The Reduction of the Defected Block Rubber using Lean Six Sigma Approach

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Abstract

The purpose of the research was to reduce the proportion of block rubber contaminated with iron from the production process while all relevant constraints were taken into account. According to the current problem situation, the extent of the contaminated rubber was higher than the acceptable upper range. The analysis was conducted using the Cause-and-Effect diagram and the Failure Mode and Effect Analysis method (FMEA). It was found that the contamination issues were mainly caused by the lack of the iron separation machine, the inefficient magnet set used to withdraw iron debris from rubber raw materials, and the low-performance inspecting system for rubber shredder blades. Lean Six Sigma approach was then utilized to tackle the problems. The practiced alterations included the new iron separation machine installation in the production line, more magnet sets assembled inside rubber raw materials storages, at the shredded rubber screening machine and the base of the shredder blades, and a record-keeping logbook for the blades. The integrated approach decreased the fraction of the problematic iron-contaminated rubber by 17.97 percent. The capability analysis, C_{pk}, is 1.50 with a 0.05 significance level, which indicated the highly efficient process. The confidence interval of the process is $1.08 < C_{pk} < 1.93$. The forecasted reduced cost from rubber reprocessing was 924,630 Baht per year.

Keywords: *Lean Six Sigma approach, Standard Thai Rubber 20, Process capability analysis, Iron contamination problem in rubber*

1. Introduction

The rubber industry has played an important role in the global economy. China is the top importer of rubber and its products in the world (30 percent share in the global trade) followed by the USA, Japan, and India. In 2020, Thailand's share in rubber export amounts to 4.81 million metric tons (Puangthong & Daengkanit, 2020). As the world's leading producer of natural rubber, Thailand has various rubber-related industries such as block rubber, sheet rubber, crepe rubber, rubber gloves, latex condoms, and tires. The STR20 (Standard Thai Rubber 20) accounts for a significant fraction of the block rubber industries. The STR20 production comprises many steps. The raw material goes through selecting and sorting, cleaning, blending, shredding, baking, packing, and storing processes. They all have a significant contribution to the whole production line. Competing in this highly competitive rubber market, the manufacturers need to invest in human resources, machines, raw materials, and process development to increase production efficiency and to meet customer requirements. Quality control process, in particular, needs to be specifically taken into account as it strongly relates to the manufacturing costs, the functions as well as the product design. The inefficient quality control leads to substandard products (Ramasamy, 2009).

Based on the case study company for this research, the block rubbers can be divided into 3 categories using the rubber scraps to rubber sheets ratio; HO276(80:20), PO263(60:40), and PO251(40:60). The make-to-order system is adopted with a continuous production line. In 2019, HO276 was the major product with an average production of 2,515 metric tons per month, which covered 87.69 percent of total manufacturing as shown in Figure 1. Therefore, it was selected to be the case study for product improvement. All the achieved outcomes were supposed to work practically with other block rubber grades as well. According to the overall observation, the common problems in block rubber manufacturing include

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iron contamination, white spots caused by the improper drying process, impurities, and the substandard Original Wallace Plasticity (PO), Plasticity Retention Index (PRI), and Moony Viscosity (MV). The Pareto principle 80:20 rule states that the major 80 percent or greater results are often caused by 20 percent of small variables. Figure 2 shows that the impurity problem caused 162 tons of iron-contaminated rubber per month. As the fraction made up 80.60 percent of all problems, the iron contamination issue in block rubber was selected as a research question. The Lean Six Sigma approach (Breyfogle III, 2003) with the Define, Measure, Analyze, Improve and Control (DMAIC) framework was integrated to tackle the problems.

Lean Six Sigma is a process improvement strategy by eliminating waste, reducing variables, and increasing customer satisfaction towards the product quality. Maneechot and Pijitbanjong (2019) used Lean Six Sigma strategies to solve the incomplete drying process of block rubber. The waste was decreased by 72.25 percent. Amaluk (2019) applied the Lean six sigma approach combined with the Pareto chart and cause-effect diagram to reduce waste in the machine parts manufacturing process. The problem analysis cited 34.78 percent reducing waste. Mekboon and Plongmai (2017) countered the waste issue in the solid capacitor polymer production process by the Lean Six Sigma approach. The production improvement involved better material selection, renovated processes, new machines, and tools, which resulted in a 5.25 percent waste reduction in the steel cover bracket manufacturing. Ketsarapong and Sriyanalugsana (2019) reduced flaws in the refrigerator fabrication process with the Lean Six Sigma approach. After the improvement, the average defect extent went down to 26,666.76 PPM or 28.62 percent below what it was before the improvement. Lean Six Sigma provides industries potent tools to improve their performance.

