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Improving Woven Bag Quality Using Six Sigma Approach to Enhance Production Efficiency

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Abstract

General Background: Inconsistency in product quality due to process variation remains a challenge in many companies, impacting production efficiency and customer satisfaction. **Specific Background:** Similar problems often occur in the packaging industry in Indonesia. with product defect rates exceeding the 4% limit. **Knowledge Gap:** Previous study has focused mostly on using Six Sigma to improve product quality, but the integration of FTA and cost analysis has been limited. **Aims:** This study was conducted to analyse defect causing factors, analyse the cost of defective products, and evaluate the effectiveness of improved solutions in improving product quality. **Result:** The main findings show five main defect types i.e. hole in the sack defect, skewed stitching defect, melted sack defect, skipped stitching defect, and fuzzy sack defect, primarily caused by operator inattention, incorrect machine settings, and equipment malfunctions. After implementing, the defect rate decreased by 1.33% (9,894 units), and the sigma level increased from 3.98 to 4.11. This improvement generated cost savings of IDR 12,408,451. **Novelty:** Integration of Six Sigma, FTA, and cost analysis not only provides recommendations for improvement but also offers an analysis of the financial impact on the company. **Implication:** This study provides strategies for improving productivity and business sustainability through the reduction waste, cost savings, and the strengthening of practical field practices.

Highlights:

- Five defect types represented approximately 80% of total defects.
- Pilot testing reduced defects by 9,894 units, from 4.52% to 3.19%.
- The proposed solution produced IDR 12,408,451 in cost savings.

Keywords: Six Sigma, Defect, Reduce Waste, Cost Analysis, Woven Bag

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Introduction

Technological advances are driving companies to continuously improve their competitiveness by increasing the efficiency of their production processes in order to produce more consistent products [1], [2]. One of the problems often faced by every manufacturing company is defects in the production process [3]. A high number of defective products indicates process instability and weak quality control, resulting in wasted time and costs. Product defects can occur even when the industry has implemented proper quality control [4]. Based on their characteristics, defects are divided into two types, rework defects and reject defects. Rework defects include product defects with minor damage that can still be repaired and have economic value. Meanwhile, rejected defects are product defects that cannot be repaired and the product no longer has any economic value. These two types of defects often occur during the production process and incur defect costs that must be borne by the company. According to Rusindiyanto et al. [5], defects can be caused by several factors, such as dimensional errors, tool damage, or worker errors, which can be minimized through process improvements to improve overall quality.

In economic terms, defects have significant financial implications for companies. The higher the defect rate, the higher the production costs. In financial terms, defects can increase operating costs through material waste, longer production times, labor costs, inspection costs, and energy [6]. In the long term, high defect rates not only affect company profits but can also damage the company's image and reduce its competitiveness in the market [7]. When defective products reach consumers, the costs will be higher due to warranty claims, transportation costs, and the time consumers spend waiting for the product. Other negative impacts on the company include social media consumer reviews, which can erode its reputation, consumer trust, and loyalty. This will be detrimental to both the company and consumers. This defect can be categorized as the type of defect with the highest impact. The lowest impact defects occur when defects are identified during the production process and reported by the company. Based on these impacts, a standardized production process is necessary to minimize defects and meet customer expectations. The more stable the quality control system, the better it is at managing production costs, production quality, and company profits [8], [9].

Quality control is a system that verifies the production process by detecting variations and maintaining the quality of the final product in accordance with standards and consumer expectations [10]. This system is carried out through various stages, from the quality planning of raw materials to the final product, to the documentation of all processes and decisions, and to recommendations for improvement. Each product has quality aspects or indicators that are used to control and evaluate the final product in line with consumer preferences [11]. Quality control in practice generally focuses on reducing product defects without considering the financial impact of defective products. This condition also occurs at XYZ Ltd, a packaging company in Indonesia that produces Woven Bag and is currently experiencing quality problems. The company has made various improvement efforts, such as separating repaired and rejected products, implementing monitoring, and conducting quality inspections, but the defects produced remain above the company's 4% limit.

The Six Sigma approach has been proven to reduce defects and variations in products across various sectors, from manufacturing to healthcare [12]–[16]. Six Sigma was first introduced by Motorola in the 1980s, based on Japanese TQM theory to measure defects and improve quality in complex processes [17]. By integrating TQM principles, Six Sigma combines managerial practices and direct implementation to improve process quality continuously. The goal of this approach is to produce zero defect products, aiming for 3.4 Defects Per Million Opportunities (DPMO), using customer feedback as a basis for improvement [18]. Six Sigma systematically uses the DMAIC stages to reduce defects, production costs, and cycle time through fact based analysis, identify the leading causes in the production process, provide corrective actions, and control improvements [19]–[21]. This approach uses Statistical Process Control (SPC) to identify variations in the production process [22]. The Pareto chart and FTA is one of the SPC tools used in this study to determine the priority of product defect types and identifying the root causes of defects using Boolean logic. FTA facilitates the analysis of root causes at the most basic level, clearly illustrating the cause and effect relationships among the factors that contribute to defects [23].

