WASTE REDUCTION IN BRAKE LINING PRODUCTS TYPE 51 HS USING LEAN SIX SIGMA METHOD

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ABSTRACT

Every company desires a profit, and its production system must continually develop and become more productive. Companies can boost their production productivity in a variety of ways, including by enhancing their production process system and removing impediments. This research was conducted at a company in Tangerang that specialized in manufacturing brake linings. On the basis of the results of field research, manufacturing department defects and inventory have been detected. The research phases employ the DMAIC model. The define phase employs SIPOC and CTQ diagrams. Using WAM to identify waste that happens through the distribution of questionnaires during the measurement phase. According to the measure stage's calculation, the company's current efficiency level is 26.85 percent. The DPMO value is 6,222.71 and sigma number indicates a quality level of 4.91. After learning the company's status, the research continued with an FMEA examination of the root cause. On the basis of the results of the analysis, proposals for changes to the brake linings production steps were made. The research was continued in the third phase, known as control, which consisted of recalculating the company's status after the implementation of modifications. The calculation findings demonstrate an increase in process cycle efficiency to 35.33 percent. In addition, a reduction in the value of faults per million opportunities resulted in the production of 4,524.88 products and an increase in the sigma level to 5.12. This demonstrates a gain in efficiency of 8.48%, a drop-in DPMO of 1,697.83 products, and a 0.21 increase in sigma value.

***Keywords**: DMAIC, Lean Six Sigma, DPMO, Sigma Level.*

ABSTRAK

Setiap perusahaan menginginkan keuntungan, dan sistem produksinya harus terus berkembang dan menjadi lebih produktif. Perusahaan dapat meningkatkan produktivitas produksinya dengan berbagai cara, termasuk dengan meningkatkan sistem proses produksi dan menghilangkan berbagai hambatan. Penelitian ini dilakukan pada sebuah perusahaan di Tangerang yang khusus memproduksi kampas rem. Berdasarkan hasil penelitian lapangan, cacat departemen manufaktur dan inventaris telah terdeteksi. Tahapan penelitian menggunakan model DMAIC. Fase pendefinisian menggunakan diagram SIPOC dan CTQ. Menggunakan WAM untuk mengidentifikasi pemborosan yang terjadi melalui penyebaran kuesioner selama tahap pengukuran. Berdasarkan perhitungan tahap pengukuran, tingkat efisiensi saat ini sebesar 26,85 persen. Nilai DPMO sebesar 6.222,71 dan angka sigma menunjukkan tingkat kualitas sebesar 4,91. Setelah mengetahui status perusahaan, penelitian dilanjutkan dengan pemeriksaan FMEA untuk mengetahui akar permasalahannya. Berdasarkan hasil analisa tersebut maka dilakukan usulan perubahan pada tahapan produksi kampas rem. Penelitian dilanjutkan pada tahap ketiga yang disebut pengendalian, yaitu menghitung ulang status perusahaan setelah dilakukannya modifikasi. Berdasarkan perhitungan menunjukkan adanya peningkatan efisiensi siklus proses hingga 35,33 persen. Selain itu, penurunan nilai kesalahan per juta peluang menghasilkan produksi sebanyak 4.524,88 produk dan peningkatan level sigma menjadi 5,12. Hal ini menunjukkan peningkatan efisiensi sebesar 8,48%, penurunan DPMO sebesar 1.697,83 produk, dan peningkatan nilai sigma sebesar 0,21.

***Kata kunci:** DMAIC, Lean Six Sigma, DPMO, Level Sigma.*

INTRODUCTION

One of the most popular business strategies is the pursuit of customer satisfaction so that consumers remain loyal and strong relationships exist between companies and customers, especially manufacturing companies. Therefore, in order to preserve consumer loyalty, the company must achieve optimal performance in its production process by minimizing waste or operations that do not provide value to the business [1]. This study was conducted at a Tangerang company that began operations in 2002 in the field of manufacturing brake products lining or vehicle brake lining with make (MTO). Brake linings are the pads used to stop or lessen the speed of a vehicle; when they are used more frequently, they wear out and must be replaced immediately. Seven varieties of brake linings are manufactured, including CP, CP13, 51HS, Non Asbest, Non Asbest 2, Non Asbest Australia, and TVS. The company has conducted quality control tests using a military sample by constructing sampling processes and tables, identifying risk-category-based parameters, and entering into agreements with suppliers. Based on the results of the interviews, the company has experienced two waste issues: inventory waste and defect waste. What constitutes a waste in terms of inventory is the insufficiency of storage places for raw materials and finished goods as a result of the sudden high demand from consumers. As a result, there is an exchange of good raw materials and bad raw materials (which have been separated beforehand), which will be processed later using processing machines, as well as the accumulation of goods, which occasionally impedes and obstructs the passage of workers. Regarding the problem with defective waste, the company has a number of defects from the results of the production process, the majority of which are caused by hot press machines whose engine temperature is set too high, resulting in cracked production results, or as a result of the number of poor raw materials used in the production process. Figure 1 depicts an example of a defect brake lining product of type 51 HS.

