dale, B.G., Wiele, T. and Iwaarden, J. (2007), *Managing Quality*, 5th ed., Blackwell Publishing Ltd, Oxford.

Deming, W.E. (1993), *The New Economic for Industry, Government, Education*, MIT Center for Advanced Engineering Studies, Cambridge, MA.

Dennis, P. (2002), *Lean Production Simplified*, Productivity Press, New York, NY.

Devore, J. and Peck, R. (1993), *Statistics: The Exploration and Analysis of Data*, 2nd ed., Wadsworth, Inc., Belmont, CA.

Eckes, G. (2001), *Making Six Sigma Last: Managing the Balance Between Cultural and Technical Change*, Wiley, New York, NY.

Garza-Reyes, J.A., Oraifige, I., Soriano-Meier, H., Harmanto, D. and Rocha-Lona, L. (2010), "An empirical application of Six Sigma and DMAIC methodology for business process improvement", *Proceedings of the 20th International Conference on Flexible Automation and Intelligent Manufacturing* (*FAIM*), *San Francisco, CA, 12-14 July*, pp. 92-100.

GE Annual Report (2002), *General Electric Inc. Annual Report*, General Electric, Inc., Fairfield, CT.

George, M.L., Rowlands, D., Price, M. and Maxey, J. (2005), *The Lean Six Sigma Pocket Toolbook*, McGraw-Hill, Boston, MA.

Gijo, E.V., Scaria, J. and Antony, J. (2011), "Application of Six Sigma methodology to reduce defects of a grinding process", *Quality and Reliability Engineering International*, Vol. 27 No. 8, pp. 1221-1234.

Goh, T.N. (2002), "A strategic assessment of Six Sigma", *Quality and Reliability Engineering International*, Vol. 18 No. 5, pp. 403-410.

Grant, E.L. and Leavenworth, R.S. (2000), *Statistical Quality Control*, 7th ed., Tata McGraw-Hill, New Delhi.

Griffin, A. and Hauser, J.R. (1993), "The voice of the customer", *Marketing Science*, Vol. 12 No. 1, pp. 1-27.

Hammer, M. and Goding, J. (2001), "Putting Six Sigma in perspective", *Quality*, Vol. 40 No. 10, pp. 58-63.

Harry, M.J. (1998), "Six sigma: a breakthrough strategy for profitability", *Quality Progress*, Vol. 31 No. 5, pp. 60-64.

Harry, M.J. and Schroeder, R. (2000), *Six Sigma: The Breakthrough Management Strategy Revolutionising the World's Top Corporations*, Doubleday, New York, NY.

Harry, M.J., Mann, P.S., de Hodgins, O.C., Hulbert, R.L. and Lacke, J.C. (2010), *Practitioners Guide to Statistics and Lean Six Sigma for Process Improvement*, Wiley, New York, NY.

Hendricks, C.A. and Kelbaugh, R.L. (1998), "Implementing Six Sigma at GE", *Journal for Quality & Participation*, Vol. 21 No. 4, pp. 48-53.

Hirsch, J. (2008), *A Guide to Raw Material Analysis Using Fourier Transforms Near-Infrared Spectroscopy*, Thermo Fisher Scientific Inc., Madison, WI.

Honeywell Annual Report (2002), *Honeywell Inc. Annual Report*, Honeywell, Inc., Morristown, NJ.

Ishikawa, K. (1982), *Guide to Quality Control*, Asian Productivity Organization, Bunkyo.

Islam, K.A. (2006), *Developing and Measuring Training the Six Sigma Way: A Business Approach to Training and Development*, Pfeiffer, San Francisco, CA.

Iversen, G.R. and Gergen, M. (1997), *Statistics: The Conceptual Approach*, Springer, New York, NY.

Jugulum, R. and Samuel, P. (2008), *Design for Lean Six Sigma*, Wiley, New York, NY.

Kumar, C.S. and Nijasure, A.M. (1997), "Vulcanisation of rubber", *Resonance*, April, pp. 55-59, available at: www.ias.ac.in/resonance/Apr1997/pdf/Apr1997p55-59.pdf (accessed 8 November 2012).