Previous studies have mainly used the Six Sigma approach to reduce product defects, reporting increases in sigma values and improvements in process stability through the implementation of corrective solutions, without analyzing the costs incurred due to product defects. Some of these studies ended after providing corrective solutions or implementations, without linking them to the savings the company achieved through these improvements [24]. This poses a new challenge for industry players, as implementing long term improvement solutions often requires significant resources in terms of cost, time, and labor [25]. Another challenge is that companies have limited budgets or resource allocations to implement comprehensive improvements [26]. This condition can encourage companies to prioritize improvements solely based on defect frequency, without clear, measurable cost information. Cost analysis plays a crucial role for companies in making decisions based on the economic impact of product defects, whereby improvements can be prioritized in areas that contribute to the most significant losses. Decision making is not only based on defect frequency, but companies can also identify the losses caused by defective products.

This study focuses on analyzing the factors causing defects, analyzing costs, and evaluating the effectiveness of improvement solutions using the Six Sigma approach through the DMAIC stage to improve the quality control of Woven Bag. The research scope is based on historical quality control data from XYZ Ltd for Woven Bag measuring 61 × 101.5 cm. The approach in this study provides insights and an initial overview of the losses the company can avoid through the implementation of quality improvements. This study is expected to make it easier for XYZ Ltd to monitor

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and optimize process performance on an ongoing basis, as well as provide insights for industry players. The findings of this study cannot be generalized directly to similar companies or industries that have different processes and operations.

Method

This study began with the collection of primary and secondary data. Secondary data was obtained through direct observation and interviews with the Woven Bag production manager, head of Quality Control (QC), and head of maintenance to identify the production process flow and the factors that cause defects in Woven Bag products. Meanwhile, the primary data used for the research analysis included production data and historical defect Woven Bags from January 2024 to June 2024, data types of defects Woven Bags, salaries and the number of rework employees, the cost of goods sold (COGS) for the 61x101.5 cm product, data on active workdays per month, and the cost of replacing materials for rework products. Data processing and analysis were conducted using the Six Sigma approach based on the DMAIC framework to identify the main causes of defects in the production process. The DMAIC framework is integrated with quality control tools specifically Pareto charts to identify priority defect types, and FTA to analyze the root causes of priority defect types. Furthermore, this study calculates the costs of losses caused by defective products and analyzes the feasibility of investing in improvements using the Benefit Cost Ratio (BCR). BCR was chosen because it can provide an overview of the economic feasibility of proposed improvements or trade offs to the company. Companies can consider implementing the proposed improvement solutions in the long term. Figure 1. shows the systematic flow of research based on the Six Sigma framework.

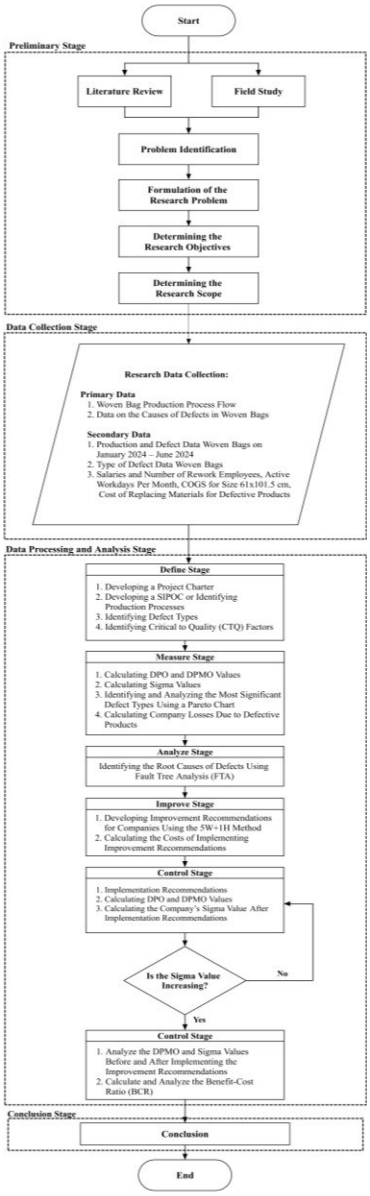

Figure 1. Systematic Flow of Research

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Result and Discussion

A. Define

The Define phase is the first phase in the DMAIC framework. The research begins with the creation of a SIPOC diagram and CTQ to describe the production process and to identify the types of defects based on quality standards at XYZ Ltd, as shown in Figure 2 and Figure 3. The CTQ for Woven Bag products refers to the types of defects that frequently occur during production, as determined interviews with quality control managers. The Key Process Output Variables (KPOV) in the CTQ Tree indicate the characteristics a product must have to be in good condition. Meanwhile, the Key Process Input Variables (KPIV) indicate the control inputs provided to run the process correctly.