Figure 1. Defective Product

Based on literature study, implementation of lean manufacturing is essential to the process of reducing waste [2,3,4]. Several recent studies [5,6], have suggested that the effectiveness of lean manufacturing has persuaded researchers to transfer the lean idea to the business sector. Lean manufacturing is a set of techniques designed to reduce machine downtime, inventory, rework, and waste [7]. In addition, the six-sigma method has been shown successful for a company's systematic improvement, which can increase customer satisfaction and profit [8,9]. The integration of the two tools (lean and six sigma), helps the organization to attain an optimum outcome, which might not be achieved when either one is employed [9,10]. Belekoukias, et al. [11], and Chiarini and Bracci [12] all utilized the Define-Measure-Analyze-Improve-Control (DMAIC) method. To attain six sigma performance levels in the production process, a lean six sigma approach is required to identify and reduce waste or non-value contributed operations through continuous improvement [13]. In the manufacturing industry, there is study on the adoption of lean six sigma approach, such as the research by Joes et al. [14], Purnomo and Lukman [15], and A. Chiarini and E. Bracci, [12]. However, there is no specific research has been conducted on the application of lean six sigmas in the brake lining industry. So, this is the first study undertaken on the production process for brake linings.

The goals of this research are to discover and analyze the causes of waste in the brake lining production process, as well as to assess the value of process cycle efficiency (PCE), Defects Per Million Opportunities (DPMO) and sigma value. In addition, the research intends to map the current value stream mapping and future value stream mapping to make the company's state easier to comprehend and express. At the conclusion of the investigation, proposals for enhancements designed to increase the efficiency and quality of brake lining production will be provided.

RESEARCH METHODS

The initial step is a field study, which consists of factory inspections in accordance with the ultimate project's concept. Then, identify challenges associated with enterprise-wide issues. Next, a research-related literature review is conducted and delivered in the form of journal or book citations. Furthermore, refer to the research objectives, specifically identifying the research objectives based on the existing problem formulation, and data collection, namely primary and secondary data collection, with primary data collected through direct interviews and secondary data derived from historical data concerning product quality, production machinery, and production inputs. The obtained data will next undergo processing and analysis using the DMAIC steps. The define phase will identify issues utilizing SIPOC (suppliers, inputs, process, outputs, customers) diagrams, and Critical to Quality (CTQ). The measure phase will map the existing value stream and calculate PCE, DPMO, and sigma level. The analyze phase will employ Fault Tree Analysis (FTA), and Failure Mode and Effects Analysis (FMEA) to conduct a causal analysis. The improve phase will map the future value stream mapping and make suggestions for enhancements. At the last phase of control, the value of PCE, DPMO, and sigma level will be recalculated. The research concluded with proposed modifications and ideas that are in line with the research's initial aims, which were to boost the production process's efficiency and the quality of brake lining products.

RESULTS AND DISCUSSION

Based on the stages stated in the research methodology, this study will explore the application of lean six sigmas with the DMAIC principle in order to identify and make recommendations for improvements to the production process for brake linings in terms of efficiency and quality.

Define Stage

The define phase focuses on problem identification, defect count, and process objective**.** According to the calculation results derived from data collected over the previous three months, the average defect rate prior to the investigation was 2.84 percent. Table 1 displays information regarding the type of 51 HS products with problems from January to March.

Table 1. Data Type of Defective Brake Lining Products 51 HS

Product Type	Month (2022)	Total Products (Pcs)	Number of Product Defects (Pcs)	Product Defect Percentage (%)
51 HS	January	282	17	6.02
	February	734	8	1.09
	March	112	7	6.25
	Total	1,128	32	2.84

The second part of the define phase is to identify specific customer requirements using SIPOC Diagram. The SIPOC Diagram is utilized for documenting and tracking every business process from the first stage to the final step of a production process [16]. Figure 2 depicts the SIPOC Diagram for the 51 HS kind of product.

