Quality Control Analysis Using DMAIC Method and DPMO Calculations on Low Voltage Cable Production (Case Study at PT XYZ Jakarta)

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Abstract
Quality is a measure of how close a product is to a certain standard. Standards may relate to time, materials, performance, reliability, or quantifiable (objective and measurable) characteristics. Products will be declared quality if they comply with predetermined standards. PT XYZ is a manufacturing company that produces cables. During the production process, the quality of the cable is constantly monitored, and the cables will go through a final test carried out by the Quality Assurance department, which includes electrical tests and dimensional tests. The production process is certainly not free from mistakes and can result in defective products. Quality control must maintain the product quality using the DMAIC method, which consists of five stages: defining, measuring, analyzing, improving, and controlling with the object of observation is a low voltage cable. The purpose of this research is to find the cause of the defects and reduce the percentage of existing defects. The analysis results show that the biggest causes of the defect products are short cables and rough/wound/torn insulation with a DPMO calculation result is 279.4336811 and a sigma level that is equal to 4.951 sigma.

Keywords:
Quality, DMAIC, final test, DPMO, Six Sigma

1. Introduction

PT XYZ is a manufacturing company engaged in the cable industry. Established since 1970, PT XYZ has produced many cables of high quality and has customers both from national and international. One of the products produced by PT XYZ is Low Voltage Power Cable that is produced by going through several processes. The finished cable will go through a final inspection process to ensure that the cable is fit the standard until it reaches the customer

Quality is a dynamic condition that are interconnected with various aspects, including products, workforce, processes and tasks, and the environment to meet consumer's expectations (Garvin,1988). The production process is certainly not free from mistakes and can result in defect products. Therefore, quality control is needed to maintain product quality. If a product does not comply with the standard, then an evaluation process and system are carried out to find the cause of the defect. After that, a repair and control process will be performed.

Because the production process is certainly not free from mistakes, quality control action must maintain the product quality by using the DMAIC method to find the causes of defect products using a fishbone diagram and corrective and control actions that can be taken. This research will calculate the DPMO of the low voltage cable production using data in 2020. The purpose of this research is to find the cause of the defects and reduce the percentage of existing defects.

2. Literature Review

The literature reviews that are used in this research are:

2.1 DMAIC

DMAIC stands for Define, Measure, Analyze, Improve, and Control. DMAIC is part of the Six Sigma framework and is a method for making continuous improvement. The stages of this approach are in the form of problem determination, measuring capabilities and objectives, improving processes and reducing the causes of problems, and implementing long-term process control (Asnan, 2019; Fransiskus et. al., 2014).

2.2 SIPOC Diagram

SIPOC stands for Supplier, Input, Process, Output, Customer. SIPOC is a visual tool used to describe business processes from start to finish and identify relevant elements of the improvement project that will be undertaken(Ahmad, 2019).

2.3 Fishbone Diagram

A Fishbone diagram is a diagram used to identify the various causes of an event or process. This diagram identifies and shows the relationship between cause and effect to find the root cause of a problem. This Fishbone Diagram is also known as a cause-and-effect diagram (Render & Jay, 2001).

3. Methods

Material that is needed in this research is obtained through field studies by doing observation in low voltage plant at PT XYZ and interview with the production and quality assurance department and literature studies from books and journals. The methods that have been done in this research can be seen in the flowchart in Figure 1.

