# Quality Improvement with the DMAIC Approach Using the Implementation of Benchmarking and KPI Methods

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## Abstract

The garment industry, especially the knitted socks industry and the like, experienced a decline in production due to defects that did not meet the target. This study aims to determine the leading causes of dominant defects, increase the sigma level, and propose improvements to be included in the KPI method so that the relevant department can control it using the Define Measure Analyze Improve Control (DMAIC) approach. This study found that the dominant factor causing the socks defect was the inappropriate linking needle at 504 RPN, the yarn hardness was varied at 441 RPN, and the thread clumps cutter was 384 RPN, the sock that went straight into the plate was 294 RPN. All causes of the problem are taken corrective action, and as a result, the level of sigma has increased from sigma 3.7017 before improvement to sigma 3.9614 after improvement. To control the sigma level, it is proposed to be included in the Key Performance Indicator (KPI) so that the knitting department can control and be enthusiastic in continuous improvement. Furthermore, this will affect the results of the monthly defect percentage being reduced from 11.08% to 5.54%, with a target of 7% on the Lonati Knitting machine.

## Keywords
Benchmarking, DMAIC, KPI, Quality Improvement, Socks

## 1. Introduction
The production process of socks in Indonesia should increase 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. Implementing Six Sigma with the DMAIC approach has often been used in various industrial sectors, including the garment industry. 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 stockings, and how the DMAIC approach can measure the magnitude of the sigma level.

The Six Sigma - DMAIC methodology will be applied to solve the problem. Therefore, the collection centre will no longer have economic losses due to impurity discounts (Herrera et al., 2019). Using Six Sigma and the DMAIC methodology in this home appliances company has reduced the number of defective aluminium parts, significantly affecting customer satisfaction and cost savings (Ahmed et al., 2018). It is expected that we can boost the performance of the traditional boat building industry by implementing Six Sigma (Praharsi et al., 2020).

The conditions in this study are almost the same as previous studies, meaning that the DMAIC approach can reduce the percentage of defects and increase the level of sigma. The rate of defective products produced is 1.4% exceeding the tolerance limit of 1% with a sigma level of 4.14 which means the possibility of faulty products is 4,033.39 opportunities per million products (Kurniawan & Prestianto, 2020). 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 (Fithri, 2019). The development of current and future status value flow maps will be completed. The interactions between elements can be identified using the Design of Experiment (DoE) method in the textile industry (Yame & Ali, 2019)

### 1.1 Objectives
In this study, the import is carried out using the DMAIC approach with Six Sigma: Benchmarking, Pareto Diagram, Critical to Quality (CTQ), FMEA, 5W+2H, and KPI method. This research aims to determine the leading causes of dominant defects with the Failure Models and Effects Analysis (FMEA) method, increase the sigma level with Six Sigma methods, and propose improvements to be included in the KPI method. This research was conducted on single type socks at the Lonati Knitting machine. This research is at PT Gunze Socks Indonesia (GSI) in the Lippo Cikarang area, Bekasi, West Java, Indonesia.

## 2. Literature Review
The DMAIC approach and the DoE method can reduce non-conforming products in polyester bypass fibres in Indonesia (Syafwiratama et al., 2017). 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 (Fithri, 2019). 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 Cp from 0.2 to 1.47 (Abbes et al., 2018). 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% (Shafira & Mansur, 2018). The waste weight of defective products is 26.25%, the waiting time for waste is 16.02%, the DPMO value is 2,150, and the sigma value is 4.36 (Nurprihatin et al., 2017). The defect rate decreased from 4.13 to 1.25 daily production data (Reaz et al., 2020).

The results of the research input from the average index value of productivity, material (98.85%), and energy (95.11%) (Bakar et al., 2017). 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 (Sihombing & Sumartini, 2017). 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 (Adikorley et al., 2017). Reducing production costs while improving quality in the garment industry, using 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 (Zaman & Zerin, 2017). 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 sigma value after implementing improvements of 3.31 (Wardana et al., 2015).