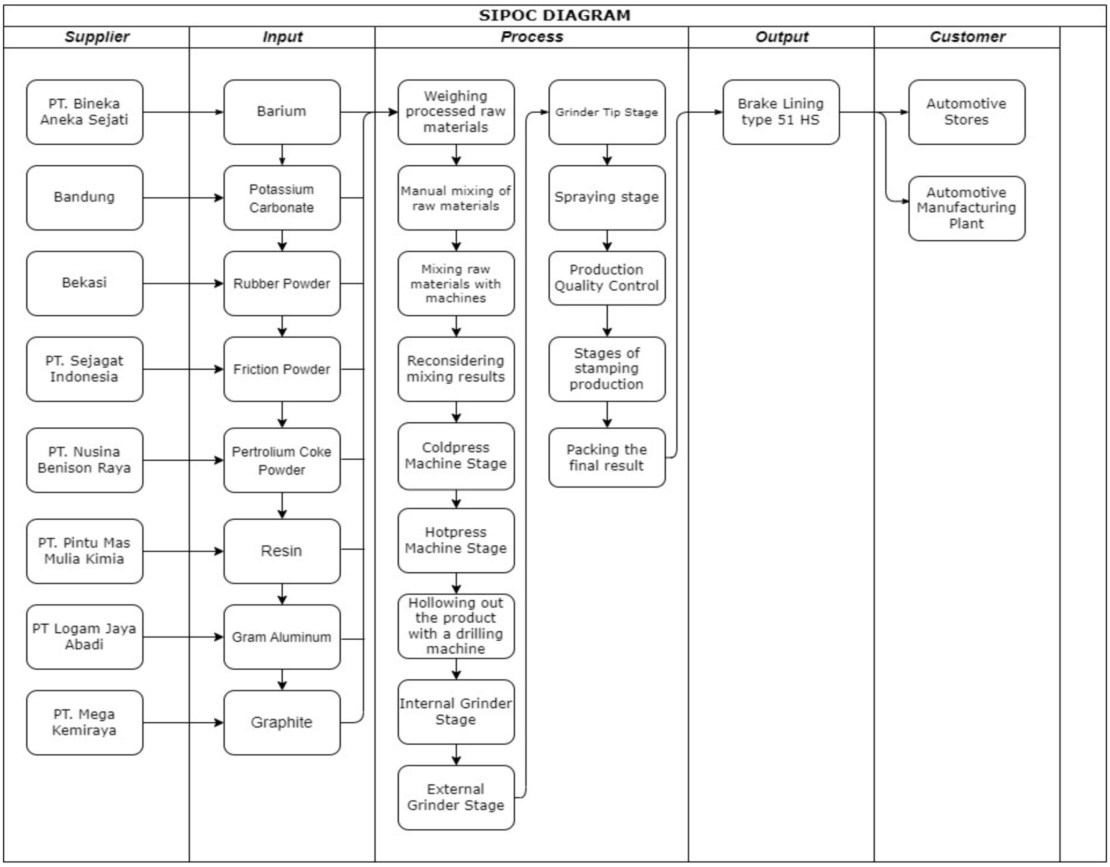

Figure 2. SIPOC diagram of product type 51 HS

Then, collecting and analyzing data is followed by identifying the CTQ associated with the process during the define phase. The CTQ tool intends to serve as a component of the activity process that has a direct impact on the attainment of the required quality. The following diagram depicts the CTQ of the 51 HS product type.

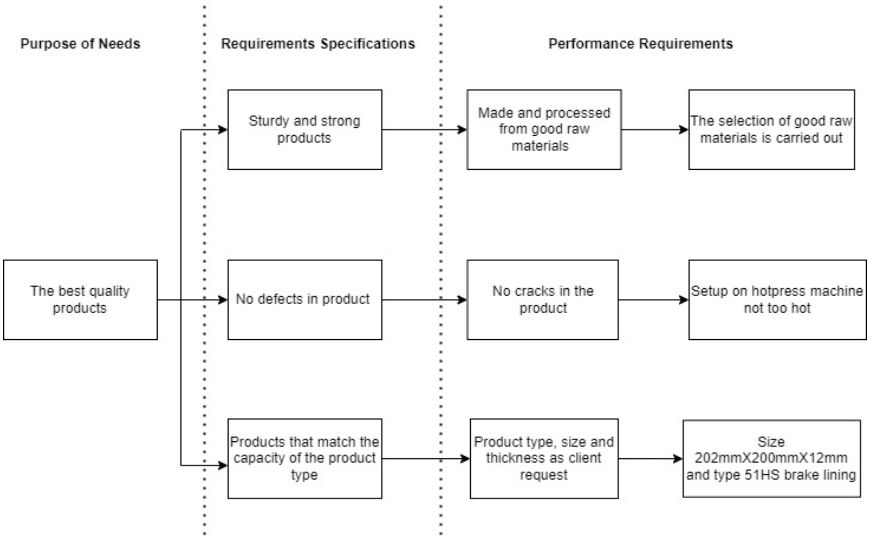

Figure 3. Critical to Quality of the 51 HS Product Type

Measure Stage

Following the completion of the define stage is the measure stage. The measure stage is an objective stage that is a data collection step and tries to establish current company performance criteria. At the measure stage, the steps used in this study were to calculate PCE, Waste Relationship Matrix (WRM) and Waste Assessment Questionnaire (WAQ), Current Value Stream Mapping (CVSM), control charts and DPMO. PCE is a measurement method used to determine the productivity of a plant, as it reveals the proportion of processing time to total production time [17]. To determine the PCE value, the following formula should be applied:

$$Process\ Cycle\ Efficiency = \frac{Value\ Added\ Time}{Total\ Lead\ Time} x100\% = \frac{2820}{10500} x100\% = 26.85\%$$

The PCE value was calculated to be 26.85 percent, which indicates that the process is not yet classed as lean because a lean process has a PCE value more than 30 percent [17].

