Quality Control Analysis For Reducing Defects In Rayon Ne 30 Yarn Using Six Sigma Dmaic

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Abstract

Background : The textile industry is required to consistently produce high-quality products to maintain competitiveness in an increasingly competitive global market. One of the major quality challenges in spinning industries is the occurrence of product defects that reduce production efficiency and increase manufacturing costs

Purpose : This study aimed to analyze the quality control performance of Rayon Ne 30 yarn production at PT. X using the Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) methodology.

Methodology : A quantitative descriptive approach was employed using historical production and quality control data collected from January to April 2026. Data were analyzed through Critical to Quality (CTQ) identification, Pareto analysis, Defects Per Million Opportunities (DPMO), Sigma capability measurement, Statistical Process Control (SPC) using P-chart, Fishbone analysis, and Five Whys analysis to identify dominant root causes.

Findings : The results indicated that the production process experienced fluctuating defect levels throughout the observation period, with the highest defect rate occurring in April. Crossing was identified as the dominant defect, followed by Ring and Loose Winding, collectively contributing approximately 85% of total production defects.

Implications : Process capability analysis showed that the production process had not yet achieved the Six Sigma performance target, while SPC analysis indicated the presence of process variation requiring further investigation. Root cause analysis revealed that machine setting instability, inadequate preventive maintenance, inconsistent operating methods, and operator-related factors were the primary contributors to defect occurrence.

Originality : Based on these findings, several improvement strategies were proposed, including preventive maintenance scheduling, machine calibration standardization, operator competency improvement, and standardized operating procedures. Since the proposed improvements were not implemented during the study period, their effectiveness could not be statistically validated. Future studies are recommended to conduct industrial implementation and long-term monitoring to evaluate the impact of the proposed improvements on process capability and defect reduction.

Keywords: *Six Sigma, DMAIC, Statistical Process Control, Rayon Yarn, Quality Control, Textile Industry*

INTRODUCTION

The textile industry has undergone a significant technological transformation over the past decade, compelling manufacturers to enhance quality performance while maintaining production efficiency (Sharma & Singh, 2023). In the era of globalization, industrial competition has intensified, requiring manufacturing firms to improve product quality to sustain market competitiveness. High product quality contributes to production efficiency, cost reduction, and market sustainability (Evans & Lindsay, 2010). In the spinning industry, yarn defects remain a primary quality issue due to

their direct impact on subsequent production processes and the final quality of the fabric. Product quality has also emerged as a critical factor influencing customer satisfaction and corporate sustainability (Forno et al., 2023).

The production of rayon yarn specifically Rayon Ne 30 demands high precision regarding machine settings, raw material consistency, and operator performance to ensure product conformity. However, under actual production conditions, defects such as crossing, ring, loose winding, and excess material frequently occur, contributing to production inefficiencies. According to Oakland (2014), manufacturing defects often stem from variations in machine conditions, methods, and human factors. Revenue growth is driven by increased sales of high-value, quality products. Conversely, defective products in the yarn spinning process can escalate operational costs and waste generation while undermining supply chain reliability (Cate, 2025). PT. X is a textile manufacturing company specializing in the spinning of various yarn types, including cotton, non-cotton, and blended yarns. A major challenge facing the company is the occurrence of defects in Rayon Ne 30 yarn that exceed established tolerance standards. Despite the implementation of quality control measures, fluctuations in defect rates persist, indicating process instability. This situation suggests that the current quality control system is not yet fully effective in preventing recurring defects. This issue has a negative impact on productivity and operational efficiency.

Several previous studies have applied quality improvement methods within the textile industry. Six Sigma is a quality management approach aimed at reducing process variation and defects to achieve near-perfect production performance (Gaspersz, 2007) Prior research indicates that Six Sigma has proven to be an effective quality improvement strategy in textile manufacturing. Heny at al. (2019) found that implementing Six Sigma reduced defect rates by 32% in the spinning industry. Similar findings were reported by Ngọc et al. (2026), demonstrating that Pareto analysis and fishbone diagrams are highly effective in identifying dominant defects in woven textile products. Furthermore, Gubencu et al. (2025) highlighted that integrating Statistical Process Control (SPC) with Six Sigma significantly enhances production stability. Internationally, Ahmmed, et al. (2026) showed that Six Sigma reduced process variation by 27% in synthetic yarn production, while Hamzah et al. (2025) emphasized its effectiveness in optimizing machine reliability and reducing downtime.

Based on existing literature, few studies have specifically examined defects in Rayon Ne 30 yarn using an integrated Six Sigma framework supported by textile testing standards. Therefore, this study addresses that gap by comprehensively applying the DMAIC method to enhance yarn quality performance. Through the DMAIC methodology, companies can systematically identify, measure, analyze, improve, and control quality-related issues. This study aims to analyze the application of quality control in the production of Rayon Ne 30 yarn using Six Sigma and identify the main factors causing product defects. This study contributes a more comprehensive defect evaluation framework by integrating monthly defect fluctuation analysis, sigma capability measurement, and Fishbone 7M analysis specifically for Rayon Ne 30 yarn production. The practical application of Six Sigma in textile yarn manufacturing, particularly in improving process capabilities and reducing defect rates.