## 3. Methods
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 (Devica, 2015) in his book quoting back about losses/defects by Taguchi. Quality improvement is when the company identifies the problem, creates a repair team, analyses the root cause, and eliminates it (Saxena & Srinivas Rao, 2019). Kaizen is an organization making it an absolute priority until an emergency problem (Medinilla, 2014). Practical methods for reducing costs, improving quality, and fostering continuous improvement in products or processes (Radziwill, 2014) in his book Six Sigma. In his book, the Kaizen process of implementation and quality improvement (McLoughlin & Miura, 2017) 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 (Patel, 2017).

The Six Sigma program has a five-phase cycle: Define-Measure-Analyze-Improve-and Control (DMAIC) for process improvement, becoming increasingly popular in Six Sigma organizations (Saxena & Srinivas Rao, 2019). The DMAIC stage is just a workflow used to determine what the customer wants (Carroll, 2013). The article understudy was developed according to the stages of the DMAIC methodology Figure 1.

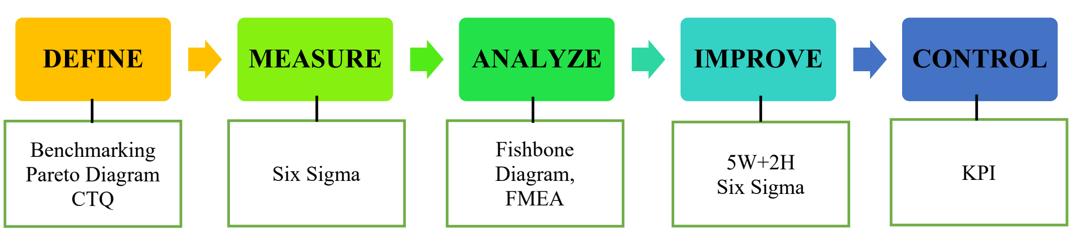



Figure 1. DMAIC Methodology

# 4. Data Collection

## 4.1 Define Stage

Benchmarking is the process of comparing something to learn how to improve the process (Global & Practice, 2012). The benchmarking research method used is processed benchmarking, namely benchmarking that compares work processes. Making a single type of socks will be compared to produce which part has the most significant production loss. Data collection from production and defect reports during January 2020 for each sock-making process is included in Table 1.

Table 1. Benchmarking Method of Socks Process

| Socks Process Column | Production (pair) A | Defect (pair) B | % Defect C | Socks Price (Rp/pair) D | Loss Production (Rp/month) E |
|---|---|---|---|---|---|
| Section name | Prodution Jan | Defect Jan | $\frac{B}{A+B}x100\%$ | Price per Jan | B x D |
| Etc. | .. | .. | .. | .. | .. |
| Grand Total | | | Total C | | Total E |

Pareto Diagram 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 (Dana. Ginn, 2004). 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.

CTQ is a defect problem that significantly affects production (Abbes et al., 2018). 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.

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 |

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.

## 4.1 Measure Stage

To determine the sigma level, the research method is to take production report data and defects on a single type knitting machine for 40 lots and input 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 (DPU) $= (\text{Amount Defect})/(\text{Amount Unit})$ (1)

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

c) Defect Per Million Opportunities (DPMO) $= \text{DPO x } 1{,}000{,}000$ (3)

d) $\text{Level Sigma} = \text{NORM.S.INV}\ ((1{,}000{,}000 - \text{DPMO}))/1{,}000{,}000 + 1.5$ (4)

### 4.3 Analyze Stage

Fishbone Diagram is an analysis 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).

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, further in-depth research is carried out using why-why analysis.

### 4.4 Improve Stage

5W+2H is a structured method to generate ideas using a series of questions related to the problems or goals set (Saxena & Srinivas Rao, 2019). In this study, the data analysis method was obtained during the Focus Group Discussion in a meeting where the content of the meeting discussion determined 5W+2H with the results of mutual agreement.