Then, the production process activities for brake linings are mapped utilizing the CVSM. Value steam mapping is a technique for visualizing activity processes as a useful flow mapping chart to map all activities that provide value to the lean process [17]. Figure 4 depicts a flowchart of the present production process

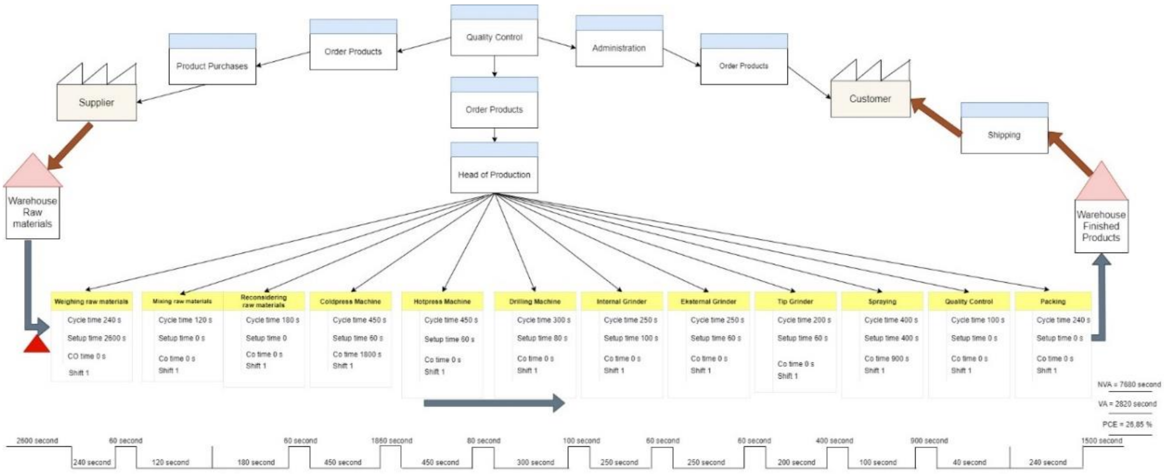

Figure 4. Current Value Stream Mapping

According to the CVSM, the overall value contributed time in the brake lining production process is 2820 minutes, whereas the total non-value-added time is 7680 minutes. The following stage is Waste assessment model (WAM) using WRM (Waste Relationship Matrix) and WAQ (Waste Assessment Questionnaire). WAM is a model that is developed to identify waste concerns by establishing WRM and WAQ and combining their respective values. WRM and WAQ analysis are crucial research methods for determining a company's impediments [18]. The waste relationship matrix is a matrix composed of rows and columns whose purpose is to examine and analyze the waste that occurs and the waste relationship using a matrix based on classification criteria [10]. The following is a summary of the company-distributed questionnaire, which may be found in Table 2.

Table 2. Recapitulation Results of WAM

	O	**I**	**D**	**M**	**T**	**P**	**W**	**Total**
Score (Yj)	0.260	0.184	0.194	0.176	0.169	0.131	0.187	1.301
Pj Factor	282.16	237.58	285.77	154.15	124.66	111.20	182.88	1378.4
Final Result (Yj Final)	73.36	43.71	55.44	27.13	21.07	15.56	31.19	267.46
Final Result (%)	15.9	16.49	17.95	12.7	10.45	12.17	14.34	100
Rank	**3**	**2**	**1**	**5**	**7**	**6**	**4**	

A control chart is a control tool that operates to track variations and changes of a quality through time, with data presented as maps or tables [17]. Through the calculation of Centre Line (CL), Upper Centre Line (UCL), and Lower Centre Line (LCL), it is possible to determine whether or not a product's quality has been measured in order to determine how much data is still categorized as controlled. Figure 5 depicts the results of the calculation of CL, UCL, and LCL in the form of a graph.