METHODOLOGY

This study employed a quantitative descriptive research design to analyze quality control in Rayon Ne 30 yarn production at PT. X, Bandung, Indonesia. The research was conducted from January to April 2026. The object of this study was the production process and defect occurrence in Rayon Ne 30 yarn products. The research aimed to identify the dominant defect types, measure the defect level, analyze root causes, and propose improvement strategies using the Six Sigma approach. To ensure data reliability, defect records were cross-checked with production supervisors and quality control documentation.

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A. Research Design

This study employed a quantitative descriptive research design to evaluate the quality performance of Rayon Ne 30 yarn production at PT. X using the Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) methodology. The research focused on identifying production defects, measuring process capability, analyzing dominant root causes, proposing quality improvement strategies, and developing a sustainable quality control plan. The DMAIC framework was selected because it provides a systematic and data-driven approach for continuous quality improvement in manufacturing industries (Gaspersz, 2007).

B. Data Collection Techniques

The data used in this study were collected through the following methods:

1. Literature Study
   Literature study was conducted by reviewing books, scientific journals, previous research, and relevant online sources related to quality control, Six Sigma, and textile defect analysis. This method provided theoretical foundations for the research.
2. Observation
   Direct observations were carried out in the production area to understand the yarn manufacturing process, identify defect occurrences, and observe machine conditions, operator performance, and production flow.
3. Interviews
   Semi-structured interviews were conducted with production supervisors, machine operators, and quality control staff to obtain detailed information regarding production problems, defect causes, and current control systems.
4. Production Defect Documentation
   Secondary data in the form of production reports and defect records during the January–April 2026 period were collected. These documents included total production output, defect quantity, and classification of defect types.

C. Data Analysis Method

1. Research Site and Data Collection

The research was conducted at PT. X, a textile manufacturing company producing Rayon Ne 30 yarn. Historical production data were collected from January to April 2026. Both primary and secondary data were utilized.

Primary data were obtained through direct observations of the spinning process and interviews with production supervisors, quality control personnel, and machine operators to understand production practices and identify factors contributing to product defects.

Secondary data consisted of production reports, quality inspection records, defect reports, machine maintenance documentation, and company quality control records. These documents were used to calculate production performance indicators, determine defect characteristics, and evaluate process capability throughout the observation period.

2. Data Analysis Using the Six Sigma DMAIC Framework

Quality improvement was conducted using the DMAIC (Define–Measure–Analyze–Improve–Control) methodology. Each phase was designed to systematically identify production problems, evaluate process performance, determine dominant root causes, formulate improvement strategies, and establish a sustainable quality control framework.

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a. Define Phase

The Define phase aimed to identify the primary quality problems occurring during Rayon Ne 30 yarn production. Production records and defect data were initially analyzed to determine the baseline quality performance of the manufacturing process. Subsequently, Critical to Quality (CTQ) characteristics were identified by classifying all defect types according to their occurrence frequency.

To determine improvement priorities, Pareto Analysis was performed based on the Pareto principle (80/20 rule), which assumes that a relatively small number of defect categories contribute to the majority of quality problems (Juran, 1999). The outputs of this phase included the identification of dominant defect categories, CTQ characteristics, and improvement priorities for subsequent analysis.

b. Measure Phase

The Measure phase evaluated the capability and stability of the production process using quantitative quality indicators.

First, the production defect rate was calculated from weekly production records. Process capability was then evaluated using Defects per Million Opportunities (DPMO) and Sigma Level, which are widely applied indicators in Six Sigma methodology for measuring manufacturing performance (Rahman, 2013). To evaluate process stability, Statistical Process Control (SPC) was applied using a P-chart, which is suitable for monitoring the proportion of defective products in attribute data. The statistical parameters were calculated as follows:

- Defect proportion (p)
- Center Line (CL)
- Upper Control Limit (UCL)
- Lower Control Limit (LCL)

Each observation point was interpreted to determine whether process variation originated from common-cause variation or special-cause variation, thereby identifying whether corrective action was required. The outputs of this phase included defect rate, DPMO, Sigma Level, P-chart, and statistical interpretation of process stability.

c. Analyze Phase

The Analyze phase focused on identifying the dominant causes responsible for production defects. The analysis began by interpreting the results of the Pareto Analysis to determine the most significant defect categories. Subsequently, a Fishbone Diagram (Ishikawa Diagram) was developed to classify potential root causes into seven categories (7M): Man, Machine, Method, Material, Measurement, Management, and Mother Nature (Environment). To strengthen the qualitative findings, Five Whys Analysis was conducted based on observations, production documentation, and interviews with production personnel. This approach enabled deeper exploration of the underlying causes of each dominant defect. Finally, the consistency among Pareto Analysis, Fishbone Diagram, and Five Whys Analysis was used to verify the most probable dominant root causes affecting Rayon Ne 30 yarn quality.

d. Improve Phase

Based on the verified root causes, several improvement strategies were developed to reduce production defects and improve process capability. The proposed improvements focused on machine performance, operator competency, production methods, preventive maintenance, standard operating procedures, and process monitoring. Each recommendation was formulated by considering the actual production conditions at PT. X and supported by quality management literature related to Six Sigma implementation. Because this study was conducted using historical production data, the proposed improvements were not implemented during the research period. Consequently, the effectiveness of the recommendations could not be statistically evaluated through before-and-after comparisons of defect

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rates, DPMO, or Sigma Level.

e. Control Phase

The Control phase aimed to establish a sustainable quality management framework capable of maintaining future process improvements. A proposed control plan was developed consisting of routine quality inspections, preventive maintenance scheduling, standardized machine setting procedures, operator performance monitoring, Statistical Process Control implementation, documentation of production quality, and periodic management evaluation. These control activities were designed as preventive measures to minimize process variation and support continuous quality improvement. However, since industrial implementation was beyond the scope of this study, the proposed control plan remains conceptual and requires validation in future research.

