Lean Six Sigma as A Strategy for Increasing Knitting Manufacturing Profitability Through Fabric Quality and Work Efficiency Improvement

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Abstract

Recently, global cotton prices have increased by 107.15% in the last two years, and the demand for fabrics has decreased, having a significant impact on the company's profitability by 15%. This research was conducted at a manufacturing company specializing in knitting fabrics made from polyester, tetron cotton, and chief value cotton. During observation, it was found that the company's expectations regarding the good quality of the fabrics produced were different from the reality that almost 75% of the fabrics produced had to go through the repair/rework stage due to defects. The purpose of this study is to prepare a strategy for companies to increase profitability during a crisis in company profitability. This research focuses on the production area, from the raw material preparation process in the warehouse, the knitting process, the quality checking process, and the storage process in the warehouse. One month of production data was utilized in the study. This research begins by observing the production process, interviewing employees, and collecting daily production data and waste identification using WAQ and a WRM. The problem-solving process uses the DMAIC method, starting by defining the problem and measuring the capability of the production process. WRM and WAQ are used to analyze the type of waste, and the root of the problem is analyzed with a fishbone diagram. The results of this study indicate that the most common types of defects are holes in the fabric, broken threads, and broken needles that cause other waste in the production process. The root of the problem is that there are no QC procedures for raw materials, machine operating procedures, or periodic inspection procedures. The proposed improvement to overcome this problem is to conduct QC inspections on incoming raw materials and make a periodic machine inspection procedure. From the validation process for the proposed improvements, it shows that lead time was reduced by 15.13%, efficiency increased by 11.23%, and profitability by 6.17%.

Keywords
Lean six sigma, Waste, Defects, Profitability, Process cycle efficiency.

1. Introduction

The products quality is the main weapon in business competition that provides guarantees for consumers regarding the products that they used (Mitra, 2008). According to Walujo et al. (2020), quality is closely related to the company's success in engineering quality to increase profitability and consumer confidence. Intense business competition in improving product quality makes quality is the main focus for companies in complex systems and limited resources. Based on data obtained from trading economics (2022), recently the price of cotton has increased by 107.15% from January 2, 2020. Based on the results of interviews with several knitting factories, there are companies that reducing product quality to reduce costs such as eliminating the finishing process which is considered not to affect the main core of the production process. This activities has a bad impact where consumer satisfaction and trust potentially decrease due to a decrease in the quality of the products used (Vinayagam et al., 2017). Meanwhile, the deteriorating performance of one of the companies to produce high-quality products also has an impact on other companies, which also affects production and other operational costs.

To overcome this problem, this study was held to improve the quality of fabrics produced by knitting manufacturing and increase the profitability of knitting companies due to the crisis experienced by the company due to profitability which has continued to decrease by 15% in the last two years. During observation process, there is a gap between expectations and the reality faced where a fabric produced is impossible to achieve zero defect. According to company data, almost 75% of the fabric produced must entering repair or rework stage due to defects in the fabric. According to Rawabdeh (2005), defects is one type of waste that can affect other types of waste such as waste of overproduction, waste of inventory, and waste of overprocessing. Waste and defects that occur in the production process adversely affect the efficiency of the company's work and increasing other costs such as raw material costs for the sewing process, knitting, operational costs such as electricity costs and overtime costs for production operators (Modi & Thakkar, 2014).

1.1 Objectives

This research was conducted at knitting manufacturing which produces fabrics from cotton and polyester yarns. The scope of this study is to improve work efficiency by reducing waste and defects that occur to reduce the cost of fabric production. Waste and minimized defects become strategies to improve work efficiency also to decreasing the total lead time and increases company savings due to reduced costs needed for raw materials and operations. With this strategy, increasing company's profitability can be achieved so that the company can survive during a crisis in the textile industry.

2. Literature Review

Lean six sigma (LSS) is a combination of lean philosophy that identifies the type of waste that occurs, eliminates waste, activities that do not provide added value, and continuous improvement with the six sigma technique which aims to reduce the number of defects in products and services simultaneously (Gasperz & Fontana, 2011; M. L. George, 2002; Sheridan, 2000; Smith, 2003).

LSS uses the DMAIC method in the process of solving problems that exist in five phases, namely the design phase, measure phase, analyze phase, improve phase, and control phase that continuously to improve the efficiency of the production process and reduce the number of defects to close to zero defects (Bettini et al., 2012).