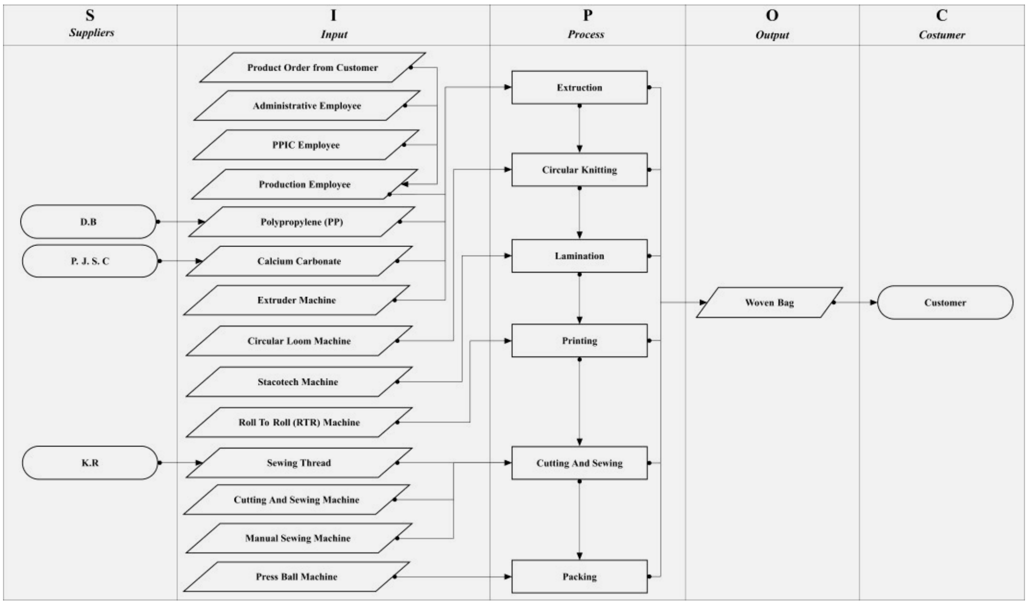

Figure 2. SIPOC Diagram Woven Bag Product

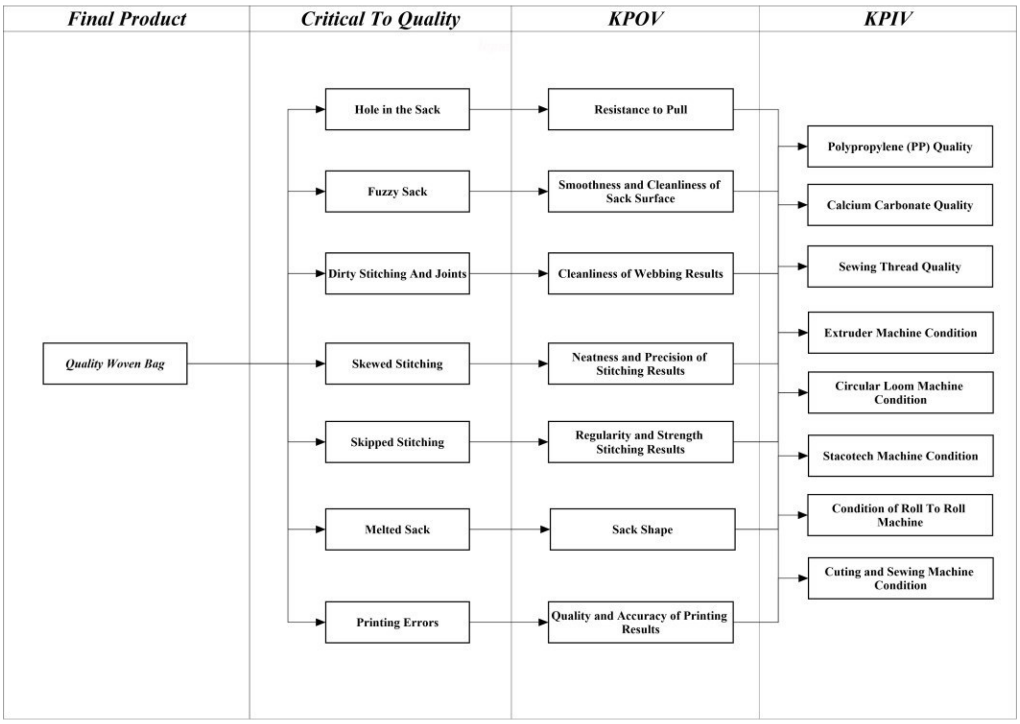

Figure 3. Critical To Quality (CTQ) Tree Woven Bag Product

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The quality aspects of Woven Bag products refer to defects identified during the production process, totaling seven defects, which are described below:

a. Hole in the sack is a hole in the sack that occurs during the weaving process.
b. Skewed stitching is stitching that is not in the correct position and is slanted.
c. Melted sack is when one of the sack's openings melts due to excessive heat at the beginning of production.
d. Skipped stitching defect is when some stitches are missed or not connected, causing gaps between stitches.
e. Fuzzy sack defect is the presence of fibers that protrude during knitting, causing the sack surface to appear fuzzy.
f. Printing error defect is images and colors that are not printed clearly or are blurred.
g. Dirty knitting and joint defects are dirty knitted surfaces or stains, and there are soldering marks indicating new and old knitting joints.

B. Measure

The measure stage began by processing the Woven Bag defect data in size 61 × 101.5 cm, collected from January to June 2024. Total production amounted to 23,084,109 units with 785,585 defective units from 140 samples. Production process performance is determined by calculating the company's DPMO and sigma value, as shown in Table 1.

Table 1. Recapitulation of Sigma and DPMO Values

	Month	Total Production (Unit)	Total *Defect* (Unit)	Average DMPO Value (Unit)	Average *Sigma Level*
2024	January	3.627.575	42.066	7.438	3,95
	February	3.652.548	160.383	6.332	4,00
	March	4.592.453	196.132	6.240	4,00
	April	3.431.494	23.342	5.483	4,01
	May	4.173.412	187.250	6.566	3,98
	June	3.606.627	176.412	7.117	3,96
		Average		6.529,39	3,98

Quality control at XYZ Ltd. over the past six months has been implemented quite well, with average DMPO and sigma values of 6,529 units and 3.98, as shown in Table 1. This sigma value indicates that the company's quality control is in line with the industry average in Indonesia, with 99.34% specification compliance. Although specification compliance is relatively high, there is still room for improvement to achieve Six Sigma (6σ) in line with the target of 3.4 defects per million products produced [27], [28]. After that, priority identification was conducted using Pareto chart for defect types that have a significant impact on quality issues. The Pareto chart uses the 80/20 principle, where 80% of the issues are caused by 20% of the causes, as shown in Figure 4 [29].

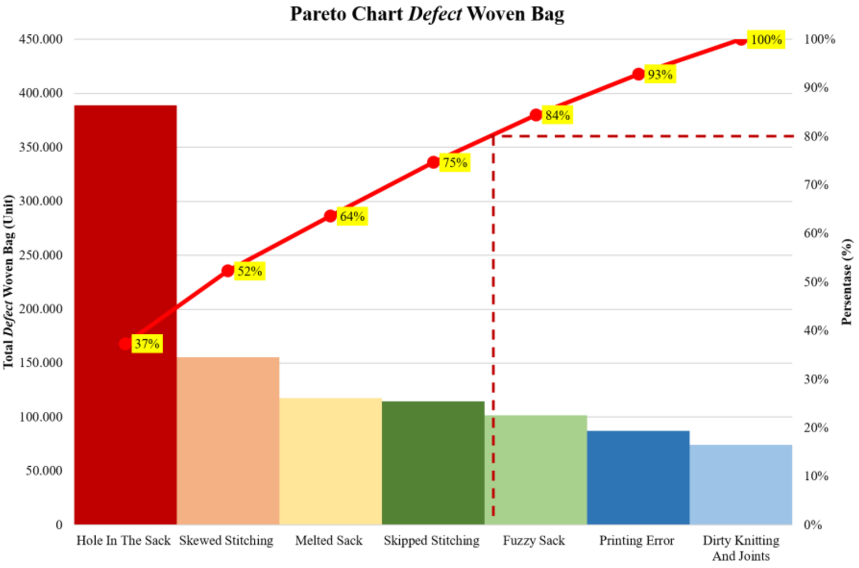

Figure 4. Pareto Chart Woven Bag Product

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There are five priority defect types that account for around 80% of total defects such as hole in the sack defects (37%), followed by skewed stitching (15%), melted sack (11%), skipped stitching (11%), and fuzzy bags (10%). By focusing improvements on dominant factors, companies can reduce overall quality problems [30].

A cost analysis then conducted to determine the financial impact from product defects, rework costs, and product rejection costs. C_d refers to the total cost of rejected defective products, C_r refers to the cost of replacing materials and the wages of employees who carry out the repairs. The details of the required materials and costs are obtained through interviews with the head of QC and production manager. Based on Table 2, the company suffered a significant loss of IDR 934,389,000 over the six months due to product defects.