D. Research Flow

The research procedure can be summarized as follows:

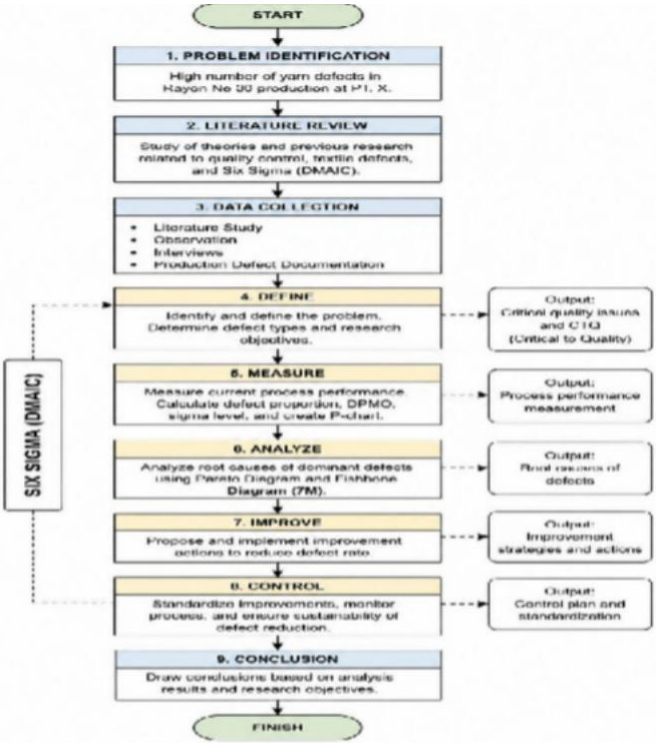


Figure 1. Research Flowchart

This research framework was designed to systematically identify production quality problems and provide effective recommendations for defect reduction and process improvement. The methodology ensures that the analysis is data-driven and aligned with industrial quality management standards.

RESULT AND DISCUSSION

1. Production Defect Overview

The results of this study indicate that PT. X experienced fluctuations in the number of defects in Rayon Ne 30 yarn production during the observation period from January to April 2026. Based on production records, the total number of defects varied each month, showing inconsistency in the production quality process (Table 1).

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Table 1. Monthly Production Defect Data

Month	Total Production (kg)	Total Defect (kg)	Defect Percentage (%)
January	18,450	142	0.77
February	17,980	128	0.71
March	19,200	87	0.45
April	18,760	212	1.13
Total	**74,390**	**569**	**0.76**

The production data revealed that the highest defect percentage occurred in April, reaching 1.13%, while the lowest defect percentage was found in March, at 0.45%. Although the defect level remained below the company's tolerance limit of 2%, the variation indicated instability in process performance and potential inefficiencies in quality control.

This fluctuation suggests that production quality was influenced by several internal factors such as machine conditions, operator performance, and material consistency. Therefore, further analysis using the Six Sigma DMAIC method was necessary to identify the critical defects and their root causes. Defect fluctuation in Rayon Ne 30 yarn production from January to April 2026 shown in Figure 2

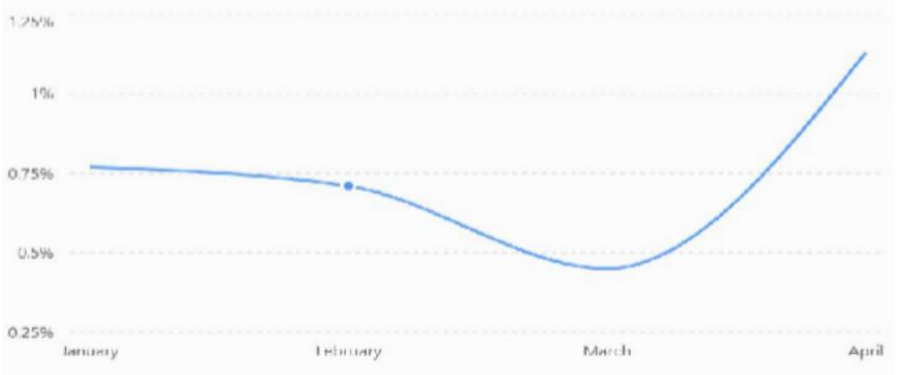


Figure 2. Monthly Defect Trend

Figure 2 show fluctuations in defect percentage over four months. The lowest defect occurred in March (0.45%), indicating better production stability, while April showed the highest defect rate (1.13%), suggesting process disturbance. The sharp increase in April may indicate machine wear, unstable raw materials, or operator inconsistency. The defect fluctuation pattern indicates that the production process still contains assignable variations, which require immediate corrective action to improve process stability.

This finding is consistent with Widyanto (2020), who found that textile defect fluctuations are strongly related to machine maintenance frequency and operator skill variability. However, unlike previous studies focusing only on defect percentage, this study integrates fluctuation analysis with Six Sigma capability measurement, which strengthens its novelty.

