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Application of Six Sigma for Quality Optimization in Textile Raw Material: A Case Study on TRC 1 Yarn

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ABSTRACT

This study aims to analyze quality control in the production process of TRC 1 yarn at PT. SA by implementing the Six Sigma approach. The TRC 1 product exhibits a defect (reject) rate of 4.1%, which significantly exceeds the company's standard of 1%. The research adopts the DMAIC method (Define–Measure–Analyze–Improve–Control). The measurement phase involves the creation of histograms, both attribute and variable control charts, and the calculation of DPMO and Cp. The results indicate that the process is statistically unstable, with a sigma level 2.2 and a DPMO of 245,000. The process capability index (Cpk) of 0.503 demonstrates that the process is incapable. Root Cause Analysis (RCA) and Failure Mode and Effect Analysis (FMEA) identified the primary causes as the absence of measuring instruments for raw material composition and the lack of a standard operating procedure (SOP) for machine inspections. The improvement phase was carried out using the 5W1H approach, resulting in solutions such as developing measurement tools, nozzle labeling, and issuing operational memos. After four months of implementation, the defect rate decreased to 3.24%. Although improvements were observed, the result still exceeds the company's target, indicating the need for continuous process control. This study contributes to applying Six Sigma for quality improvement in the integrated textile industry.

INTRODUCTION

The global demand for personal protective equipment (PPE) has increased significantly in recent years, particularly for products such as gloves, which are crucial in ensuring occupational safety across various industrial sectors. PT. SA is one of the leading players in this industry, specializing in producing various types of gloves, including those made from 100% pure cotton, polyester-cotton blends, PVC-dotted gloves, Terry gloves, and cut-resistant gloves. As a manufacturer focused on fulfilling customer needs in both export and domestic markets, PT. SA emphasizes the importance of high product quality, particularly in terms of yarn uniformity, weight, size, and color consistency, while maintaining competitive prices and reliable service.

To uphold strict quality standards, PT. SA produces its cotton yarn internally, the primary raw material for glove manufacturing. However, the company faces challenges in maintaining the quality of its yarn. In particular, the TRC 1 yarn product has shown a high rejection rate, averaging 4.1% between January and December 2024, based on the company's internal quality reports —significantly exceeding the internal threshold of 1%. This has resulted in a sigma level of approximately 2, far below the company's target of 4 sigma. Rejected products require time-consuming and resource-intensive rework processes, including removing neps and unprocessed impurities and reprocessing through carding machines to produce sliver that meets company standards. These issues cause delays in glove production, especially when nearing shipment deadlines, leading to increased working hours, reduced administrative and workforce productivity, and potential damage to the company's market reputation. Inconsistent delivery times and product quality may also cause customers to switch to competitors who offer faster service and higher quality.

A structured and data-driven quality improvement approach is essential to address these issues. Six Sigma, a methodology focused on reducing defects and improving process capability, offers a proven framework for quality improvement in manufacturing environments [1]. The DMAIC cycle (Define, Measure, Analyze, Improve, Control) within Six Sigma has been widely applied to identify root causes of defects, reduce variation, and optimize production processes [2], [3]. Previous studies have shown that the implementation of Six Sigma can improve operational performance, reduce product defect rates, and enhance customer satisfaction [4], [5], [6], [7]. However, to date, there has been limited research applying Six Sigma systematically in the yarn production process within the glove industry, particularly in integrated production lines where the quality of raw materials directly affects the final product.

In broader textile manufacturing, several studies have successfully implemented Six Sigma and Lean Six Sigma to address quality-related challenges. Jiménez-Delgado et al. [8] demonstrated how DMAIC can reduce production cycle time and defect rates in textile sectors. Hussein and Taifa [9] applied Six Sigma to minimize defects in yarn manufacturing processes. These findings underscore the methodology's effectiveness in textile quality control. Nevertheless, applications targeting raw material input quality in glove-oriented yarn production remain scarce.

