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DOCTOR OF PHILOSOPHY

A LEAN SIX SIGMA FRAMEWORK FOR IDENTIFYING SOURCES OF WASTE IN MANUFACTURING SECTOR IN INDONESIA

ACADEMIC SESSION: 2021/2022

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A LEAN SIX SIGMA FRAMEWORK FOR IDENTIFYING SOURCES OF WASTE IN MANUFACTURING SECTOR IN INDONESIA

MUHAMMAD KHOLIL

A thesis submitted in
fulfilment of the requirement for the award of the degree of
Doctor of Philosophy in Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
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JULY 2022

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged

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ACKNOWLEDGEMENTS

Thanks to the grace of Allah SWT, God the Almighty, until now, I have been able to and am still completing the Thesis very well and with full responsibility.

Furthermore, on this occasion, allow me to express my gratitude first and foremost to my supervisor, Dr. Reazul Haq bin Abdul Haq and Profesor Emeritus Dr. Sulaiman bin Hj. Hassan for his valuable advice, support, and patience throughout my PhD studies. Their extraordinary knowledge and abundant experiences have propelled me in all my academic research time and daily life. I want to thank all Persatuan Pelajar Indonesia (PPI) members in Malaysia, especially the Parit Raja area and UTHM's Beloved Campus Study Place. Their kind help and support made my studies and my life at UTHM an exciting time. On this occasion, I also want to express my gratitude to the theme of peer lecturers who have helped a lot in completing this thesis until the end of the completion, and the last one, I would like to thank my parents, wife, and children. Without their understanding and tremendous encouragement in the last few years with such great trials, I hope to face them with sincerity. It would be impossible for me to complete my studies.

That is the introduction that I can convey. I hope that all the participation, energy, thoughts and morals, and other abilities, no matter how small, will become a very extraordinary act of worship because people who study knowledge will be elevated, and Allah SWT will reward those who participate in the slightest. The One and Only, as stated in the Qur'an surah (Al-Zalzalah: 7), "Whoever does the slightest kindness, will undoubtedly see the reward."

ABSTRACT

Manufacturing activities until the beginning of 2020 shows an increment and continue to grow at 210 trillion value or contributes 30.4 percent of Indonesia's investment. Therefore, manufacturing companies need to create an appropriate system to support demand in this sector. In this research, the define-measure-analysis-identify-control (DMAIC) model, value stream mapping (VSM), and value stream analysis tool (VALSAT) are integrated in conducting an in-depth analysis for identifying the sources of waste in 33 manufacturing companies around the Java Islands. There are three main wastes can be identified, namely, (i) defects, (ii) inappropriate processes, and (iii) waiting time. In order to minimize the waste, several solution steps for the root cause error were proposed. Based on man & material root cause error, an adequate training and education need to be provided to all employees in production and non-production. Based on method root cause error, it is necessary to regularly establish standard operating procedures with a clear work instruction, and followed by periodic procedure review. In this category, it is also suggested to develop a specific procedure for predictive and preventive maintenance of an engine factor. Based on environmental root cause error, the manufacturing company need to reinspect the condition of the work location and area to store raw materials and finished goods. In general, this research has provided a new perspective in realizing minimum waste practice in the manufacturing sector.

ABSTRAK

Aktiviti pembuatan sehingga awal tahun 2020 menunjukkan peningkatan dan ia terus berkembang pada nilai 210 trillion atau menyumbang sebanyak 30.4 peratus dalam pelaburan Indonesia. Justeru, syarikat-syarikat pembuatan perlu mewujudkan satu sistem yang sesuai bagi menyokong permintaan dalam sektor ini. Dalam penyelidikan ini, model takrif-ukur-analisis-kenalpasti-kawal (DMAIC), pemetaan aliran nilai (VSM) dan alatan analisis aliran nilai (VALSAT) disepadukan dalam menjalankan analisis mendalam bagi mengenalpasti punca-punca sisa di 33 syarikat pembuatan di sekitar Kepulauan Jawa. Terdapat tiga sisa utama yang dapat dikenalpasti iaitu: (i) kecacatan, (ii) proses yang tidak sesuai dan (iii) masa menunggu. Bagi meminimumkan sisa, beberapa langkah penyelesaian kepada punca ralat telah dicadangkan. Berdasarkan punca ralat pekerja & bahan, latihan dan pendidikan yang sesuai perlu disediakan kepada semua pekerja dalam pengeluaran dan bukan pengeluaran. Berdasarkan punca ralat kaedah, adalah perlu untuk sentiasa mewujudkan prosedur operasi piawai dengan arahan kerja yang jelas dan diikuti dengan semakan prosedur berkala. Dalam kategori ini, adalah juga dicadangkan untuk membangunkan prosedur khusus bagi penyelenggaraan pencegahan dan penyelenggaraan jangkaan faktor engin. Berdasarkan punca ralat alam sekitar, syarikat pembuatan perlu membuat pemeriksaan semula tentang keadaan lokasi tempat kerja dan kawasan untuk menyimpan bahan mentah dan barang siap. Secara umum, penyelidikan ini telah memberikan perspektif baru dalam merealisasikan amalan sisa minimum dalam sector pembuatan.

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CHAPTER 1

INTRODUCTION

Manufacturing activities until the beginning of 2020 are increasing and continue to grow at 210 trillion of Indonesia's investment; manufacturing contributes 30.4% of Indonesia's total investment. Furthermore, even in pandemic conditions, investment in the manufacturing industry increased to 44.7% in the first quarter of 2020 (Kemenperin, 2020). Manufacturing companies must create a system to support this increase in manufacturing activities. The system must adopt a lean method to improve efficiencies and reduce waste. In implementing muscular manufacturing systems, including the division of 7 groups of waste that affect manufacturing is, excess production, waiting time, transportation, over-processing, inventory, movement, and defects/rejection. Based on the methods of previous studies in identifying waste in one manufacturer by integrating DMAIC, VSM, and VALSAT, this research will identify waste in several types of manufacturing in Indonesia in the Java area.