2. Define Phase

Following the identification of production quality performance, the next step in the Define phase was to determine the Critical to Quality (CTQ) characteristics. CTQs represent the defect categories that contribute most significantly to overall quality deterioration and therefore become the primary focus of process improvement. The distribution of defect types is summarized in Table 2. Among the six identified defect categories, Crossing was the most dominant, contributing

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approximately 50% of total defects. This was followed by Ring (20%) and Loose Winding (15%). Collectively, these three defect categories accounted for approximately 85% of all production defects, indicating that improvement efforts should primarily target these defects to achieve the greatest reduction in overall defect rates.

Table 2. Critical to Quality (CTQ) Identification

Rank	Defect Type	Frequency (Cone)	Percentage (%)	Cumulative (%)	Priority
1	Crossing	1,252	50	50	Critical
2	Ring	501	20	70	Critical
3	Loose Winding (Gembos)	376	15	85	Critical
4	Overslah	200	8	93	Major
5	Rebond	100	4	97	Minor
6	Dirty	76	3	100	Minor
Total		**2,505**	**100**		

Source: Defect classification records of PT. X, January–April 2026.

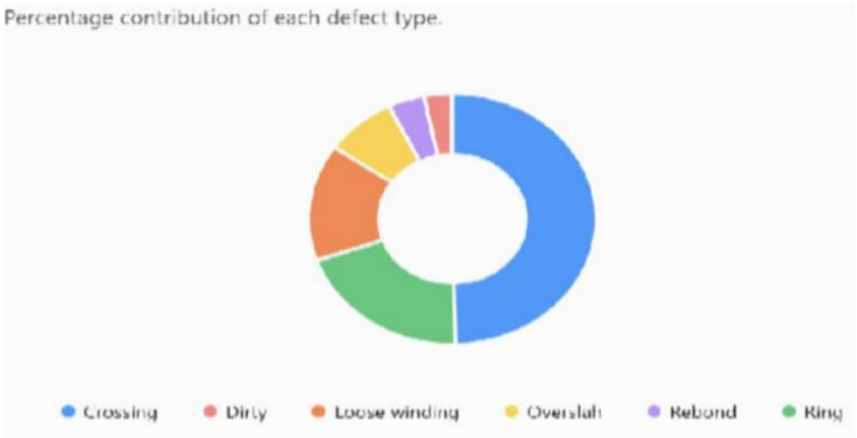


Figure 3. Defect Distribution

The predominance of Crossing defects indicates that winding quality remains the principal challenge in Rayon Ne 30 yarn production. Similar observations have been reported in textile manufacturing studies, where unstable machine settings, improper yarn tension, and inconsistent operating procedures were identified as major contributors to yarn defects. Consequently, improvement initiatives should prioritize the reduction of Crossing, Ring, and Loose Winding defects before addressing less significant defect categories. The CTQ analysis also provides the foundation for subsequent Six Sigma stages. Since these three defect types account for approximately 85% of all observed defects, they were selected as the primary focus for the Measure Phase, where process capability will be evaluated using DPMO, Sigma Level, and Statistical Process Control (SPC).

3. Measure Phase

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The Measure phase was conducted to quantitatively evaluate the stability and capability of the Rayon Ne 30 yarn production process. This phase employed Statistical Process Control (SPC), Defects per Million Opportunities (DPMO), and Sigma Level analysis to determine whether the existing manufacturing process satisfied the required quality standards. The results obtained in this phase provide the quantitative baseline for identifying the root causes of production defects during the Analyze phase.

A. Statistical Process Control (P-Chart Analysis)

Statistical Process Control (SPC) was applied to evaluate the consistency of the production process using a P-chart because the weekly production quantities varied throughout the observation period. During January–April 2026, PT. X produced 340,453 cones of Rayon Ne 30 yarn with 2,946 defective products, of which 2,505 defects belonged to the three Critical to Quality (CTQ) characteristics identified in the Define phase. The average defect proportion (Center Line) was calculated as follows:

$$CL = 0.007358$$

The Upper Control Limit (UCL) and Lower Control Limit (LCL) for each observation period were calculated using:

$$UCL = CL + 3\sqrt{\frac{CL(1-CL)}{n}}$$

$$LCL = CL - 3\sqrt{\frac{CL(1-CL)}{n}}$$

where n represents the production quantity of each observation period. Because the sample size varied weekly, the control limits were also different for each observation.

For example, for January – Week 1 (n = 18,717):

$$UCL = 0.007358 + 3\sqrt{\frac{0.007358(1-0.007358)}{18{,}717}}$$

$$LCL = 0.007358 - 3\sqrt{\frac{0.007358(1-0.007358)}{18{,}717}} = 0.014664$$

Likewise, the calculated control limits for the remaining observation periods were:

- February – Week 1: UCL = 0.017129, LCL = −0.002414
- March – Week 3: UCL = 0.017038, LCL = −0.002322
- April – Week 1: UCL = 0.018614, LCL = −0.003898

Table 3. Statistical Process Control Parameters

Observation Period	Sample Size (n)	CL	UCL	LCL
January – Week 1	18,717	0.007358	0.014664	0.000052
February – Week 1	7,827	0.007358	0.017129	0.000000*
March – Week 3	8,047	0.007358	0.017038	0.000000*
April – Week 1	5,119	0.007358	0.018614	0.000000*

Negative Lower Control Limit (LCL) values were adjusted to zero because the proportion of defective products cannot be negative.