Therefore, this study aims to analyze quality control in the production process of TRC 1 yarn using the Six Sigma approach. By identifying key sources of variation and implementing process improvements through the DMAIC framework, this research advances both theoretical and practical aspects of quality management in the integrated textile industry. The novelty of this study lies in its focus on the quality of raw material inputs in glove manufacturing—an area rarely explored in Six Sigma literature—and its implications for downstream production efficiency and market competitiveness. To strengthen the focus and contribution of this study, the following research questions are formulated: (1) What are the most significant defects occurring in the TRC 1 yarn production process? (2) What are the root causes behind these defects based on Six Sigma analytical tools? And (3) How effective are the implemented improvements in reducing the defect rate and enhancing process capability?.

MATERIALS AND METHODS

This study analyzes the factors influencing quality control in producing TRC 1 yarn at the Yarn Division of PT. SA. The research site was selected based on initial observations of a high defect (reject) rate in the yarn production process. The steps of the research process are outlined as follows:

1. Data Collection

   Data were collected from the production process of the Yarn Division using two types of sources:

   a. Primary Data:

      1. Directly observe the yarn production workflow, including processing stages, machine conditions, and operator interactions.
      2. Identification of defect types in TRC 1 yarn through visual inspection and documentation by the production quality control team.

   b. Secondary Data:

      1. Monthly yarn production recapitulation reports obtained from internal production records.
      2. Historical data on the quantity and types of monthly product defects were obtained from the quality control archives.

2. Research Steps

   This study adopts a quantitative approach using the Six Sigma methodology through the DMAI (Define–Measure–Analyze–Improve) framework.

   a. Define Stage

      At this stage, the key quality characteristics, or Critical to Quality (CTQ) attributes of the TRC 1 yarn product, are identified based on customer requirements. The CTQ analysis facilitates the identification of defect types in the TRC 1 yarn.

   b. Measure Stage

      Several analyses are conducted at this stage, including the construction of a histogram chart of defect types to identify the most frequent defects, as well as statistical data processing using attribute and variable control charts and process capability analysis**.** These tools provide a quantitative foundation to assess the statistical stability and efficiency of the TRC 1 yarn production process.

   c. Analyze Stage

      The Root Cause Analysis (RCA) tool is used to identify the primary causes of product defects through a systematic and exploratory approach. This technique is based on iterative "why" questioning to trace the most fundamental root causes [10], [11]. Subsequently, Failure Mode and Effect Analysis (FMEA) is used to identify and prioritize potential process and product failures. Each failure mode is evaluated based on three key parameters: Severity, Occurrence, and Detection**,** with scores ranging from 1 to 10. The total score is used to calculate the Risk Priority Number (RPN) to determine the most critical areas for improvement [12], [13].

   d. Improve Stage

      To design the improvement action plan, the 5W1H (What, Why, Where, Who, When, How) method is used. This approach helps develop targeted, specific, and practically implementable solutions [14].

RESULT AND DISCUSSION

The data collected will be processed using the Six Sigma DMAI approach. It was carried out through direct observation at the site of production. This research was conducted to identify issues related to the yarn product and develop solutions for controlling its quality. To facilitate a structured discussion of quality performance in TRC 1 yarn production, this section provides an overview of the existing manufacturing workflow. The process involves a sequence of operations and inspections, ranging from raw material receiving and blending to yarn spinning, strength testing, and final packaging.