1.1 Research Background

More than 700 manufacturing companies are listed on the Indonesian stock exchange by 2019 with various sub-sectors, including garment and textile sub-sectors, plastic and packaging sub-sectors, metal sub-sectors, and automotive and component sub-sectors. In this research, several data from manufacturing companies have been selected, which have reviewed the rejected data that occurred during the last three years. It is closely related to the company's efficiency, loss, and profit. The companies are divided into three classifications:

(i) A: made from fiber for furniture and clothing needs. Manufacturing products: Sofas and Bags

(ii) B: made from paste or paper fiber. Manufacturing products include packing boxes, medicine bottles, and paper.

(iii) C: made from steel and mining and functions as transportation needs. Pipes, automotive parts, and tin

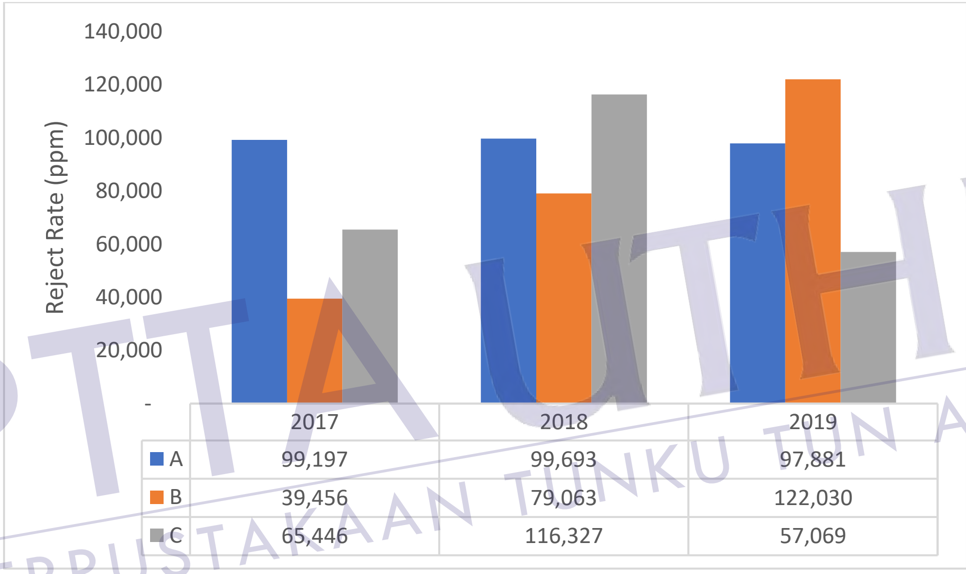


Figure 1.1: Rejection rate for Manufacture A, B, C

The graph in Figure 1.1, shows the reject ratio of the three manufacturing categories exceeds 1000 ppm every year. It tends to increase, especially in the plastic and packaging industries, which is B classification. Further identification needs to occur in order.

Therefore, this study was carried out by focusing on taking cases from 33 manufacturing companies in the Java area. This will give a good indication of the manufacturing industries in the area.

Further analysis is needed to obtain a manufacturing system standardization that can be used in general to reduce waste and increase the efficiency of manufacturing companies. The method used for waste identification is by integrating

DMAIC, VSM (Value Stream Mapping), and VALSAT (Value Stream Analysis Tools).

1.2 Problem Statement

Based on the graph in Figure 1.1, the reject ratio of the three manufacturing categories exceeds 1000 ppm every year. It tends to increase, especially in the plastic and packaging industries, B classifications. The high reject rate in each manufacturing sector impacts the company's profit and loss. High repair costs carried out manually, high machine downtime, scrap raw materials, and wasted finish. It shows lack of knowledge about 4M+1E that can cause low productivity, as the data from Figure 1.1

The previous research (Guo et al., 2019) focused on Air Conditioner Assembling Line by integrating lean's VSM and DMAIC from six sigma explores the integrity of DMAIC and VSM in manufacturing. Still, the first problem is the analysis process done by figuring out techniques generally by significant picture mapping of VMS, and all the results focused on the production process only. One of the tools for waste analysis is Value Analysis Stream Tools (VALSAT). VALSAT has a method to get more accurate analysis and improvement methods. Second, there is not much research on manufacturing, especially in Java Area.

Decision-making in selecting companies in this study has many underlying aspects, so 33 companies were chosen for this study. According to (Roscoe, 1982), the appropriate sample size in this study is 30 to 500. According to the Ministry of Industry, the manufacturing industry in Java has an essential role in Encouraging national economic growth; the manufacturing industry is considered to increase efficiency and ease of infrastructure provision, wide employment opportunities, and attract investment. The industrial herd on the island of Java for manufacturing is a labor-intensive, capital-intensive, and high-tech sector. According to the Ministry of SOEs, the island of Java is a manufacturing center in Indonesia, so the researchers chose Java as the object of this research. The sample taken in this study is a manufacturing company on the island of Java are (Banten, DKI Jakarta, West Java, Central Java, East Java) which has the most significant contribution to the structure of the gross domestic product (GDP), which is 59.00%, followed by Sumatra Island by 21.3%, and Kalimantan Island by 8.05% (Indonesian Statistics Agency, 2020).

Selected companies for this study based on the classification have different manufacturing quantities following the highest growth of manufacturing in Indonesia from metal then paper and textile (Industrial Ministry, 2017).

Therefore, this research analyzed waste in kind of manufacturing in the Java Area by integrating DMAIC, VSM, and VALSAT. Much research on Lean but not much on integrated DMAIC and VSM. A few mentioned their achievement. In a manufacturing firm, handbrake products, researchers implement VSM Method for line balancing. Value stream map and identify the waste areas in the assembly line. Secondly, use the Kaizen activities to effectively VSM for assembly line improvement. It consequently resulted in improved productivity by 20%, reduced workforce by 47%, and improved line balancing efficiency by 62%. After improvement, the no of workers was reduced from 21 to 11, and line balancing efficiency has also been improved from 54% to 88% (Tabassum & Khan, 2016). This activity has focused on method and process only, not in detail on other factors such as man, machine environment, which also have the potential to be the root cause of the problem in the emergence of waste, so it is necessary to do more analysis with integration using other supporting tools.

