TEKSTİL VE MÜHENDİS

(Journal of Textiles and Engineer)

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Implementation of Six Sigma in the DMAIC Approach for Quality Improvement in the Knitting Socks Industry

Örgü Çorap Sektöründe Kalite İyileştirme İçin DMAIC Yaklaşımında Altı Sigma Uygulaması

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Online Erişime Açıldığı Tarih (Available online):31 Aralık 2021 (31 December 2021)

Bu makaleye atıf yapmak için (To cite this article):

Hibarkah KURNIA, Choesnul JAQIN, Humiras Hardi PURBA, Indra SETIAWAN (2021): Implementation of Six Sigma in the DMAIC Approach for Quality Improvement in the Knitting Socks Industry, Tekstil ve Mühendis, 28: 124, 269-278.

For online version of the article: https://doi.org/10.7216/1300759920212812403

TMMOB Tekstil Mühendisleri Odası
UCTEA Chamber of Textile Engineers
Tekstil ve Mühendis
Journal of Textiles and Engineer

Yıl (Year) : 2021/4
Cilt (Vol) : 28
Sayı (No) : 124

Araştırma Makalesi / Research Article

IMPLEMENTATION OF SIX SIGMA IN THE DMAIC APPROACH FOR QUALITY IMPROVEMENT IN THE KNITTING SOCKS INDUSTRY

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Gönderilme Tarihi / Received: 04.08.2021
Kabul Tarihi / Accepted: 16.12.2021

ABSTRACT: This study aimed to determine the level of sigma defects of socks and provide suggestions for quality improvements in reducing the percentage of socks defects. The scope of this research is in one of the garment industries with socks produced on the Lonati Single brand Knitting machine, which has decreased production due to production defects that do not meet the target. The methodology used in this study is the Define Measure Analyze Improve Control (DMAIC) approach and implementation of Six Sigma. The results of this study that the level of Sigma before a repair is 3.7017 and after the repair is 3.9614 and proposes that all improvement efforts be included in the Standard Operational Procedure (SOP) to be documented and applied because the percentage of socks defects decreased from 11.08% to 5.54%.

Keywords: DMAIC, Knitting Socks, Six Sigma, Quality Improvement

ÖRGÜ ÇORAP SEKTÖRÜNDE KALİTE İYİLEŞTİRME İÇİN DMAIC YAKLAŞIMINDA ALTI SİGMA UYGULAMASI

ÖZET: Bu çalışma, çorapların sigma kusurlarının seviyesini belirlemeyi ve çorap kusur yüzdesinin azaltılmasında kalite iyileştirmeleri için önerilerde bulunmayı amaçlamıştır. Bu araştırmanın kapsamı, üretim hatalarının üretim hedeflerinin karşılanamaması problemine neden olduğu, bu sebeple üretimi azalmış olan ve Lonati Single marka örme makinesinde üretilen çorapların yer aldığı hazır giyim sektörlerinden biri üzerinedir. Bu çalışmada kullanılan metodoloji, Define Measure Analyze Improve Control (DMAIC) yaklaşımı ve Altı Sigma'nın uygulanmasıdır. Onarım öncesi Sigma seviyesinin 3.7017 ve onarım sonrasının 3.9614 olduğu bu çalışmanın sonuçları; tüm iyileştirme çabalarının dokümantasyonunun sağlanması ve uygulanabilmesi için Standart Operasyonel Prosedüre (SOP) dahil edilmesini önermektedir çünkü çorap hataları çalışma ile 11.08%' den 5.54%' e düşürülebilmiştir.

Anahtar Kelimeler: DMAIC, Örme Sccs, Altı Sigma, Kalite İyileştirme

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***DOI:** https://doi.org/10.7216/1300759920212812403   www.tekstilvemuhendis.org.tr*

1. INTRODUCTION

In the production process of socks in Indonesia, it should increase the quantity of production and reduce production defects to compete well in the global market. This study discusses how socks products can increase production and reduce defects according to the target. The implementation of Six Sigma with the DMAIC approach has often been used in various industrial sectors, including the knitting socks industry sector. Still, for socks products, there is no literature discussing Six Sigma.

Therefore, the background of this research problem is to analyze the main factors that cause dominant defects in socks, how to improve the chief weaknesses in stocks, and how the DMAIC approach can measure the magnitude of the sigma level. This study aimed to determine the sigma defects of socks and suggest quality improvements in reducing socks defects.

The contribution of this research is to serve as a scientific work that can answer the improvement of the quality of socks, especially the single type, and practice can be used as literature material in similar research. Six Sigma and its application areas are investigated, and as a result of the obtained findings, six sigma applications have been made in the textile industry where the quality is desired to be improved [1]. Continuous quality improvement can be achieved by implementing Failure Models Effects Analyze (FMEA) in automotive SMEs. Then the identified improvement points and their effects were different for individual case companies, but all showed continuous quality improvement. Six Sigma is a customer-driven approach representing the systematic implementation of various statistical methods, tools, and techniques for quality improvement and customer satisfaction [2].

The Six Sigma - DMAIC methodology will be applied to solve the problem. Therefore, the collection center will no longer have economic losses due to impurity discounts [3]. Using Six Sigma and the DMAIC methodology in this home appliances company has reduced the number of defective aluminum parts, significantly affecting customer satisfaction and cost savings [4]. It is expected that we can boost the performance of the traditional boat building industry by implementing Six Sigma [5]. A product is said to be of high quality if the product meets the criteria set by the company and is following the wishes of consumers [6]. Customer complaint management was carried out in a company from the plastics industry by applying the Six Sigma project management methodology [7].