The calculated control limits varied according to the production volume in each observation period. Smaller production quantities produced wider control limits, whereas larger production quantities generated narrower control limits. This characteristic is consistent with the application of P-charts for attribute data with unequal sample sizes. Consequently, each weekly observation was evaluated against its corresponding control limits rather than a single constant limit.

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Table 4. Weekly P-Chart Calculation of Rayon Ne 30 Yarn Production

Week	Production (n)	Defects (np)	Proportion (P)	UCL	CL	LCL	Process Status
1	18,717	195	0.010418	0.014664	0.007358	0.000052	In Control
2	15,571	139	0.008927	0.015127	0.007358	-0.000412	In Control
3	13,008	63	0.004843	0.015605	0.007358	-0.000890	In Control
4	18,442	63	0.003416	0.014701	0.007358	0.000014	In Control
5	4,335	12	0.002768	0.019255	0.007358	-0.004539	In Control
6	7,827	12	0.001533	0.017129	0.007358	-0.002414	In Control
7	18,025	89	0.004938	0.014756	0.007358	-0.000041	In Control
8	19,160	108	0.005637	0.014607	0.007358	0.000108	In Control
9	13,583	36	0.002650	0.015486	0.007358	-0.000770	In Control
10	406	4	0.009852	0.033560	0.007358	-0.018844	In Control
11	0	0	0.000000	0.000000	0.007358	0.000000	No Production
12	0	0	0.000000	0.000000	0.007358	0.000000	No Production
13	8,047	16	0.001988	0.017038	0.007358	-0.002322	In Control
14	22,612	117	0.005174	0.014219	0.007358	0.000497	In Control
15	14,256	37	0.002595	0.015358	0.007358	-0.000642	In Control
16	5,119	100	0.019535	0.018614	0.007358	-0.003898	Out of Control
17	38,684	743	0.019207	0.013086	0.007358	0.001629	Out of Control
18	41,722	479	0.011481	0.012951	0.007358	0.001764	In Control
19	45,180	107	0.002368	0.012798	0.007358	0.001918	In Control
20	35,759	185	0.005174	0.013245	0.007358	0.001471	In Control

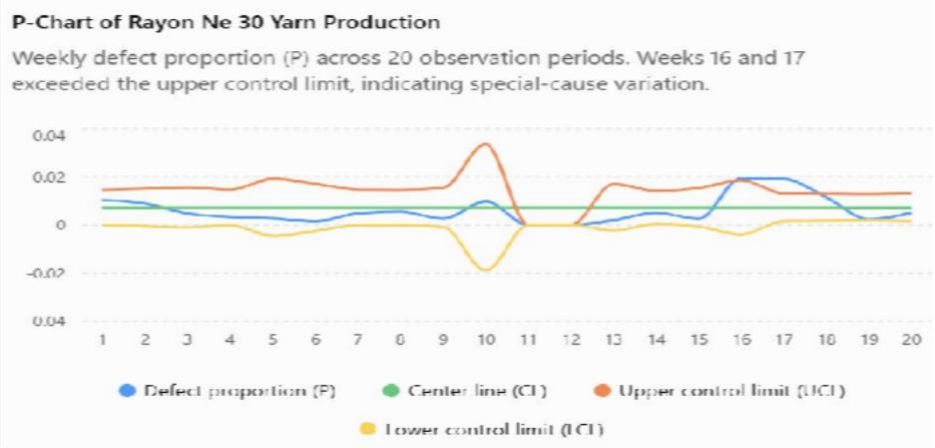


Figure 4. P-Chart of Rayon Ne 30 Yarn Production

As presented in Table 4 and Figure 4, the defect proportion fluctuated throughout the twenty observation periods. Most observations remained within the control limits, indicating that the Rayon Ne 30 yarn production process was generally under statistical control. However, Weeks 16 and 17 exceeded their respective Upper Control Limits (UCL), demonstrating the occurrence of special-cause variation. According to SPC principles, observations above the UCL indicate abnormal process conditions that require immediate investigation and corrective action. The original production records attribute these abnormal conditions to machine deterioration, unstable machine settings, prolonged machine operation, operator fatigue, reduced concentration, and inadequate work discipline. These findings indicate that both technical and human factors simultaneously contributed to process instability

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during the production period.

B. Defects per Million Opportunities (DPMO)

Following the Statistical Process Control analysis, the production process capability was evaluated using the Defects per Million Opportunities (DPMO) metric. DPMO is one of the primary performance indicators in the Six Sigma methodology because it standardizes defect measurements regardless of production volume and enables comparison with international manufacturing performance benchmarks. The DPMO value was calculated using the following equation:

$$DPMO = 1{,}275$$

The calculation result indicates that approximately 1,275 defects would occur for every one million production opportunities under similar production conditions.