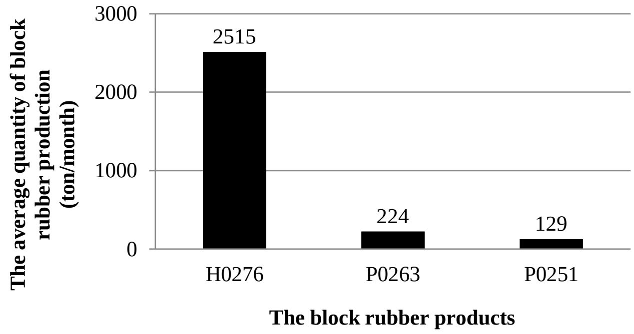

Figure 1 The production quantity of block rubbers

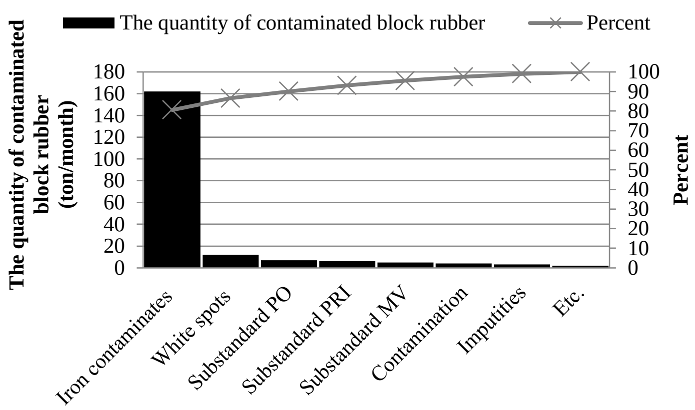

Figure 2 The quantity of problematic block rubber

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2. Objectives

The objective of the research was to decrease the proportion of block rubber contaminated with iron from the production process by using the Lean Six Sigma approach to increase process efficiency.

3. Methodology

The research methodology based on the Lean Six Sigma approach (Pyzdek & Keller, 2018) consisted of 5 phases; Define, Measure, Analyze, Improve, and Control (DMAIC), as shown in Figure 3.

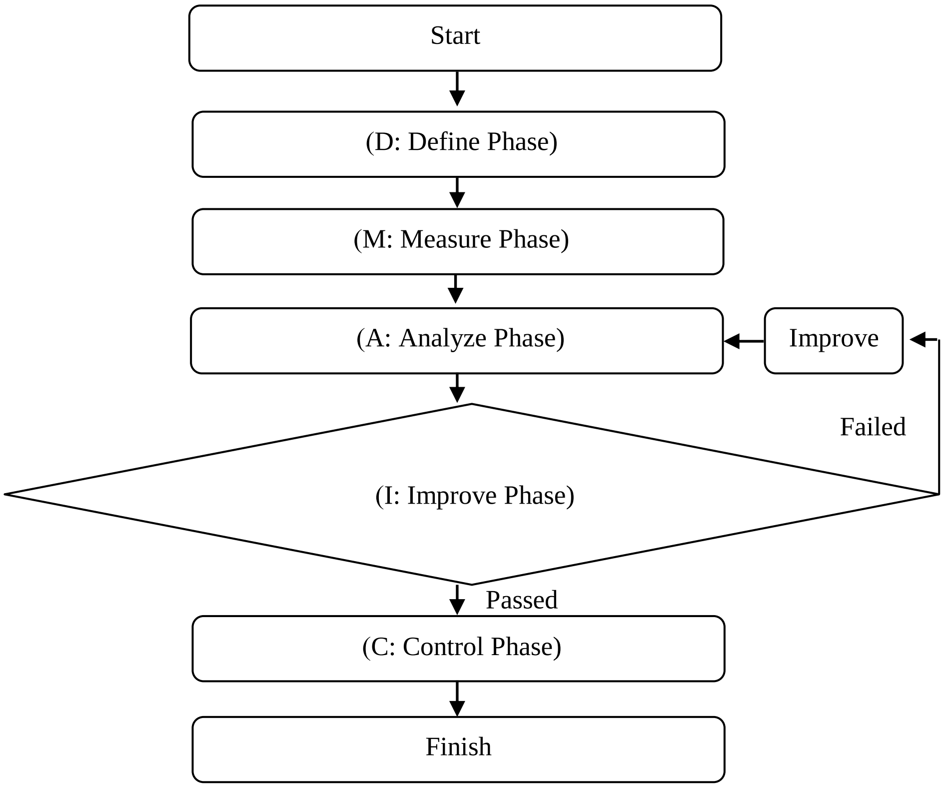

Figure 3 Methodology process diagram

Iron contamination in block rubber occurs when tough rubber sheets or scrapes are shredded. The friction generated by the extremely dense texture tears off iron debris from the blades. The rubber standard states the acceptable upper limit of size and amount of iron contaminants in rubber. Table 1 shows the criteria for iron contamination inspection.

Table 1 The criteria for iron contamination in block rubbers

Iron contaminants	Determine
Level A: Not found	acceptable
Level B: size ≤ 2.5 mm., location ≤ 5 spots	acceptable
Level C : size ≤ 2.5 mm., location > 5 spots	unacceptable
Level D : size > 2.5 mm., location ≥ 1 spot	unacceptable

Source: The production department of the case study factory

Process capability analysis, C_{pk}, defines the manufactural ability whether the process is meeting the product specification limit. It determines the uniformity of the process variation (Montgomery, 2005). The meaning of C_{pk} values are as follows:

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1. $C_{pk} < 1$	Inefficient	2. $C_{pk} = 1$	Poor
3. $1 < C_{pk} < 1.33$	Fair	4. $C_{pk} > 1.33$	Excellent