2. LITERATURE REVIEW

The priorities were included in the Quality Function Deployment (QFD) in the voice of the customer, and the quality house was established with the addition of technical requirements [8]. The development of TiO2/SiO/GLYMO based nanocomposite solution by sol-gel method and the improvement of the fastness properties of the garment leathers by using the nanocomposite on leather in the finishing process with lacquer has been investigated [9]. Indoor air quality is an essential factor that affects human health and comfort. Then indoor air contains various pollutant gases such as NO_x, SO_x, CO_x, and volatile organic compounds development of current and future status value flow maps will be completed [10]. The interactions between elements can be identified using the Design of Experiment (DoE) method in the textile [11]. Identify and analyze the quality control process to determine the main factors causing the occurrence of defective products. The method used is Six Sigma and FMEA. With the research results, the Defect value per Million Opportunity (DPMO) obtained is 181.67, and the sigma value is 5.07 [6].

They are improving product quality with the method used in Six Sigma and Fishbone Diagram. With the results of his research, a new set of optimal combinations is applied to the lay carriage to increase the sigma level from 0.7 to 2 and Capability (Cp) from 0.2 to 1.47 [12]. The measurement results obtained that the average sigma level is 3.32, and the sigma level included in Sigma three will cause a 25-40% [13]. The waste weight of defective products is 26.25% and the waiting time for waste is 16.02%, the DPMO value is 2,150, and the sigma value is 4.36 [14].

The DMAIC approach and the DoE method can reduce non-conforming polyester bypass fibers in Indonesia [15]. The results of the research input from the average index value of productivity, material (98.85%), and energy (95.11%) %) [16]. Raw material quality control and process quality control hurt the number of defective products and quality (Cost of Quality). In contrast, the quantity of faulty products positively affects production costs [17]. The research results can increase the sigma level from 3.74 and reduce contamination in the third row resulting in a sigma level of 4.32 [18].

Reducing production costs while improving quality in the garment industry, with the methods used are Six Sigma, Pareto Diagrams, and Fishbone Diagrams with research results before the sigma level improvement is 2.69. After repairs, it increases to 2.80 [19]. Furthermore, it reduces the number of perforated defects in prayer rug products in the garment industry with the method used in Six Sigma with the results of the sigma value after implementing improvements of 3.31 [20]. Cost of Poor Quality (COPQ) is known as the cost of quality, meaning how much cost is incurred due to failure of quality; COPQ also means the cost or price the company must pay when it is not perfect or the costs incurred as a result of wrong or product failure that does not meet customer standards [21]. Statistical Process Control (SPC) is a well-established technique in a context that has recently been used in software production [22]. Lean Six Sigma (LSS) approach is a structured and systematic methodology for improving a process focused on reducing process variance as much as possible, minimizing defects (products/services that fall outside of specifications) by using statistics and problem-solving tools intensively [23].

3. MATERIAL AND METHODS

3.1 Material

Dominant defects in several socks industries in Indonesia generally occur almost the same in all types of knitting machines, especially single knit machines, there has been a problem phenomenon in the knitting process where if the process is not smooth, defects will occur, thus disrupting the resulting production. decrease.

The secondary data population obtained in this study is production data and defect data for a certain period in one of the socks industries in Indonesia. One of these industries is already representative of the other socks industry because machines and making socks are almost identical. The sample in this study is a sample of socks checked by a QC operator, and the results of the inspection results are recorded in a production check sheet and defects. To make a sample of socks, the material is from several color threads consisting of a composition of yarn consisting of 50% cotton, 30% acrylic, 7% polyester, 3% nylon, and 10% spandex**.**

3.2 Methods

According to previous studies, that this defect improvement is very necessary to be able to reduce the dominant defects in the apparel industries, therefore this research needs to use methods in handling it so that the repair of these defects can be directed. From previous research, several industries in terms of defect repair use the Six Sigma method with the DMAIC approach. This study will also measure the level of sigma in ready-to-wear clothing, especially socks because previous studies have not had a sigma level target. Then in the DMAIC cycle, especially in the Improve stage, we will use the Design of Experiment (DoE) tool due to the combination experiment between needle types and variations in yarn.

The methodology used was based on PDCA/DMAIC, with the following stages: Define, Measure, Analyze, Improve, and Control, DMAIC can explore the optimization of the internal process is assumed as a critical factor to be capable of answering to the molds industries [24]. Quality variations exist in product specifications, losses/defects are in the form of unsatisfactory products, poor quality repair problems, sizes too tiny, sizes too large, or other issues [25], in his book quoting back about losses/defects Taguchi. Quality improvement is when the company identifies the problem, creates a repair team, analyses the root cause of the problem, and eliminates it [21].

Kaizen is an organization making it an absolute priority until an emergency problem [26]. Practical methods for reducing costs, improving quality, and fostering continuous improvement in products or processes [27] in Six Sigma. In his book, the Kaizen process of implementation and quality improvement redistributes Hitoshi Yamada. The success of six Sigma depends upon the selection of different tools and techniques at each stage. Furthermore, the tools and techniques selection depends on the type of problem [28].

The Six Sigma program has a five-phase cycle, namely DMAIC for process improvement, becoming increasingly popular in Six Sigma organizations [21]. The DMAIC stage is just a workflow used to determine what the customer wants [29]. The article understudy was developed according to the stages of the DMAIC methodology Figure 1.