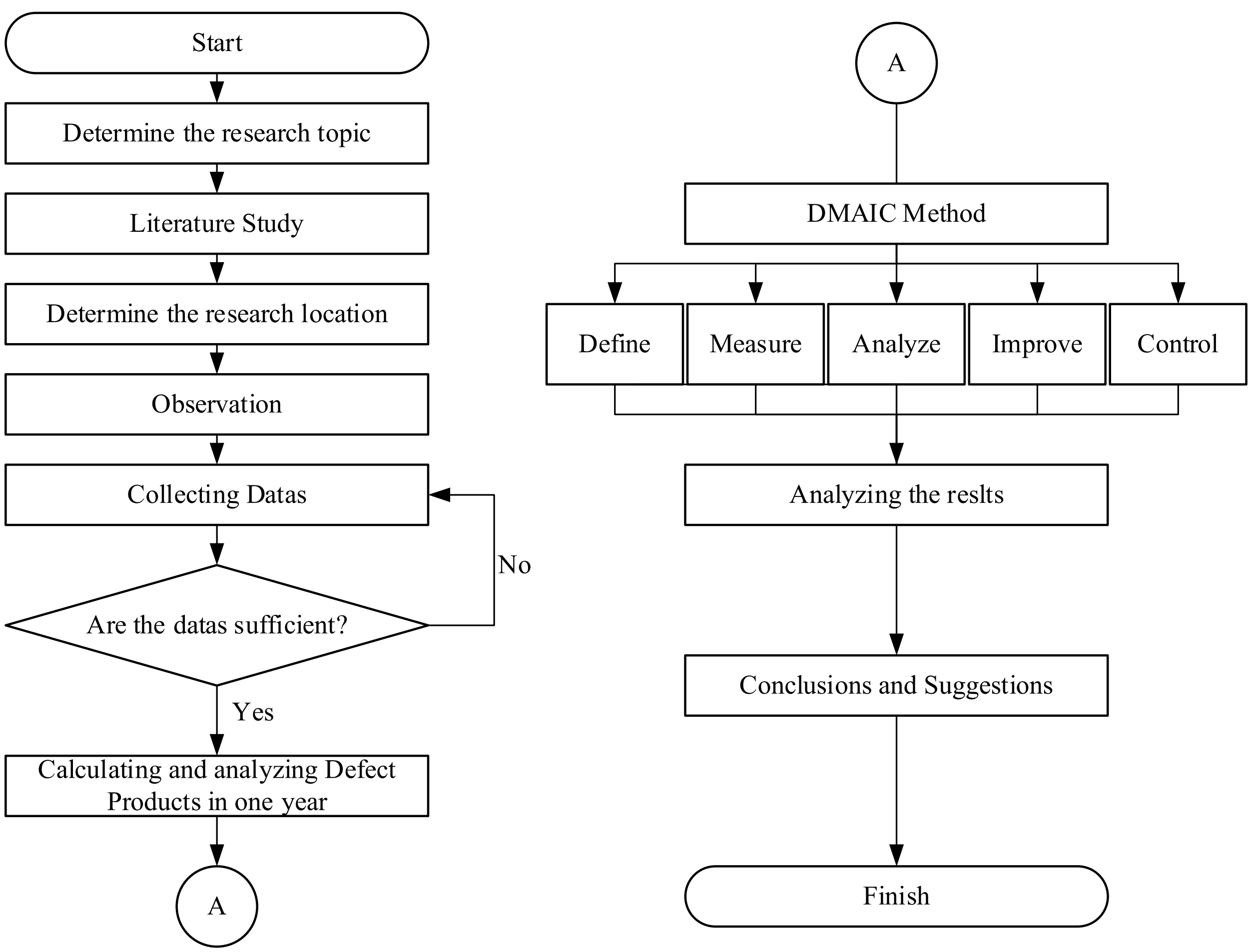


Figure 1. Methods Flow Chart

4. Data Collection

After calculating the proportion of defects to see whether the resulting defect is still within the control limit, the proportion of defects in the Low Voltage Cable in 2020 is controlled because it is still under Upper Control Limit (UCL) and above Lower Control Limit (LCL). Data on the proportion of product defects for Low Voltage Cables can be seen in Table 1, and the P Control chart (Kholil and Pambudi, 2014) can be seen in Figure 2