4. Results and Discussion

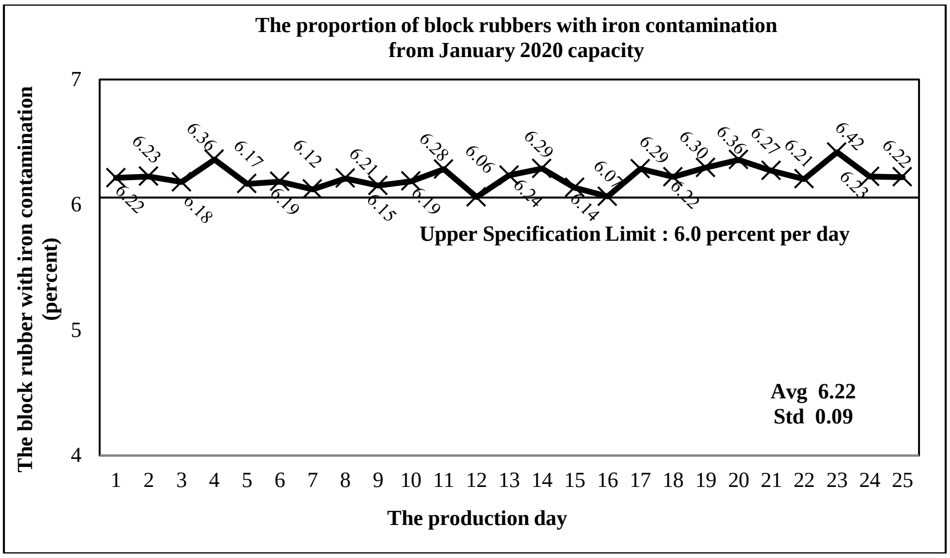
4.1 Define Phase

The on-site data was collected to reflect the actual problem situation at the case study factory. A period of 21 hours is divided into three 7-hour shifts per day. The data was collected for 25 days from January to February 2020. The total 75 data sets were statistically calculated to determine the process efficiency, as shown in Figure 4 and Table 2.

Figure 4 shows that the average contaminated block rubber fraction from January 2020 (A) and February (B) capacities were 6.22 percent per day (SD. = 0.09) and 6.21 percent per day (SD. = 0.11), respectively. The values exceeded the upper limit at 6.0 percent per day.

Table 2 Statistical parameters calculated from the product performance before the iron contamination improvement from January to February 2020

Statistical parameters	Before improvement
The average proportion of the block rubber contaminated with iron (percent/day)	6.216
Standard deviation (percent/day)	0.097
The upper limit of the average proportion of the block rubber contaminated with iron At a 95% confidence interval (percent/day)	6.239



(A)

Figure 4 The proportion of block rubber with iron contamination from (A) January - (B) February 2020 production capacity

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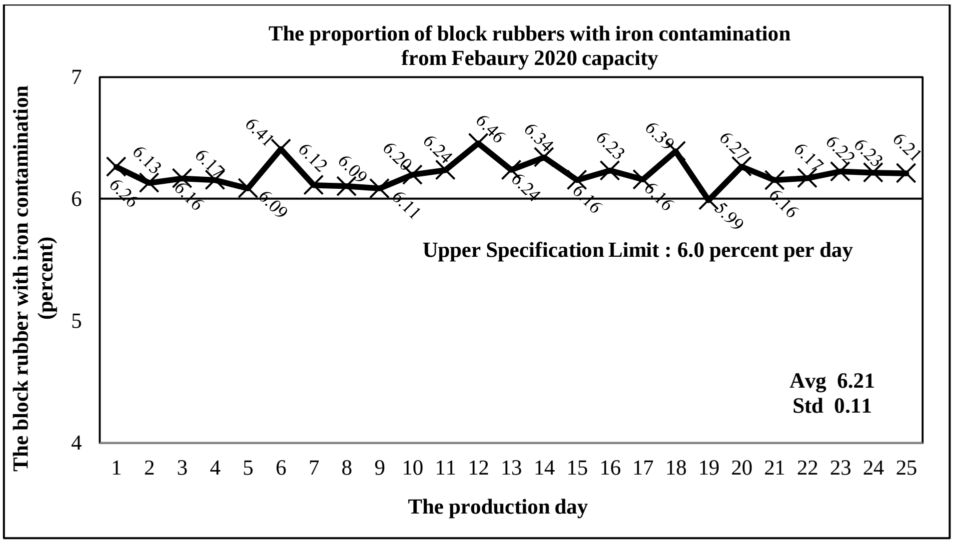

(B)

Figure 4 The proportion of block rubber with iron contamination from (A) January - (B) February 2020 production capacity (Cont)

Figure 5 revealed the poor C_{pk} at -0.70, which indicated the inefficient process because of the high proportion of the block rubber contaminated with iron.

4.2 Measure Phase

The Cause-and-Effect diagram was generated to achieve the big picture of the focusing problem. This effective diagram combines brainstorming with a mind map to locate potential causes. It acknowledges all contributed ideas and comments regardless of sources. Therefore, all possible causes of a problem are considered, rather than just the most obvious ones (Chutima, 2002). Figure 6 shows the Cause-and-Effect diagram using the 4M rule to explore the iron contamination problem.