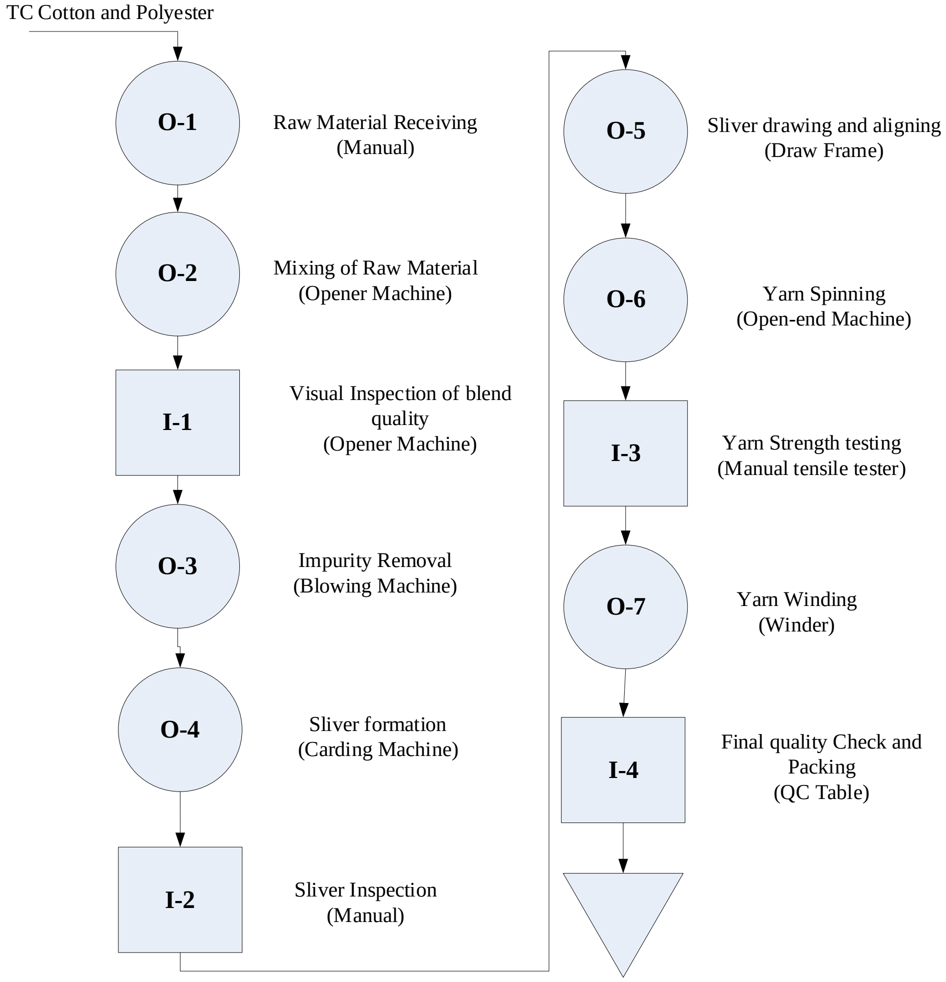


Figure 1. Operation Process Chart of TRC 1 Yarn Production

Figure 1 presents the Operation Process Chart (OPC), outlining the core production stages using standard symbols. Circles represent operational activities such as mixing, spinning, and winding, while squares indicate key inspection points including blend verification, tensile strength testing, and final quality control. This overview offers a contextual foundation for understanding the production environment in which quality deviations have been observed.

While the current section focuses on mapping the production flow, specific stages associated with process instability and defect generation will be examined in detail in the subsequent analysis. This includes the identification of contributing factors and prioritization of improvement areas based on data gathered through structured observation and statistical assessment.

1. *Define*

In this stage, the yarn product's Critical to Quality (CTQ) attributes are identified, as shown in Table 1. The quality standards for the TRC 1 yarn product include strength and visual appearance. Furthermore, the types of defects (rejects) during the production process are defined, as illustrated in Table 3.

Table 1. Critical to Quality of Yarn Product

CTQ	Spesifikasi	Description	Type of defect
Strength	*Min* = 65 *Mean* = 76 *Max* = 84	The product must not fall below the strength standard set by the company.	Insufficient Yarn Strength (*Kekuatan Benang kurang*)
Visual	The yarn produced from the production process must be of good quality.	The winding result of the product must be even and free from any impurities.	Mbelubut Nep

Table 2. Yarn Product Standards

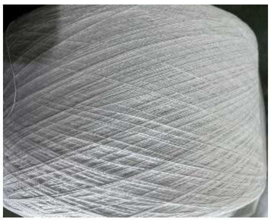
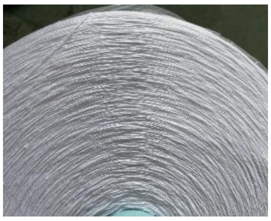
Front View	Side View
	

Table 3. Rejected Yarn Products

Type and Description	Image
Insufficient Yarn Strength The yarn strength is below the standard operating procedure (SOP) set by the company.	
Mbelubut The yarn product is fuzzy and cannot be used by the glove division.	
Nep There are specks of dirt present on the yarn product.	