3.2.1 Define Stage

3.2.1.1 The COPQ

The data analysis technique in this study by recording all types of quality complaints from customers for one year so that costs are needed for repair and prevention of repeated complaints from customers. As for what is included in the COPQ in the socks industry, namely, return costs from customers, employee rework costs, inspection costs, training costs, and socks defect costs.

However, collect data reports and types of complaints, stockwork in process, warehouse stock, overtime costs, and training costs for two periods (June 2019 ~ May 2020) before improvement and the period (June 2020 ~ May 2021) after improvement which are the source of the problem in the Knitting and input into Microsoft Excel. More details can be seen in Table 1.

3.2.1.2 Pareto Diagram

Pareto is a bar graph that shows problems based on the order of the number of events. The order starts from the number of the issues that occur the most to those that occur the least [30]. The data analysis methods in this study are to take a data report on the check sheet for defects and types of defects filled in by the inspector for 40 lots, then input them into the computer in Microsoft Excel. Next, perform the addition of defects according to the type of defects. Finally, input defect data and kind of defect into Minitab-19 software, then a Pareto Diagram graph will be formed.

3.1.2.3 CTQ

CTQ is a defect problem that significantly affects the production process [12]. As for the steps to determine CTQ, collect production data reports (pairs) and defects (pair) from January 2020~June 2020 on single type knitting machines and input them into Microsoft Excel, as shown in Table 2.

To find out the CTQ of the types of defects that often appear for six months, the next step is to break down the number of defects according to the kind of defect. Furthermore, the types of defects that often appear or critical qualities will be identified in this study.

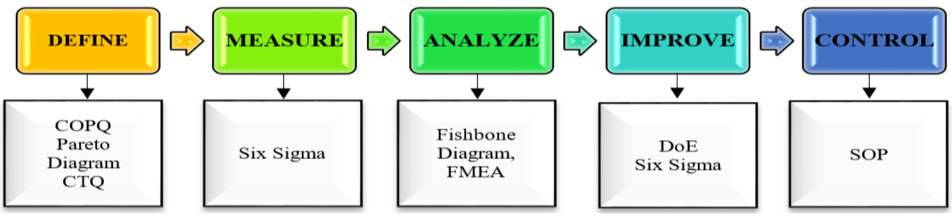


Figure 1. DMAIC Methodology

Table 1. COPQ Metodhology in PT Gunze Socks Indonesia (GSI)

No	Cost of Parameter	Before Improvement (June 2019 ~ May 2020)		After Improvement (June 2020 ~ May 2021)		Charge Cost for
		COPQ (Rp)	COPQ (%)	COPQ (Rp)	COPQ (%)	
1	Inspection					Knitting
2	Defect/scrap					Knitting
3	Rework					Finishing
4	Return					Finishing
5	Training					Knitting
Grand Total						

Table 2. CTQ Research Method

No Column	Month – Year	Production (pair) A	Total defect (pair) B	Defect (%) C
1	Jan-20	production	defect	$\frac{B}{A+B}x100\%$
..	..	..	..	..
6	Jun-20	..	..	..
Grand Total		Total Production	Total Defect	Average Defect

3.2.2 Measure Stage

To determine the sigma level, the research method takes production report data and defects on a single type knitting machine for 40 lots before improvement and then inputs it into Microsoft Excel. Determining the sigma level can use the help of Microsoft Excel and calculation of DPU, DPO, and DPMO with the formula:

a) Defects Per Unit = $\left(\frac{Amound\ Defect}{Amound\ Unit}\right)$ (1)

b) Defects Per Opportunity (DPO) = $\frac{DPU}{CTQ}$ (2)

c) Defect Per Million Opportunities (DPMO) = DPO x 1,000,000 (3)

d) Level Sigma = NORM.S.INV $\left(\frac{(1,000,000 - DPMO)}{1,000,000}\right) + 1,5$ (4)

3.2.3 Analyze Stage

3.2.3.1 Fishbone Diagram

Fishbone is an analysis that is carried out by starting from the consequences or problems that arise and then in a structured way looking for possible causes. In general, six factors can cause deviations in business processes, namely 4M (Material, Method, Machine, Man) and 1E (Environment). In this study, data on the main root causes were obtained from brainstorming meetings with operators and leaders who have expertise in repairing knitting defects.

3.2.3.2 FMEA

This study's FMEA data analysis method is to make a Focus Group Discussion (FGD) at the meeting and determine the failure factors included in the FMEA table. Then, it is continued by assessing the risk priority number (RPN) value of the potential failure mode. Each of the three risk factors is usually assigned a deal on a numerical scale ranging from 1 to 10. After there is a Risk Priority Number (RPN) value with the formula RPN = OxSxD, where Occurrence (O) is the probability, Severity (S) is the seriousness of the failure, and Detection (D) is the ability to detect failure before the impact of the failure effect manifests. The next step is to prioritize the RPN value that has been determined (rating scale). After FMEA analysis, a further in-depth research is carried out using why-why analysis.

3.2.4 Improve Stage

3.2.4.1 DoE

This check phase study analyzed the experimental results between 2 factorials (needle type and yarn hardness variation). This experiment is expected to reduce the hole in the sock product to become a reference in mass production later. Design of Experiment (DoE) is the action applied in the previous step analyzed, before and after comparisons are made to verify if there is improvement and if the set goals are achieved. The data analysis technique in this study used an experimental composition between two factors that were carried out to correct the defects of socks on the Lonati Single machine, namely the needle type factor and the yarn hardness variation factor. These two factors will produce six levels of variation in the experimental combination, resulting in the percentage of defects for each level of interpretation by experimenting with each combination of variables on the same machine resulting in a production sample lot of 25 lots. Perform this experiment with duplicate experiments to ensure that this experiment produces valid data. After getting 12 experimental data, input into the Minitab-19 software, then the optimal parameters will be known.