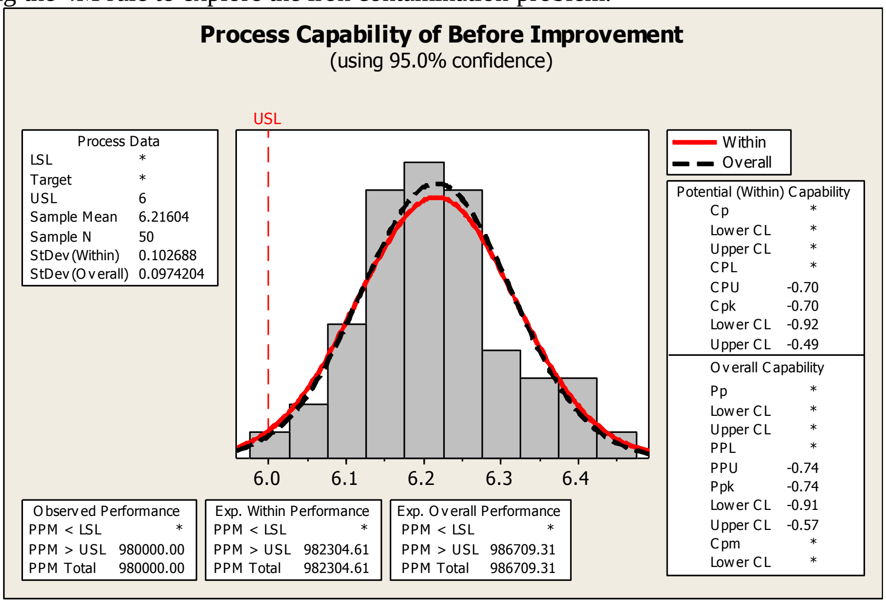

Figure 5 Process capability analysis of block rubber proportion contaminated with iron before process improvement

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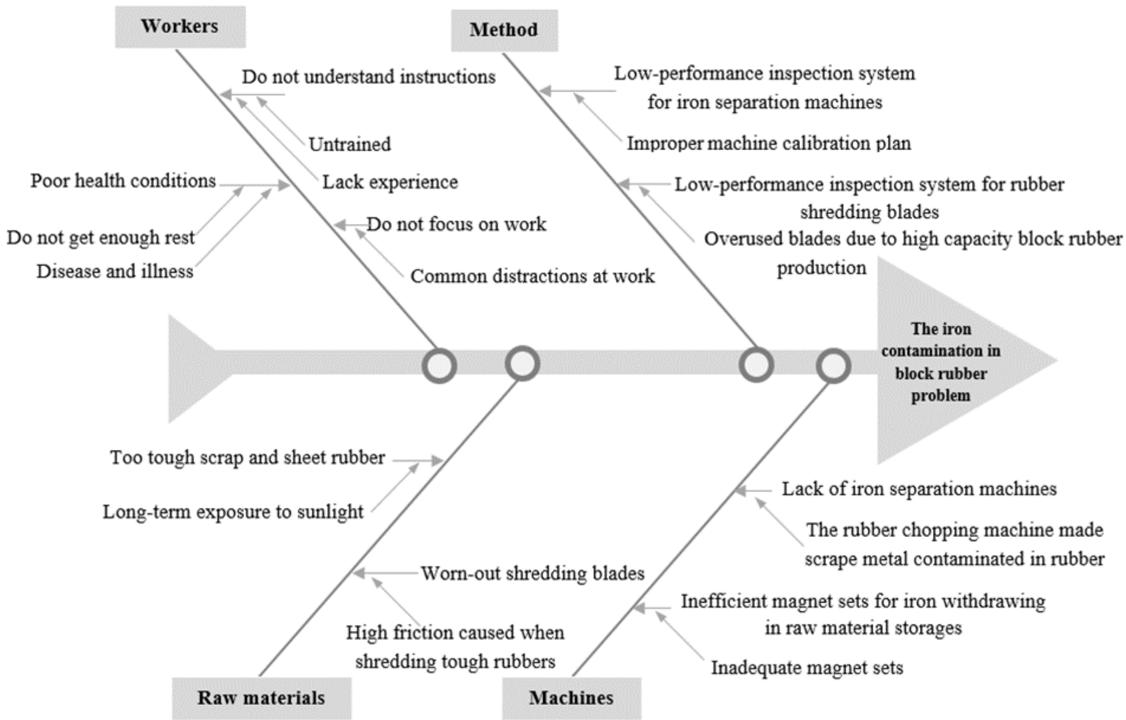

Figure 6 The Cause-and-Effect diagram to explore the iron contamination in block rubbers problem

According to the diagram, all causes can be categorized into four parts; human errors, machines, practicing processes, and raw materials. However, the human errors section was intentionally avoided. They are considered a different issue altogether that can be solved by proper employee training.

4.3 Analyze Phase

Failure Mode and Effect Analysis (FMEA) was then applied to analyze the focusing problems. It is a technique designed to systematically analyze production activities to extract all the possible flaws. It can be done by taking the risk priority number (RPN) into consideration: RPN covers severity evaluation, occurrence probability, and defect detection capability. Moreover, the Pareto diagram was used to single out the major cause of the problem. The Pareto principle 80:20 rule states that the major 80 percent or greater results are often caused by 20 percent of small variables (Montgomery, 2009).