Table 1. Proportion Data of Defect Low Voltage Cable

Type of Defect	Total Production (drum)	Total Defect	Proportion of Defect	UCL	CL	LCL
Thin Insulation Thickness	5386	0	0	0.02103	0.00056	-0.0199
Thin Outer Sheat Thickness	5386	0	0	0.02103	0.00056	-0.0199
Low IR	5386	0	0	0.02103	0.00056	-0.0199
Cu Oxidation	5386	0	0	0.02103	0.00056	-0.0199
Rough/Perforated OS Visual	5386	0	0	0.02103	0.00056	-0.0199
Sticky Bedding	5386	0	0	0.02103	0.00056	-0.0199
Coarse/Wound/Tears Insulation	5386	1	0.0001857	0.02103	0.00056	-0.0199
Sticky Insulation	5386	0	0	0.02103	0.00056	-0.0199
Pore Insulation	5386	0	0	0.02103	0.00056	-0.0199
Less Length	5386	0	0	0.02103	0.00056	-0.0199
Over Length	5386	0	0	0.02103	0.00056	-0.0199
Short (Leaking)	5386	2	0.0003713	0.02103	0.00056	-0.0199
High CR	5386	0	0	0.02103	0.00056	-0.0199
Rolls Not Neat	5386	0	0	0.02103	0.00056	-0.0199
Incorrect Emboss/ Marking	5386	0	0	0.02103	0.00056	-0.0199

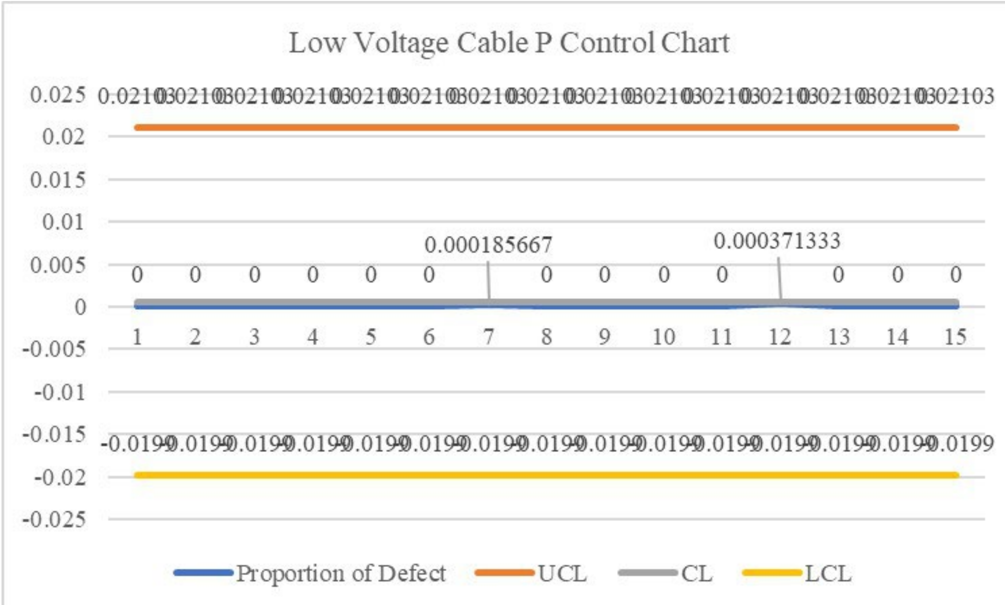


Figure 2. Low Voltage Cable P Control Chart

Data regarding the types of defects that occur in low voltage cable in are sorted from the most frequent to the rarest that can be seen in the cumulative percentage, which can be seen in Table 2 and the Pareto diagram in Figure 3