Kumar, U.D., Nowicki, D., Ramirez-Marquez, J.E. and Verma, D. (2008), "On the optimal selection of process alternatives in a Six Sigma implementation", *International Journal of Production Economics*, Vol. 111 No. 2, pp. 456-467.

Lucas, J.M. (2002), "The essential six sigma", *Quality Progress*, Vol. 35 No. 1, pp. 27-31.

Markarian, J. (2004), "Six Sigma: quality processing through statistical analysis", *Plastics, Additives and Compounding*, Vol. 9 No. 4, pp. 28-31.

Montgomery, D.C. (2001), *Introduction to Statistical Quality Control*, 4th ed., Wiley, New York, NY.

Montgomery, D.C. (2009), *Design and Analysis of Experiments*, 7th ed., Wiley, Hoboken, NJ.

Moore, D.S., McCabe, G.P. and Craig, B.A. (2009), *Introduction to the Practice of Statistics*, 7th ed., W.H. Freeman and Company, New York, NY.

Murugappan, M. and Kenny, G. (2000), "Quality improvement – the Six Sigma way", paper presented at APAQS, The First Asia-Pacific Conference on Quality Software, 30-31 October, Hong Kong.

Näslund, D. (2008), "Lean, six sigma and lean sigma: fads or real process improvement methods?", *Business Process Management Journal*, Vol. 14 No. 3, pp. 269-287.

Nonthaleerak, P. and Henry, L. (2008), "Exploring the six sigma phenomenon using multiple case study evidence", *International Journal of Operations & Production Management*, Vol. 28 No. 3, pp. 279-303.

Omachonu, V.K. and Ross, J.E. (2004), *Principles of Total Quality*, 3rd ed., CRC Press LLC, Boca Raton, FL.

Palermo, R.C. and Watson, G.H. (1993), *A World of Quality: The Timeless Passport*, ASQC Quality Press, Milwaukee, WI.

Pande, P.S., Neuman, R.P. and Cavanagh, R.R. (2000), *The Six Sigma Way: How GE, Motorola, and Other Top Companies are Honing Their Performance*, McGraw-Hill, New York, NY.

Pyzdek, T. (2003), *The Six Sigma Handbook: A Complete Guide for Green Belts, Black Belts, and Managers at All Levels*, McGraw-Hill, New York, NY.

Pyzdek, T. and Keller, P.A. (2010), *The Six Sigma Handbook: A Complete Guide for Green Belts, Black Belts, and Managers at All Levels*, 3rd ed., McGraw-Hill, New York, NY.

Roy, R.K. (2001), *Design of Experiments Using the Taguchi Approach*, Wiley, New York, NY.

Schiller, M.R., Miller-Kovach, K. and Miller, M.A. (1994), *Total Quality Management for Hospital Nutrition Services*, Aspen Publishers, Gaithersburg, MD.

Slack, N., Chambers, S. and Johnston, R. (2010), *Operations Management*, 6th ed., FT/Prentice-Hall, London.

Stamatis, D.H. (2004), *Six Sigma Fundamentals: A Complete Guide to the System, Methods and Tools*, Productivity Press, New York, NY.

Tadashi, S. and Yoshiaki, Y. (1995), *The QC Storyline: A Guide to Solving Problems and Communicating the Results*, Asian Productivity Organization, Bunkyo.

3M Annual Report (2003), *3M Annual Report Inc.*, 3M Inc., St Paul, MN.

Westcott, R.T. (2006), *The Certified Manager of Quality/Organizational Excellence Handbook*, 3rd ed., American Society for Quality, Quality Press, Milwaukee, WI.

About the authors

Ploytip Jirasukprasert is a Field Engineer in the oil and gas industry. Ploytip obtained her Bachelor degree in industrial engineering (first class honours) from King Mongkut's Institute of Technology Ladkrabang, Thailand. She then completed her Master degree in engineering business management from University of Warwick, UK. During her studies, she also attended a summer training programme at Tokai University in Japan which concentrated on the "Taguchi Methods" combined with nano technology applied to aid diabetic patients. Her current interests consist of supply chain management, business development processes and quality improvement.