### 4.5 Control Stage

The research methods in this KPI report at PT GSI have been running since 2019 with item parameter cost, delivery, quantity, and no quality-related to a sigma level. Make it propose it serves to control the results of daily quality improvements. The quality factor will be included in the monthly KPI targets to monitor the production team's quality improvement projects. Submit sigma level items/parameters, especially in the single Lonati Knitting machine, to the KPI coordinator with the person's approval in charge of the KPI. This makes it a new target for this section to keep motivating the continuous improvement routine.

## 5. Results and Discussion

### 5.1 Define Stage Results

The benchmarking results were comparing the production process with production losses during the manufacture of socks. Each part of making the legs will be known which part of the production loss is the highest. So this research will focus on that part. The benchmarking results can be seen in Table 3.

Table 3. Comparison of Loss Production at Knit Socks Process

| Knit Socks Process | Prices of Socks (Rp/pair) | Before Improvement | | After Improvement | |
|---|---|---|---|---|---|
| | | Defect (pair) Jan 2020 | Loss Production (Rp/month) | Defect (pair) Mar 2021 | Loss Production (Rp/month) |
| Knitting | Rp 11,000 | 44,360 | Rp 487,960,000 | 25,100 | Rp 276,100,000 |
| Sewing | Rp 11,900 | 590 | Rp 7,021,000 | 460 | Rp 5,474,000 |
| Rotary Inspection | Rp 12,000 | 2,560 | Rp 30,720,000 | 2,310 | Rp 27,720,000 |
| Embroidery | Rp 12,300 | 860 | Rp 10,578,000 | 750 | Rp 9,225,000 |
| Setting | Rp 12,600 | 580 | Rp 7,308,000 | 490 | Rp 6,174,000 |
| Pairing | Rp 12,700 | 6,520 | Rp 82,804,000 | 5,580 | Rp 70,866,000 |
| Packing | Rp 14,000 | 100 | Rp 1,400,000 | 60 | Rp 840,000 |
| Final Inspection | Rp 14,500 | 450 | Rp 6,525,000 | 240 | Rp 6,525,000 |
| Grand Total | | | Rp 634,316,000 | | Rp 402,924,000 |

From Table 3, it can be discussed that the most significant production loss is the knitting section both before and after repairs. But with the improvement, the production loss can be reduced or reduced by 56%. That means that the handling that Knitting has done affects decreasing production loss.

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 repair, the Pareto diagram can be seen in Figure 3, which means that the socks defect data after repairing.