The three major causes are shown in Figure 7. These high RPN causes included the lack of the iron separation machine, the inefficient magnet set used to withdraw iron debris from rubber raw materials, and the low-performance inspecting system for rubber shredder blades. Consequently, they were targeted for further process improvement.

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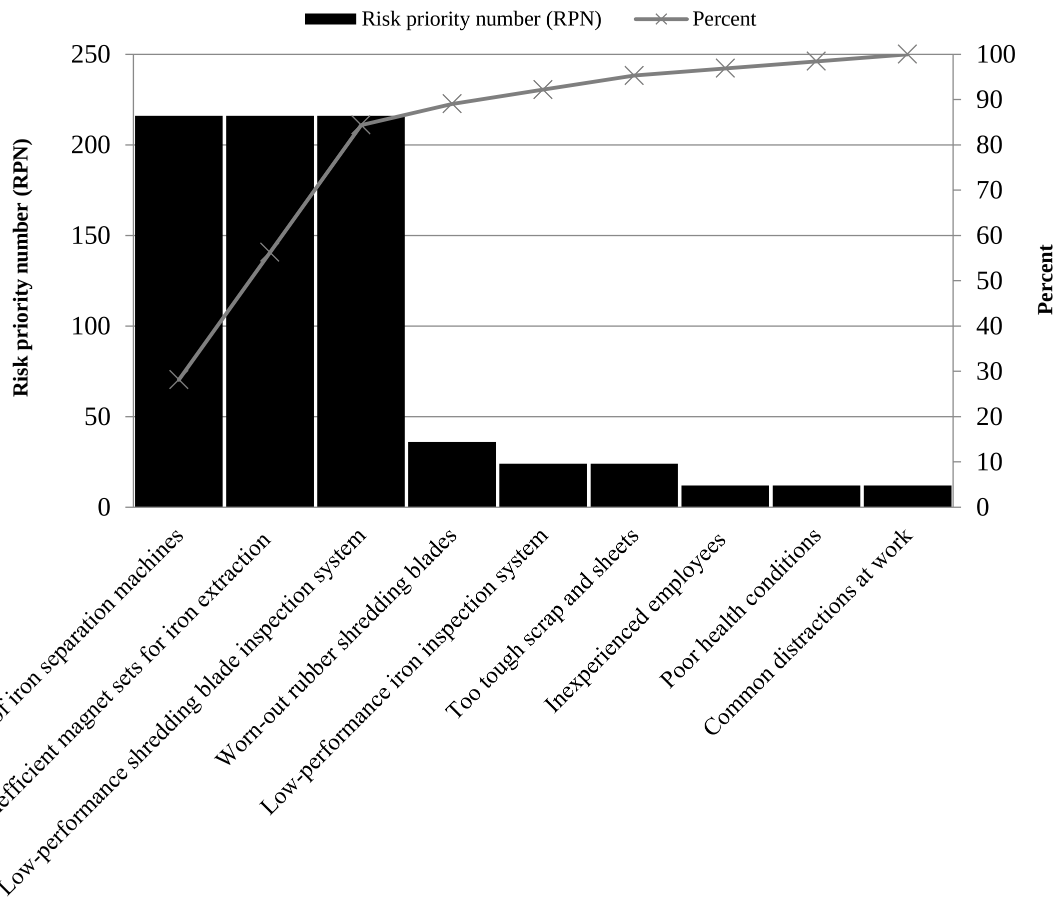

Figure 7 The Pareto diagram of RPN in determining possible causes for the block rubber contaminated with iron from the production process

4.4 Improve Phase

All the significant problems were the results of long-term poor practices. The brainstorming strategy was incorporated to address practical problem-solving practices, as shown in Table 3.

Table 3 Problem-solving practices

Defects	Causes	Corrective actions
The problem of the block rubber contaminated with iron from the production process.	Lack of the iron separation machine	Install a new iron separation machine, as shown in Figure 8.
	Insufficient magnet sets for iron extraction	More magnet sets are assembled inside rubber raw materials storage (A), at the shredded rubber screening machine (B), and the base of the shredder blades (C), as shown in Figure 9.
	Low-performance inspection system for rubber shredding blades.	Use a record-keeping logbook to inspect the blades 2 times per shift. The utilization rate must not exceed 1.8 mm./hr., as shown in Figure 10.

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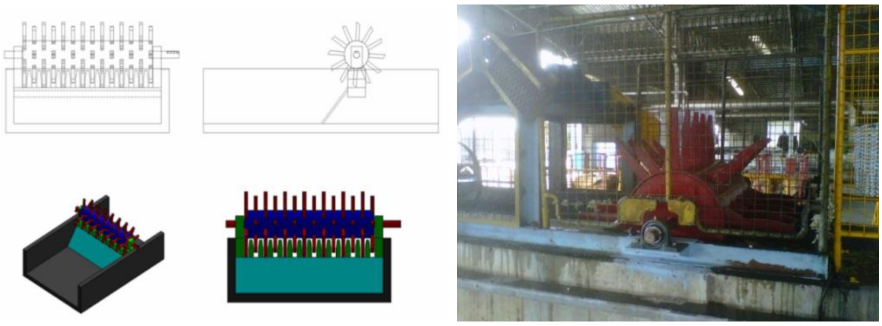

Figure 8 The iron separation machine

(A) (B) (C)

Figure 9 The magnet sets installation for iron extraction at the raw rubber pond (A), in the rubber screening machine (B), and at the bottom of the rubber shredding blades (C)

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Record Utilization rate of knife

- o Pre-Clening Process (SH-1)
- o Mixing Process (SH-1)
- o Mixing Process (SH-2)

Note : The result of Utilization rate of knife that passes or not ???
Refer to title (5) [Must be less than 1.8 mm./hr.]
If the value is greater than this,
notify the supervisor to take corrective action immediately.