LSS measures work efficiency by calculating process cycle efficiency (PCE). PCE is a metric for measuring the efficiency of ongoing processes in a business based on the percentage of time on activities that add value to the total lead time in value stream mapping. Here is the formula for determining the PCE value (Gasperz & Fontana, 2011):

$$\text{PCE} = \frac{\text{Total Value Added Time}}{\text{Total Lead Time}} \times 100\%$$

According to Gasperz and Fontana (2011), a process can be categorized as lean if the PCE value obtained >30%. The work efficiency calculated by PCE is impossible to reach 100%. This happens because there is waste that occurs along the value stream. Value stream mapping tools are used to map all processes in the business that are relevant to business processes and can identify suspected waste that occurs. Value Stream mapping is a visual map that maps the entire work or activity to the steps in the production process of the entire business process related from start to finish. VSM maps directly the flow of materials and information from customer orders to the product reaching the hands of consumers. VSM serves to identify the type of waste that occurs along the value stream (M. George et al., 2005). Value streams can be divided into two, namely current value stream mapping (CVSM) and future value stream mapping (FVSM). CVSM serves to map the value stream to the current process conditions, while FVSM maps future conditions based on the results of improvements provided to the company (M. George et al., 2005).

A waste assessment is needed in the form of a questionnaire to identify each waste that occurs in detail. The questionnaires used are the waste assessment questionnaire (WAQ) and the waste relationship matrix (WRM) questionnaire. According to Rawabdeh (2005), WRM is a matrix for analyzing the dominant type of waste in a production process and mapping the relationship between one type of waste and another. In the WRM matrix, the degree of influence and percentage of influence of one type of waste on another type of waste and the degree of impact and percentage of impact of waste that occurs due to other waste simultaneously are obtained.

WRM began with a questionnaire totaling 186 questions consisting of 31 combinations of two types of waste mapped by Rawabdeh. In this study, respondents from the questionnaire were parties who had authority over the entire production process in a company. WAQ is a follow-up questionnaire after the WRM questionnaire to analyze the type of waste that is dominant against other types of waste along with the rank of waste that occurs simultaneously (Rawabdeh, 2005). WAQ consists of 68 questions based on two categories, namely category A and category B. WAQ is used to map the ranking of each waste based on the percentage of dominance of one waste over other waste to determine the necessary improvement priorities. In this study, respondents from WAQ were parties from companies that had authority over the entire production process.

LSS not only focuses on work efficiency; it also focuses on improving product quality with the support of the six-sigma method. By using production data and data on the number of defects per unit, the control chart is used to identify the current production process. Control chart is a tool in statistics that describes the production process of the object under study. The control chart consists of upper control limit, lowe control limit, center line, and plot data based on the type of data observed (M. George et al., 2005; Martin, 2014).

Control charts can be divided into several types depending on the type of data observed such as data continuity, sample size, defects per unit, or the number of defects. In this study, a C-chart was used to observe the plot of defect data per one roll of fabric in one month. DPMO is a metric that measures the number of defects per million opportunities. DPMO can be used to calculate the sigma value that shows the capability level of the production process other than Cp and Cpk. DPMO can be calculated using the following formula (M. George et al., 2005):

$$\text{DPMO} = \frac{\text{Total Defects}}{\text{Total Units} \times \text{Total Opportunities}} \times 1.000.000$$

After analyzing the factors that affect the quality of the product, the pareto chart is used to give priority to each factor to be resolved based on the magnitude of the impact given. The root cause of the problem that causes the factor to occur will be analyzed using a fishbone diagram.

Pareto diagram is one of the problem-solving tools that are widely used to determine the priority of improvement (Martin, 2014). Pareto diagram analysis uses the 80/20 principle as a basis for determining priorities based on the dominance of the impacts caused by the type of waste and the type of defect being observed (M. L. George, 2002). A fishbone diagram is a diagram that maps the cause and effect of a problem being observed. The fishbone diagram systematically maps each factor that causes a problem concisely and in detail based on 6 aspects, such as human, material, method, measurement, machine, environment (Gasperz & Fontana, 2011).

3. Methods

This study uses a LSS approach to solve work efficiency and defect problems in fabrics simultaneously through five phases of DMAIC, design phase, measure phase, analyze phase, improve phase, control phase. Expectations regarding profitability improvement can be achieved by increasing work efficiency and reducing the frequency of defects that occur in fabrics.

In the design phase, SIPOC diagram will be made to map in detail the supplier, raw materials, production process, products produced, and customers who use the product. After mapping in detail, the process flow from supplier to customer, the aspects that affect the quality of fabrics from the customer's perspective will be mapped using a critical to quality tree (CTQ).

In the measure phase, manufacturing lead time will be calculated through observational data on each existing activity, from the observation data on each activity will be classified into value added activities and non-value-added activities. PCE can be calculated by determining the percentage of value-added activities against the total manufacturing lead time. After calculating the PCE and total manufacturing lead time, current value stream mapping will be made to map the entire series of processes that occur within the company and to identify allegations of waste. Analysis of waste type and impact magnitude produced using WRM and WAQ. The C-Chart will be used to identify the number of defects per roll of fabric within the statistical tolerance limits. DPMO and sigma levels will be determined based on the number of defect types, the number of defects, and the amount of production for one month.

In the analyze phase, the types of defects and waste identified at the measure stage will be prioritized using the Pareto diagram. The types of defects and waste obtained through the results of the analysis on the Pareto diagram will be further analyzed using a fishbone diagram to map in detail the causative factors.