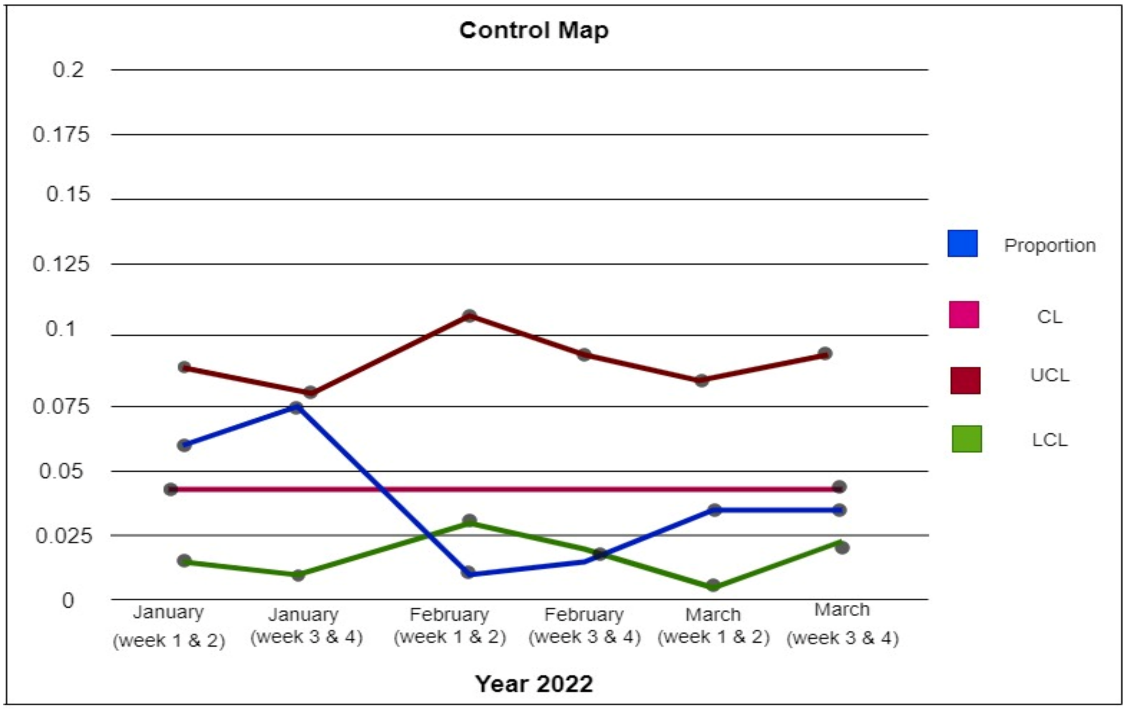

Figure 5. P Control Chart

Following the determination of waste categories using the WAM questionnaire and control chart, the DPMO is calculated. DPMO is the number of opportunities or potentials that can result in defects from existing opportunities [19]. The following is the calculation of the DPMO formula and the calculation results are as follows:

$$DPMO = \frac{Number\ of\ Defects}{Sample\ Size\ x\ Defect\ Opportunity}\ x\ 1{,}000{,}000 = \frac{57}{1832\ x\ 5}\ x\ 1{,}000{,}000 = 6{,}222.71$$

The sigma level values for brake linings of type 51 HS are:

$$Sigma\ Value = NORMSNV\left(\frac{1{,}000{,}000 - DPMO}{1{,}000{,}000}\right) + 1.5 = NORMSNV\left(\frac{1{,}000{,}000 - 6{,}222.71}{1{,}000{,}000}\right) + 1.5 = 4.91$$

Therefore, based on the DPMO calculation and Sigma value, it can be determined that the sigma value is at level 4, which indicates that it is still not ideal and must be improved in order to reach the lean six sigma goal.

Analyze Stage

Following the measure phase comes the analyze phase. At this stage, the objective is to be able to detect problems by determining how to close the performance gap between the current system or process and the anticipated outcome [21]. This study utilized Fault Tree Analysis (FTA) and Failure Mode and Effects Analysis (FMEA)Figures 6, 7, and 8 pertaining to the FTA forms of impairment.