2. *Measure*

At this stage, the number of each type of defect found in the TRC 1 yarn product is identified. Analysis using a histogram chart shows that the most frequent type of defect is due to insufficient yarn strength.

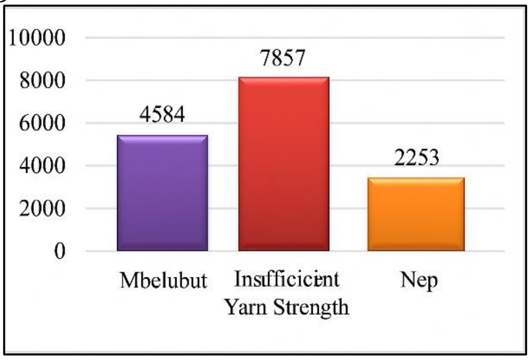


Figure 2. Number of Rejects by Type of Defect

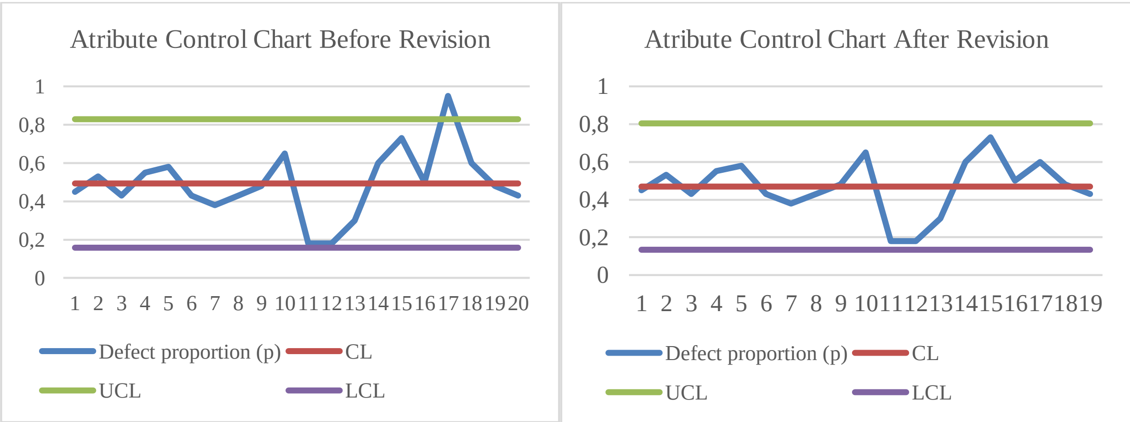
Next, data processing will be carried out using control charts and process capability analysis to provide a quantitative basis for assessing the stability and efficiency of the production process. The data were obtained through direct observation during the production process and used to construct two control charts: an attribute control chart for analyzing defects such as fuzzy yarn (mbelubut) and neps, and a variable control chart to analyze defects related to insufficient yarn strength.

a. Attribute Control Chart

In the initial stage, the analysis was conducted on unmodified production data, resulting in the following findings:

1. Upper Control Limit (UCL) = 82,8%
2. Lower Control Limit (LCL) = 15,8%
3. There was a sample with a reject proportion as high as 95.5% (exceeding the Upper Control Limit/UCL)

From Figure 3a, it is also observed that there a data points outside the UCL and LCL range. This condition indicates that the production process is not yet under statistical control. Data modification was then performed to obtain a valid control chart by removing the three extreme data points that exceeded the control limits. The revised results in Figure 3b show that all data points fall within the specified UCL and LCL boundaries.