3.2.4.2 Six Sigma

To determine the sigma level, the research method takes production report data and defects on a single type knitting machine for 40 lots after improvement and then inputs it into

Microsoft Excel. The steps to get the sigma level are the same as before at 3.2.

3.2.5 Control Stage

Standard Operational Procedure (SOP) is the data analysis technique in this research is to document every action before and after the repair into the SOP. In this study, the conditions of the observations or improvements are recorded in SOPs, One Point Lesson (OPL), Work Instructions (WI), and other documents. This is done so that all forms of rules or instructions can be socialized to employees so that new employees will understand the procedures that already exist in the company factors. A suggestion for improvements that can be made to reduce the type of rust defects in the roof panel packaging process is by making an antirust spraying SOP [31].

4. RESULT AND DISCUSSION

In this section, the results of several DMAIC stages will be reported according to the method used. The results of several methods used will be discussed following the stages.

4.1 Define Stage

4.1.1 COPQ

The results of the related COPQ regarding the cost parameters that the Knitting section has issued can be seen in Table 3

Table 3 shows that the knitting section includes inspection fees, scrap costs, and training costs. The results showed that the company spent IDR 4,035,000 for quality before repair and IDR 3,235,000 after repair. So there is a cost reduction for poor quality repairs of IDR 800,000. Meanwhile, the reward and return parameters are the burdens of the finishing section.

4.1.2 Pareto Diagram

The results of the Pareto Diagram before the repair can be seen in Figure 2. It means that the data on the defect of the socks before taking corrective action is the initial data. After restoration, the Pareto diagram can be seen in Figure 3, which means that the socks defect data after repairing.

Based on Figure 2, the most Pareto or dominant defects (red block color) are hole defects of 42.6%. Therefore, these perforated defects must be followed up immediately for improvement.

In Figure 3, it can be seen that the dominant defect before improvement, namely the hole defect in the red beam, becomes the 2nd position after the loosened yarn defect. Disability after repair decreased by 16.7% which means decreased by 139%.

4.1.3 CTQ

To get a CTQ, the data needed is a production report document and a six-month defect report. Testing when determining the type of defect that often appears is more accurate because socks defects vary widely in types defects. The report data documents can be seen in Table 4.

Table 3. COPQ analysis

No	Cost of Parameter	Before Improvement (June 2019 ~ May 2020)		After Improvement (June 2020 ~ May 2021)		Charge Cost for
		COPQ (Rp)	COPQ (%)	COPQ (Rp)	COPQ (%)	
1	Inspection	Rp 1,925,000	46%	Rp 1,075,000	32%	Knitting
2	Defect/scrap	Rp 710,000	17%	Rp 360,000	11%	Knitting
3	Rework	Rp 140,000	3%	Rp 100,000	3%	Finishing
4	Return	-	-	-	-	Finishing
5	Training	Rp 1,400,000	34%	Rp 1,800,000	54%	Knitting
Grand Total		Rp 4,175,000	100%	Rp 3,335,000	100%	

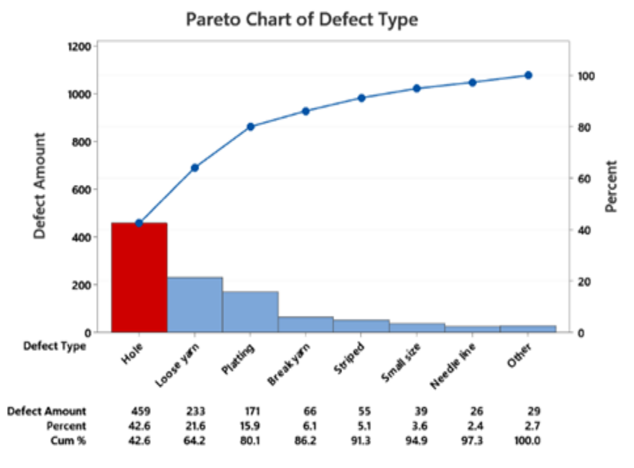


Figure 2. Pareto Diagram of Socks Defect Before Improvement

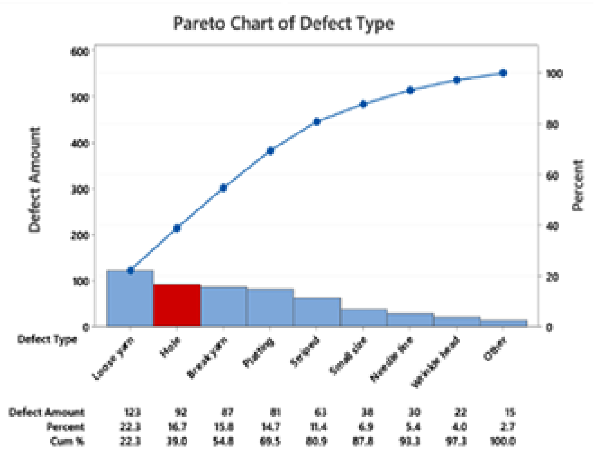


Figure 3. Pareto Diagram of Socks Defect After Improvement

Table 4. Production Report and Defects of Single Socks in Knitting Lonati Machine