Dr Jose Arturo Garza-Reyes is a Senior Lecturer in operations and supply chain management at the Centre for Supply Chain Improvement, Derby Business School, the University of Derby, UK. He holds a PhD in manufacturing systems and operations management from the University of Manchester (UK), an MBA from the University of Northampton (UK), an MSc in production and quality from the Autonoma de Nuevo Leon University (Mexico), a Postgraduate Certificate in teaching and learning in higher education from the University of Derby (UK), and a BSc in mechanical management engineering from the Autonoma de Nuevo Leon University (Mexico). He has published a number of articles in leading international journals and conferences, and two books in the areas of quality management systems and manufacturing performance measurement systems. Jose Arturo has participated as Guest Editor for special issues in the *International Journal of Lean Enterprise Research* (*IJLER*), *International Journal of Engineering Management and Economics* (*IJEME*), and *International Journal of Engineering and Technology Innovation* (*IJETI*). He is currently serving in the editorial board of several international journals as well as has contributed as member of the scientific and organising committees of several international conferences. His research interests include general aspects of operations and manufacturing management, operations and quality improvement, and supply chain improvement. Jose Arturo is a Chartered Engineer (CEng), a certified Six Sigma-Green Belt, and has over six years of industrial experience working as Production Manager, Production Engineer and Operations Manager for several international and local companies in both the UK and Mexico. He is also a member of the Institution of Engineering and Technology (IET) and a fellow member of the Higher Education Academy (FHEA). Jose Arturo Garza-Reyes is the corresponding author and can be contacted at: j.reyes@derby.ac.uk

Dr Vikas Kumar is a Lecturer in management at Dublin City University Business School, Republic of Ireland. He holds a PhD in management studies from Exeter Business School, UK and a Bachelor of technology (first class honours) degree in metallurgy and material science engineering from NIFFT, India. In past, he has worked as a Research Assistant with the Department of Industrial and Manufacturing Systems Engineering at The Hong Kong University. He also holds a status of "Associate of the Higher Education Academy" (AHEA). He has published more than 40 articles in leading international journals and international conferences including the *International Journal of Production Research, Computers & Industrial Engineering*, *Journal of Engineering Manufacture* and the *International Journal of Service Industry Management*. He is a Reviewer of more than ten leading international journals and a Guest Editor of special issues in production planning and control (PPC), *International Journal of Lean Enterprise Research* (*IJLER*), *International Journal of Engineering Management and Economics* (*IJEME*), and *International Journal of Engineering and Technology Innovation* (*IJETI*). He serves on the editorial board of six international journals including *International Journal of Services, Economics and Management* (*IJSEM*), *International Journal of Manufacturing Systems (IJMS)*, *International Journal of Lean Enterprise Research* (*IJLER*), and *International Journal of Network and Mobile Technologies* (*IJNMT*). He also serves on a number of scientific, technical, and programme board committees of several international conferences. His current research interests include healthcare management, supply chain management, process modelling, service operations management, and operations strategy.

Prof. Ming K. Lim is currently a Professor of supply chain and logistics operations and Head of Centre for Supply Chain Improvement at Derby Business School, University of Derby, UK. His research interest is in the area of radio-frequency identification technology (RFID), agile/lean principles, reconfigurable manufacturing systems/logistics network, system optimisation, multi-agent systems, simulation, and heuristic algorithms. He has published in leading journals, such as *European Journal of Operational Research*, *International Journal of Production Research*, *Expert Systems with Applications*, and *Journal of the Operational Research Society*. He is an Editor of *International Journal of Information Processing and Management and Advances in Information Science*. In addition, he is also an Adjunct Professor at MIT Centre of Transportation and Logistics' Global SCALE Centre in Malaysia (MISI), Advisory Council Member and Board of Trustees of Asia Pacific Business Innovation and Technology Management, Chairman of European Business Innovation and Technology Management, and Board Member of International Federation for Information Processing (IFIP) WG5.7.