(a) (b)

Figure 3. Attribute Control Chart of TRC 1 Yarn Product

From Figure 3b, it is evident that the company is still facing issues related to the product reject rate exceeding the established standard limit. The reject threshold set by the company is 1%, whereas the current reject rate reaches as high as 80,4%, approaching 100% in some observed data, with the lowest at 13,4% and an average reject rate of 47%, which is significantly above the standard limit. Therefore, further analysis is necessary to identify and reduce the contributing factors behind these product defects.

b. Variable Control Chart

The variable control chart is used to monitor the stability of the TRC 1 yarn production process, particularly for defects related to yarn strength not meeting the required standards. The objective of this analysis is to ensure that the yarn tensile strength parameter falls within statistical control limits and meets the company's technical specification thresholds. The initial control chart was constructed based on yarn strength sample data. The measurement results showed:

1. The average yarn strength ($\bar{X}$) = 70,3 kg/lbs
2. Upper Control Limit (UCL) = 75,0 kg/lbs
3. Lower Control Limit (LCL) = 66,6 kg/lbs

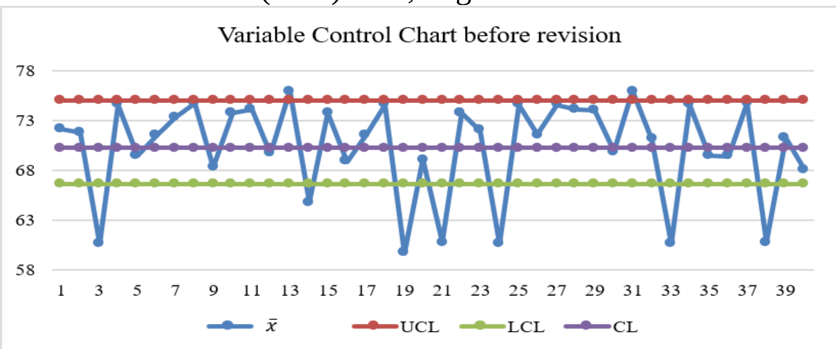


Figure 4. Variable Control Chart of Yarn Strength Defect (Insufficient Strength) Before Revision

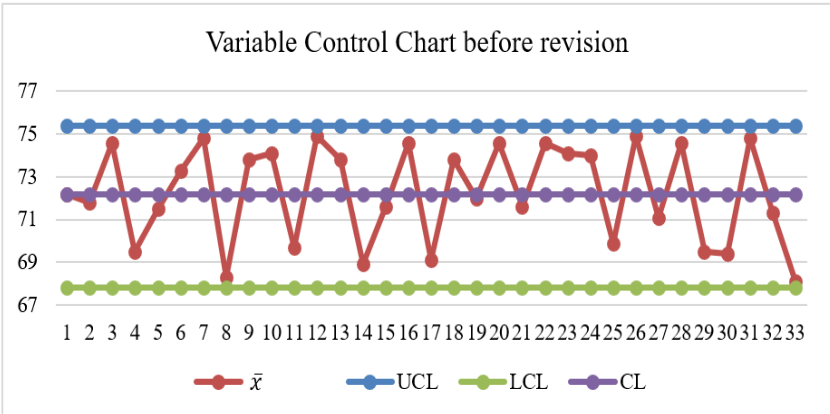


Figure 5. Variable Control Chart of Yarn Strength Defect (Insufficient Strength) After Revision

From Figure 4, it can be seen that several sample data points fall outside the control limits. Therefore, an elimination process was carried out to remove those out-of-control data points. This step was taken to obtain a more representative view of the process, free from the influence of special cause variation. The revised results are shown in Figure 5, indicating that the TRC 1 yarn production process, in terms of yarn strength, is statistically under control and consistently remains within specification limits.

c. Process Capability Measurement

To ensure an efficient production process that meets specifications, further measurements were conducted by calculating the indicators Defect per Million Opportunities (DPMO) and the Process Capability Index (Cp). These measurements aim to evaluate the degree to which the process conforms to specification limits and to identify the need for process improvements.

1. DPMO and Sigma Value

Based on the sample production data, it was found that:

a. DPMO value (Defect per Million Opportunities): 245.000
b. Sigma value: 2,2

A DPMO value of 245,000 indicates that out of one million defect opportunities, 245,000 defects were identified. This figure is considerably high and reflects that the process is still far from the ideal Six Sigma condition. A sigma value of 2.2 suggests that the process is not stable and exhibits a significant degree of variation.

2. Calculation of Cp, Cpl, Cpu, and Cpk

Process capability (Cp) measures the extent to which a process is capable of producing products within the defined technical specification limits.