Date / shift Start knife	Date / shift Check knife (2 time per shift)	Recorder	(1) Usage Hours Knife ; hr.	(2) Knife length (Start) ; mm.	(3) Knife length (Remain) ; mm.	(4) Knife length (Used) ; (2)-(3) ; mm.	(5) Utilization rate of knife (4) / (1) ; mm./hr.	Results		Remark
								PASS	NOT PASS	

Figure 10 The record of the utilization rate of rubber shredding blades

The case study factory was assigned to practice all the process alterations. The on-site data was then collected in the same fashion to investigate the improvement. The data was collected for 25 days from May to June 2020. The total 75 data sets were statistically calculated to determine the process efficiency, as shown in Figure 11 and Table 4.

Figure 11 shows that the average contaminated block rubber fraction from May 2020 (A) and June (B) capacities were 5.12 percent per day (SD. = 0.18) and 5.08 percent per day (SD. = 0.16), respectively. The values were 17.63 and 18.28 percent lower than those from January and February, respectively. It was seen that the process alterations based on the Lean Six Sigma approach significantly improved the process capability.

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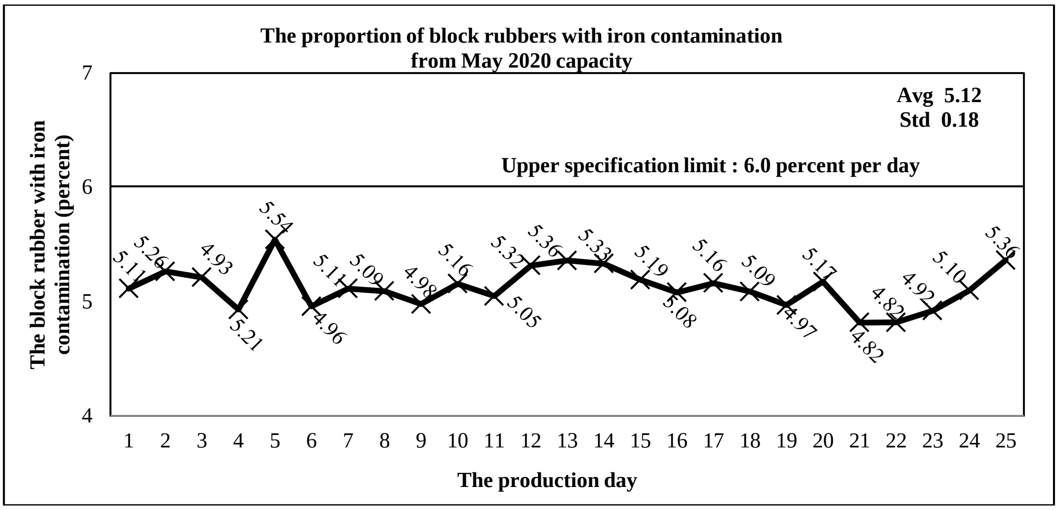
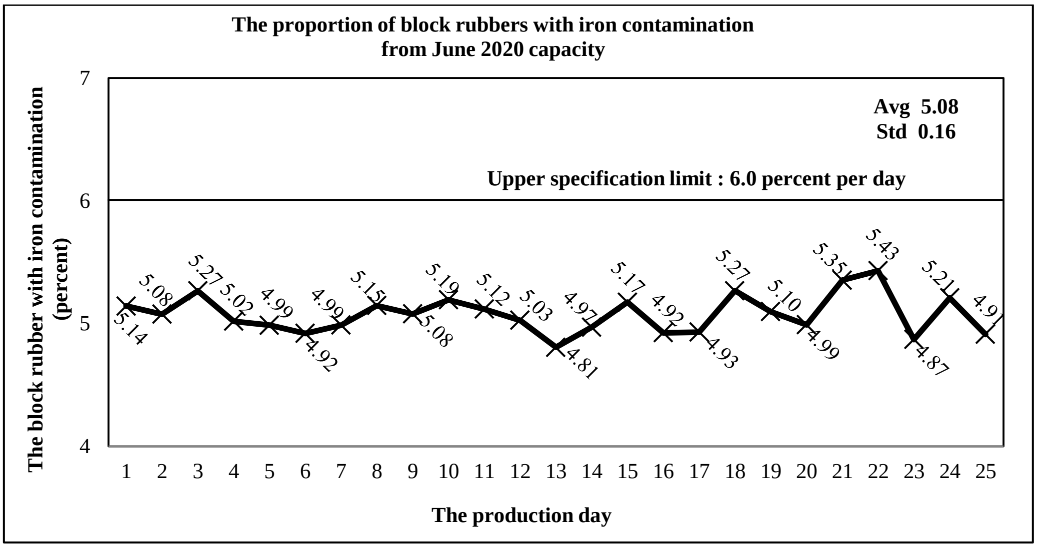
Table 4 Statistical parameters calculated from the production performance after the iron contamination improvement from May to June 2020