No	Month - Year	Production (pair)	Total Defect (pair)	Defect (%)
1	Jan-20	65,370	5,307	7.51%
2	Feb-20	85,110	6,523	7.12%
3	Mar-20	87,152	7,200	7.63%
4	Apr-20	46,596	4,749	9.25%
5	May-20	23,956	2,573	9.70%
6	Jun-20	17,020	1,441	7.81%
Total		325,203	27,793	7.87%

Table 4 shows that the sample taken from January 2020 to June 2020 for 6 months resulted in a total of 27,793 defects with a defect percentage of 7.87%. After getting the total defects, still in the form of quantity defects and the types of socks defects have not been seen, then the next step is to break down the fundamental weaknesses into types of defects. So it will be seen the kinds of imperfections that often appear or are called CTQ. For more details, see Table 5.

Table 5. Types of Defects in Knitting Machine Lonati Single

No	Defect Type	Total Defect (pairs)
1	Hole	10,468
2	Loose yarn	7,737
3	Platting	4,094
4	Break yarn	2,657
5	Striped	1,352
6	Wrinkle head	795
7	Small size	421
8	Needle line	269
Total		27,793

Based on Table 5, it can be concluded that the CTQ in this study amounted to 8 types of defects that often appear. The most dominant CTQ is a hole in the single socks because the Knitting QC inspector will see this defect during a visual inspection of the socks that have just come out of the machine.

4.2 Measure Stage

Before and after repairing the socks defect, the sigma level can be determined by entering all production data and defects in Microsoft Excel software and using formulas 1 to 4 in section 3.2. The results of data processing for Six Sigma can be seen in Table 6.

Table 6 shows that the defect (%) before improvement is 11.08% and after improvement is 5.54% while the target is 7% so that the defect is decreased by 50% and has reached the target. The DPMO results decreased by 50% so that the sigma level increased by 6.50%.

4.3 Analyze Stage

4.3.1 Fishbone Diagram

Based on the results of meetings with operators and leaders using brainstorming and why-why analysis, the main factors causing the root of the problem were obtained. The next step from the results of the Fishbone Diagram is to use Microsoft Visio software, and it will look like Figure 4.

Figure 4 shows that the main causes of perforated defects in machines, methods, and materials. While the root causes consist of: the linking needle does not match, sewing thread hardness varies, clumps of thread in the cutter, and socks go straight to the plate. The report of the four main causes was obtained from brainstorming with a single machine operator.

4.3.2 FMEA

Based on the meeting results in the focus group discussion activity, which consisted of 11 members from the leader level to the president director who had the capacity as an expert judgment in determining FMEA scores. The results can be seen in Table 7.

Table 6. Sigma Level Comparison

Parameter	Unit	Before Improvement	After Improvement	Remark
Total Production	pcs	9,733	9,952	
Total Defect	pcs	1,078	551	
Defect	%	11.08	5.54	Target 7.00%
DPU	unit	0.1108	0.0554	
DPO	opportunity	0.0138	0.0069	
DPMO	PPM	13,845	6,921	
Level Sigma	sigma	3.7017	3.9614	

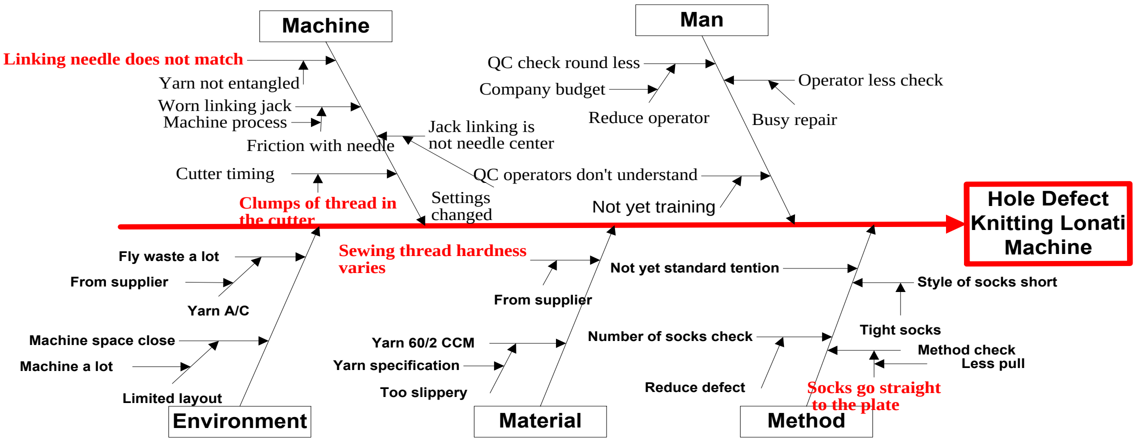


Figure 4. Fishbone Diagram Result

Table 7. FMEA Analysis of Hole Defects

Potential Failure Mode	Sev	Potential Failure Effects	Occ	Potential Cause of Failure	Det	RPN	Rank
The linking needle does not match	9	Hole defects	8	Yarn not entangled	7	504	1
Worn linking jack	6	Machine stop	5	Friction with needle	5	150	5
Cutter timing	8	Production down	6	Clumps of thread in the cutter	8	384	3
Jack linking is not needle center	6	Machine stop	5	Settings changed	4	120	6
QC check round less	4	Delay check	4	Reduce operator	6	96	7
QC operators don't understand	4	Missed defects	4	Lack of training	5	80	8
How to check socks	6	Missed defects	7	Socks go straight to the plate	7	294	4
Sewing thread hardness varies	9	Yarn tension varies	7	From supplier	7	441	2
Machine space close	4	Machine stop	5	Limited layouts	3	60	9

Table 7 is the result of the FMEA showing that four main causative factors result in dominant defects. Therefore, the organization may decide that any RPN above 200 creates an unacceptable risk. In this study, FMEA analysis by an experienced repair team during FGD.