Lean manufacturing and Six Sigma principles improve processes and create efficiencies in the overall manufacturing process. Lean manufacturing also strives to maintain or increase productivity while minimizing waste to create the maximum possible efficiency. Six Sigma is a process of evaluation and adjustment in management and processes, with the same end goal as lean manufacturing. Six Sigma principals strive to cut costs, improve processes, and maximize production value. The entire lean manufacturing process requires maximizing production while minimizing waste. The goal is to create the highest possible output without sacrificing quality. Ultimately, this systematic approach to running a lean operation will maximize profitability. Toyota pioneered the process by identifying seven specific ordinary wastes removed from the production process to add value and reduce costs. While Lean Manufacturing is not necessarily the best approach for every business, it has proven effective at a large scale for numerous manufacturing-based companies. The exact definition of Lean Manufacturing also changes somewhat, depending on the source, and it is subject to variation based on perspective. It is not an exact science but a set of guidelines and principles for management teams. Many leaders choose to modify definitions and adjust the process to fit within their specific business model.

Lean Six Sigma is the most popular method for continuous improvement in the manufacturing and service sectors. Lean is a continuous effort to eliminate waste and increase the value-added products (goods/services) to provide more value to the customer (Gasperz & Fontana, 2011). The focus of Lean is to identify and eliminate non-value-added activities in design, production (for manufacturing) or operations (for services), and supply chain management that are directly related to customers. There are eight types of waste: production, transportation, delays, process, inventories, movement, defective products, and defective design (Wan & Frank Chen, 2008). Six Sigma was formed at Motorola, which emphasizes variation (Antony, 2011). Six Sigma is defined as a business strategy that increases and reduces defects and failures, increases productivity, and reduces cycle time and production costs. Six Sigma is a statistical method used for reducing variations in any process (Chakravorty & Shah, 2012), reducing costs in manufacturing and services, making savings in the bottom line, increasing customer satisfaction (Drohomeretski et al., 2014), measuring defects, improving quality of product, and reducing defects to 3.4 parts per million of opportunities in the organization (Lee & Wei, 2010). Lean Six Sigma is defined as a methodology and strategy for businesses to improve process performance, customer satisfaction, and outcomes. LSS is a strong strategy in process management to eliminate defects and reduce variations in product manufacturing service processes, which leads to excellent business processes (Snee, 2010). The LSS aims to improve the organization's capabilities, reduce production costs (Chen & Lyu, 2009), and maximize stakeholders' value by improving quality (Setijono et al., 2012). In theoretical, conceptual studies, LSS leads to a gradual increase in product quality level and process reliability and thus supports the implementation of lean practices such as JIT, TPM, and others. In addition, LSS eliminates rework time, increases productivity, increases flexibility system, and reduces inventory levels between workstations (Chen et al., 2010).

The above research explores the integrity of DMAIC and VSM in manufacturing, but the first problem is the analysis process done by figuring out processes generally by significant picture mapping of VMS, and all the results focused on the production process only. One of the tools for waste analysis is Value Analysis Stream Tools (VALSAT). VALSAT has a method to get more accurate analysis and improvement methods. Second, there is not much research on manufacturing, especially in Java Area. Therefore, for analyzing waste in kind of manufacturing in the Java Area in this research by integrating DMAIC, VSM, and VALSAT. Much research on Lean but not much on integrated Lean Six Sigma DMAIC and VSM. This research proposes a method to overcome and improve efficiencies in manufacturing.

1.3 Research Objectives

Based on the background that has been explained in the previous section, then The objectives of this research are as follows:

(i) To give a good indication on how the manufacturing industries make waste and what are the main cause of the product rejection that contributes to waste.

(ii) To develop a new lean six sigma framework based on manufacturing industries.

(iii) To identify the source of waste in the production process based on a developed improvement policies framework.

1.4 Research Scopes

The limitations of the problem in this study are as follows:

(i) Waste identification is focused on the types of major rejects that occur in each manufacturer in Java from 2017 to 2019.

(ii) The manufactures studied are from garment and textile manufacturing sectors, paper, plastic and packaging sub-sectors, metal sub-sectors, and automotive and component sub-sectors.

1.5 Significance of The Study

This thesis contributes some benefits in several sector such as industry, government, and society.

(i) Industry: Recommendations for improvement obtained from this research can be used as a manufacturing guide in running a production system to reduce losses and increase the efficiency of the company.

(ii) Employees: Recommendations for improvement can increase the level of employee awareness of discipline to reduce waste.

1.6 Thesis Organization

Chapter 1: Chapter 1 contains a background that relates to problems that occur in manufacturing and followed by problem statements. The research gap connects research to be conducted with prior research, research objectives, research scopes, and significance of the study in industry and employees.

Chapter 2: Chapter 2 discusses literature review on manufacturing, DMAIC, VSM, VALSAT, and its integration method.

Chapter 3: Chapter 3 contains the research steps, starting from distributing questionnaires to find out the leading causes of waste in manufacturing. They were followed by the analysis phase 4M + 1E. The analysis phase also uses the PFMEA (Process Failure Mode Effect Analysis) tool.

Chapter 4: Chapter 4 contains the stages of the discussion process in integrating DMAIC, VSM, and VALSAT to reduce waste in manufacturing, distributing questionnaires, and processing data. Analysis results of the integration of lean and six sigma by using DMAIC, VSM, and VALSAT. Also, it discusses recommended corrective actions to reduce waste.

Chapter 5: Chapter 5 contains conclusions that answer objective research and provide recommendations for improvement.

1.7 Summary

The high level of rejection rate makes it reduce the efficiency and productivity of these manufacturers. Therefore, further analysis is needed to identify the wastes that generally occur in the Indonesian manufacturing industry by integrating DMAIC, VSM and VALSAT method approaches. This research is expected to make a major contribution in the identification of waste in manufacturing so that the improvement phase can increase the efficiency and profit of the company and be applied in all manufacturing in Indonesia.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The DMAIC method is the primary method in which seven waste questionnaire tools support it in the VALSAT method and the depiction of current general mapping and future general mapping in VSM. Lean Manufacture contributes to the industry 4.0 revolution as the basis of problem identification to find out the process pain point.

2.2 Manufacture

Manufacturing in industrial engineering is process of transforming raw materials into a product includes product design, material selection, and the process steps in which the product is made. The big area of manufacture industry make it as a back bone of a country (Supriyanto et al., 2013).

2.3 Lean

Lean Manufacturing can improve the production system by waste identification by identifying waste in the production process (Singgih & Tjiong, 2011). Another Lean concept also can be applied by analyzing maintenance lead time; reducing it can increase productivity (Adrianto & Kholil, 2015). Lean also can be applied in the distribution process by analyzing the waste from analyzing the main performance measure (Villareal et al., 2012).