Further calculations were conducted for the defect type "insufficient yarn strength", with the following results:

a. Cpu = 0,812
b. Cpl = 0,503
c. Cpk = min(Cpu, Cpl) = 0,503

A Cpk value below 1.0 indicates that the process incapable, meaning that a significant portion of the products produced are likely to fall outside the quality specification limits set by the company.

3. *Analyze*

At this stage, all collected data were analyzed using the Root Cause Analysis (RCA) tool to identify the root causes of product defects. Subsequently, the Failure Mode and Effect Analysis (FMEA) tool was applied to determine the improvement priorities for enhancing the quality of the TRC 1 product. Table 5 until table 7 below presents the results of the RCA analysis, while Table 8 shows the outcomes of the FMEA analysis.

Table 4. RCA for Defect Type: Insufficient Yarn Strength

Reject	*Why 1*	*Why 2*	*Why 3*
Insufficient yarn strength	Insufficient polyester composition during the mixing process	Raw material collection is carried out manually and the quantities are not always precise	There is no measuring tool or equipment available to accurately measure the composition of raw materials
	Machine rotation becomes unstable after a certain period of time	No machine inspection is performed by the operator	There is no standard operating procedure (SOP) for periodic machine rotation checks

Table 5. RCA For Defect Type: Fuzzy Yarn (Mbelubut)

Reject	*Why 1*	*Why 2*	*Why 3*
Mbelubut	Use of an inappropriate nozzle	The mechanic incorrectly installed the nozzle	The mechanic has difficulty selecting the appropriate nozzle

Reject	*Why 1*	*Why 2*	*Why 3*
	The rotor stops before the designated time	The rotor is blocked by lint (*avalan*)	Lint does not enter the dash pipe during the opening roll process

Table 6. RCA For Defect Type: Fuzzy Yarn (Mbelubut) (Continued)

	Why 4	Why 5	Why 6	Why 7	Why 8
Mbelubut	There are no markings on the nozzle				
	The opening roll is unable to separate single fibers from lint (avalan)	The quality of the sliver produced by the carding machine is poor	The quantity of neps and lint (avalan) is too high, making it impossible for the carding machine to fully separate them	The blowing machine is unable to separate impurities contained in the raw materials	The composition of the raw materials is poor

Table 7. RCA for Defect Type: Nep

Reject	***Why 1***	***Why 2***	***Why 3***	***Why 4***
Nep	Nep cannot enter the dash pipe	The dash pipe is clogged	Blocked by lint (avalan)	The quality of the sliver produced by the carding machine is poor

Reject	***Why 5***	***Why 6***	***Why 7***
Nep	The quantity of neps and lint (avalan) is too high, making it impossible for the carding machine to fully separate them	The blowing machine is unable to separate the impurities present in the raw materials	The raw material composition is poor

The next step is to determine improvement priorities by calculating the Risk Priority Number (RPN), as shown in the table below.

Table 8. FMEA of TRC 1 Product

No	**Jenis Reject**	**Mode Kegagalan**	**Efek Kegagalan**	**S**	**Penyebab Kegagalan**	**O**	**Kontrol Kegagalan**	**D**	**RPN**	**Prioritas**
1	**I**nsufficient yarn strength	Insufficient yarn strength does not meet the company's standards	The product produced does not meet the company's product standards	9	There is no measuring tool or equipment to accurately measure the composition of raw materials	8	The failure is detected during inspection by Quality Control (QC)	4	288	1
		The machine rotation does not comply with the	The strength of the produced product is reduced, making it	9	There is no standard operating	5	The failure is detected by the operator	4	180	4

No	Jenis Reject	Mode Kegagalan	Efek Kegagalan	S	Penyebab Kegagalan	O	Kontrol Kegagalan	D	RPN	Prioritas
		standard rotation table	non-compliant with the company's product standards.		procedure (SOP) for periodic machine rotation checks		on the open-end machine			
2	Mbelubut	The yarn comes out of the Cones spool	The produced product does not meet the company's product standards	8	There are no markings on the nozzle	7	The failure is detected by the operator on the open-end machine	5	280	2
		The yarn comes out of the Cones spool	The produced product does not meet the company's product standards	7	The raw material composition is poor	5	The failure is detected by the operator on the open-end machine	5	175	5
3	Nep	Dirt particles adhering to the yarn	The product does not meet the specifications, making it unsuitable for distribution	7	The raw material composition is poor	7	The failure is detected during inspection by Quality Control (QC)	4	196	3