Statistical parameters	After improvement
The average proportion of the block rubber contaminated with iron (percent/day)	5.099
Standard deviation (percent/day)	0.167
The upper limit of the average proportion of the block rubber contaminated with iron At a 95% confidence interval (percent/day)	5.139



(A)



(B)

Figure 11 The proportion of block rubber with iron contamination from May-June 2020 production capacity

Figure 12 shows the improved C_{pk} at 1.50 with a 0.05 significance level, which indicated the highly efficient process because of the reduced proportion of the block rubber contaminated with iron. The confidence interval of the process was $1.08 < C_{pk} < 1.93$.

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From Table 5, the contaminated rubber reproduction process cost 2.38 Baht/kg (Sriwarin et al., 2014). According to the after-improvement analysis, the fraction of the contaminated rubber was reduced by 17.97 percent, which equaled 388,500 kg/year. Therefore, the improvement immensely lowered the cost of reprocessing process. The forecasted reduced cost was (388,500*2.38) = 924,630 Baht per year. Hassan (2013) and Kaushik and Khanduja (2011) also received the positive outcome using Lean Sig Sigma to reduce production costs.

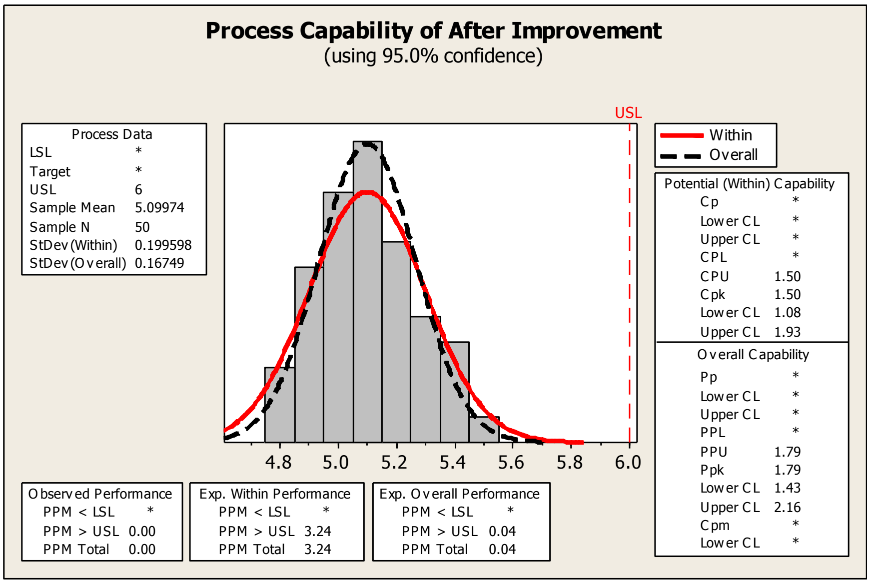

Figure 12 Process capability analysis of block rubber proportion contaminated with iron after process improvement

Table 5 Cost of the reproduction of the block rubber contaminated with iron.

List	Baht/kilogram
Fixed cost	
- property, plant, equipment, scales, forklifts	0.18
- administrative expense	0.09
- working capital interest	0.58
Variable cost	
- labour cost	0.72
- maintenance cost	0.07
- electricity cost	0.50
- LPG gas cost	0.17
- underground water cost	0.03
- other costs	0.04
Total	2.38

Source: Accounting department of the case study factory

4.5 Control Phase

To establish long-term improvement, standardized work instructions were established for general practices and training. The follow-up analysis was performed to confirm the improvement process sustainability. The on-site data were collected from July to August 2020. The total 50 data sets were statistically calculated to confirm the process stability.

4.5.1 Statistical analysis

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The follow-up data analysis was conducted to confirm the method's consistency. The analysis was done with a 95% confidence interval. The results are shown in Table 6.

Table 6 Statistical parameters calculated from the production performance confirmation the iron contamination improvement from July to August 2020

Statistical parameters	Confirmation
The average proportion of the block rubber contaminated with iron (percent/day)	4.954
Standard deviation (percent/day)	0.121
The upper limit of the average proportion of the block rubber contaminated with iron At a 95% confidence interval (percent/day)	4.983

4.5.2 Two independent sample hypothesis testing (Montgomery, 2009)

1) The variance test was performed to investigate the consistency of the block rubber contaminated proportion at a 0.05 significance level. The data were collected two times. The hypothesis was as follows:

$$H_0 : \sigma_1^{\ 2} = \sigma_2^{\ 2}$$
$$H_1 : \sigma_1^{\ 2} \neq \sigma_2^{\ 2}$$