Notable rewards have been reported by European firms through this effort, not only in manufacturing sectors but also in service fields such as retail, healthcare, travel, and financial services (Piercy & Rich, 2009). Lean Manufacturing is widely regarded as a potential methodology to improve productivity and decrease manufacturing organizations' costs (Sanders et al., 2016). Lean Manufacturing can be optimized with support software to improve communication between departments (Stephen, 2004). Organizational culture is influencing Lean Manufacturing performance based on further analysis by using VALSAT with human resources survey (Hardcopf et al., 2021). Even though Lean Manufacture is already known for a long time, it is still the basis of the industry 4.0 revolution (Tortorella et al., 2019). One of the versatile tools in lean Manufacturing is VSM (Singh & Sharma, 2009).

2.4 DMAIC

DMAIC is a systematic method used in solving problems in detail, starting from Define, Measure, Analyze, Improve, Control (Sordan et al., 2020). The DMAIC cycle is a crucial process for continuous improvement toward Six Sigma targets. DMAIC is carried out systematically based on science and facts. The following activities and tools are needed (Brue & Howes, 2006).

(i) Define the stage of determining the project's purpose and scope, gathering information from customers, knowing the process in determining the project to be carried out.

(ii) Measure the stage of determining what measurements are needed to quantify the problem.

(iii) Analyze the analysis phase of the gap between current performance and desired performance through existing data and analyze the root causes of the problems found.

(iv) Improve this stage selects the product characteristics or process performance that must be improved and the causes of errors that must be eliminated.

(v) Control, this stage controls the performance of the process and establishes a corrective action plan.

DMAIC helps determine the information and potential problems that need to be eliminated by the improvement activity (Saryanto et al., 2020). DMAIC study also occurred in several kinds of manufacturers, such as pharmacies, by focusing on material and production processes (Winatie et al., 2020). Printing for work cell efficiency to reduce defect issues by using DMAIC to identify the root cause (Yapilando & Octavia, 2013). DMAIC is also applied for cause-and-effect identification of tire manufacturers with the result that retained air need to be adjusted (Barbosa et al., 2017). Cigarette industry defect reduction by collecting the data from the rejected output and getting the root cause is the method of the process (Usman & Hutasoit, 2019), paper industry rejects reduction (Ahmad et al., 2020) and fabric industry reject reduction (Pratiwi & Syukri, 2016). DMAIC is also applied in general manufacturing problems such as variability process reduction (Chakrabortty et al., 2013). Productivity-increasing by mapping the waste of process in make-to-order manufacture using DMAI (Faritsy Al Zaqi & Suseno, 2015). Scrap reduction (Matathil et al., 2012), quality improvement (Nurullah et al., 2014), quality solution (Tan, 2012), production process effectiveness (Prasetyo & Salazar, 2020), quality control (Susetyo et al., 2011), defect reduction (Putri, 2019), rework reduction (Dambhare et al., 2013), material handling system improvement (Charistheo et al., 2020), time waste reduction (Kanyinda et al., 2020), and reject the claim (Saptaaji & Rimawan, 2017). DMAIC is one of the tools in Six Sigma to combine in Lean Manufacturing and turn it into Lean and Six Sigma (Sordan et al., 2020). On the other hand, DMAIC also can be implemented in the small enterprise (Amitrano et al., 2016), in the service industry to reduce the waiting time of the service (Alpasa & Fitria, 2014), and combined with recent research methods such as Data Mining (Fitriana et al., 2020).

2.5 VSM (Value Stream Mapping)

VSM is a method of mapping the production flow and information flow to produce one product or one product family, which is not only in each work area but at the level of total production and identifies activities that include value-added and non-value-added (Rother & Shook, 2003). Waste activities can impact production activity lead time (Kholil & Arifin, 2018). VSM classifies activities that exist on the production floor into value-added and nonvalue added activities (Saraswat et al., 2014), so this will enable to identify which activities can provide added value and which do not provide added value to eliminate existing wastage (Pramadona & Adhiutama, 2013), idle time of material (Widiatmoko & Pribadi, 2013), transportation lead time (Dewi et al., 2013), IT process management (Jeong & Yoon, 2016), simulation approach for process cycle efficiency (Widodo et al., 2017), purpose scenario for coalescer filter gas (Febianti & Kulsum, 2018), and identification to the root cause of the problem (Syawalluddin, 2014). VSM can increase the competitiveness of a company by improving in production method (Gherghea et al., 2020).

Waste has a correlation to productivity, which means the impact on production process performance (Hossain & Uddin, 2015). Value Stream Mapping can help to reduce the cycle time of production (Andri & Sembiring, 2019) and increase the production output (Khannan & Haryono, 2017). This method also helps to identify manpower balancing in the production process (Tabassum & Khan, 2016).

In the design of VSM, four stages must be carried out (Magnier, 2003), namely:

(a) Determine the Product or Product Family

One important thing that needs to be clearly understood before making a value stream is that the mapping should focus on the product families. Please do not do a mapping of all products in the production flow because it will be very complicated. Value stream mapping means walking and drawing process steps (material and information) from one of the product families from the goods entrance to the factory's goods exit. Some products are said to be families if they go through the same process and common facilities. In the product family, there are several products, and the selection of products to be mapped is based on several considerations the number of outputs per day, demand, and frequency in certain period.

There are two methods to select product families which are (Tapping et al., 2002):

(i) Product quantity analysis

Product quantity analysis is used to see which products have high production volumes; in this method, a Pareto diagram can better understand which products reach 80% of total production. Pareto charts compare various categories of events arranged according to size, from the largest on the left to the smallest on the right. This arrangement will help us determine the importance or priority of the categories of events or causes of events being studied or find out the main problems of the process.

(ii) Analysis of product routes (production process matrix)

This production process matrix contains all types of products that are in the value stream.

(b) Develop current state map

The current state map enables readers to understand the process and material flow of a predetermined product. The current state map will be the basis for creating a proposed improvement state map. The current state map has a function to identify the present waste in a simple picture (Midilli & Elevli, 2020). Some data needed to create a current state map as following :

(i) Data about customers, such as who the customer is, actual requests in days/weeks/months, forecast demand, cycle issues, order frequency, shipping procedures, delivery reports, etc.