Table 2. Recapitulation of Cost Calculations for Total Defective Products

No	Type of Cost	Total Cost (6 Month)
1.	C_d	IDR 770.011.000
2.	C_r	IDR 164.378.000
	Total	IDR 934.389.000

C. Analyze

The analysis stage begins by identifying the root causes for each of the five defect priority types using Fault Tree Analysis (FTA). This Fault Tree Analysis (FTA) was compiled from interviews with the head of QC, head of maintenance, and production manager to identify the causes of each Woven Bag defect. The identification was carried out using the 4M+1E (Man, Machine, Method, Material, Environment) factors, according to the needs of each type of product defect.

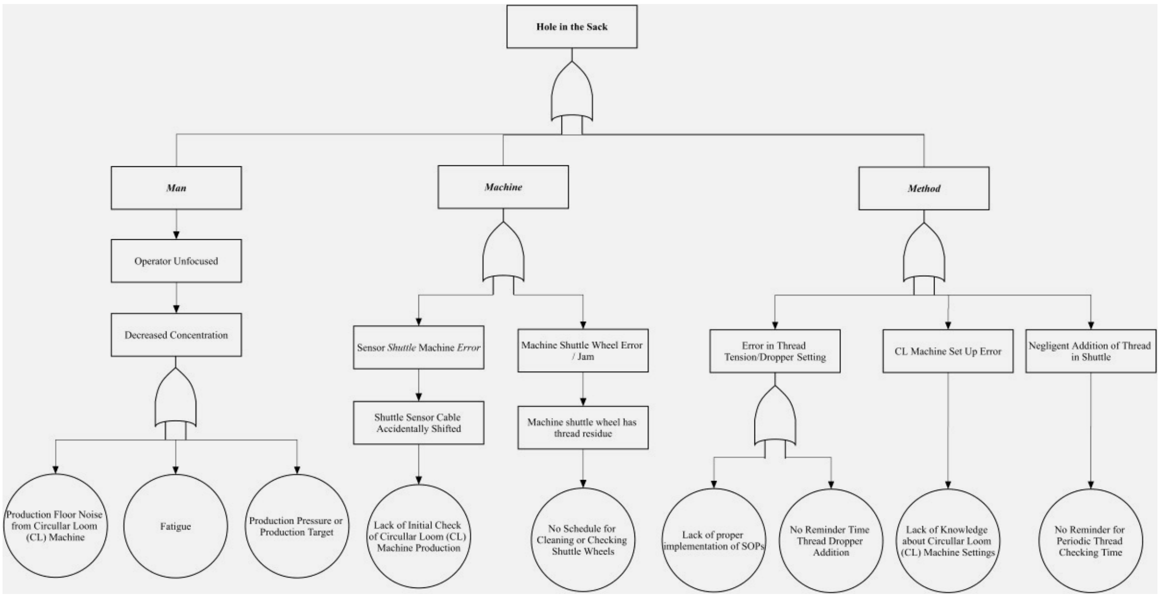

Figure 5. FTA Hole in The Sack Defect

A hole defect in the sack occurs during the weaving process on the Circular Loom (CL) machine. These defects occur when the WA and WE yarns are pulled together with different weights, resulting in an imperfectly woven pocket or holes. The causes of defects in the sack are three main factors i.e. man, machine, and method, as shown in Figure 5. The man factor relates to operator distraction due to decreased concentration caused by noise from the CL machine, fatigue, and pressure from daily production targets. The machine factor includes sensor errors and shuttle wheel stoppages on the CL machine, which are generally caused by misaligned sensor cables and residual knitted yarn due to insufficient machine checks and cleaning before production. The method factor includes errors in tension or yarn dropper settings, machine setup errors, and negligence in adding yarn to the shuttle due to a lack of SOP implementation, limited operator knowledge, and the absence of periodic check reminders. These conditions cause an imbalance in the knitting points resulting in product defects.

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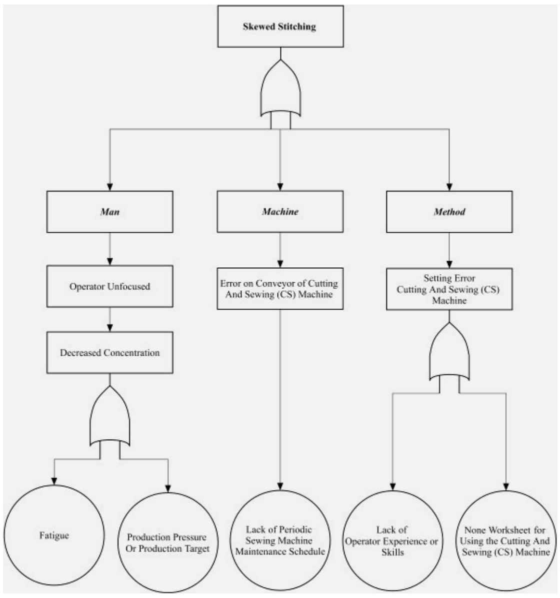