In the improve phase, the root of the problem obtained from the analyze phase becomes the basis for decision making improvements. Proposed improvements are formulated to improve work efficiency and profitability of the company so that the gap between the company's desire for reality can be reduced. Future value stream mapping will be created to map the new process flow based on proposed improvements and the new PCE and manufacturing lead time values can be calculated. In this phase, the amount of change in the company's profitability will be determined due to changes in the value of PCE after implementing system improvements.

4. Data Collection

The data collection process in this study starts from making observations to observe the entire ongoing production process from the process of preparing raw materials to the process of packaging fabrics to be sent to consumers. The data collected are data on the number of daily productions for one month, the number of defects per type of defect for one month, and the cycle time of each activity in the production process. Data on the number of daily production and the number of defects is obtained from the company's internal data in the form of quality control check sheets as shown in Table 1 and defects data based on defects type can be seen in Table 2.

Table 1. Fabric Production and Defects Data for One Month

Period	Daily Production in Rolls	Total Defects in a Roll
1st week	19	46
2nd week	23	60
3rd week	80	167
4th week	165	292

Table 2. Defects Data Based on Defects Type

Defects Type	Perforated	Broken Thread	Oil Stain	Freckles	Broken Needle	Bloomed Needle	Striped Color
Total Defects	184	134	40	53	141	9	4

Based on Table 1 and Table 2, there are 565 defects that occurs in one month. The next data that also need to be collected is cycle time of each activity by observing each existing activity 30 times using a stopwatch.

5. Results and Discussion

In this study, the problem-solving process will go through five stages of DMAIC, design phase, the measure phase, the analyze phase, the improve phase, and the control phase.

5.1 Design Phase

In the design phase, a SIPOC diagram is made to map suppliers, raw materials, production processes, output products, and customers. The following is a SIPOC Diagram can be seen in Figure 1.

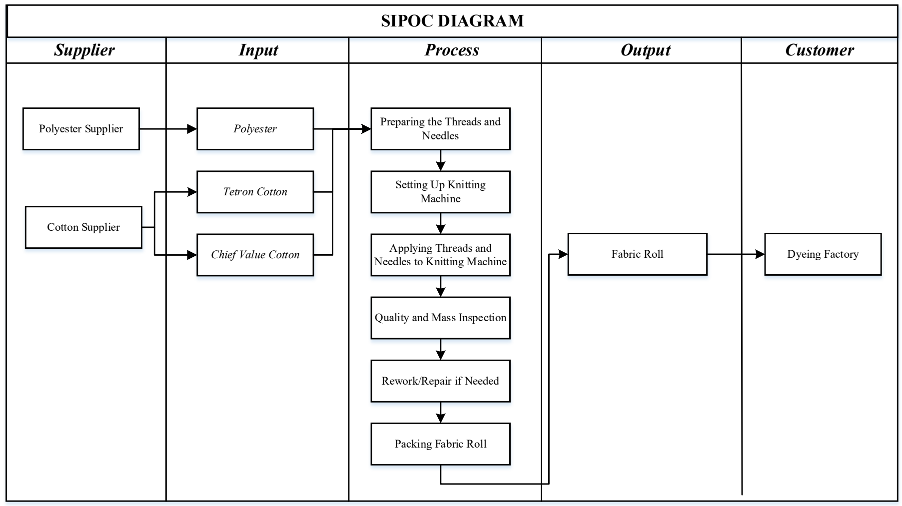

Figure 1. SIPOC Diagram

In the SIPOC diagram in Figure 1, the suppliers needed are polyester suppliers and cotton suppliers with raw materials in the form of polyester, tetron cotton, and chief value cotton. The raw materials that have been prepared will enter the knitting process which produces fabric in the form of a roll to be sent to the dyeing factory.
After mapping the entire process with a SIPOC diagram, the quality aspects that are important to consumers need to be mapped using a critical to quality tree. The aspects that are mapped are critical aspects of the customer so that if they are not fulfilled, it will have a bad impact on product quality from the customer's perspective (Gasperz & Fontana, 2011). CTQ is made based on the voice of customer as in Figure 2.