Table 2. Cumulative Percentage of Defect Products for Low Voltage Cables

No	Type of Defect	Amount	Percentage (%)	Cumulative Percentage (%)
1	Short (Leaking)	2	66.67	66.67
2	Coarse/Wounds/Tears Insulation	1	33.33	100.00
3	Thin Insulation Thickness	0	0.00	100.00
4	Thin Outer Sheat Thickness	0	0.00	100.00
5	Low IR	0	0.00	100.00
6	Cu Oxidation	0	0.00	100.00
7	Rough/Perforated OS Visual	0	0.00	100.00
8	Sticky Bedding	0	0.00	100.00
9	Sticky Insulation	0	0.00	100.00
10	Pore Insulation	0	0.00	100.00
11	Less Length	0	0.00	100.00
12	Over Length	0	0.00	100.00
13	High CR	0	0.00	100.00
14	Rolls Not Neat	0	0.00	100.00
15	Incorrect Emboss/Marking	0	0.00	100.00

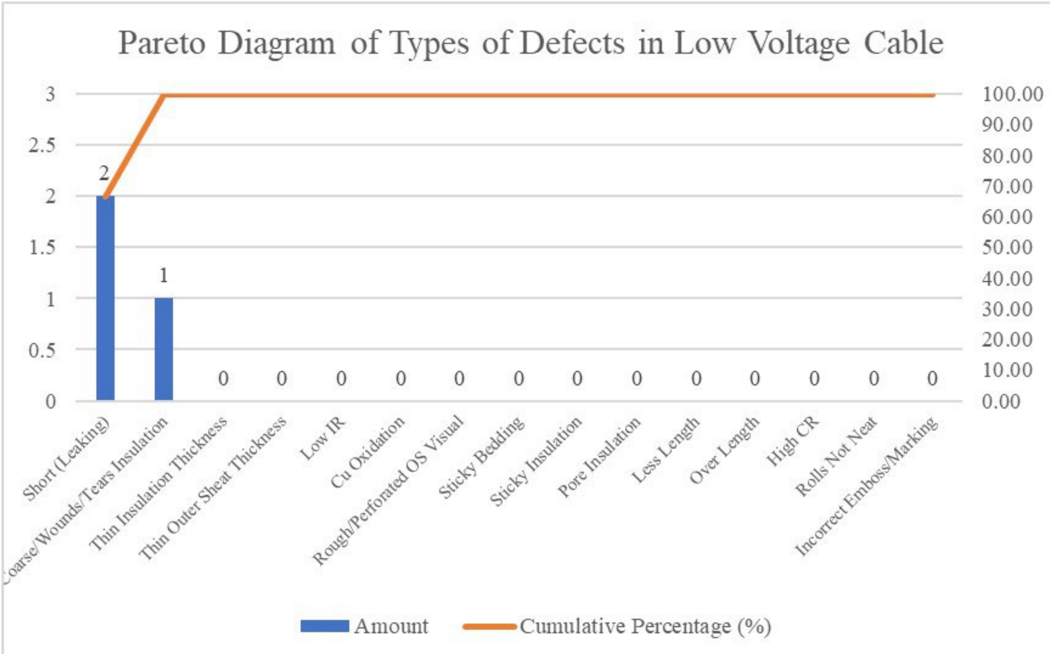


Figure 3. Pareto Diagram of Types of Defects in Low Voltage Cable

Based on the data, the type of defect that caused 66.67% of the total defective product was a short cable with 2 defect units, and the cause of 33.33% of the total defect product was rough/wound/torn insulation with 1 defect unit. 1.

Even there is only three defect products in this research, defect is still a defect and can generate waste. Not only a waste of money, but also time and energy. Therefore, this research wants to find the problem causing the defect and give suggestions to eliminate it

5. Results and Discussion

5.1 Define

At this stage, a SIPOC diagram is made to help identify the making process of low voltage cables. The SIPOC diagram can be seen in Figure 4