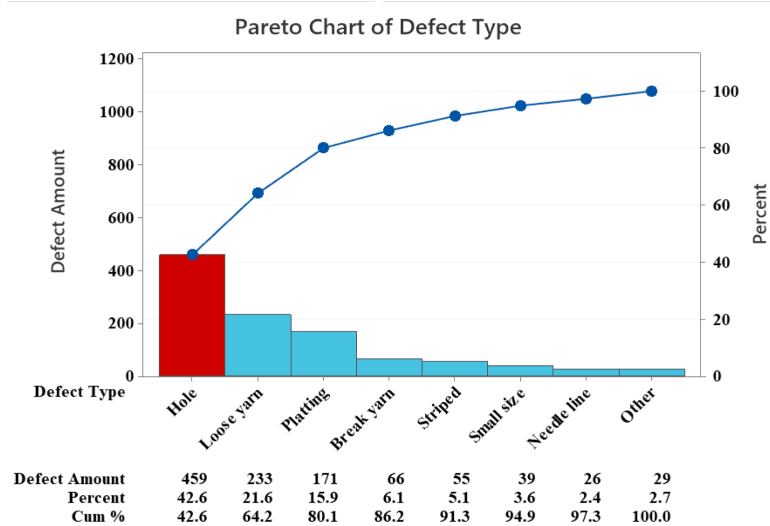



Figure 2. Pareto Diagram of Socks Defect Before Improvement

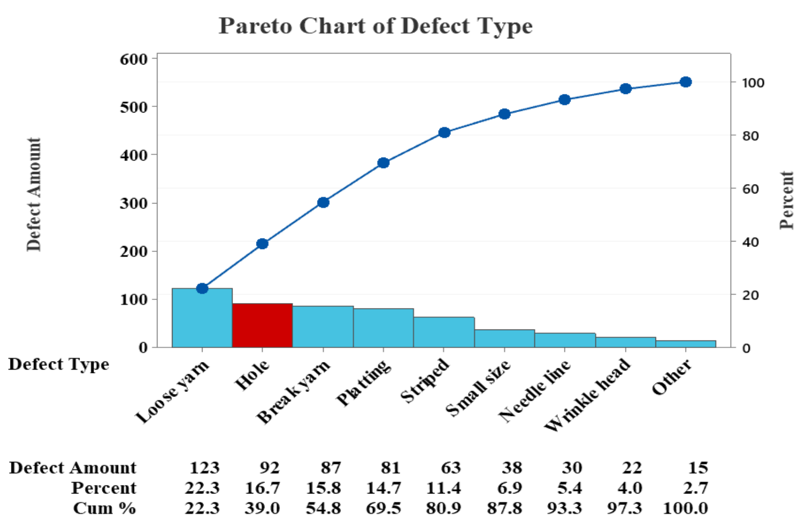



Figure 3. Pareto Diagram of Socks Defect After Improvement

Based on Figure 2, the most Pareto or dominant defect is a perforated defect of 42.6%. Therefore, this perforated defect must be immediately followed up for repairs. In Figure 3, it can be seen that the perforated defect decreased by 16.7%, which means it decreased by 139%.

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

| 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% |

After getting the total defects, still in the form of quantity defects and the types of socks defects that have not been seen, the next step is to break down the total defects into types of defects. So it will be seen the types of defects 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.

## 5.2 Measure Stage Result

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 4.1. The results of data processing for Six Sigma can be seen in Table 6.

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 | |

Based on Table 6, it can be concluded that the DPMO value after improvement decreased from 13,847 to 6,921 or decreased by 50%, while the sigma level increased from 3.7017 to 3.9614 or increased by 7.00%. This is in line with the decrease in defects from 11.08% to 5.54%, or a decrease of 50%.

### 5.3 Analyze Stage Result

Based on the results of meetings with operators and leaders using brainstorming and why-why analysis, the main factors causing 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.

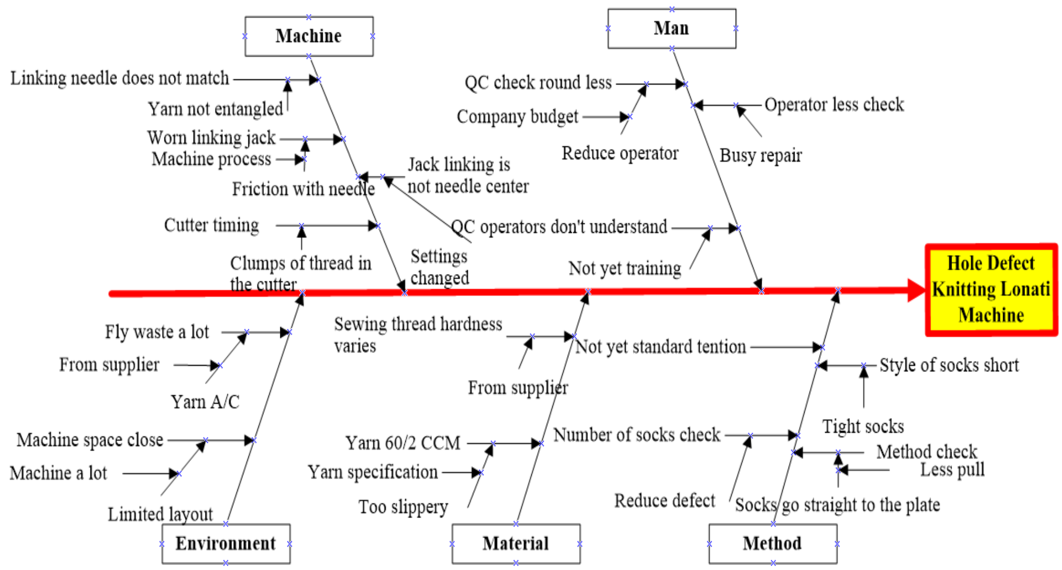



Figure 4. Fishbone Diagram Result

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 to expert judgment in determining FMEA scores. The results can be seen in Table 7.

