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A Case Study of Defects Reduction in a Rubber Gloves Manufacturing Process by Applying Six Sigma Principles and DMAIC Problem Solving Methodology

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Abstract

The Six Sigma's problem solving methodology DMAIC has been one of several techniques used to improve quality. This paper demonstrates the empirical application of Six Sigma and DMAIC to reduce product defects within a rubber gloves manufacturing organisation. The paper follows the DMAIC methodology to investigate defects, root causes and provide a solution to reduce/eliminate these defects. 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. In particular, the design of experiments (DOE) and two-way analysis of variance (ANOVA) techniques were combined to statistically determine the correlation of the oven's temperature and conveyor's speed with defects as well as to define their optimum values needed to reduce/eliminate the defects. As a result, a reduction of about 50% in the "leaking" gloves defect was achieved, which helped the organisation studied to reduce its defects per million opportunities (DPMO) from 195,095 to 83,750 and thus improve its Sigma level from 2.4 to 2.9.

Keywords

Defects reduction, DMAIC, rubber gloves, Six Sigma

1. Introduction

In today's world, business has become more and more competitive. All industries and organisations have to perform well in order to survive and be profitable. 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. From this point, not only does an organisation waste its resources and time to re-manufacture the products, but it also contributes to the loss of customers' satisfaction and trust. As a result, this has driven a particular Thai gloves manufacturing organisation to improve the quality of its products in order to create a competitive strategic advantage for its business and introduce itself to become a global organisation for further prospects. This paper investigates quality issues at a Thai rubber gloves manufacturing company and provides a solution to reduce/eliminate the most common defects. In order to

accomplish this, the paper evocates the principles and tools of one of the most effective quality management and improvement methodologies, Six Sigma. In particular, the DMAIC (Define-Measure-Analyse-Improve-Control) problem-solving and improvement model of Six Sigma is followed. Under the umbrella of this model, several statistical and quality improvement tools such as fishbone diagram, Pareto chart, Design of Experiments (DOE) and two-way analysis of variance (ANOVA) have been used. As an initial step, the paper briefly reviews some of the relevant theory of Six Sigma and DMAIC, paying particular attention to 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

Six Sigma was proposed by Motorola, in the mid-1980s, as an approach to improve production, productivity and quality, as well as reducing operational costs [1]. 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 [2]. In the Six Sigma's terminology, the "Sigma level" is denoted as a company's performance [3]. Particularly, a Six Sigma level refers to 3.4 defects per million opportunities (DPMO) [4], or in other words, to have a process which only produces 3.4 defects per every one million products produced.

Besides being a measure of variability and organisation's quality performance, Brue and Howes [5] mention that Six Sigma is also a management philosophy and strategy 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. In particular, 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 [3, 4, 6, 7]. Markarian [8] suggests that not only can the process improvement generated by Six Sigma be used in manufacturing operations, as it is the case for the project presented in this paper, but it can also be expanded to improve business sectors such as logistics, purchasing, legal and human resources. In addition, Kumar et al. [9] state that although Six Sigma is normally used in defects reduction (industrial applications), it can also be applied in business processes and to develop new business models. Banuelas et al. [10] claim that other benefits such as (1) an increase in process knowledge, (2) participation of employees in Six Sigma projects and (3) 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 tools and techniques were employed. Therefore, skills in the use of these 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.

One of the Six Sigma's distinctive approaches to process and quality improvement is DMAIC [11]. The DMAIC model refers to five interconnected stages (i.e. define, measure, analyse, improve and control) that systematically help organisations to solve problems and improve their processes. Dale et al. [6] 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 [12].
- **Measure** – this stage includes selecting the measurement factors to be improved [2] and providing a structure to evaluate current performance as well as assessing, comparing and monitoring subsequent improvements and their capability [4].
- **Analyse** – this stage centres in determining the root cause of problems (defects) [2], understanding why defects have taken place as well as comparing and prioritising opportunities for advance betterment [13].
- **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 [2].
- **Control** – finally, this last stage within the DMAIC process ensures that the improvements are sustained [2] and that ongoing performance is monitored. Process improvements are also documented and institutionalised [4].

DMAIC resembles the Deming's continuous learning and process improvement model PDCA (plan-do-check-act) [14]. Within the Six Sigma's approach, DMAIC assures the correct and effective execution of the project by providing a structured method for solving business problems [15]. Pyzdek [16] 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) [11].

3. Rubber gloves manufacturing processes

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 vulcanizing, (5) stripping and tumbling, (6) quality control and (7) packing. These process steps are illustrated in Figure 1.