4.4 Improve Stage

4.4.1 DoE

After getting the improvement plan, the next step is to carry out a Design of Experiment (DoE) with a combination of needle types and variations of yarn hardness. The results of data processing using Minitab-19 show that:

- Multilevel Factorial Design: Design Summary

Factors:	2	Replicates:	2
Base runs:	6	Total runs:	12
Base blocks:	1	Total blocks:	2

- Number of levels: 2, 3
- General Factorial Regression: Average Defect versus Blocks, Needle Type, Hardness Yarn.

To find out the factors and variables used can be seen in Table 8.

Table 8. Factor Information

Factor	Levels	Values
Needle Type	2	Old Type, New Type
Hardness Yarn	3	Scale 45, Scale 55, Scale 65

Table 8 shows that the factors used in DoE have 2 factors including needle type and variations in the degree of yarn hardness. While the variables used consisted of 2 variables of needle type and 3 variables of the degree of thread hardness. Below is a calculation using Analysis of Variance(ANOVA) of the factors used and the correlation relationship of the two elements. More details can be seen in Table 9.

Table 9. Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	0.007870	0.001312	159.90	0.000
Blocks	1	0.000000	0.000000	0.04	0.856
Linear	3	0.007865	0.002622	319.62	0.000
Needle Type	1	0.007415	0.007415	903.99	0.000
Hardness Yarn	2	0.000450	0.000225	27.43	0.002
2-Way Interactions	2	0.000004	0.000002	0.25	0.791
Needle Type*Hardness Yarn	2	0.000004	0.000002	0.25	0.791
Error	5	0.000041	0.000008		
Total	11	0.007911			

In Table 9, it is interpreted that individually, each factor is not significant with a P-Value value of 0.000 for the needle type factor and 0.002 for the yarn hardness factor. In contrast, the interaction between the two elements is significant, with a P-Value value of 0.791. Therefore, it can be concluded that the input variable does not significantly affect the response value (percentage of defects). From the above calculations, it can be seen that the model summary determines R sq (adj). More details can be seen in Table 10.

Table 10. Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0028641	99.48%	98.86%	97.01%

Based on Table 10, the result of data is R-Sq(adj) = 98.86%, which means > 65%, the needle type, and hardness yarn contributed 98.86% to the dominant defect repair test results. The results of the percentage of defects after carrying out a series of corrective actions can be seen in Table 11

Table 11 shows that the comparison of improvement defects both before and after. the result is that after the improvement is still within the standard of the predetermined target of 21%.

4.4.2 Six Sigma

After improvements in the socks defect, the sigma level can be determined by entering all production data and defects in Microsoft Excel software and using formulas 1 to 4 in section 3.2. The results of data processing for Six Sigma can be seen in Table 6.

4.5 Control Stage

The SOP is socialized to all employees. The SOP is intended so that the employee can know and make corrective and consistent improvements. This becomes the basis for process control that can improve product quality. The SOP to improve holes in Knitting Lonati Single SbyS Machines can be seen in Table 12.

4.6 Quality Improvement Recommendation

After making improvements by implementing Six Sigma in the DMAIC approach, the recommendations that will be carried out so that the quality of single socks can be maintained and even can be improved are:

a) The use of a new type of linking needle with 2 indentations for all Single Lonati Knitting Machines. This condition may change at any time if there is a new type again, it is necessary to experiment again with the DoE method.

b) Every arrival of Nylon 70/2 denier thread material as sewing thread, it is necessary to carry out a random inspection of the quality of the hardness of the thread. The standard obtained is between hardness 52 - 58, otherwise, the thread may not be used or returned to the supplier.

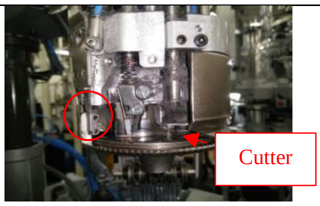
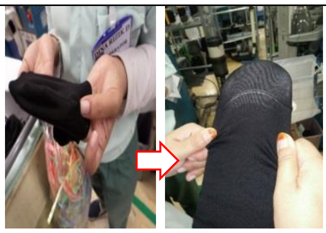
c) For every new item of socks that will be mass-produced, the Intellectuals party will set up the timing cutter according to the type of socks. So that this timing cutter adjusts the cutting time so that there are no holes in the socks.

d) Inspection of the quality of the socks when they come out of the machine is very important because the quality of the socks will be seen visually by the inspector. The standard of visual inspection before entering the plate is that the inspection is carried out by pulling both hands so that the quality of the socks at the end of the sock can be checked, after that it is only checked with the sock plate tool.