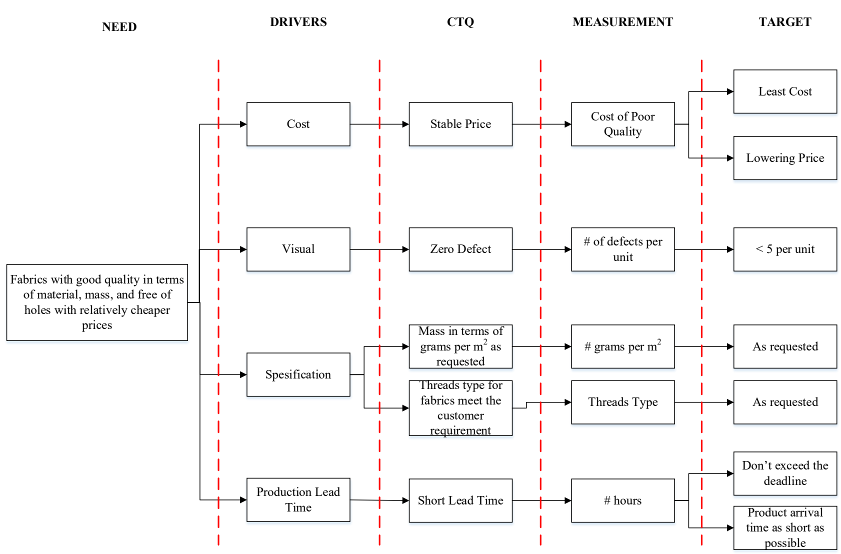

Figure 2. Critical to Quality Tree

5.2 Measure Phase

In the measure phase, process cycle efficiency will be calculated by calculating the total value added activities against the total manufacturing lead time. The total manufacturing lead time required is 1275.92 minutes with a total value added activities of 473 minutes. Below is the PCE calculation:

$$\text{PCE} = \frac{473 \text{ minutes}}{1275.92 \text{ minutes}} \times 100\% = 37.07\%$$

According to Gasperz and Fontana (2011), PCE >30% indicates that the current process in the lean category. The time of each activity in the running process will be data in making current value stream mapping as in Figure 3.

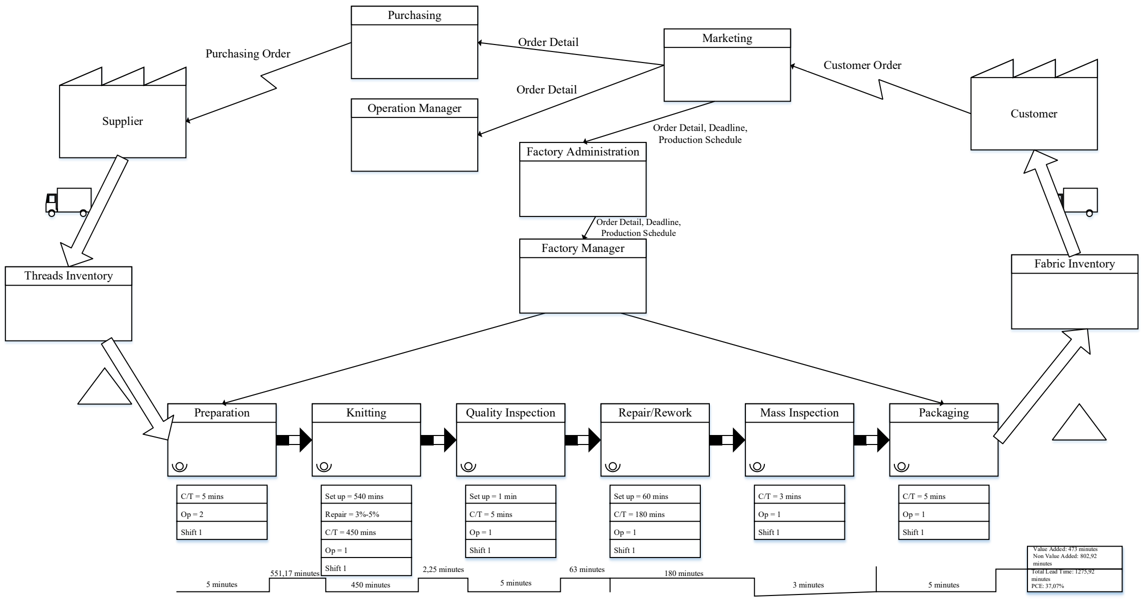

Figure 3. Current Value Stream Mapping

From the current value stream mapping above Figure 3, it can be concluded that the fabric production process has implemented a pull system because the factory manager only coordinates to the raw material preparation and packaging department. The one piece flow system has also been implemented because there is no WIP in the production process, so the production process can be said to be quite efficient. However, the repair/rework process for defective fabrics is not included in the desired process because more costs are needed for the threads used, worker costs, and operational costs.

Based on the allegations in the results of current value stream mapping of the existence of waste of defects which results in waste of overproduction and waste of waiting, WRM and WAQ are used as tools to analyze the type of waste that occurs throughout the production process. The results of the WRM and WAQ analysis are presented in Table 3.