Figure 1: Gloves manufacturing processes

- **Step 1. Raw material testing**

According to Hirsch [17], 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 vulcanizing**

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 vulcanizing 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 have a role to perform 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 and delivered to customers.

4. Six Sigma and DMAIC Application – A Case study

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 (i.e. customer requirements) and goals of the project [12]. 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.

Indicating the project's scope was the next step within the "define" stage of DMAIC. Nonthaleerak and Hendry [18] 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 [18, 19, 20]. 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. [21] listening to customers is critical for a business to be successful. Therefore, the voice of the customer (VOC) concept, which means identifying what the customers want and serving priorities to their needs [22], was used in this project to define, based on customer requirements, the selected project's objective. From this point, VOC also ensured that the project problem, which was defects reduction, became the first priority for the improvement team and organisation.

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. Finally, a project charter, which is a tool used to document the targets of the project and other parameters at the outset [21], was employed to state and present the project's information structure. The project charter, in other words, summarised the project's scope, boundary, VOC, goal and the team's role in this research project. The project charter is presented in Table 1.

Table 1: Project charter

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 Goal: To reduce the defects by 50% 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 the defects reduction
Expected Customer Benefits:	Receiving the product with the expected quality

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) [16], which in this research 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 [2]. Also, a collection plan was adopted for the data to be gathered efficiently. 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. The defects data was collected for twenty days. The results are summarised in Table 2.

Table 2: Defects summary (before the improvement)

Type of defects	Number of defects	Percentage of defects
Leaking	4495	19.51
Miscellaneous	1686	7.32
Dirty	788	3.42
Total	6969	30.25

As a next step, a Pareto analysis [23, 24] was carried out to identify the utmost occurring defects and prioritise the most critical problem which was required to be tackled. The collected data was generated in the form of a Pareto chart, which is illustrated in Figure 2. The Pareto chart shown in Figure 2 indicated that the highest rate of defects was caused by leaking gloves. In particular, this type of defect contributed to over 60 percent 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". 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 goal in terms of the gloves process improvement. These are shown in Table 3. The next stage in the Six Sigma project, and following the DMAIC methodology, consisted in analysing the root causes of this particular problem, as well as identifying an appropriate solution.

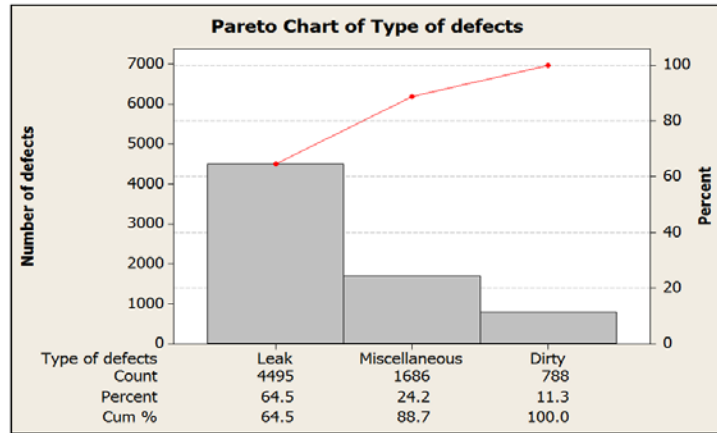


Figure 2: Gloves defects Pareto chart

Table 3: Gloves manufacturing process – current and expected states

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

C*= Current process performance; E*= Expected process performance after the completion of the Six Sigma project

4.3 Analyse

This phase in the DMAIC improvement methodology 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 goal(s) [11]. 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) [7]. In order to gain an enhanced comprehension and understanding of the glove production process, which according to Aguilar-Saven [25] is a main requirement for improvement, the analysis phase of this project started from illustrating the manufacturing process using a flow chart, see Figure 3. Figure 3 presents 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 flow chart, 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 to why the leaking problem in gloves occurred. 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 known as a systematic questioning technique for seeking root causes of problems [23] by providing a relationship between an effect and all possible causes of such effect [2]. Once completed, the diagram helps to uncover the root causes and provide ideas for further improvement [6]. There are five main categories normally used in a cause-and-effect diagram, namely: machinery, manpower, method, material and measurement (5M) [6] plus an additional parameter: environment. The possible root causes brainstormed are illustrated in the cause-and-effect diagram shown in Figure 4.

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.