Table 11. Comparison of Defect Improvement Results

Parameter	Unit	Before Improvement	After Improvement	Remarks
Production amount	pcs	9,733	9,952	
Defect amount	pcs	1,078	551	
Defect	%	11.08	5.54	Target 7%

Table 12. SOP Handling of Holes in Single Socks

No	Figure of Improvement	Remarks
1		The replacement of the old type of connecting needle (one groove) to the new style (two tracks) is carried out in stages per machine, making sure before installing the hand there is no ugly and dirty. The estimated lifetime of 3 months, PIC is technicians, and supplier from PT Groz Beckert Indonesia.
2		Every arrival of Nylon 70/2 material must be a yarn hardness inspection with a standard scale of 55 (tolerance +/- 3) and check the received Certificate of Analysis (CoA) for yarn hardness test results the supplier for each material arrival lot. The name of the incoming yarn inspection tool is the hardness tester, PIC is QC incoming material, and the supplier is PT Surya Barutama.
3		Every new sock article must have a cutter timing check when changing the thread of each part of the sock, and this is to reduce the remaining lumps of yarn on the cutter, resulting in a hole in the cutter sock. Improved cutter timing data size and PIC is merchandiser (set after the thread is working, cut directly by the cutter).
4		Each QC round, the operator must check the gore line end of the sock by pulling the hose with both hands. This is done because if it goes directly into the acrylic plate, the defect will be challenging to see, especially the gore line/tip of the sock. Do a random check every ten pcs socks. If three pcs are defective, then they must check 100% and vice versa. If only two pcs are wrong, then only random checks.

5. CONCLUSION

Based on the results and discussion in the previous chapter, it has been found that the largest COPQ is in the knitting section (Table 3), and CTQ has 8 types of defects that often appear in the knitting section (Table 4), and the most dominant defect is hollow defects (Figure 2). These findings indicate that the knitting part of the sock process is the part with the most defects so that it needs continuous improvement.

This study also resulted in the number of defects reduced in percentage after making repairs. The improvement effects increase the sigma level by 7% from 3.7017 to 3.9614. At the same time, improvement defects can reduce defects before improvement is 11.08% and after improvement is 5.54%. Sigma level may increase if the DPMO yield decreases and to prove this conclusion can be seen in Table 6.

Other researchers researched the Garment industry which aims to reduce the number of perforated prayer mats. The method used is Six Sigma with the results of the sigma level after repairs of 3.31 [20]. Meanwhile, in this study, the import was carried out using the DMAIC method with Six Sigma, Pareto, Fishbone, DoE, and SOP tools aimed at improving the quality of single-type socks to reduce the number of defects or increase the sigma level. So if you look at previous research, there has never been any research on improving the quality of socks.

Several proposals for improvement of dominant defects include repairing hole imperfections, namely by experimenting with two types of needles combined with experiments with three types of yarn hardness using the DoE method, improving the size of the cutter timing data and before entering the plate, check by hand. The results from DoE find the best variable composition, namely new needle type and hardness yarn scale 55. The needle type and hardness yarn contributed 98.86% to the dominant defect improvement test results, and to prove this conclusion can be seen in Table 10.

The theoretical implications of the results of this study are expected to provide an overview and information about the problem, the causes that occur, provide an alternative to repair defects in socks in detail, and know the prevention of socks defects. The practical implications of the results of this research can be used to reference those interested in researching the same or similar problems. Future research is recommended to improve the production process by integrating lean methods to effectively and efficiently produce.

ACKNOWLEDGMENT

This article was made with moral support and direction from Mercu Buana University, Jakarta, Indonesia, to motivate students and lecturers to have innovative research. Thank you to my friends for masters of industrial engineering class 26, who have provided input and suggestions in completing this article.