Table 3. Calculation Result of WRM and WAQ

	O	I	D	M	T	P	W	Total
Score (Yj)	0.6200907	0.3290126	0.5070748	0.3345607	0.3229292	0.9297069	1.0840471	4.1274219
Pj *Factor*	239.80035	175.78125	312.5	131.2934	86.805556	175.78125	173.61111	1295.5729
Final Result (Yj *Final*)	148.69796	57.834238	158.46088	43.925608	28.032046	163.42505	188.20261	788.57839
Final Result Percentage	18.86%	7.33%	20.09%	5.57%	3.55%	20.72%	23.87%	100.00%
Rank	4	3	5	2	1	6	7	

Based on the results in Table 3, it was found that the types of waste that occur and must be prioritized are waste of waiting, waste of overprocessing, waste of defects, and waste of overproduction. Based on the results of observations and interviews with factory managers, waste of waiting, waste of inventory, waste of unnecesarry motion, waste of transportation, waste of overprocessing, and waste of waiting are interrelated consequences due to waste of defects in fabric.

To analyze more deeply about defects in fabrics, the C-chart is used to measure whether the number of defects per roll of fabric is within the limits of statistical tolerance. Plotted data is the number of defects per roll of fabric during one month of observation which can be seen in Figure 4.

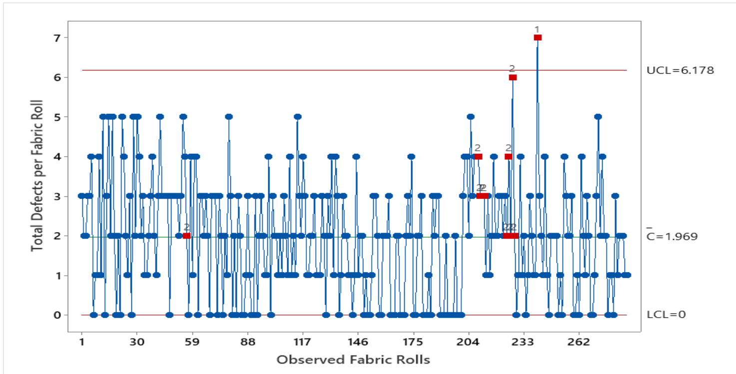

Figure 4. C-Chart

In the C-chart above, there are 11 data that are out of control statistically, this shows a gap between expectations about the quality of the fabric produced and the reality of the number of defects on the fabric. The gap between expectations and reality for the quality of fabrics needs to be minimized by integrated quality improvements in the aspects of man, methods, materials, machines, measurement, and environment. To support all the results of the analysis in this measure phase, the process capability, DPMO, and sigma level will be calculated so that the ongoing production process can be quantified its capability in producing fabrics with quality in accordance with specifications. Process capability, DPMO, and sigma levels can be seen in Table 4.

Table 4. Process Capability, DPMO, and Sigma Level Result

Metrics	
Cp	1.06
Cpk	0.99
DPMO	281234.445
Level Sigma	2.08

Based on Table 4, a Cpk<1 value is obtained so that quite a lot of fabrics produced have many defects, while the sigma level is at the level of 2.08 where 31% of one million productions are defects.

5.3 Analyze Phase

In the measure phase, the problem that occurs will be prioritized and analyzed using a fishbone diagram to identify the root cause. In section 5.2, the type of waste that needs to be completed has been prioritized, in this section it will be analyzed the type of defect that needs to be prioritized using the Pareto diagram. The following is a pareto diagram for the types of defects that occur and their numbers can be seen in Figure 5.

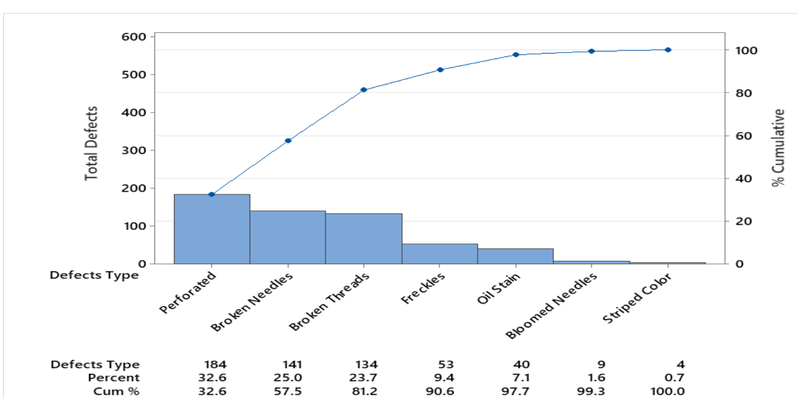

Figure 5. Pareto Diagram Based on Defects Type

Based on the results of the analysis in the Pareto diagram above, it can be concluded that the types of defects that must be prioritized for solving defect problems are perforated, broken needles, and broken threads. The type of defect will be analyzed for the cause to the root of the problem using a fishbone diagram. Below is a fishbone diagram for perforated fabrics, broken needles, and broken threads can be seen in Figure 6, Figure 7, and Figure 8.