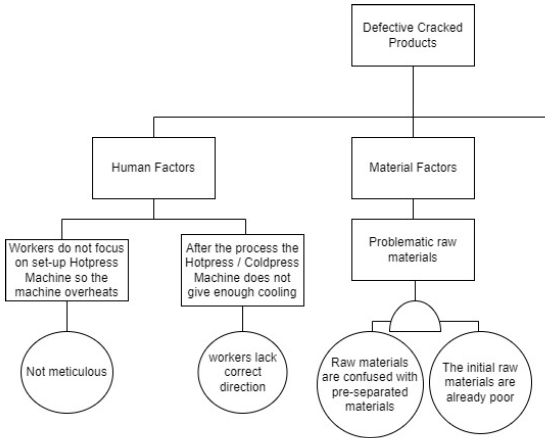

Figure 6. Fault Tree Analysis Types of Cracked Product Defects

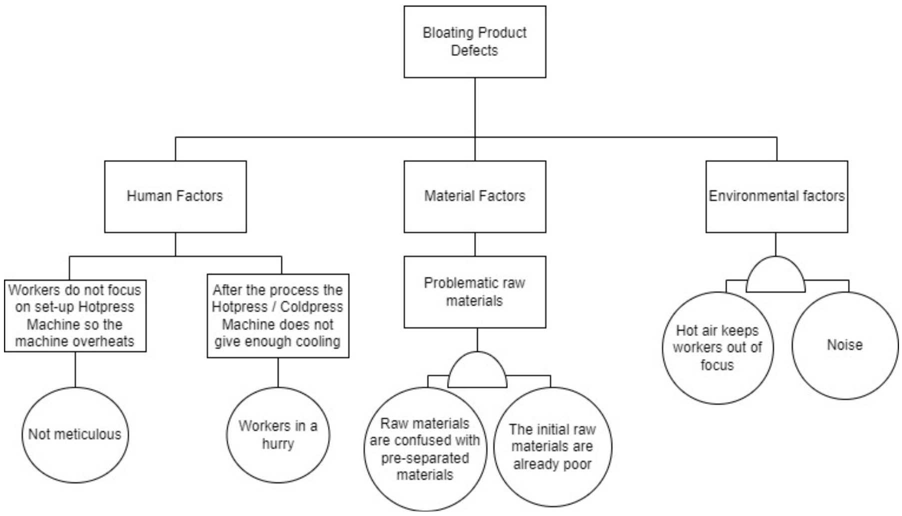

Figure 7. Fault Tree Analysis Types of Bloated Product Defects

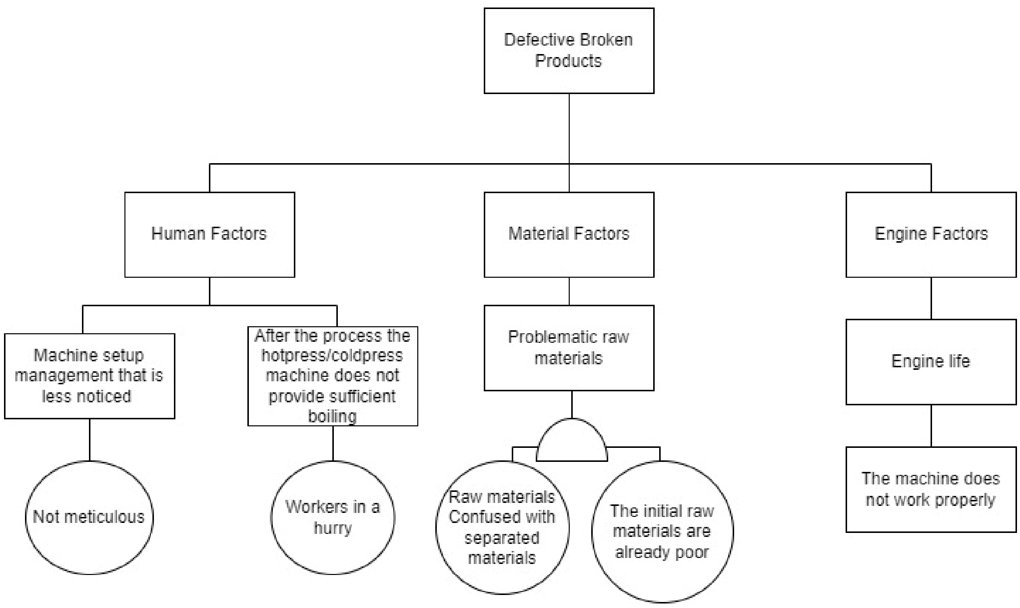

Figure 8. Fault Tree Analysis Types of Product Defects Broken

FMEA is one of the analysis strategies used to identify effects or consequences that are likely to cause errors in a product or production process [17].

Table 3. Failure Mode and Effect Analysis

Potential Failure Mode	Product Effect or Failure	S	Potential Cause	O	Current Process Control	D	RPN	Rank	Action recommended
Crack Defect	Hot press machine setup that is too hot during use	8	The operator's inaccuracy in setting the Hot press machine temperature	7	Reset with engine temperature to keep the temperature stable	6	336	1	Further training for operators and chief operators to be better trained and understand the machine.
Bloating Defect	The initial raw material found is not good	8	More initial raw materials are not good	7	Re-checking of incoming raw materials or mixing of raw materials	5	240	2	Making SOPs or labels for measuring data in the mixer machine area, carrying out periodic monitoring by the chief operators
Broken Defect	After processing the Hot press machine or Coldpress machine does not give the product cooling time according to the rules	6	Inaccuracy from operators who do not ensure the time to inhabit the product after the Hot press machine or Coldpress machine process or from poor initial raw materials so that progress to the next stage fails	4	Re-check from operator or chief operator to provide adequate cooling	4	96	3	Making SOPs regarding giving time intervals after the Hot press machine process with the next process and more training for workers
Fragile Defect (Thin)	Insufficient raw materials during the weighing process or the hot press machine setup is too hot	5	Operator error not focusing on weighing raw materials so that the product becomes thin or the Hot press machine operator error setting the machine temperature too hot.	2	Re-weighing of initial raw materials and re-checking for machine setup	5	50	4	Carry out more inspections or checks in order to balance the less good and good raw materials, making more places to put the raw materials that have been separated so as not to be confused
Untidy Side Cut Defect	Cutting or sharpening is not neat on the Grinder machine process	4	There is a cutting or sharpening of the product at the time of the Grinder machine.	3	Re-sharpening to make it tidier and according to production rules	2	24	5	Carrying out further training for Grinder machine operators so as not to do the job repeatedly, making SOPs

On the basis of the FMEA analysis, it can be stated that there are three major issues that need to be addressed: crack defects with an RPN value of 336, bloating defects with an RPN value of 240, and broken defects with an RPN value of 96.