(ii) Data about the supplier, such as who the supplier is, the order cycle, the order forecast, the delivery of raw materials from the supplier, the ordering procedure, the lead time of the order, and others.

(iii) Working hours, shifts, overtime, holidays, breaks, meetings, and more.

(iv) Data control production systems, such as who is in charge of controlling, manual or automated, and others.

(v) Data regarding the production process, such as workstation characteristics, number of operators, production equipment and equipment, process flow, defect rate, set up time, change over time, the procedure for giving production orders.

(vi) The amount of inventory (raw materials, WIP, and finished right), safety stock, buffer stock in each process.

(vii) Takt time, the speed of the value stream itself so that it can balance with existing demand. Takt time is obtained by dividing the available time (net available time) in a certain period by the number of requests.

(viii) Cycle time, the time from the completion of one part to a process until the next part is processed.

(ix) The distance between processes through material, operators, data, and others.

(x) Value-added time and non-value added time.

After all, data is obtained and processed; the current state map can be drawn following existing data. An example of a current state map is shown in the following Figure 2.1.

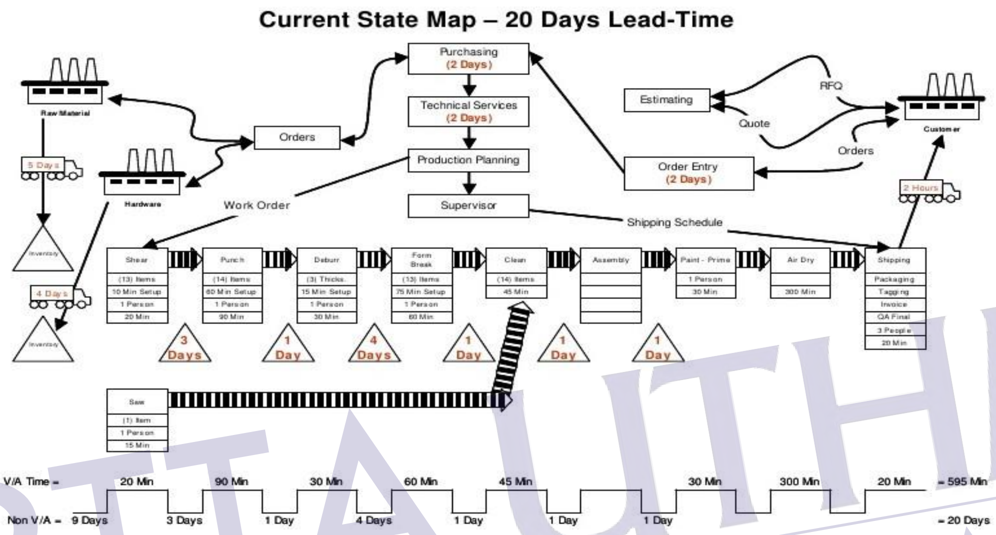


Figure 2.1: Current State Map (Magnier, 2003)

(c) Develop new future map

The purpose of value stream mapping is to identify and eliminate waste sources by applying proposed-state value streams (Ngadono et al., 2020). VSM is quite important for implementing lean manufacturing, allowing the visualization of the value stream, composed of the flows of processes, materials, and information, helping to identify wastes and their sources (Rosa & Ferreira, 2009).

Some directions from the Toyota Production System for implementing lean in value stream mapping, namely:

(i) Producing according to takt time.

(ii) Make flow continuos wherever possible.

(iii) Using supermarkets to control production if the continuous flow is not possible.

(iv) Give a production order to one of the processes, namely the last process (pacemaker process).

(v) Designing the level of production (pitch).

(vi) Develop the ability to produce every day.

VSM Method helps analyze potential problems process in detail each activity (Indriati et al., 2019). Figure 2.2 shows future map as explained before.

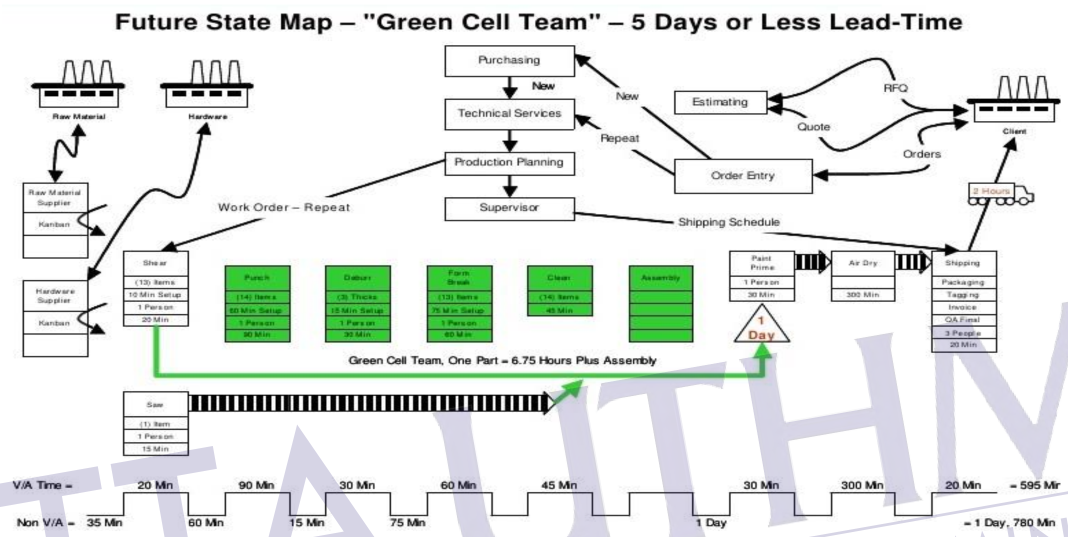


Figure 2.2: Future State Map (Magnier, 2003)

The following Table 2.1 shows the symbols used in value stream mapping:

Table 2.1: Symbols in Value Stream Mapping (Rother and Shook, 2003)

Symbol	Description
 Supplier / Customer	This symbol represents the Supplier when placed on the top left, which is a starting point that is commonly used in depicting material flows. While the image will represent the Customer if placed at the top right, usually as the end point of material flow.
 Dedicated Process	This symbol represents the process, operation, machine or department through which material flows. In particular, to avoid mapping any undesired process steps, this symbol usually represents a department with a continuous internal flow