Figure 6. FTA Skewed Stitching Defect

Skewed stitching occurs when the pocket folds are misaligned, causing the pocket that should produce a straight stitch line to become skewed on the Cutting Sewing (CS) machine. The FTA for the skewed stitching defect is shown in Figure 6. Skewed stitching defects are caused by several primary factors i.e. man, machine, and method. In terms of man factors, operator distraction is the leading cause, driven by decreased concentration due to work fatigue and daily production targets. In terms of machine factors, damage or errors in the CS machine conveyor, particularly unbalanced conveyor pulling, can cause bags to skew, resulting in substandard stitching. This condition is influenced by the lack of a regular maintenance schedule, considering that the CS machine operates continuously. Meanwhile, in terms of method, defects occur due to errors in the CS settings or adjustments to the bag fold distance caused by the operator's limited skills and the unavailability of worksheets or machine usage guidelines.

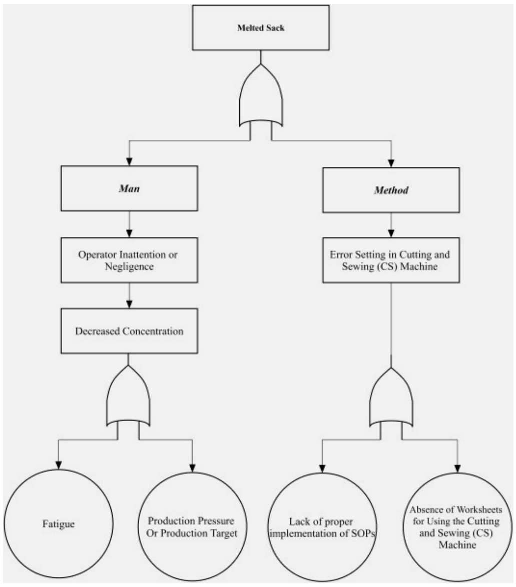

Figure 7. FTA Melted Sack Defect

The melted sack defect occurs when sacks are exposed to high temperatures, leading to deformation, such as shrinkage on the Cutting Sewing (CS) machine. Defects in melted sacks are caused by factors, man and method, as shown in Figure 7. In terms of man factors, operator distraction or negligence is the leading cause, driven by decreased concentration due to fatigue during the production process and the pressure of daily production targets. In terms of method, defects occur due to errors in machine settings, both during initial production settings and when changing sack sizes. This is exacerbated by inconsistent SOP implementation and the lack of CS machine worksheets as guidelines and reminders for operators, thereby increasing the potential for defects.

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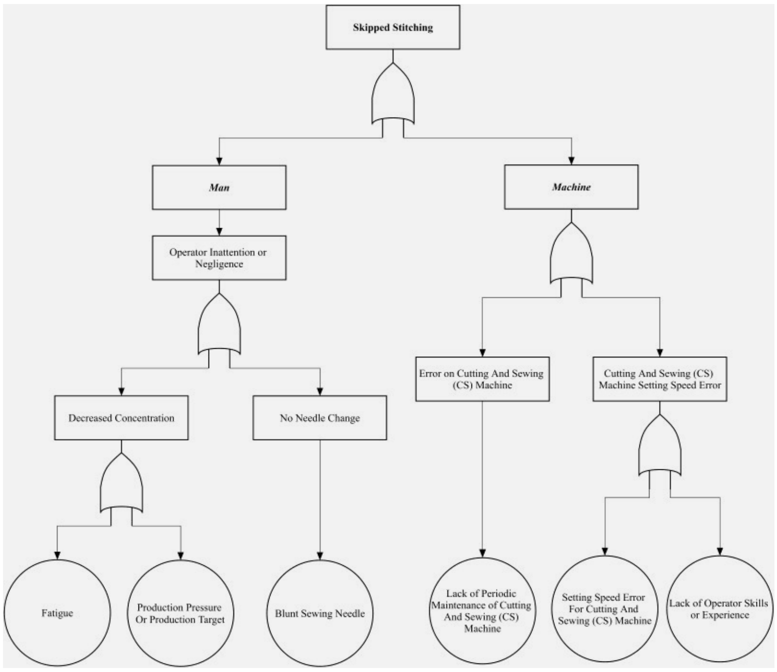

Figure 8. FTA Skipped Stitching Defect

The skipped stitching defect occurs on the CS machine, causing it to skip specific stitching points and creating gaps between stitches. Both man and machine factors cause defective skipped stitches, as shown in Figure 8. Man factors include operator distraction and failure to replace needles, leading to loss of concentration and dull needles, resulting in skipped stitches. Loss of concentration is caused by fatigue and daily production targets. Machine factors include damage or errors in the CS machine and incorrect machine speed settings. Machine errors occur due to a lack of regular maintenance, while incorrect speed settings are caused by the unavailability of CS operating manuals or the operator's limited skills and experience.