Table 5. Defects per Million Opportunities (DPMO) Calculation

Parameter	Value
Total Production (Units)	340,453 cones
Total Defective Products	2,946 cones
Critical to Quality (CTQ) Opportunities	6
Defects per Million Opportunities (DPMO)	1,275

The DPMO value of 1,275 indicates that approximately 1,275 defective products are expected in every one million production opportunities under similar operating conditions. This result demonstrates that the production process has achieved a relatively good level of quality performance compared with many conventional manufacturing systems. Nevertheless, the process has not yet reached the theoretical Six Sigma benchmark of 3.4 defects per million opportunities, indicating that opportunities for further quality improvement still exist. The DPMO findings are also consistent with the Statistical Process Control analysis presented in the previous section.

C. Sigma Level Analysis

The final evaluation performed during the Measure phase was the determination of the Sigma Level, which represents the overall capability of the production process. The Sigma Level was obtained by converting the DPMO value using the standard Motorola Six Sigma conversion table. This indicator provides an overall measure of process capability by considering both defect frequency and production opportunities.

Based on the calculated DPMO value of 1,275, the Rayon Ne 30 yarn production process achieved a Sigma Level of 4.54, indicating that the manufacturing process performed above the average industrial standard but remained below the ideal Six Sigma target.

Table 6. Process Capability Based on Sigma Level

Performance Indicator	Value
DPMO	1,275
Sigma Level	4.54
Process Capability	Good

The Sigma Level of 4.54 indicates that the Rayon Ne 30 yarn production process has achieved a relatively high level of manufacturing capability. In Six Sigma practice, a process operating at approximately 4–5 Sigma generally demonstrates good quality performance with a relatively low defect

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rate. However, this capability remains below the Six Sigma benchmark (6.0 Sigma), which corresponds to only 3.4 defects per million opportunities. The difference between the current Sigma Level and the Six Sigma target suggests that process variation has not yet been fully eliminated. The abnormal observations identified in Weeks 16 and 17 through the P-chart analysis indicate that several special-cause variations continue to affect production consistency. Therefore, identifying the underlying causes of these variations is essential before implementing corrective actions.

4. Analyze Phase

The Analyze phase was conducted to identify the dominant sources of production defects and determine the underlying factors responsible for process variation. Based on the quantitative measurements obtained during the Measure phase, this stage focused on identifying the most significant quality problems before proposing improvement strategies. Two analytical tools were employed: Pareto Analysis to prioritize defect categories and Fishbone (Cause-and-Effect) Analysis to investigate the root causes of the dominant defects.

The Measure phase demonstrated that the production process achieved a DPMO value of 1,275 and a Sigma Level of 4.54, while the P-chart revealed two observation periods (Weeks 16 and 17) that exceeded the Upper Control Limit. These findings indicate that although the overall process capability was relatively good, abnormal process variation still occurred and required further investigation to identify its primary causes. Therefore, the Analyze phase was performed to determine which defect types contributed most significantly to production losses and to explain why these defects continued to occur.

A. Pareto Analysis

Pareto Analysis was conducted to determine the priority of production defects based on their contribution to the total number of defective products. This analysis follows the Pareto Principle (80/20 rule), which states that a small number of defect categories generally account for the majority of quality problems. By identifying these dominant defects, improvement efforts can be concentrated on the factors that provide the greatest potential impact on overall process performance.

The production records identified six categories of defects during the observation period. Their frequency distribution is presented in Table 7.

Table 7. Pareto Analysis of Production Defects

Rank	Defect Type	Frequency	Percentage (%)	Cumulative (%)
1	Crossing	1,473	50	50
2	Ring	590	20	70
3	Loose Winding	442	15	85
4	Overslah	147	5	90
5	Rebond	147	5	95
6	Dirty	147	5	100

As shown in Table 7, the Crossing defect represented 50% of the total production defects, making it the most dominant quality problem encountered during the observation period. The second and third highest defect categories were Ring (20%) and Loose Winding (15%), respectively. Collectively, these three defect types accounted for approximately 85% of all production defects.

This distribution is consistent with the Pareto Principle, which suggests that a limited number of causes contribute disproportionately to overall process losses. Consequently, quality improvement initiatives should prioritize these three dominant defect categories because reducing their occurrence would have the greatest impact on overall process capability.

The Pareto analysis also supports the findings obtained during the Measure phase. The elevated

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defect proportions observed during Weeks 16 and 17 can reasonably be associated with the increased occurrence of these dominant defects, particularly Crossing. Therefore, understanding the operational factors responsible for these three defect categories is essential before proposing improvement strategies.

B. Fishbone Analysis

Although Pareto Analysis successfully identified the dominant defect categories, it does not explain why these defects occurred. Therefore, a Fishbone (Cause-and-Effect) Analysis was performed to investigate the underlying factors contributing to the occurrence of Crossing, Ring, and Loose Winding defects. The analysis adopted the 7M framework, consisting of Manpower, Machine, Method, Material, Media, Motivation, and Money.