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 centre | 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 |

The results of the FMEA show 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.

### 5.4 Improved Stage Results

The proposed improvements using the 5W+2H method were carried out during the FGD meeting attended by 11 expert judgments from the leader level to the president director. The results of 5W+2H will be submitted for improvement plans, and the results can be seen in Table 8.

Table 8. Determine 5W+2H for Planning Improvement

| No | What | Why | How | Who | When | Where | How Much |
|---|---|---|---|---|---|---|---|
| | What is the problem? | Why should it be dealt with? | How to deal with it? | Who is in charge? | When will it be implemented? | Where is it carried out? | How much will it cost? |
| 1 | The linking needle does not match | Reduce frequent loose threads & perforated socks | Experiment with two types of needles | AlFikron | December 23, 2020 | Communication with suppliers | Rp 1,750,000 |
| 2 | Sewing thread hardness varies | Reduce the frequent snagging of threads | Experiment with three kinds of yarn hardness | Mizani | November 5, 2020 | Communication with suppliers | Rp 5,650,000 |
| 3 | Clumps of thread in the cutter | Reduce socks with holes from threads that often break | Fixed-size data cutter timing | Hary S | February 2, 2021 | Knitting machine cylinder | - |
| 4 | Socks go straight to the plate | Perforated defect inspection visualization | Before entering the plate, check by hand | Endang H | February 26, 2021 | Knitting machine front area | Rp 3,000,000 |

Table 8 shows that four factors cause perforated defects in the proposal for the repair of perforated defects. This proposal also costs PT GSI as much as Rp 10,400,000 to treat the dominant defect, namely a hole in the single socks. For the next step, each person in charge of repairs takes corrective actions with the team that has been formed. The repair team takes corrective actions according to the repair plan made to not clash with other work. The results of the repair of the four causes of the problem can be seen in Table 9.

Table 9. Improvement of Hole Defects

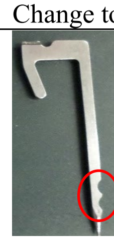
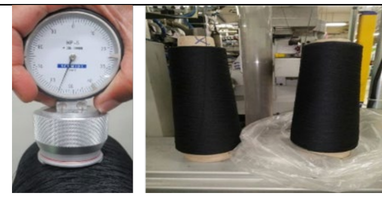
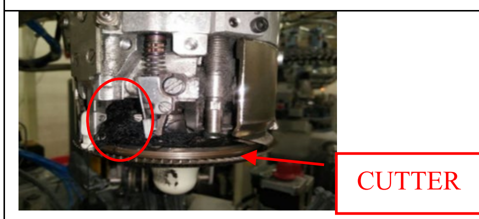
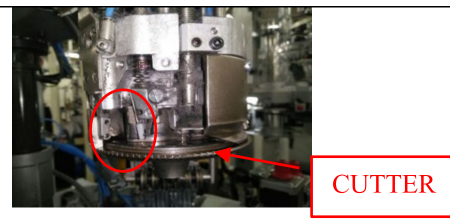
| | The Method of Improvement Hole Defect on Knitting Machines Lonati Single | | | | |
|---|---|---|---|---|---|
| No | Factor | × | Before Improvement | √ | After Improvement |
| 1 | Machine | Use old type linking needle | | Change to new type linking needle | |
| | |  | |  | |
| | | There is one groove on the tip of the needle | | There are two grooves on the tip of the needle | |