Table 2.1 (continued)

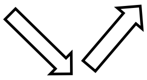
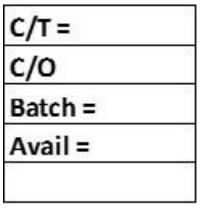
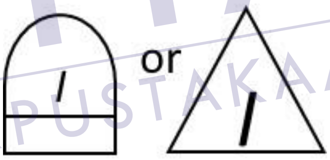
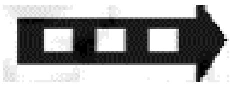
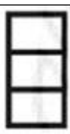
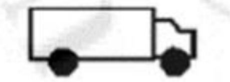
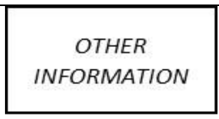
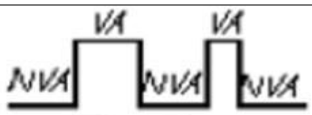
Symbol	Description
 Shared Process	This symbol represents the operation, process, department or work station with families who share in the value stream. The estimated number of operators needed in the value stream is mapped, not the number of operators needed to produce the entire product
 Shipments	This symbol represents the movement of raw material from the supplier to the final storage warehouse in the factory. Or the movement of the final product in the factory warehouse to reach the consumer.
 Data Box	This symbol has symbols in it which state the information / data needed to analyze and observe the system. C / T is the cycle time needed to produce one item until the next product to come. C / O is changeover time which is the time of production change of one product in a process for other. Uptime is the percentage of time that is available on the machine for the process.
 Inventory	This symbol indicates the existence of an inventory between two processes. When mapping the current state, the amount of inventory can be estimated with a quick calculation, and the amount is written below the triangle image. If there is more than one inventory accumulation, use one symbol for each inventory. This symbol can also be used to represent storage for raw materials and finished goods
 Push Arrow	This symbol represents the movement of material from one process to the next process.
 Safety Stock	This symbol symbolizes a "hedge" inventory (safety stock) that overcomes problems such as downtime, to protect the system in dealing with fluctuations consumer orders suddenly or occur damage to the system.

Table 2.1 (continued)

Symbol	Description
 External Shipment	This symbol means shipping made from suppliers to consumers or factories to consumers using external transportation (outside the factory).
 Operator	This symbol represents the operator. This symbol shows the number of operators needed to carry out a process
 Other	State information or other important things
 Timeline	Shows the time that gives added value (cycle time) and the time that does not add value (waiting time). Use this symbol to calculate Lead Time and Total Cycle Time.

Value Stream Mapping has been implemented in a wide sector of industry, such as the textile industry, to improve the working environment (Suhardi et al., 2020), small-medium enterprise (Kholil et al., 2018), improving quality control by reducing unnecessary activities (Ikatrinasari & Kosasih, 2018). VSM even can be applied in sustainable manufacturing programs (Faulkner & Badurdeen, 2014). There is a significant problem that makes value streams not lean, namely overproduction. This overproduction causes much waste, including excess inventory, inventory maintenance costs, a place to put inventory, and others (Verrico, 2018). VSM Method helps analyze potential problems process in detail each activity (Indriati et al., 2019).

Value Stream Mapping has been implemented in a wide sector of industries, such as the textile industry, to improve the working environment (Suhardi et al., 2020), small-medium enterprises (Kholil et al., 2018), improving quality control by reducing unnecessary activities (Ikatrinasari & Kosasih, 2018). VSM even can be applied in sustainable manufacturing programs (Faulkner & Badurdeen, 2014).

2.6 VALSAT (Value Stream Analysis Tools)

Value Stream Mapping Tools (VALSAT) is defined as a tool that helps to view and understand the flow of materials and information from the entire business process, which involves identifying seven wastes (De Steur et al., 2016). VALSAT is a tool derived from value stream mapping used for the further waste analysis process (Fernando & Noya, 2014). It can help to prioritize the improvement of the most impactful waste (Rizky et al., 2014) and make the purpose of improvement (Irsyad, 2019). This method can help to improve the garment industry by identifying the waste from defects and waiting (Nurprihatin et al., 2017), reducing scrap rejection in tug boat production (Arifin et al., 2013), packaging process (Ma'arif, 2014), liquor waste identification (Satria & Yuliawati, 2018), and waste in the automotive industry (Herwindo et al., 2017). VALSAT can be integrated with DMAIC to identify waste in the production process (Zaman & Farihah, 2019). There are seven types of detailed mapping tools most commonly used as follows:

(a) Process Activity Mapping

It is a technical approach that can be used in activities on the production floor. This expansion of tools can be used to identify lead time and productivity in both physical product flow and information flow, not only within the company's scope but also in other areas of the supply chain. In the process activity mapping, there are four types of streams with different symbols (Hines & Taylor, 2000) namely:

(i) O= Operation

(ii) T = Transportation

(iii) I = Inspection

(iv) D = Delay

(v) S = Storage

The basic concept of this tool is to map each phase of activities that occur starting from operations, transportation, inspection, delay, and storage, then grouping into the types of activities that exist from value-adding activities, necessary non-value adding activities and non-value adding activities (Amrina et al., 2019). All of the process stages need to be checked to get the critical process for further study (Mahendra & Susanty, 2019). The stages carried out in this approach are divided into five stages, including:

(i) Understand the process flow.

(ii) Identifying waste.

(iii) Consider whether a process can be overcome again into a more efficient sequenced.

(iv) Consider better flow patterns, which involve different flow layouts or transportation routes.

(v) Consider whether everything that is being done at each stage is needed and what will happen if the excess activity is eliminated.

(b) Supply Chain Response Matrix

It is a graph that illustrates the relationship between inventory and lead time on the distribution channel so that it can be seen an increase or decrease in inventory levels and distribution time in each area in the supply chain (Indrawati et al., 2018). From the functions provided, then it can be used as a material for management consideration to estimate stock needs if it is associated with achieving short lead times can help to improve productivity (Septiani et al., 2019). The aim is to improve and maintain the level of service in each lane. Every activity both physically or information need to be collected to make right improvement (Ferdiansyah et al., 2013).