Improve Stage

Following the conclusion of the analyze phase is the improve phase. The improvement phase aims to find answers to issues that lead to defective brake lining products. The proposals for improvement in the form of production process suggestions as shown below:

1. Existing operators and chief operators require additional training to properly comprehend the machines they operate.
2. Creating SOPs or labels for measuring data at the mixer machine area or at the time of physically mixing the initial raw components, and supervising employees to ensure they adhere to the system.
3. Provide a time gap in line with the company's SOP, which has been in place since 2008 and is approximately 12 minutes, between the Hot press machine process and the following step, so that the product is not fractured or cracked after the heating process.
4. Perform further inspections or checks in order to balance the quality of the worse and better raw materials, and provide more storage space for the separated raw materials so that they are not mixed up.
5. Conducting additional training for Grinder machine operators so that they do not perform the same tasks repeatedly, and creating standard operating procedures.

Control Stage

Control stage is the final stage of the DMAIC method used for research; at this stage, data analysis will be conducted before and after the manufacturing process is improved. The first step in the control phase is to create a One Point Lesson (OPL). OPL is a type of visual and quickpresentation that provides an explanation of what can and cannot be done throughout the production process in a single point [17]. Figure 9 concerning OPL is shown below.

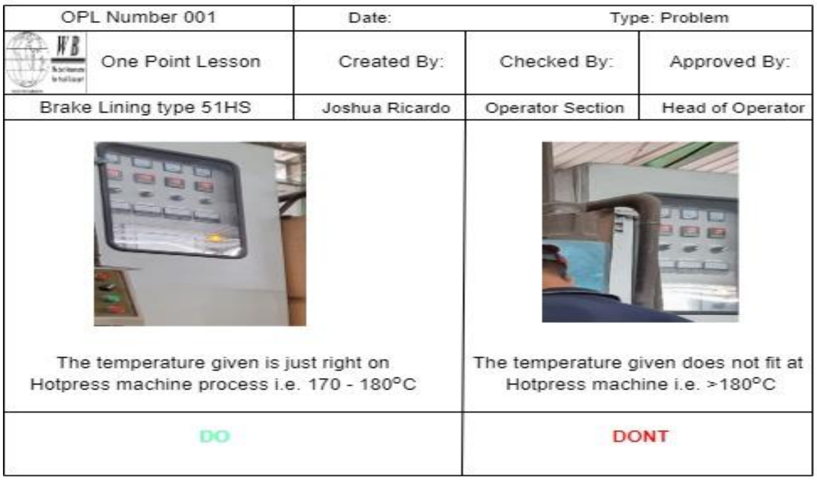

Figure 9. One Point Lesson

The following stage is to implement the proposal by reorganize the storage area by clearly separating good raw materials, bad raw materials, and raw materials that have been mixed with good and bad raw materials, so as not to confuse good raw materials and bad raw materials (which have already been separated) that will be processed using a production process machine to reduce inventory waste in the company (Figure 10). The next implementation is to reduce non-value-added time at the machine stage to other machines, such as on a Hot press machine by bringing a drilling machine within 100 cm. The head of the company's operator believes that relocating the machine can reduce non-value-added time in the production process by saving additional travel time (Figure 11).

Figure 10. Storage Space Rearrangement Implementation

Figure 11. Implementation of Machine Distance Approach

After implementing the proposed improvements, the future value streammapped, and the value of PCE, DPMO and sigma value will be calculated after adopting the proposed improvements. A comparison of the outcomes before and after implementation can be seen in Table 4.

Table 4. The Comparison Between Current and Future Value Stream Mapping

Aspect	**Current**	**Future**	**Results**
Value added time	2820 seconds	2820 seconds	Steady
Non-Value added time	7680 seconds	5160 seconds	Decreased by 2520 seconds
PCE	26.85%	35.33%	Increased by 8.48%

The following is the calculation of the DPMO formula after improvement are as follows:

$$DPMO = \frac{Number\ of\ Defects}{Sample\ Size\ x\ Defect\ Opportunity}\ x\ 1{,}000{,}000 = \frac{5}{221\ x\ 5}\ x\ 1{,}000{,}000 = 4524{,}88$$

The sigma level values for brake linings of type 51 HS after improvement are:

$$Sigma\ Level = NORMSNV\left(\frac{1{,}000{,}000 - DPMO}{1{,}000{,}000}\right) + 1.5 = NORMSNV\left(\frac{1{,}000{,}000 - 4{,}524.88}{1{,}000{,}000}\right) + 1.5 = 5.12$$

CONCLUSION

From research conducted in companies that produce Brake Lining Type 51 HS, it can be concluded that there are two types of waste that are the most constraining to the company, namely inventory and defect waste. Companies are offered recommendations such as OPL to clarify the flow or difficulties in the production process, rearranging storage space and bringing machines closer together to reduce non-value added time. After carrying out the implementation, the monitoring and evaluation process is continued by recalculating the PCE, DPMO, and sigma levels. Based on the current and future value stream mappings, it can be concluded that the comparison of the PCE value and non-value added time is 7,680 seconds before improvement and 5,160 seconds after an improvement. The DPMO value decreased from 6,222.71 to 4,524.88, and the sigma level value increased from 4.91 Sigma to 5.12 Sigma. Recommendations that can be given to firms in order to eliminate waste and explain the flow of the manufacturing process, among other things, by offering direct or indirect instruction, in order to clearly enhance the workmanship of workers in each part and reduce the repetition of the same errors. This study was limited in a number of ways, including the fact that the research object was limited to a single type of brake lining product and the research duration was constrained, preventing the implementation of a significant improvement proposal. Further suggestions include expanding the scope of the investigation and paying attention to other potential wastes so that a comprehensive conversation and analysis of the company's state may be conducted.