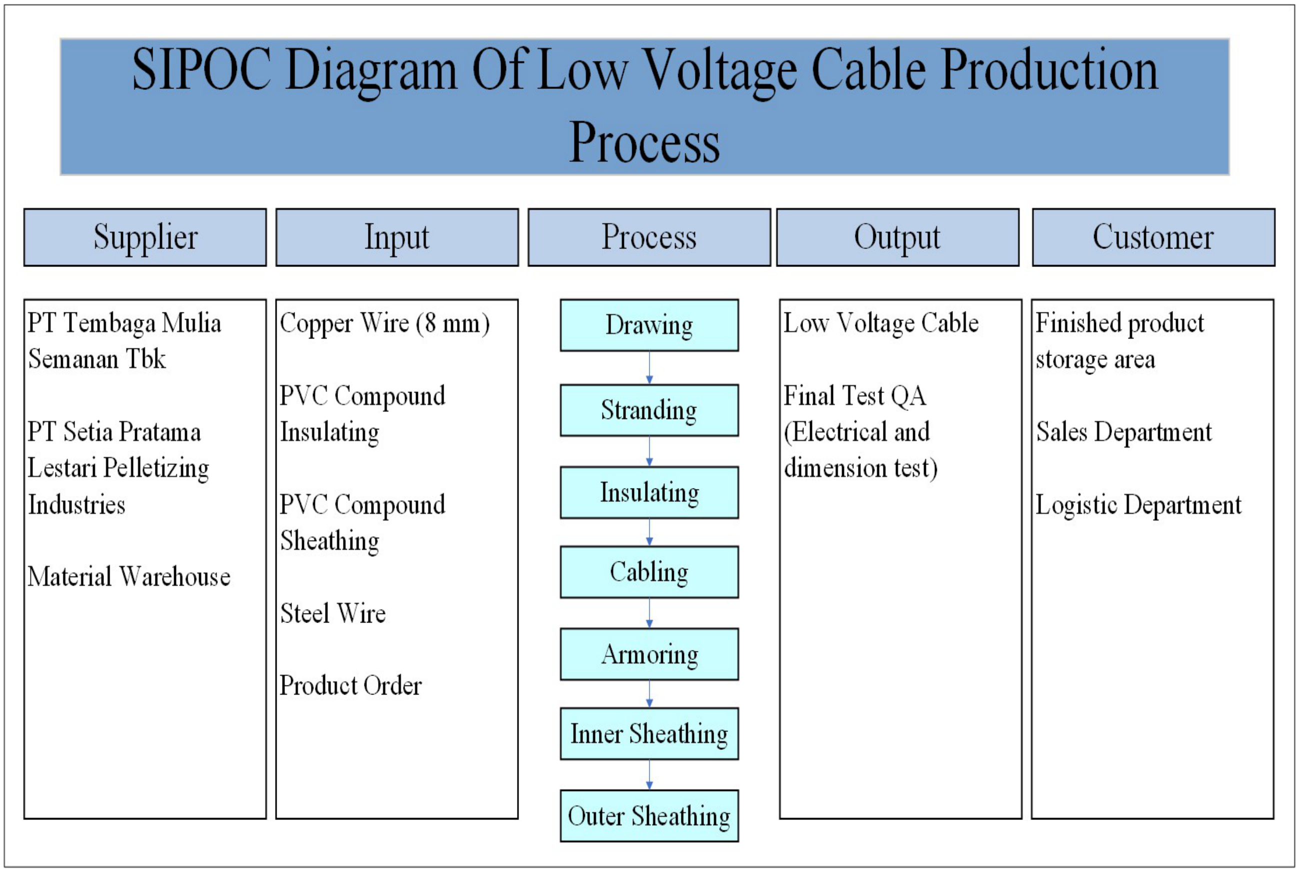


Figure 4. SIPOC Diagram of Low Voltage Cable Production Process

The processes that can produce defect products in low voltage cables are the extrusion process in the extruder machine and the armoring process. The extrusion process is the process of cloaking conductors and cable cores with PVC material. This process can cause defects if the settings on the machine are not suitable and the quality of the PVC material used is not good. This condition can cause the visual of the extrusion to become rough and lumpy and can cause leakage in the extrusion product. The armoring process is a process to coat cables with steel wire as mechanical protection. The cables have been coated for protection. This protection is done by a pressing process. The coated shield in outer layer of the cable is made by the extrusion process. If the steel wire is not installed according to the standard, this will cause leakage in the cable, causing the cable to experience a short circuit.