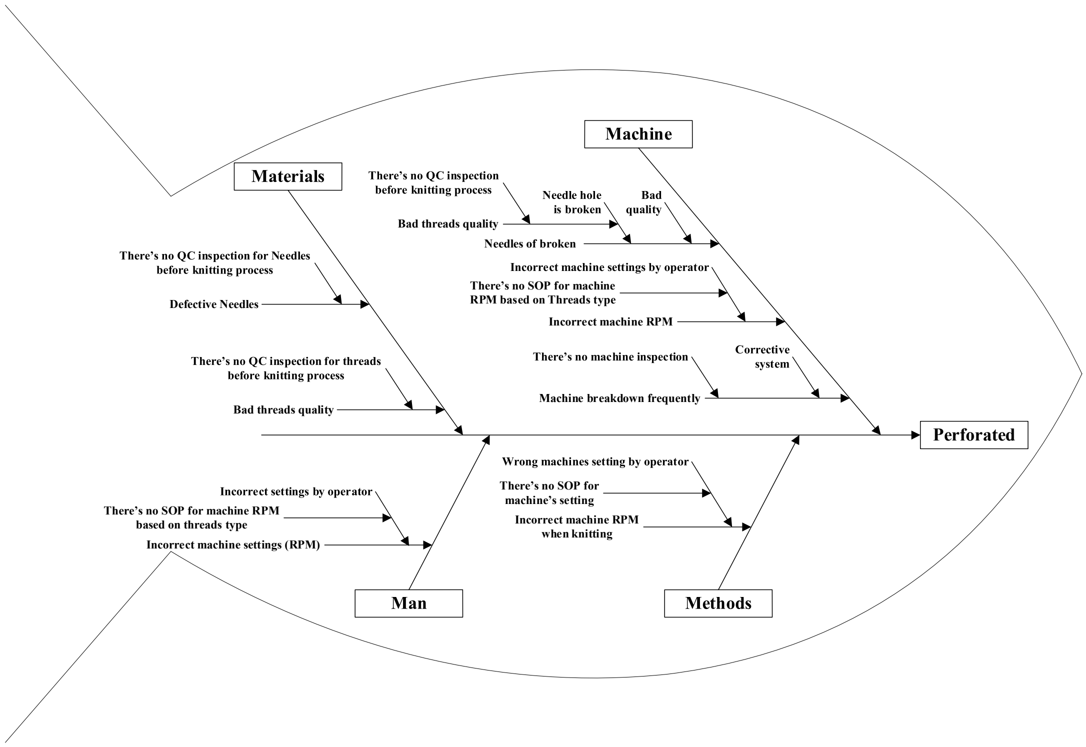

Figure 6. Fishbone Diagram for Perforated Fabrics

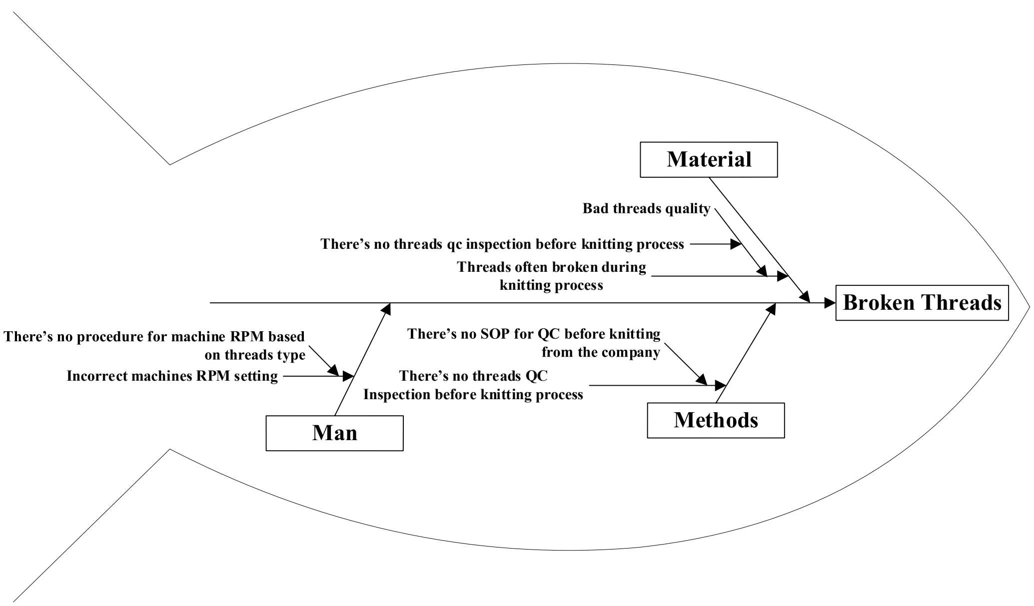

Figure 7. Fishbone Diagram for Broken Threads

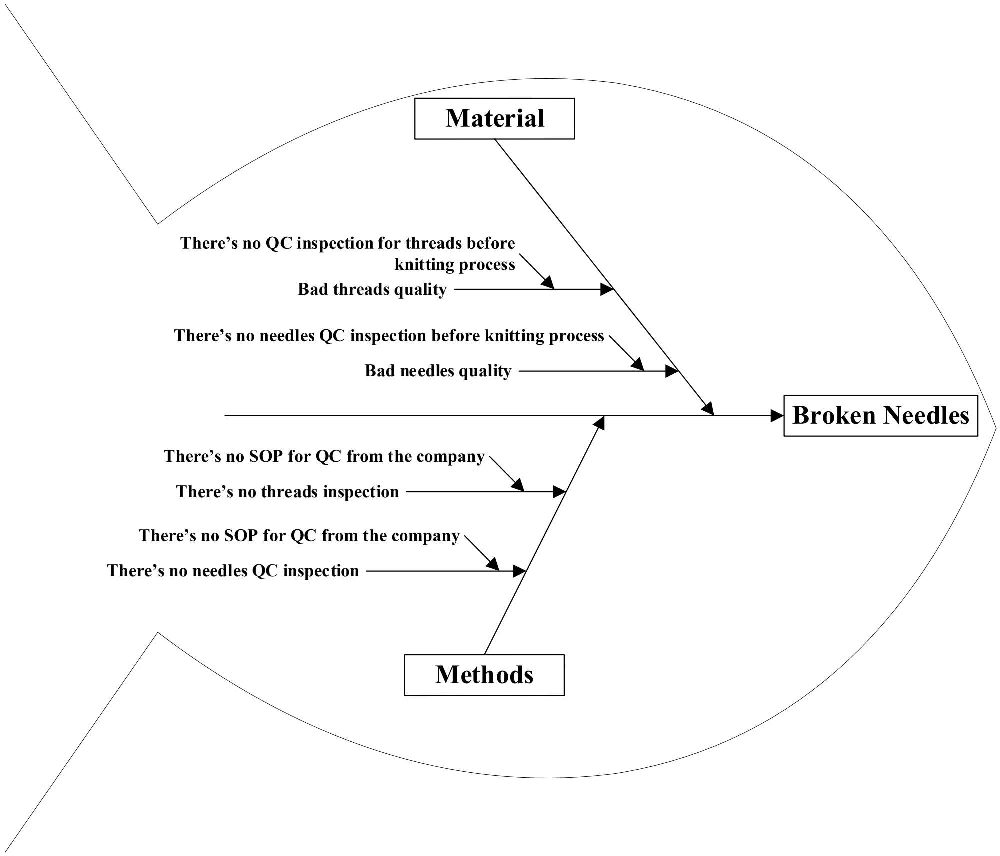

Figure 8. Fishbone Diagram for Broken Needles

Based on the fishbone diagrams in Figure 6, Figure 7, and Figure 8, the root cause of the perforated fabric, broken needles, and broken threads is as follows:

1. There's no quality inspection for needles and threads before knitting process
2. There's no evaluation program for supplier performance based on products quality and responsiveness
3. There's no SOP for schedule inspection and maintenance for all machines
4. There's no specific procedur for knitting machine operator to set up machine's RPM during knitting process, they preferred to use trian and error methods when setting up machine RPM.

5.4 Improve Phase

In the analysis phase, the root of the problem has been obtained which has the potential to trigger defects and waste in the knitting process. Based on the results of the analysis, the following improvements will be given:

1. SOP for Scheduled Maintenance and Machine Inspection
   Corrective mainenance system can be changed into schedule maintenance to prevent the occurrence of engines that often break down during the knitting process.
2. SOP for Machine RPM Settings Based on Threads Type
   During the knitting process, the appropriate RPM will minimize the number of broken threads so that the work efficiency increases, the knitting process is faster, and the result of the fabric produced is better.
3. QC Inspection for Needles and Threads Before Knitting Process to Evaluate Supplier Performance
   Quality inspection is vital in the manufacturing process, including for raw materials from suppliers to evaluate supplier performance. From a supply chain perspective, the overall performance of the supply chain from suppliers, factories, to distributors plays a very important and crucial role in winning business competition with competitors. So to support this process, a quality inspection process for threads and needles is needed before the knitting process.

In the validation process for proposed improvement, an evaluation process will be carried out through PCE value, manufacturing lead time, and profitability changes that are expected to occur positive and profitable changes for the company such as increasing PCE value, reducing manufacturing lead time, and increasing company profitability. Based on the results of the review on proposed improvement, the total value added activities are 523 minutes by eliminating the repair/rework process and adding a yarn and needle quality inspection process. The total manufacturing lead time was reduced by 193 minutes to 1082.92 minutes. So the PCE for this proposed imrpovement is

$$\text{PCE} = \frac{523 \text{ minutes}}{1082.92 \text{ minutes}} \times 100\% = 48.30\%$$

Based on the calculation results above, PCE increased by 11.23% from before the implementation of the proposed improvement. The following is a map illustrating the entire process after applying proposed imrpovement with FVSM can be seen in Figure 9.