Table 9. Improvement of Hole Defects

| | The Method of Improvement Hole Defect on Knitting Machines Lonati Single | | |
|---|---|---|---|
| No | Factor | × Before Improvement | √ After Improvement |
| 2 | Material | Hardness yarn varies | Hardness yarn scale 55 |
| | |  |  |
| | | There is no standard for hardness yarn accepted by PT GSI | Made a standard hardness yarn scale of 55 and included in the Certificate of Analysis (COA) every arrival lot |
| 3 | Machine | Clumps of thread left on the cutter, the cutter timing data size is too long | Improved timing cutter data size and cleaning schedule 1 shift two times |
| | |   |   |
| | | Timing Cutter on data size is too long while working | Reset the Cutter timing on the size data when working each part of the sock (set after the thread is working, the cutter will immediately cut it) |
| 4 | Method | The socks go straight into the acrylic plate | The socks have a check for the pull of both hands at the end position of the gore-line linking |
| | |   |   |
| | | Visual inspection of the sock on the acrylic plate is less deformed | Before entering the scale, the socks are pulled beforehand with both hands so that visually defects can be seen |

## 5.5 Control Stage Results

The results of the KPI report in this study function to control the results of quality improvements, where quality factors will be included in the monthly KPI targets so that management can monitor quality improvement projects carried out by the production team as validation. The results of the KPI Knitting Department can be seen in Table 9.

Table 9. Key Performance Indicators Department Knitting

| Core Program | No | Descriptions | Unit | Point (%) | Target | Record 2019 | Record 2020 | Target 2021 | Record 2021 to May |
|---|---|---|---|---|---|---|---|---|---|
| Quality | 1 | Loss Production/Defect | % | 15.0 | 81% | 9.3 | 8.6 | 7.0 | 6.3 |
| | 2 | Sigma Level (Special Lonati Single SbyS) | Sigma | 10.0 | 106% | N/A | 3.7017 | 3.9500 | 3.9670 |
| Quantity | 3 | Production Result | Deka | 20.0 | 117% | 44,385 | 25,654 | 30,000 | 28,400 |
| | 4 | Consume Needle Part | n/deka | 12.5 | 92% | 0.6321 | 0.0542 | 0.0498 | 0.0486 |
| Delivery | 5 | First Production Test Report (Average) | Hour | 7.5 | 75% | 24.5 | 16.0 | 12.0 | 11.7 |
| | 6 | Change Item Production Report (Average) | Hour | 7.5 | 71% | 8.0 | 7.0 | 5.0 | 5.4 |
| Cost | 7 | Cost Complain | USD | 7.5 | 83% | 1,230 | 1,351 | 1,128 | 986 |
| Safety | 8 | Total Incidence (Light, Moderate, Severe) | Time | 10.0 | 100% | 1 | 0 | 0 | 0 |
| Improvement | 9 | Idea Realization/ Suggestion System | Times /Year | 10.0 | 108% | 10 | 13 | 14 | 8 |
| Total | | | | 100 | | | | | |

## 6. Conclusion

The conclusions that can be put forward in this study include: The factors that cause dominant defects are hole defects, which consist of the machine, material, and method factors. The factors that cause the machine consist of a mismatched linking needle, clumps of thread in the cutter. The causative factor of the material is the varying yarn hardness. The causal factor of the method is the socks going straight to the plate. FMEA analysis were unsuitable linking needles at 504 RPN, yarn hardness varied by 441 RPN, thread clumps in cutter 384 RPN, direct socks entering the plate is 294 RPN.

The result of the improvement affects increasing 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%. Therefore, future research is recommended to improve the production process by integrating lean methods to effectively and efficiently produce

The improvement efforts that have been made are: change to new type linking needle, made a standard hardness yarn scale of 55 and included in the Certificate of Analysis (COA) every arrival lot, Improved timing cutter data size and cleaning schedule 1 shift two times, and the socks have a check for the pull of both hands at the end position of the gore-line linking. To control the sigma level, it is proposed to be included in the KPI so that the knitting department can control and be enthusiastic in continuous improvement.

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