(c) Production Variety Funnel

It is a visual mapping technique that tries to map the number of product variations at each stage of the manufacturing process. This tool can be used to identify points in a generic product processed into several specific products.

(d) Quality Filter Mapping

It is a tool used to identify the location of quality defect problems in the existing supply chain. Evaluation of quality loss that often occurs is done for short-term development (Lukmandono et al., 2019). This tool can describe three different types of quality defects, as follows:

(i) Product defects

Physical defects of products that pass to the customer because they have not been successfully selected during the inspection process.

(ii) Scrap defect

Often referred to as internal defects, where these defects are still within the company's internal and successfully selected during the inspection process.

(iii) Service defect

Problems perceived by customers are related to service quality defects. The most important thing related to service quality defects is the wrong delivery time (late or too fast).

(e) Demand Amplification Mapping

The map is used to visualize changes in demand along the supply chain. This phenomenon adheres to the law of industrial dynamics, where demand transmitted along the supply chain through a series of order and inventory policies will experience increasing variations in each movement from downstream to upstream.

(f) Decision Point Analysis

Shows various production system options, with a trade-off between the lead time of each option and the inventory level needed to cover during the first time process.

(g) Physical Structure

It is a tool used to understand supply chain conditions at the production level. This is necessary to understand the industry's condition, how it operates, and in directing attention to areas that may not have received enough attention for development.

Table 2.2 shows the Seven Stream Tools to calculate the correlation between the waste and the mapping tools.

Table 2.2: The Seven Stream Tools (Hines & Rich, 1997)

Waste	Process Activity Mapping	Supply Chain Response Matrix	Production Variety Funnel	Quality Filter Mapping	Demand Amplification Mapping	Decision Point Analysis	Physical Structure
Overproduction	L	M		L	M	M	
Waiting	H	H	L		M	M	
Transportation	H						L
Inappropriate Processing	H		M	L		L	
Unnecessary Inventory	M	H	M		H	M	L
Unnecessary Motion	H	L					
Defect	L			H			

Information:
H = (High correlation and usefulness) High use and correlation multipliers is 9
M = (Medium correlation and usefulness) Medium use and correlation multiplier factor is 3
L = (Low correlation and usefulness) Low usability and correlation multiplier factor is 1

The basic concept of this tool is to map each phase of activities that occur starting from operations, transportation, inspection, delay, and storage, then grouping into the types of activities that exist from value-adding activities, necessary non-value adding activities and non-value adding activities (Amrina et al., 2019). All of the process stages need to be checked to get the critical process for further study (Mahendra & Susanty, 2019).

2.7 FMEA (Failure Modes and Effects Analysis)

FMEA is a systematics of activities that identify and evaluate potential failure rates that exist in a system, product or process, especially at the root functions of the product or process on the factors that affect the product or process (Caesaron & Simatupang, 2015).

In FMEA, there are three points that related to the point of priority called Severity, Occurrence and Detection.

(a) Severity

Severity is the ranking that is related to the most severe effect of the previous one. Table 2.3 shows the rangking of FMEA Severity Levels with the effect and criteria.

Table 2.3: FMEA Severity Levels

Effect	Criteria: Product Severity (Effect on Customers)	Ranking	Effect	Criteria: Product Severity (Effect on Customers)
Failure to comply with safety regulations	Potential failures that affect the safety of safe operations and involve government regulations without warning	10	Failure to comply with safety regulatio ns	Harm the operator in the machine or assembling process without warning
	Potential failures that affect the safety of safe operations and involve government regulations with warning	9		Harm the operator on the machine or assembling process with a warning

Table 2.3 (continued)

Effect	**Criteria: Product Severity (Effect on Customers)**	**Ranking**	**Effect**	**Criteria: Product Severity (Effect on Customers)**
Loss or The loss The main function	Loss of main function (vehicle cannot be operated, no affect the safe operation of the vehicle).	8	Main Disorders	100% of products have to discard. Production lines stop operating and stop sending products to customers.
	Loss of function (vehicles can be operated, however at a reduced rate	7	Important Disorders	A portion of production run must be made. Deviations from Main processes included decrease in production line or production speed the addition of labor
Loss or The loss Secondary Function	Loss of secondary functions (vehicle can be operated, but comfortable / comfort function inoperable).	6	Moderatt e Disorders	100% of the production process is possible must be reworked and the conditions accepted by the Customer.
	Secondary degradation function (the vehicle can be operated, but comfort / convenience function at the reduction rate performance).	5		A part of the production process is possible must be reworked and the conditions accepted by the Customer.
Disturbance	Appearance or Audible Sound, vehicles can be operated, goods are not not suitable and considered by most customers (> 75%).	4	Moderatt e Disorders	100% of the production process is possible must be reworked at the work station before processing
	Appearance or Audible Sound, vehicles can be operated, goods are not not suitable and considered by most customers (> 50%).	3		A part of the production process is possible must be reworked at the work station before processing
	Appearance or Audible Sound, vehicles can be operated, goods are not not suitable and considered by most customers (> 25%).	2	Minor Disorders	Mild inconvenience to process, operation, or operator
There is no effect	There are no visible effects	1	There is no effect	There are no visible effects

(b) Occurrence

Occurance is the possibility that certain Causes / Mechanisms (listed in the previous column) will appear. Levels of Occurrence ranking based on possible causes is shown in Table 2.4 below.

Table 2.4: Levels of Occurence PFMEA (Ford Motor Company, 2011)

Failure Possibility	Possible Causes (Incident per Item)	Ranking
Very High	≥ 100 per thousand; ≥ 1 in 10	10
	50 per thousand; 1 in 20	9
High	20 per thousand; 1 in 50	8
	10 per thousand; 1 in 100	7
Moderate	2 per thousand; 1 in 500	6
	0.5 per thousand; 1 in 2,000	5

Table 2.4 (continued)

Failure Possibility	Possible Causes (Incident per Item)	Ranking
Low	0.1 per thousand; 1 in 10,000	4
	0.01 per thousand; 1 in 100,000	3
	<0.001 per thousand 1 in 1,000,000	2
Very Low	Failure is eliminated through preventive control	1

(c) Detection

Detection is a relative ranking, within the scope of individual FMEA. To achieve a lower rank, generally the planned process control must be improved (Ford Motor Compay, 2011). Table 2.5 is the detail of detection rate with the opportunity and criteria to asses the ranking.