Table 8. Root Cause Analysis Based on the 7M Framework

Factor	Root Causes
Manpower	Operator fatigue, insufficient technical skills, inadequate supervision
Machine	Machine wear, unstable machine settings, damaged components
Method	Absence of standardized machine setup procedures
Material	Inconsistent raw material quality
Media	Dust contamination around production machines
Motivation	Low awareness of quality procedures
Money	Limited maintenance budget

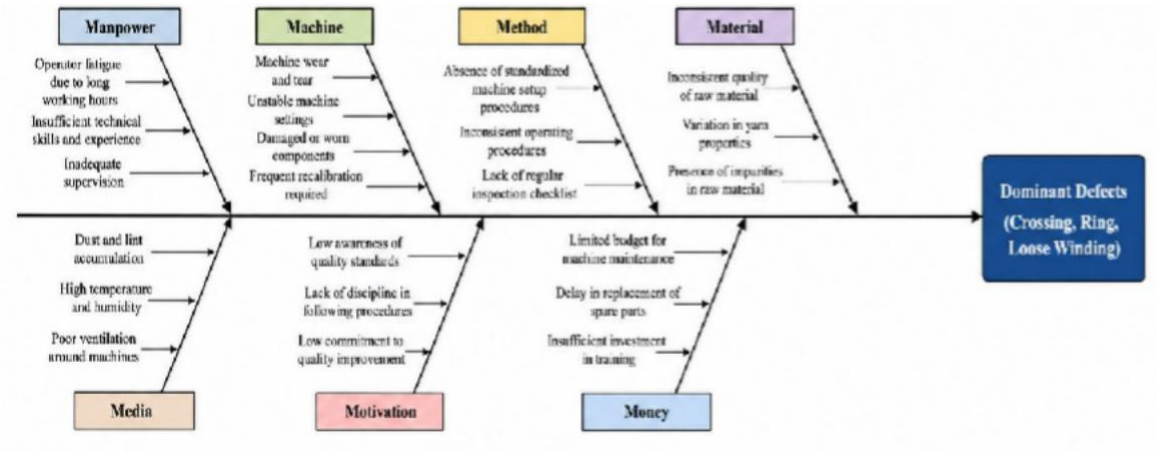


Figure 5. Fishbone Diagram of the Dominant Defects

The Fishbone analysis revealed that the occurrence of Crossing, Ring, and Loose Winding defects was not attributable to a single factor but rather to the interaction of multiple technical and organizational conditions. Among the seven categories, Machine and Manpower emerged as the most influential contributors. Machine-related problems included worn mechanical components, unstable operating settings, and the need for frequent recalibration after prolonged production. These conditions directly affected yarn tension and winding stability, increasing the likelihood of Crossing and Ring defects. In addition, operator fatigue, declining concentration, and inconsistent adherence to production procedures reduced the effectiveness of machine monitoring, allowing process deviations to remain undetected during operation.

Method-related issues, particularly the absence of standardized machine setup procedures, further amplified process variation because operators relied heavily on individual experience rather than documented operating standards. Material inconsistency and dust contamination also contributed to

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production variability, although their influence was less significant than machine and operator factors. Overall, the Analyze phase demonstrates that the dominant production defects originated from the interaction between equipment reliability and human performance rather than from isolated technical failures. These findings provide a logical explanation for the out-of-control observations identified during the Measure phase and establish a clear basis for selecting targeted corrective actions in the Improve phase.

5. Improve Phase

The Improve phase was conducted to formulate corrective actions that directly address the root causes identified during the Analyze phase. Rather than proposing general quality improvement recommendations, the improvement strategies were systematically developed by linking each corrective action to the corresponding root cause identified through the Fishbone analysis. This approach ensures that the proposed actions target the dominant sources of process variation responsible for Crossing, Ring, and Loose Winding defects.

Because the Fishbone analysis identified Machine and Manpower as the primary contributors to process instability, the proposed improvements emphasize equipment reliability, operator competency, process standardization, and production monitoring. These actions are expected to reduce process variation and improve the overall capability of Rayon Ne 30 yarn production.

Table 9. Improvement Plan Based on Root Cause Analysis

Root Cause	Corrective Action	Expected Outcome
Machine wear and unstable machine settings	Establish a preventive maintenance schedule and perform routine machine calibration	Reduced machine instability and fewer Crossing defects
Worn machine components	Replace worn tension-control components according to maintenance standards	Improved yarn tension consistency
Operator fatigue and reduced concentration	Optimize work rotation and provide adequate rest scheduling	Reduced human error during production
Insufficient operator competency	Conduct periodic technical training on machine setting and defect identification	Improved machine adjustment accuracy
Lack of standardized operating procedures	Develop and implement standardized machine setup SOPs	Reduced process variation among operators
Inconsistent raw material quality	Strengthen incoming material inspection procedures	More consistent yarn quality
Dust contamination around machines	Increase workplace cleaning frequency and improve environmental control	Reduced contamination-related defects
Limited maintenance planning	Develop a preventive maintenance checklist and maintenance documentation system	Improved equipment reliability

The proposed improvement plan demonstrates that effective defect reduction requires an integrated approach involving equipment, personnel, methods, and production management. Machine-related improvements are expected to reduce abnormal process variation by maintaining stable operating conditions, while operator-focused improvements address human factors that contribute to incorrect machine settings and delayed responses to production abnormalities.

The introduction of standardized operating procedures is also expected to minimize variability caused by differences in operator experience, thereby improving production consistency. In addition, strengthening preventive maintenance and raw material inspection may reduce the likelihood of recurring defects by preventing process deterioration before defects occur.

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Overall, the proposed improvement strategies emphasize preventive quality management rather than corrective action after defects have already occurred. Such an approach is consistent with the Six Sigma philosophy, which prioritizes defect prevention through systematic process control.