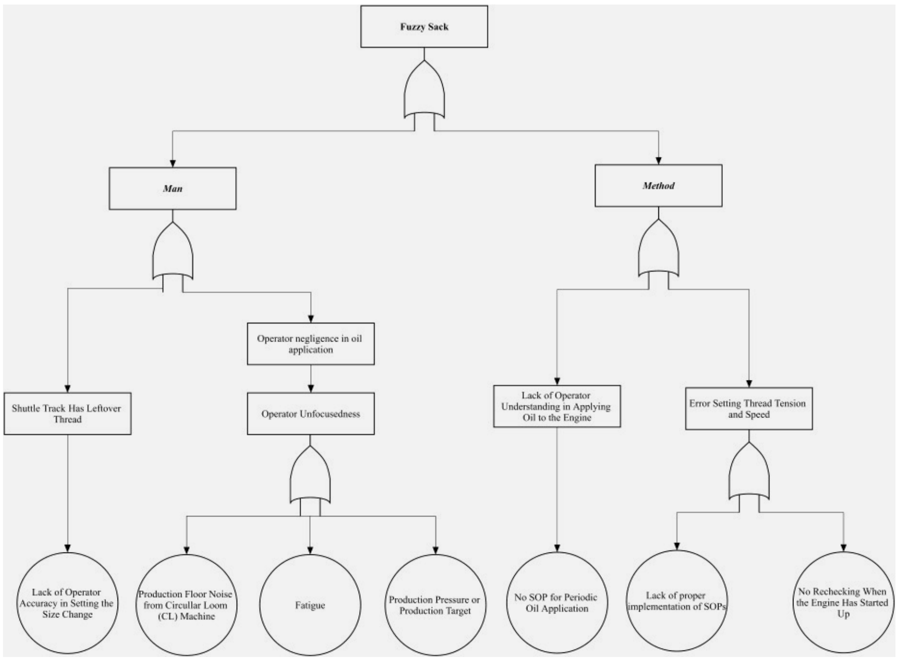

Figure 9. FTA Fuzzy Sack Defect

The fuzzy sack defect is characterized by fine, raised fibers on the sack's surface, which can degrade appearance. This defect occurs on the Circular Loom (CL) machine. Fuzzy sack defects are caused by man and method factors, as shown

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in Figure 9. The man factors include operator negligence in oiling and the presence of thread residue on the shuttle track, which disrupts subsequent production. Method factors include the lack of clear SOPs for regular machine oiling. The oil refill schedule is based on the operator's memory or instinct. This defect is also caused by operator errors in setting the thread tension and machine speed. Unstable thread tension and high speed can cause the knitting to become loose or have hairy gaps. These setting errors are caused by the operator's failure to implement SOPs properly and by the lack of machine rechecking after startup.

D. Improve

The improve stage involves developing corrective solutions for each main cause of defects, as explained through the 5W+1H analysis. These improvement recommendation were developed based on interviews with the production manager and quality control manager to obtain recommendations that could be directly applied and have an impact on the company, as shown in Table 3.

Table 3. Recommendations for Improvement Based on Root Causes

Why	Type of Defect	What	Who	Where	When	How
Lack of Proper SOPs Implemen-tation	Hole in the sack, Fuzzy sack	Developing SOPs for machine operation	CL Machine Operator	CL Work-station	Before and during the product-ion process	Develop daily inspection SOPs in accordance with machine operating procedures, as well as preventive maintenance procedures such as lubrication and tension or dropper
The lack of a reminder for work activities and machine maintenan -ce	Hole in the sack, Skewed stitching, Skipped stitching, Fuzzy sack	Providing work reminders and implement-ing preventive maintenance	CL/CS Machine Operator, Technic-ian	CL/ CS Work-station	During the product-ion process and schedul-ed mainte-nance	Create daily and monthly maintenance activity checklists in accordance with the maintenance schedule
Lack of coordinati-on, experience, and operator skills	Hole in the sack, Skewed stitching, Melted Sack	Improving operator skills	CL/CS Machine Operator	CL/ CS Work-station	During the Product-ion Process	Conduct briefings at least twice a day and provide training on a regularly basis
Machine noise	Hole in the sack, Fuzzy sack	Controlling machine noise	CL Machine Operator	CL Work-station	During the Product-ion Process	Providing wired earplugs

E. Control

The control stage was carried out by implementing improvement solutions (pilot testing) for 6 days, involving 56 workers in the production area. A comparison of performance before and after pilot testing was carried out, as shown in

Table 4.