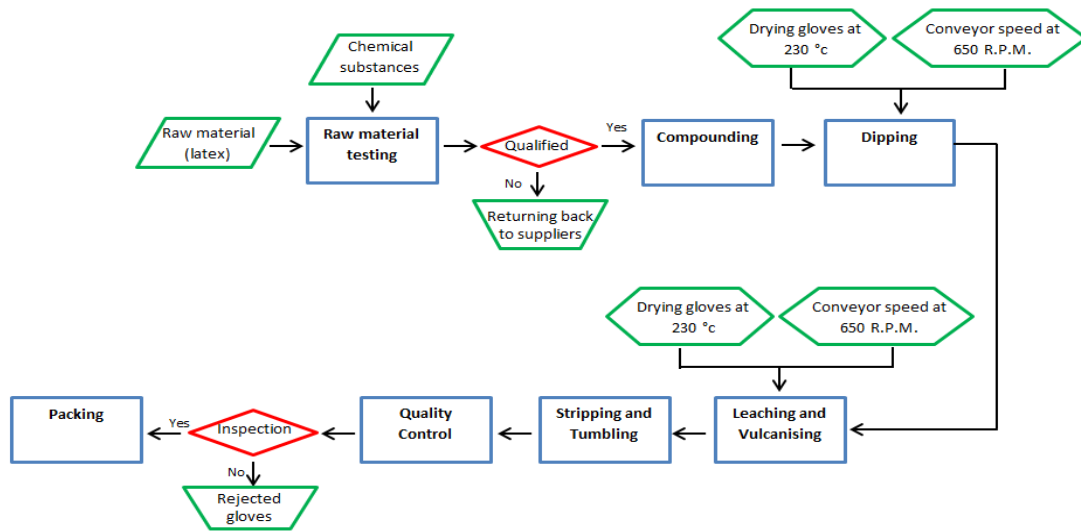


Figure 3: Gloves manufacturing process flowchart

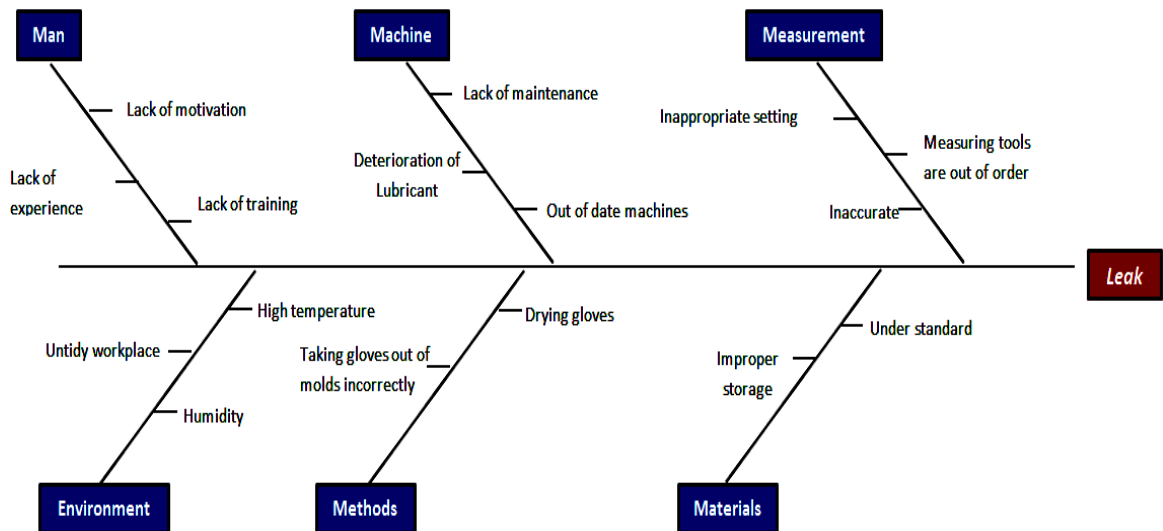


Figure 4: Cause-and-effect diagram related to the leaking gloves quality problem

4.4 Improve

After the root cause(s) has/have been determined, the DMAIC's "improve" phase aims at identifying solutions to reduce and tackle them [2]. Stamatis [4] suggests the use of design of experiments (DOE), which is defined as a statistical technique to investigate effects of multiple factors [26, 27], in the "improve" phase. According to Montgomery [28], 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 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 parameters of both oven's temperature and rollers' speed had a negative effect on the process, causing leaking gloves. 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 [29]. However, if there are two sources of data (like in this case) that need to be investigated, two-way ANOVA, which is a statistical methodology for analysing the effect of two factors, is required [29]. The two factors which were mentioned earlier (i.e. oven's temperature and conveyor's speed) were investigated with four different ranges 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 team members, specifically the production manager and shop-floor operator. From this point, the experiment was conducted with two parameters (i.e. temperature and speed) at four levels. Pyzdek and Keller [3] suggest the two-way ANOVA with replication as the most effective tool to be used for this type of analysis. As the statistical test aimed at investigating whether the two factors (i.e. oven's temperature and conveyor's speed) resulted in defective gloves, a hypothesis that indicated that a variation in the number of defects would occur if the oven's temperature and conveyor's speed were varied was formulated. The results of two-way ANOVA analysis with replication are shown in Table 4.