Implementation Priority

To facilitate industrial implementation, the proposed improvement strategies were prioritized according to their expected impact on defect reduction and implementation feasibility.

Table 10. Improvement Priority Matrix

Priority	Improvement Action	Main Objective
High	Preventive maintenance program	Stabilize machine performance
High	Machine calibration standardization	Maintain consistent operating conditions
High	Technical training for operators	Reduce operator-related defects
Medium	Standardized machine setup SOP	Standardize production procedures
Medium	Incoming material inspection	Improve raw material consistency
Medium	Workplace cleaning program	Reduce environmental contamination
Low	Maintenance documentation system	Support continuous monitoring

The priority matrix indicates that actions addressing machine reliability and operator competency should receive immediate attention because these factors were identified as the dominant sources of variation during the Fishbone analysis. Improvements related to standardization and environmental control are recommended as supporting initiatives that enhance long-term process stability.

This phased implementation strategy enables PT. X to allocate improvement resources more efficiently while maximizing the potential reduction in dominant defects. By focusing first on high-impact interventions, the company is expected to achieve measurable improvements in process stability before expanding quality initiatives to other supporting factors.

6. Control Phase

The Control phase was designed to ensure that the proposed improvement strategies can be consistently implemented and sustained over time. The objective of this phase is not only to monitor production performance but also to prevent the recurrence of the dominant defects identified during the previous DMAIC stages. By establishing standardized monitoring procedures and continuous quality evaluation, the production process can maintain improved stability and progressively achieve higher process capability. The control system was developed based on the major improvement priorities identified in the Improve phase, particularly those related to machine reliability, operator performance, process standardization, and quality monitoring.

Table 11. Proposed Quality Control Plan

Control Activity	Frequency	Responsible Personnel	Purpose
Machine inspection	Daily	Maintenance technician	Detect abnormal machine conditions before production
Machine calibration verification	Weekly	Maintenance supervisor	Maintain machine setting consistency
Preventive maintenance	Monthly	Maintenance department	Prevent unexpected machine failure

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Production defect recording	Every shift	Quality Control staff	Monitor defect trends continuously
SPC (P-Chart) evaluation	Weekly	Quality Control engineer	Identify process instability at an early stage
Operator performance evaluation	Monthly	Production supervisor	Improve operator competency
SOP compliance audit	Monthly	Production manager	Ensure standardized production procedures
Quality review meeting	Monthly	Production management	Evaluate quality performance and determine corrective actions

The proposed control plan integrates preventive maintenance, statistical monitoring, and operator evaluation into a unified quality management system. Daily inspections and scheduled preventive maintenance are expected to minimize unexpected equipment failures, while weekly Statistical Process Control (SPC) evaluations enable early detection of abnormal process variation before it develops into significant production losses. Regular operator evaluations and SOP compliance audits further strengthen process consistency by ensuring that production activities follow standardized procedures. Monthly quality review meetings also provide an opportunity for cross-functional communication between production, maintenance, and quality control personnel to evaluate performance trends and determine additional corrective actions when necessary.

CONCLUSION

This study applied the Six Sigma DMAIC methodology to evaluate the quality control performance of Rayon Ne 30 yarn production at PT. X and to identify appropriate strategies for reducing product defects. The systematic implementation of the Define, Measure, Analyze, Improve, and Control phases enabled a comprehensive assessment of process performance, process capability, root causes of defects, and sustainable quality improvement measures.

The Define phase identified Crossing, Ring, and Loose Winding as the dominant defect categories affecting the quality of Rayon Ne 30 yarn. During the Measure phase, Statistical Process Control indicated that the production process was generally stable, although two observation periods exceeded the Upper Control Limit, indicating the presence of special-cause variation. The process achieved a Defects per Million Opportunities (DPMO) value of 1,275 and a Sigma Level of 4.54, demonstrating relatively good process capability while indicating that further improvement is required to approach the Six Sigma benchmark. Pareto analysis further showed that the three dominant defect categories contributed approximately 85% of the total production defects, making them the highest priority for quality improvement.

The Analyze phase demonstrated that the dominant defects were primarily associated with machine instability, operator performance, non-standardized operating procedures, inconsistent raw material quality, and unfavorable production environment conditions. Based on these findings, the Improve phase proposed corrective actions focusing on preventive maintenance, routine machine calibration, operator competency development, standardized operating procedures, strengthened incoming material inspection, and workplace environmental control. The Control phase subsequently established a continuous quality control framework integrating Statistical Process Control, preventive maintenance, periodic quality evaluation, and continuous monitoring to sustain process improvements.

Overall, this research demonstrates that the Six Sigma DMAIC methodology provides an effective and systematic framework for identifying quality problems, prioritizing improvement opportunities, and developing sustainable quality control strategies in textile manufacturing. Beyond improving the quality control of Rayon Ne 30 yarn production, the proposed framework offers practical

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guidance for textile manufacturers seeking to strengthen process capability, reduce process variation, and support continuous improvement initiatives.

AUTHOR'S CONTRIBUTION

Afriani Kusumadewi contributed to the conceptualization of the research, methodology design, data collection, data analysis, and manuscript writing. Susi Maulinawati contributed to research supervision, methodology validation, and manuscript review. Fadil Abdullah contributed to data interpretation, analytical framework development, and final manuscript editing. All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work.

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DECLARATION OF COMPETING INTEREST

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