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Table 4. Comparison of DPMO Value and Sigma Value Before and After Implementation

Description	Before Implementation	After Implementation
Sigma Value	3,98	4,11
DPMO Value (Unit)	6.529,39	4.554,97
Defect Percentage (%)	4.52%	3.19%

The average defect rate for Woven Bag products decreased from 4.52% to 3.19%, as shown in

Table 4. This also led to a decrease in DPMO, while the company's sigma value increased. The average DPMO value decreased from 6,529 to 4,555, a decrease of 1,974 units. This decrease in defects is equivalent to a cost saving of IDR 12,408,451. Meanwhile, the sigma value increased by 0.12, from 3.98 to 4.11. This increase in sigma value also indicates that the production process produces products with a more consistent quality equivalent to the US industry average. The results of this study are in line with Anggamawarti et al., the pilot testing helped determine the effectiveness of the improvement solution through reductions in defect rates and cost savings, which companies can use to make financial decisions to improve the effectiveness of the production process [20].

Analyzing and estimating the pilot test costs was conducted to determine the feasibility of an investment when the company implements long term improvement solutions using BCR. The prices for each material or tool were obtained from websites, e-commerce platforms, and interviews with the head of HRD at XYZ Ltd. The estimated cost of the six days pilot test was IDR 7,769,500, as shown in Table 5.

Table 5. Recapitulation of Cost Analysis for Improvement Recommendations

Improvement Solution	Material/Tools	Unit Price	Quantity	Total
SOP *Maintenance* CL	HVS Paper	IDR 500	2	IDR 1.000
SOP *Maintenance* MPJ	HVS Paper	IDR 500	1	IDR 500
Workboard	Stopwatch CL	IDR 38.000	10	IDR 380.000
	Stopwatch MPJ	IDR 19.000	6	IDR 114.000
	Workboard	IDR 4.000	16	IDR 64.000
	Cable Ties	IDR 5.000	1	IDR 5.000
	HVS Paper	IDR 500	56	IDR 28.000
Work Training For Maintenance And Operators	Hotel	IDR 500.000	2	IDR 1.000.000
	Maintenance Wage	IDR 2.000.000	2	IDR 4.000.000
	Transportation	IDR 300.000	2	IDR 600.000
	Meal Allowance	IDR 250.000	2	IDR 500.000
	Train Ticket	IDR 500.000	2	IDR 1.000.000
Worker Briefing	Operator/Technician	IDR 0	0	IDR 0
Use and Replacement of Earplug	Cable Earplug Krisbow	IDR 7.700	10	IDR 77.000
Sheet Sigma Value	Ms. Excel	IDR 0	0	IDR 0
	Total			IDR 7.769.500

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A BCR value > 1 indicates that the investment provides benefits and is feasible for the company. Meanwhile, BCR < 1 means that the investment does not provide benefits and is not feasible in the long term. Based on calculations, the BCR is 1.60 which is > 1, indicating that investing in this improvement solution is feasible and profitable for the company. This also shows that the benefits the company gains from implementing the improvement solution exceed the costs it incurs. The company can continue to implement the proposed improvement recommendations in the long term to reduce defects in Woven Bag products. The use of SOPs, machine maintenance checklists, and work boards can also serve as guidelines to control the performance of production machines, helping prevent greater machine damage. Through these recommendation, the company can achieve more consistent product quality, thereby increasing customer satisfaction.

Conclusion

This study shows that the Six Sigma approach has been successful in reducing product defects and improving quality in Woven Bag product. Based on a pilot testing for five defect priority in CL and CS machine with an estimated cost of IDR 7,769,500, reduction was achieved from 4.52% to 3.19%, equivalent to 9,894 units. The company's sigma value also increased by 0.12, from 3.98 to 4.11, resulting in cost savings of Rp 12,408,451 due to a reduction in defective products. Several improvement solutions were proposed to reduce defect, including creating Standard Operating Procedures (SOPs) and machine maintenance checklists for CL and CS machines, job training programs, briefings at least twice a day, and using wired earplug. This study not only to improve process production consistency but also to reduce waste through optimal resource management, reduce defective products, and generate cost savings for companies, thereby enhancing business sustainability, competitiveness, and customer satisfaction. Further research can be conducted by considering several factors, including implementing the proposed improvement solutions for a sufficient period to obtain accurate data on their effectiveness. In addition, pilot tests after the company has undergone a long holiday period and a detailed cost analysis of defective products for all sizes of Woven Bag can also be explored.

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