Table 4: Results of the two-way ANOVA analysis with replication

Source of Variation	SS	df	MS	F	P-value	F critical
Sample (temp)	40392.04	3	13464.01	16.73373	1.41E-07	2.798061
Columns (speed)	45322.98	3	15107.66	18.77653	3.39E-08	2.798061
Interaction	155544.6	9	17282.73	21.47981	5.57E-14	2.08173
Within (errors)	38620.97	48	804.6035			
Total	279880.6	63				

The results presented in Table 4 indicated that there was a correlation between the oven's temperature and conveyor's speed at a significance level = 0.05 [30]. Therefore, the analysis helped to statistically conclude that both temperature and speed influenced the amount of leaking gloves. After it was determined 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 form of a Boxplot in Figure 5. These figures denoted that a 230°C temperature and conveyor speed of 650 R.P.M. 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 R.P.M) defined by the experiment were the best options to provide an improvement for the gloves manufacturing process and reduce defects.

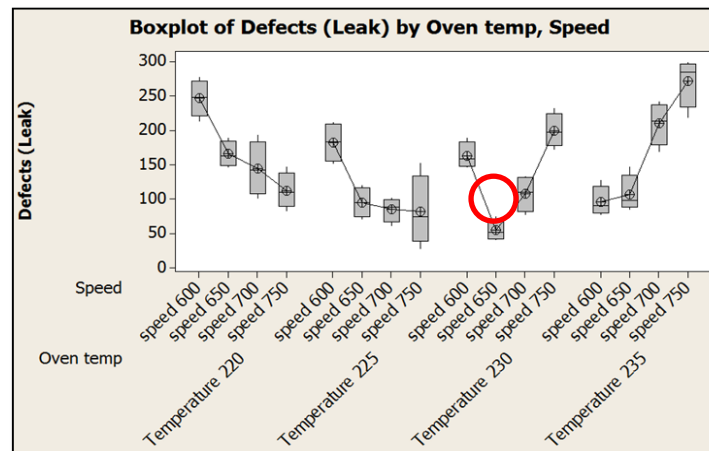


Figure 5: Boxplot of defects by oven temperature and conveyors speed

Table 5 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%. 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 Table3, were exceeded.

Table 5: Percentage of defects between before and after the improvement

Type of defects	% of defects Before the improvement	% 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

It can be concluded that, by setting up the oven’s temperate at 230°C and conveyor’s speed at 650 R.P.M., 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 illustrated in Figure 6.

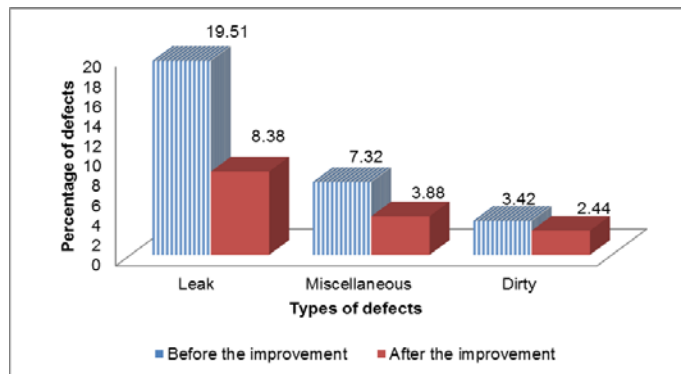


Figure 6: “Before and after” states of conducting the Six Sigma project in the gloves manufacturing process

4.5 Control

The aim of the “control” phase is to sustain the gains from processes which have been improved [2] by institutionalizing process or product improvements and controlling ongoing operations [4]. However, due to time limitation, this stage is still under implementation at the Thai rubber gloves manufacturing organisation studied in this paper.

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 Manufacturing Industrialists to guide specific process improvement projects, in their organisations, similar to the one presented in this paper. After the analyses 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 significant 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 R.P.M. 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 [31]. 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 enhanced.

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