The defect type of insufficient yarn strength is the top priority for improvement as it has the highest RPN value of 288. Improvements are made by recommending solutions to the root causes of this defect, which is the lack of a measuring tool or equipment to accurately measure the composition of raw materials. The second priority is the fuzzy yarn (mbelubut) defect with an RPN value of 280, and the last priority is the nep defect, which has an RPN value of 196.

4. *Improve*

The next step in the DMAI process is the Improve stage, which involves providing recommended solutions for each root cause of the defects. The tool used in this stage is 5W1H (What, Why, Where, Who, When, How), which helps in designing specific, targeted, and practical solutions to address the underlying issues causing the rejects.

Table 9. 5W1H Analysis of TRC 1 Yarn Product Defect Types

No	Factor	What (What happened?)	Why (Why is improvement necessary?)	Where (Where should the improvement be made?)	When (When should the improvement be made?)	Who (Who will implement the improvement?)	How (How will the improvement be made?)
1	No measuring tool to measure composition	Insufficient yarn strength	To ensure yarn strength meets the company's SOP	Opener machine – Blowing machine	To be done during the production process	Operator	Develop a container to be used as a measuring tool for raw material composition during mixing
2	There is no SOP regarding periodic machine	Insufficient yarn strength	To ensure yarn strength meets the company's SOP	open end machine	To be done during the production process	Operator and Mechanic	Create a MEMO regarding periodic machine rotation checks that must comply

No	Factor	What (What happened?)	Why (Why is improvement necessary?)	Where (Where should the improvement be made?)	When (When should the improvement be made?)	Who (Who will implement the improvement?)	How (How will the improvement be made?)
	rotation checks						with the company's SOP
3	No markings on the nozzle	Yarn coming out of the cones spool	To ensure the production process follows the established work procedures	Open-end machine	To be done during production preparation	Mechanic	Mark the nozzle with a dot: one dot for small nozzles, two dots for large nozzles
4	Poor composition	Yarn coming out of the cones spool	o ensure the production process follows the established work procedures	Blowing machine	To be done during the production process	Operator	Create a MEMO regarding the use of a measuring tool to measure the composition of raw materials for TRC 1 yarn
5	Poor composition	Nep adheres to the yarn	To ensure the production process follows the established work procedures	Blowing machine	To be done during the production process	Operator	Create a MEMO regarding the use of a measuring tool to measure the composition of raw materials for TRC 1 yarn

Below are the detailed corrective actions for each root cause of the defects leading to reject types :

a. Design of a measuring tool for measuring the raw material composition of TRC 1 yarn, as shown below:

Figure 6. Raw Material Composition Measuring Tool

b. Creation of a memo regarding periodic machine rotation checks, as shown below. This memo will be posted at several locations on the open-end machine, where it is easily visible to operators, and will be presented during each briefing before production begins.

MEMO
For All Open End Machine Operators BD Yarn Division ***Untuk Semua Operator Mesin Open End BD Divisi Benang***
Note the rotation of the open end BD engine every 30 minutes at regular intervals since BD open end machine started production according to the machine rotation speed table ***Perhatikan putaran mesin open end BD setiap 30 menit secara berkala sejak mesin open end BD mulai produksi sesuai dengan tabel kecepatan putaran mesin***
If the BD open end engine rev decreases, call the Mechanic immediately! ***Jika putaran mesin open end BD menurun, segera panggil Mekanik!***
Prioritize Occupational Safety and Health ***Utamakan Keselamatan dan Kesehatan Kerja***

Figure 7. Memo for Periodic Open-End Machine Rotation Check in "bahasa"

c. Modification of the small and large nozzle design by adding dot markings for the larger nozzles to prevent operators from mistakenly choosing the wrong nozzle. The design modification is shown in the image below.