5.2 Measure

Measurement of defect product variables that appear on Low Voltage cable products is done using the calculation (Sirine et.al.,2017) of DPMO (Defect Per Million Opportunities). The results of the DPMO calculation on the Low Voltage cable can be seen in Table 3

Table 3. Low Voltage Cable DPMO Calculation Results

Variable	January-December 2020
Unit (U)	5368
Opportunities (OP)	2
Defect (D)	3
Defect per Unit (DPU)	0.000558867
Total Opportunities (TOP)	10736
Defect per Opportities (DPO)	0.000279434
Defect per Million Opportunities (DPMO)	279.4336811
Sigma Level	4.951σ

5.3 Analyze

At this stage, an analysis is carried out by finding out the causes of defects in Low Voltage cable products with the help of fishbone diagrams of two types of defects that cause defects in Low Voltage cable products (Yulianti, 2021). The data in this fishbone diagram was obtained by conducting interviews with the Quality Assurance Plant Low Voltage supervisor and the Low Voltage Plant Production supervisor, especially in the armoring and extrusion processes. The fishbone diagram can be seen in Figure 5 and Figure 6

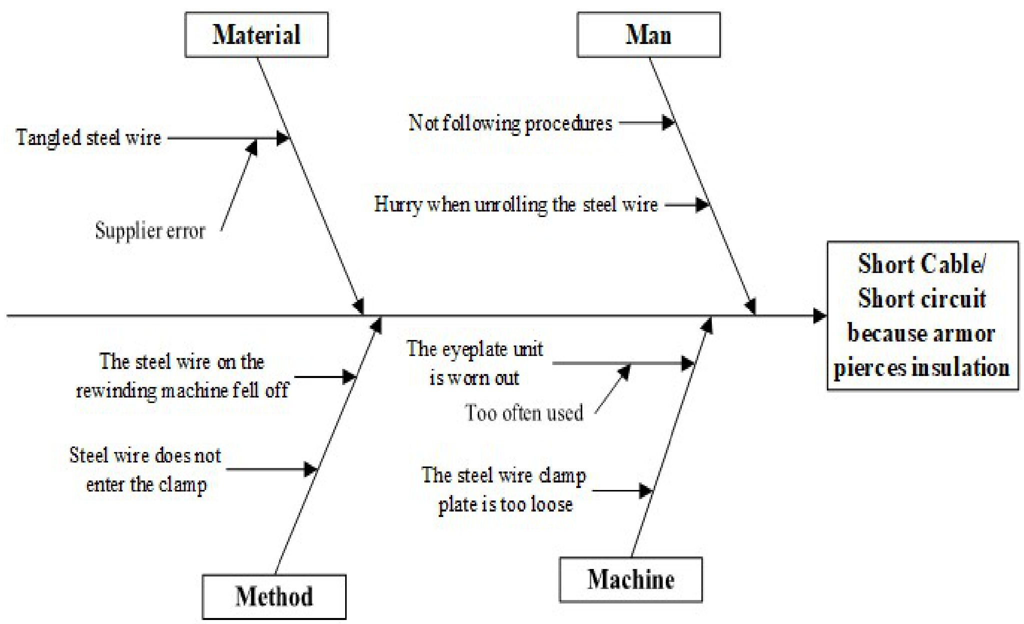


Figure 5. Fishbone Diagram of Short Cable because armor pierces insulation

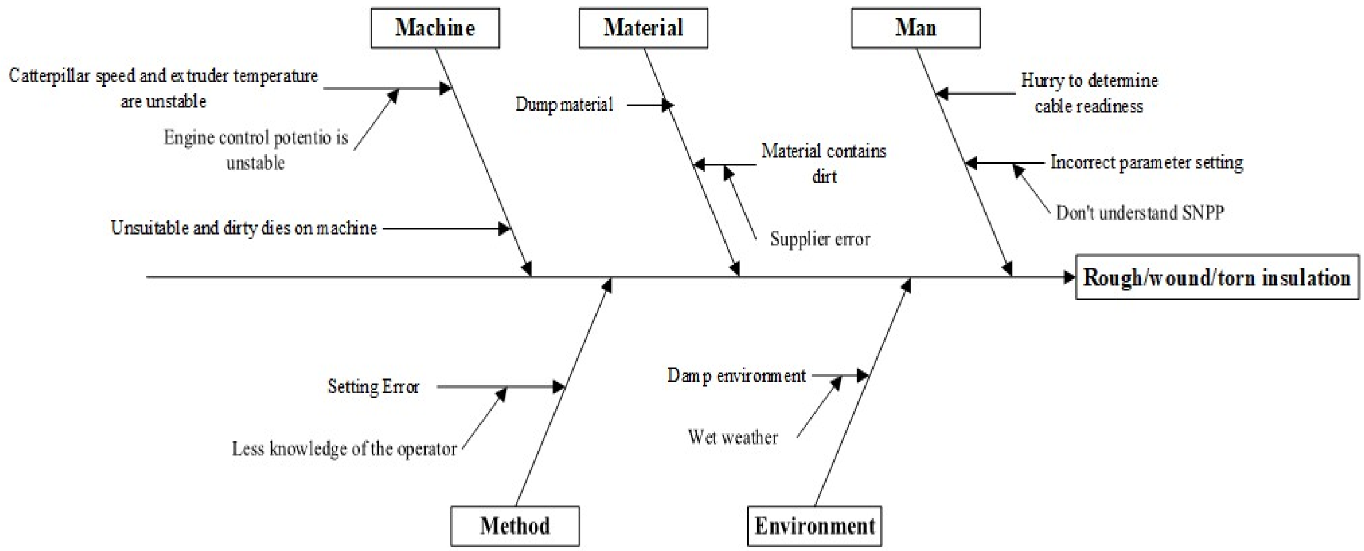


Figure 6. Fishbone Diagram of Rough/Wound/Torn Insulation

5.4 Improve

Improve is the stage of doing repairs to the causes of problems that occur in Low Voltage cables (Yulianti, 2021). The improvements made can be seen in Table 4

Table 4. Improvements Made to Repair the Causes of Problems

Problem / Category	Short Cable/ Short Circuit because Armor Pierces Insulation	Rough/ Wound/ Tore Insulation