REFERENCES

1. M. Karabulut and P. Yildiz Kumru, "Six Sigma Methodology and an Application in the Textile Sector," *Kocaeli J. Sci. Eng.*, vol. 2, no. 1, pp. 7–20, 2019, doi: 10.34088/kojose.453692.
2. J. Ravichandran, "Six Sigma-based X-BAR control chart for continuous quality improvement," *Int. J. Qual. Res.*, vol. 10, no. 2, pp. 257–266, 2016, doi: 10.18421/IJQR10.02-02.
3. A. R. C. Herrera, J. del P. U. Aguirre, and L. L. L. Leyva, "Application of six sigma in improving the quality of recyclable polymer in collection centers," *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, no. July, pp. 1053–1062, 2019.
4. N. G. S. Ahmed, H. S. Abohashima, and M. F. Aly, "Defect reduction using Six Sigma methodology in-home appliance company: A case study," *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, vol. 2018, no. SEP, pp. 1349–1358, 2018.
5. Y. Praharsi, M. A. Jami'in, G. Suhardjito, and H. M. Wee, "Six sigma implementation and analysis-An empirical study of a traditional boat building industry in Indonesia," *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, vol. 0, no. March, pp. 3092–3100, 2020.
6. P. Fithri, "Six Sigma Sebagai Alat Pengendalian Mutu pada Hasil Produksi Kain Mentah PT Unitex, Tbk," *J@ti Undip J. Tek. Ind.*, 2019, doi: 10.14710/jati.14.1.43-52.
7. G. Sisman and F. D. Orel, "Application of six sigma methodology to improve customer complaint management," *Eurasia Proc. Educ. Soc. Sci.*, vol. 19, pp. 1–10, 2020.
8. D. Tatman, "An Application about Analytical Hierarchy Process and Implementation of Quality Function in Bathrobe Product Development," *Tekst. ve Muhendis*, vol. 2020, no. June, pp. 111–122, 2020, doi: 10.7216/1300759920202711905.
9. M. (Koizhaiganova) Kaygusuz, "Improvement of the Fastness Properties of garment Leathers with TiO2/SiO2/Glymo Based Nanocomposite Solution and Lacquer Coating," *Tekst. ve Muhendis*, vol. 24, no. 108, pp. 275–280, 2017, doi: 10.7216/ 1300759920172410807.
10. D. Gazioğlu Rüzgar and Ş. Altun, "Improving Indoor Air Quality with Textile Materials," *Tekst. ve Muhendis*, vol. 23, no. 104, pp. 288–296, 2016, doi: 10.7216/1300759920162310406.
11. A. Yame and A. Ali, "Optimization of Lean Methodologies in the Textile Industry Using Design of Experiments," *World Acad. Sci. Eng. Technol. Int. J. Soc. Behav. Educ. Econ. Bus. Ind. Eng.*, vol. 10, no. 9, pp. 3208–3212, 2019.
12. N. Abbes, C. Ser, and M. Sci, "Application of Six Sigma in Clothing SMEs : A case study Application of Six Sigma in Clothing SMEs : A case study," 2018, doi: 10.1088/1757-899X/460/1/012009.
13. Y. P. Shafira and A. Mansur, "Production quality improvement analysis of grey cambric using Six Sigma Method," *MATEC Web Conf.*, vol. 154, no. 3, pp. 1–14, 2018.
14. F. Nurprihatin, N. E. Yulita, and D. Caesaron, "Usulan Pengurangan Pemborosan pada Proses Penjahitan Menggunakan Metode Lean Six Sigma," *Pros. Semin. Nas. Akunt. dan Bisnis*, 2017.
15. O. Syafwiratama, M. Hamsal, and H. H. Purba, "Reducing the nonconforming products by using the six sigma method: A case study of a polyester short cut fiber manufacturing in Indonesia," *Manag. Sci. Lett.*, vol. 7, no. 3, pp. 153–162, 2017, doi: 10.5267/j.msl.2016.12.001.
16. A. Bakar, O. Suprianto, and Y. Yuniati, "Usulan Peningkatan Produktivitas Berdasarkan Metode Mundel dan APC di PT Raffsya Media," *J. Ind. Eng. Manag.*, 2017, doi: 10.33536/jiem.v2i2.147.
17. M. I. S. Sihombing and S. Sumartini, "Pengaruh Pengendalian Kualitas Bahan Baku dan Pengendalian Kualitas Proses Produksi terhadap Kuantitas Produk Cacat dan Dampaknya pada Biaya Kualitas (Cost of Quality)," *J. Ilmu Manaj. dan Bisnis*, 2017, doi: 10.17509/jimb.v8i2.12665.
18. R. D. Adikorley, L. Rothenberg, and A. Guillory, "Lean Six Sigma applications in the textile industry: a case study," *Int. J. Lean Six Sigma*, vol. 8, no. 2, 2017, doi: 10.1108/ijlss-03-2016-0014.
19. D. M. Zaman and N. H. Zerin, "Applying DMAIC Methodology to Reduce Defects of Sewing Section in RMG: A Case Study," *Am. J. Ind. Bus. Manag.*, vol. 07, no. 12, pp. 1320–1329, 2017, doi: 10.4236/ajibm.2017.712093.
20. W. Wardana, A. Harsono, and G. P. Liansari, "Implementasi Perbaikan Kualitas Menggunakan Metode Six Sigma Untuk Mengurangi Jumlah Cacat Produk Sajadah Pada Perusahaan Pt. Pondok Tekstil Kreasindo*," *J. Online Inst. Teknol. Nas. ©Jurusan*, vol. 4, no. 2, pp. 114–123, 2015.
21. M. M. Saxena and K. V. N. Srinivas Rao, *Quality management, total quality management and six sigma*, vol. 8, no. 12. 2019.
22. H. Kurnia and M. Hamsal, "Implementation of statistical process control for quality control cycle in the various industry in Indonesia : Literature review," *Oper. Excell. J. Appl. Ind. Eng.*, vol. 13, no. 2, pp. 194–206, 2021, doi: 10.22441/oe.2021.v13.i2.018.
23. H. Kurnia and H. Hardi Purba, "A Systematic Literature Review of Lean Six Sigma in Various Industries," *J. Eng. Manag. Ind. Syst.*, vol. 9, no. 2, pp. 19–30, 2021, doi: 10.21776.
24. A. M. H. Pereira, M. R. Silva, M. A. G. Domingues, and J. C. Sá, "Lean six sigma approach to improving the production process in the mold industry: A case study," *Qual. Innov. Prosper.*, vol. 23, no. 3, pp. 103–121, 2019, doi: 10.12776/QIP.V23I3.1334.
25. S. Devica, *Quality Sixth Edition Donna*, vol. 7, no. 9. 2015.
26. Á. Medinilla, *Agile Kaizen: Managing continuous improvement far beyond retrospectives*. 2014.
27. N. Radziwill, *Quality Management for Organizations Using Lean Six Sigma Techniques*, vol. 21, no. 3. 2014.
28. M. T. Patel, "Six Sigma in Service Organization – A Critical Review," no. February 2017.
29. C. T. Carroll, *Six Sigma for Powerful Improvement*. 2013.
30. D. et al. Ginn and E. Varner, *The Design for Six Sigma Memory Jogger^{TM}*. Goal/QPC, 2004.
31. I. Setiawan and S. Setiawan, "Defect reduction of roof panel part in the export delivery process using the DMAIC method: a case study," *J. Sist. dan Manaj. Ind.*, vol. 4, no. 2, pp. 108–116, 2020, doi: 10.30656/jsmi.v4i2.2775.