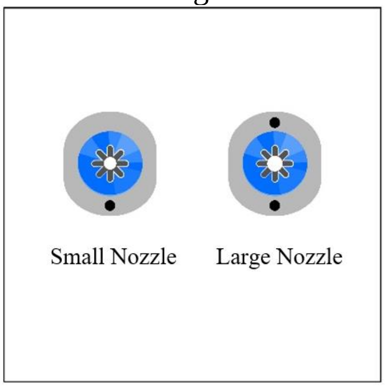


Figure 8. Design Modification of Small and Large Nozzles

d. Creation of a memo regarding the use of a measuring tool to measure the raw material composition of TRC 1 yarn, which will be posted in the blowing machine area. This is to ensure that operators consistently follow the procedures.

MEMO
For All Opener and Blowing Machine Operators ***Untuk Semua Operator Mesin Opener dan Blowing***
Use a measuring tool to measure the composition of TRC 1 yarn raw materials with a measurement of 70% TC Cotton and 30% Polyester material ***Gunakan alat ukur untuk menakar komposisi bahan baku benang TRC 1 dengan takaran bahan TC Cotton 70% dan bahan Polyester 30%***
Prioritize Occupational Safety and Health ***Utamakan Keselamatan dan Kesehatan Kerja***

Figure 9. Memo for the Use of Measuring Tool

The improvement recommendations were then implemented at the company for approximately 4 months and yielded fairly satisfactory results, with the average reject rate decreasing to 3.24%. However, it is necessary to conduct a further review and control over the applied improvements to achieve the reject target set by the company, which is 1%.

The findings of this study indicate that the implementation of Six Sigma DMAIC methodology resulted in a reduction of the defect rate from 4.1% to 3.24% within a four-month period, although the result remains above the company's target of 1%. This aligns with prior studies that demonstrate the effectiveness of Six Sigma in reducing defect rates and improving process capability in manufacturing settings.

For instance, Hussein et al. [9] applied DMAIC in yarn manufacturing and achieved a significant reduction in spinning defects, attributing their success to improved monitoring of machine calibration and operator discipline. Similarly, Jiménez-Delgado et al. [8] reported enhanced productivity and quality in textile operations by integrating DMAIC with visual control tools.

Compared to those studies, the present research adds a unique emphasis on the raw material blending stage and absence of standard operating procedures, which were not explicitly addressed in prior literature. Moreover, this study provides a focused application of Six Sigma in the upstream process of glove manufacturing, highlighting the direct link between yarn input quality and downstream production efficiency—an area that remains underexplored in current textile-related Six Sigma research.

CONCLUSION

The TRC 1 product is one of the products with the highest reject rate from the Yarn Division at PT. SA. Based on the research conducted, several conclusions can be drawn as follows:

1. The average reject rate over the past year is 4.1%, with the highest defect type being insufficient yarn strength, followed by fuzzy yarn (mbelubut), and lastly, nep defects.
2. The cause of the insufficient yarn strength defect is the absence of a measuring tool for accurately measuring the raw material composition and the lack of a standard operating procedure (SOP) for periodic open-end BD machine checks. The fuzzy yarn (mbelubut) defect occurs due to the lack of markings on the nozzle, which causes operators to frequently select the wrong nozzle, and also due to poor raw material composition. Lastly, the nep defect is caused by poor raw material composition.
3. To minimize the number of defects occurring in the TRC 1 yarn production process, several improvement suggestions were made using the 5W1H method. These include: Creating a measuring tool to accurately measure the raw material composition; The second recommendation is to create a memo to be placed on the door of the open-end BD machine, so that operators will always see and pay attention to the memo; The third recommendation is to mark the nozzle with a dot, ensuring that the mechanic installs the correct nozzle; The fourth and final recommendation is to create a memo regarding the use of the measuring tool to measure the raw material composition of TRC 1 yarn.

The implementation of the improvement recommendations over a period of 4 months showed positive results, with the average reject rate decreasing to 3.24%. However, this result is still above the company's target standard of 1%. Therefore, a review of the proposed recommendations is necessary, along with a control process to ensure the effective application of these recommendations.

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