REFERENCES

[1] Kotler, Philip and Armstrong, Garry, *Principles of Marketing*, Erlangga, Jakarta, 2008.
[2] A. Dixit and V. Dave and A.P. Singh "Lean Manufacturing: An Approach for Waste Elimination," *International Journal of Engineering Research & Technology (IJERT)*, Vol. 4 Issue 04, pp. 532-536, 2015.
[3] V. Chahal and M.S. Narwal, "Impact of Lean Strategies on Different Industrial Lean Wastes," *International Journal of Theoretical and Applied Mechanics*. vol. 12, no. 2, pp. 275-286, 2017.
[4] J.K. Orbegozo, J.M. Palomino, F.S. Raffo and E.R. Palomino, "Applying Lean Manufacturing Principles to Reduce Waste and Improve Process in a Manufacturer: A Research Study in Peru," IOP Conf. Ser.: Mater. Sci. Eng., 2019.
[5] N.A.A. Rahman, S.M. Sharif, and M.M. Esa, "Lean manufacturing case study with Kanban system implementation," *Procedia Economics and Finance*, vol. 7, pp. 174-180, 2013.

[6] D. Romero, P. Gaiardelli, D. Powell, T. Wuest, M. Thürer, "Digital Lean Cyber Physical Production Systems: The Emergence of Digital Lean Manufacturing and the Significance of Digital Waste," *IFIP International Conference on Advances in Production Management Systems (APMS)*, Aug 2018.
[7] R. Trehan, A. Gupta, and M. Handa, "Implementation of Lean Six Sigma framework in a largescale industry: a case study," *International Journal of Six Sigma and Competitive Advantage*, vol. 11, pp. 23-41, 2019.
[8] Z. Zhuo, "Research on Using Six Sigma Management to Improve Bank Customer Satisfaction," *International Journal of Quality Innovation*, vol. 5, no. 3, 2019.
[9] R. Mustapha and N.F. Habidin, "Using DMAIC in Improvement of Customer Satisfaction and Facilities Provided at Commuter Stations," *International Journal of Academic Research in Business and Social Sciences*, vol. 6, no. 12, 2016.
[10] A. Sulaksmi, "Penerapan Lean Sigma untuk Menggurangi Waste pada Produksi Benih Jagung", *Jurnal Teknik Industri*, vol. 8, pp. 88-98, 2008.
[11] I. Belekoukias, J. A. Garza-Reyes, and V. Kumar, "The impact of lean methods and tools on the operational performance of manufacturing organisations," *International Journal of production research*, vol. 52, pp. 5346-5366, 2014.
[12] A. Chiarini and E. Bracci, "Implementing Lean Six Sigma in Healthcare: issues from Italy," *Public Money & Management*, vol. 33, pp. 361-368, 2013.
[13] V. Gaspersz, *Lean Six Sigma for Manufacturing and Service Industries*, Bogor: Vinchristo Publication, 2011.
[14] S. Joes, L.L. Salomon and F.J. Daywin, "Penerapan Lean Six Sigma untuk Meningkatkan Efisiensi dan Kualitas Produk Kemasan Food Pail pada Perusahaan Percetakan", *Jurnal Ilmiah Teknik Industri*, vol. 10, no. 3, 224 – 236, 2022.
[15] D.H. Purnomo, and M. Lukman, "Reduce Waste using Integration of Lean Six Sigma and TRIZ Method: A Case Study in Wood Industry," *Jurnal Teknik Industri*, vol. 21, no. 2, 139-152, 2020.
[16] Ahmad and L.L. Salomon, "Analysis of Lean Six Sigma Implementation to Reduce Non-Value Added Time and Number of Defective Products in Powder Box Set Production," *Lecturer's Scientific Work*, vol. 7, no. 01, 2013.
[17] V. Gaspersz, *Total Quality Management*, PT Gramedia Pustaka Utama, Jakarta, 2001.
[18] M.R.F. Rochman, Sugiono and R.Y. Efranto, "Application of Lean Manufacturing Using WRM, WAQ, and VALSAT to Reduce Waste in the Finishing Process," *Journal of Industrial Engineering*, 2014.
[19] A. Hidayat, *Six Sigma Strategy Map of Quality Development and Business Performance*, Jakarta, PT Publisher, Elex Media Komputindo Gramedia Group, 2007.
[20] D.H. Stamatis, *Failure Mode and Effect Analysis: FMEA*, Wisconsin: Quality Press, 2003.