Table 2.5: PFMEA Detection Rate (Ford Motor Company, 2011)

Detection Opportunity	Criteria	Ranking	Possible Detection
There is no chance	Cannot be detected and analyzed	10	Very impossible
It is not possible to detect at any stage	Process failures are not easily detected	9	Very far
A problem has been detected in the process	Detection of the failure after the process by the operator visually, touch or audio.	8	Far
A problem has been detected from the source	Detection of the failure at the work station by the operator visually, touch or audio using the jig attribute (go not go, manual checking torque and others).	7	Very weak
A problem has been detected in the process	Detection of the failure after the process by the operator visually, touch or audio using the jig attribute (go not go, manual checking torque and others).	6	Weak
A problem has been detected in the process	Detection of the failure at the work station by the operator when using a jig or automatic control at the work station that will detect the lack of parts that are realized by the operator (example: lighting). The jig functions during initial setup and initial checking	5	Medium
A problem has been detected in the process	Detection of failures after the process through automatic control will detect the measurement of parts to prevent further processing.	4	Medium Height

Table 2.5 (continued)

Detection Opportunity	Criteria	Ranking	Possible Detection
A problem has been detected from the source	Detection of failures at the work station through automatic control that will detect the measurement of parts to prevent further processing.	3	High
Problem Prevention	Detection of process failures at work stations with automatic control that will detect failures and prevent part deficiencies from being processed	2	Very high
Problem Prevention	Detection of failure prevention based on the results of the completeness of the design	1	Almost

DMAIC method enables to start of the research to analyze the potential problem by defining the problem, measuring the problem, analyzing the root cause, planning the improvement activities, and control method. VSM is continuously able to offer analysis of every process during the mapping of the improvement plans. VALSAT and FMEA are supporting tools to execute the improvement activities. VALSAT and FMEA are able to provide the priority action to eliminate the waste based on the severity, occurrence, and detection level. Integration of DMAIC, VSM, VALSAT, and FMEA will give a good outcome to eliminate waste.

FMEA is a set of instructions, a process, and a form for identifying and prioritizing potential problems (failure) (Wahyani et al., 2010). FMEA consists of Design Failure Mode Effect Analysis (DFMEA) and Process Failure Mode Effect Analysis (PFMEA). It helps to make decision improvement points that critically impact the problem (Kholil & Mulya, 2014), enhance the quality of the manufacturing industry (Kalraiya & Kalraiya, 2017), identify the risk not only in the production process but also in the raw material quality (Rimantho & Mariani, 2017), and indicate the priority risk problem in the poultry industry (Nuchpho et al., 2019). FMEA not only can apply in manufacturing but also applied in the service industry, such as healthcare, to improve service cycle time (Salomon et al., 2020). In construction projects, FMEA is applied to risk identification for safety reasons (J. et al., 2017). Implement FMEA tools required to understand how to use it (Rath, 2008). FMEA is occurred to generate RPN values by multiplying the RPN (Risk Priority Number) value by multiplying the rating severity, occurrence, and detection values (Hidayat et al., 2014).

2.8 Research Gap and Novelty

There are some research activities in some manufacturers to reduce waste using the lean and six sigma methods. Previous research (Guo et al., 2019) researched Air Conditioner Assembling Line by integrating lean's VSM and DMAIC from six sigma. VSM is used to identify the production problems during production processes by waste identification.

Analysis methods are used to rank the production problem by input and output ratio. Meanwhile, the DMAIC method provides a structured problem-solving method for the production problem. The production station investigated includes man, machine, material, method, and environment (4M1E). Finally, the production problems and production problem sets will be reassessed for the next concurrent Lean-Kaizen. This research is successfully implemented by using DMAIC and VSM methods, but for the assembling process for PP set only. Meanwhile, there will be some potential wastes that need to be found in other production lines. VSM and DMAIC do analyze generally, so, therefore, they need other specific tools to make the improvement to reduce waste more and increase the benefit.

Previous research of the Lean Six Sigma framework used Lean and DMAIC as a step of research instead of integrating both in their study in part of a project as in Figure 2.3 below (I. da Silva et al., 2019).

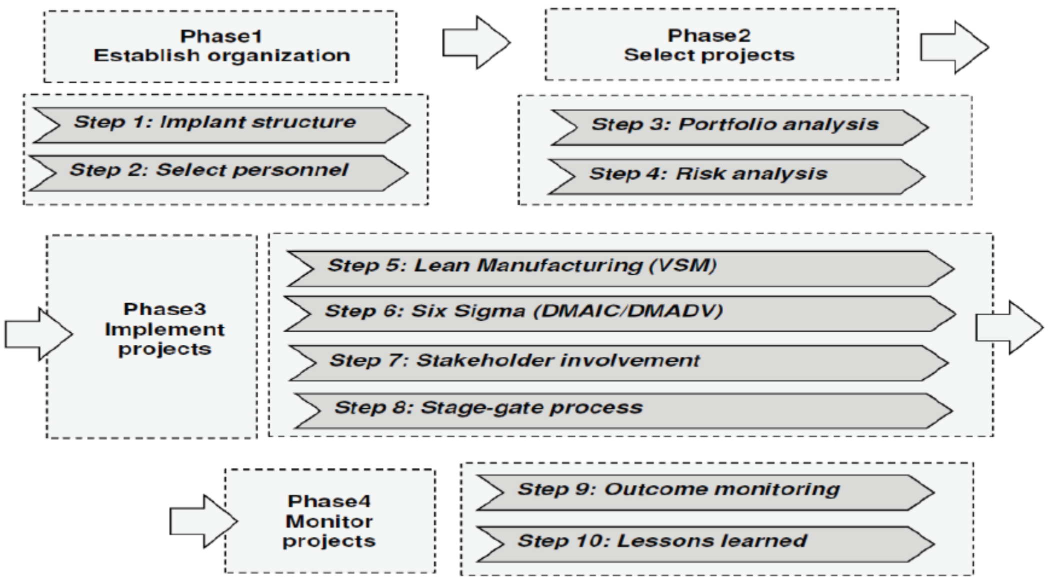


Figure 2.3: Lean Six Sigma Framework

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