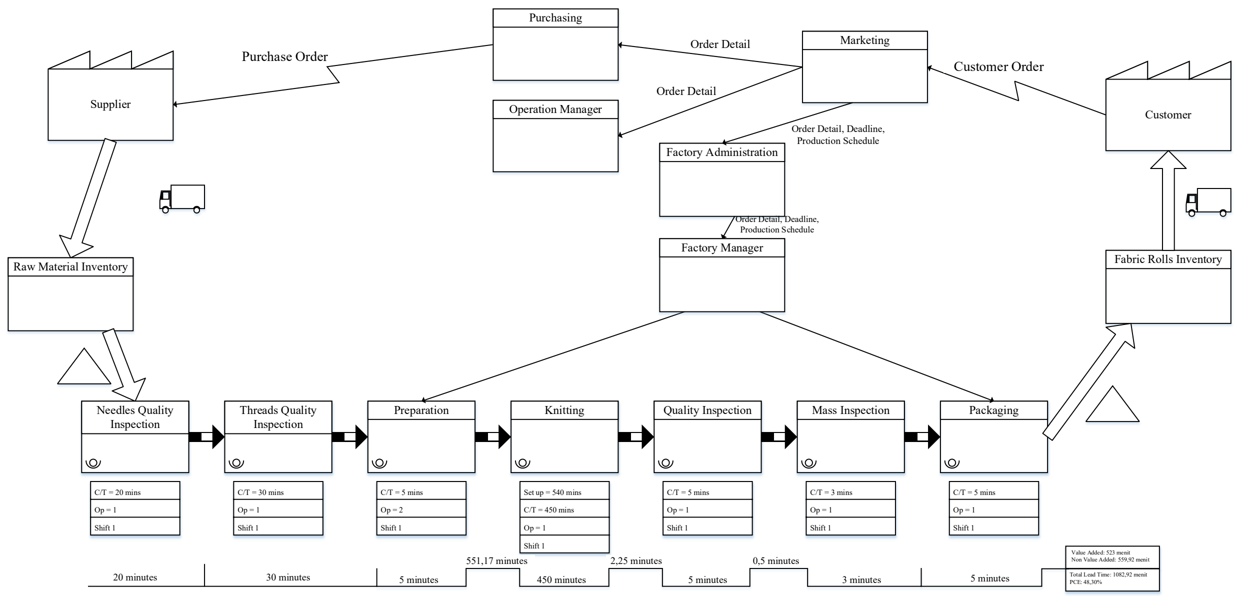

Figure 9. Future Value Stream Mapping

5.5 Control Phase

With an increase in efficiency of up to 11.23%, there are cost savings that synergize with increasing the company's profitability. Based on interviews with the company, the cost of good manufacturing for fabrics is at a percentage of 55% of the selling price, there is an increase of up to 15% due to the pandemic and an increase in the price of cotton raw materials globally. Then this increase in profitability can be calculated as follows

$$\text{Increased Profitability} = 55\% \times 11.22\% = 6.17\%$$

Based on the calculation results above, an increase in profitability of up to 6.17% was obtained if you apply the proposed improvements that have been given. So that the expected cost of good manufacturing can be determined by the following calculations

$$\text{Expected Cost of Good Manufacturing} = 55\% - 6.17\% = 48.83\%$$

With the implementation ofthis proposed improvement, there is a positive change as can be seen in Table 5.

Table 5. Impacts of Proposed Improvement

Metrics	Before	After	Results
Efficiency	37.07%	48.30%	Increased by 11.23%
Manufacturing Lead Time	1275.92 minutes	1082.92 minutes	Reduced by 193 minutes (15.13%)
Cost of Good Manufacturing	55% of selling Price	48.83% of selling price	Decreased by 6.17%
Total Savings			6.17%, from 55% to 48.83% of selling price
Increased Profitability			6.17%, from 45% to 51.17% of selling price

6. Conclusion

In the production process, quality inspection is needed for every raw material that comes from suppliers to evaluate supplier performance as part of the supply chain of the textile industry. No quality inspection process on raw materials results in receiving raw materials with poor quality so that defects in fabrics are a consequence of this.

Defects as one of the main problems in this case are the main triggers in causing other waste such as waste of waiting, waste of overprocessing, and waste of overproduction. The result of these defects and waste is reduced work efficiency, increased manufacturing lead time, and increased costs.

Based on the validation results on the proposed improvement, an increase in efficiency of 11.23%, a reduction in manufacturing lead time by 15.13%, a reduction in production costs by 6.17%, and an increase in company profitability by 6.17%.

This research limitation is about the time to research and the observation process is one month, so a study with a longer time span is needed so that the production data and defects obtained are more and the short observation time has the potential to be influenced by other factors such as the amount of seasonal fabric demand, pandemics, and so on. This research also doesn't emphasize the company's readiness for implementing lean green six sigma to maintain company's sustainability.

In the next research, an assessment of lean green six sigma readiness is needed, and the observation data must be longer to prevent some factors like seasonal demands that lead the research into bias conclusions.

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