Material	One of the causes of short cables due to piercing armor is a tangled steel wire due to supplier error. This tangled steel wire has the potential to cause the armor to pierce the cable insulation because its position is not flat (transverse), so that the sharp part will penetrate the cable insulation and cause the cable to leak. Improvements made to reduce the cause of wrinkling steel wire are to rewind the steel wire using a rewinding machine.	The cause of rough / torn / wound insulation from in material point of view is the material used as insulation is moist and contains dirt. Improvement that can be done is to store the material in a place with good air circulation and lighting so that moisture can be maintained. A dehumidifier also can be used to remove humid air. The mash is used as a material filter for dirty materials so that dirt does not enter and makes the insulation results worse. Mash must be replaced every time the process is done
Man	The cause of the short cable due to the armor-piercing the insulation from a man's point of view is due to the operator who rushes to unroll the steel wire, so the operator ignores the procedure and leaves the steel wire free from the clamp. Improvements can be made by providing in-depth training and knowledge of standard operating procedures and providing supervision to operators, and paying attention to operator conditions so that	The cause of rough / torn / wound insulation from a human point of view is the operator who is rushing to determine the readiness of the cable and making the wrong settings because the operator does not understand SNPP (Product and Process Value Standards). Improvements that can be done are providing training and supervision to operators as well as paying attention to operator conditions so that errors can be minimized