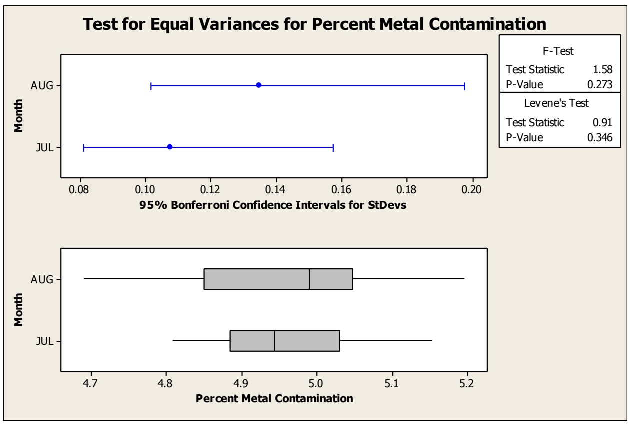

Figure 13 The Variance test for data analysis confirmation

Figure 13 concluded that the p-value was 0.273, which was higher than the significance level, 0.05. Therefore, there was no solid evidence to say that the 2 experiments had unequal variance.

2) The mean test was performed to investigate the consistency of the block rubber contaminated proportion at a 0.05 significance level. The data were collected two times. The hypothesis was as follows:

$$H_0 : \mu_1 = \mu_2$$
$$H_1 : \mu_1 \neq \mu_2$$

Table 7 The result of a mean test for data analysis confirmation

Sources	T-Value	d.f.	P-Value
The proportion of block rubber contaminated with iron	0.38	48	0.704

Table 7 shows that the p-value was 0.704, which was higher than the significance level, 0.05. Therefore, the mean from the 2 experiments was similar.

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5. Conclusion

The purpose of the research was to reduce the proportion of block rubber contaminated with iron from the production process while all relevant constraints were taken into account. The former production process had a higher fraction of contaminated rubber than the upper limit, 6 percent per day. According to the integration of the Cause-and-Effect diagram and the Failure Mode and Effect Analysis method (FMEA), It was found that the contamination issues were mainly caused by the lack of the iron separation machine, the inefficient magnet set used to withdraw iron debris from rubber raw materials, and the low-performance inspecting system for rubber shredder blades. Lean Six Sigma approach was then utilized to tackle the problems. The practiced alterations included the new iron separation machine installation in the production line, more magnet sets assembled inside rubber raw materials storages, at the shredded rubber screening machine and the base of the shredder blades, and a record-keeping logbook for the blades. The integrated approach decreased the fraction of the problematic iron-contaminated rubber by 17.97 percent. The capability analysis, C_{pk}, is 1.50 with a 0.05 significance level, which indicated the highly efficient process. The confidence interval of the process is $1.08 < C_{pk} < 1.93$. The forecasted reduced cost from rubber reprocessing was 924,630 Baht per year.

6. Acknowledgement

This work would not have been possible without the support from Nakhon Si Thammarat Rajabhat University. It was also fully supported by the case study factory. I am grateful to all of those with whom I have had the pleasure to work during this project.

7. References

Amaluk, A. (2019). Defect reduction in machine parts production processes: A case study of Supreme precision manufacturing Co., Ltd. *Thai Industrial Engineering Network Journal, 5*(1), 36-48.

Breyfogle III, F.W. (2003). *Implementing Six Sigma: Smarter Solutions Using Statistical Methods.* Texas: John Wiley & Sons.

Chutima, P. (2002). *Engineering Experimental Design.* Bangkok: Chulalongkorn University Press.

Hassan, M. (2013). Applying Lean Six Sigma for waste reduction in a manufacturing environment. *American Journal of Industrial Engineering, 1*(2), 28-35.

Kaushik, P. & Khanduja, D. (2011). DM make up water reduction in thermal power plants using Six Sigma DMAIC methodology. *Journal of Scientific & Industrial Research, 8*(1), 36-42.

Ketsarapong, P. & Sriyanalugsana, S. (2019). Reducing defective in food refrigerator production process with six sigma technique. *Kasem Bundit Engineering Journal, 9*(2), 25-37.

Maneechot, N. & Pijitbanjong, P. (2019). Defect reduction in standard thai rubber production process. *Thai Industrial Engineering Network Journal, 5*(1), 66-74.

Mekboon, S. & Plongmai, J. (2017). Defects Reduction in polymer solid capacitor production process. *Kasem Bundit Engineering Journal, 7*(1), 105-123.

Montgomery, D.C. (2009). *Introduction Statistical Quality Control.* Texas: John Wiley.

Montgomery, D.C. (2005). *Design and Analysis of Experiments.* New York: John Wiley.

Puangthong, J. & Daengkanit, A. (2020). Rubber situation in year 2019 and trends year 2020. *Para Rubber Journal, 41*(2), 36-39.

Pyzdek, T. & Keller, P. (2018). *The Six Sigma Handbook.* New York: McGraw-Hill Education.

Ramasamy, S. (2009). *Total Quality Management.* New Delhi: McGraw-Hill.

Sliva, T. and Ferreira, P. (2017). Improve the extrusion process in tire production using six sigma methodology. *Procedia manufacturing, 13*, 1104-1111.

Sriwarin, P., Petchernnoen, T., Ananta, M., & Kunilaasiri, A. (2014). The cost of processing primary rubber at the factory level. *Para Rubber Journal, 18*(3). 20-29.

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