Problem / Category	Short Cable/ Short Circuit because Armor Pierces Insulation	Rough/ Wound/ Tore Insulation
	errors can be minimized.	
Method	The cause of the short cable due to the armor-piercing the insulation from the method point of view is is that the steel wire is not attached to the clamp during rewinding properly. Improvement in the operator's briefing that rewinding the steel wire. The steel wire must pass through the steel wire clamp to detect the mismatched size and tangled steel wire. So that it can be repaired immediately before entering the armoring process.	The cause of rough insulation/tear / wound from a method point of view is a setting error. Improvements that can be made are providing briefings and supervision to operators so that there are no setting errors. During the process, the result of the machine's insulation must always be considered by feeling the results by touching the results by hand to ensure that there is no rough / torn / wound insulation.
Machine	The cause of the short cable is because the armor pierces the cable insulation from the machine point of view is the worn eye-plate unit so that the tangled steel wire during the armoring process is not detected. The improvement is made by checking the eye plate regularly and immediately replacing it with a new one if any eye plate is worn out. The loose plate steel wire clamp during the rewinding process is also the cause. The repair made is to check the clamp and immediately tighten it if it is loose so that none of the steel wire is twisted.	The cause of rough insulation / torn / wound from the machine's point of view is caterpillar speed, and extruder temperature is unstable and unsuitable and dirty dies. Improvements that can be done are to pay attention to the engine control potential. If it starts to lose, immediately change the potential so that the temperature and speed do not change by themselves. In addition, scheduled machine maintenance is also carried out and ensures that the operator understands the machine deeply so that there are no mistakes in selecting dies. Dies to be used must also be checked so that it is clean before use.
Environment	-	The cause of the rough / torn / wound insulation from environment point of view is a dump environment so that the quality of the material is reduced. Improvements that can be made are maintaining the humidity of the material storage and work environment by maintaining air circulation and lighting in the environment.

5.5 Control

Control is the control stage for improvements that have been carried out at the improvement stage (Munandar, 2020). In this research, control stage haven't been implemented. These are the proposed control stage that can be done:

1. The Socializing of Standard Operating Procedures (SOP) and Product and Process Value Standards (SNPP) regularly to all production operators so that the operators can work well.
2. Supervise and check regularly on the ongoing production process so that it can run according to procedures
3. Pay attention and ensure that the labor conditions are in a fit condition so that the quality of the products produced is good and according to standards.
4. Check the machines regularly and made the schedule to check the machine, especially the machines that often experience problems. Machine components such as eye-plate and dies are also replaced immediately if they are worn out (Yohanes and Rahardjo, 2018) .

This figure is the DMAIC Form that can be used to analyze problems (Yulianti, 2021) in low voltage cables, which can be seen in Figure 7.

Title: Reducing Defect Percentage

YB PPS Project A3

Reference | Date

1. Understand Situation

The defect percentage for Low Voltage Cable Production in December 2020 is above 0.2%

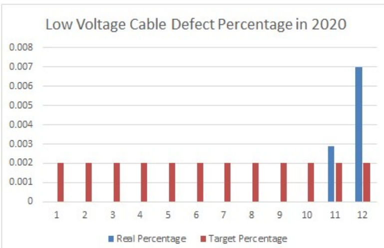
2.Project Scope

The scope of this project aims to reduce the precentage of defects to below or equal to 0.2%

Project Scope: The most defect is in the insulation and armoring process

3. Know the current condition

There is defect percentage in November 2020 and December 2020 in the amount of above 0.2%

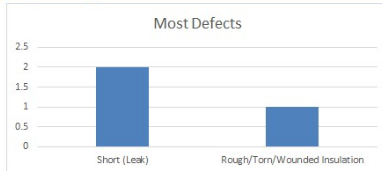


4. Set Targets

Defined Goals:
- Reduce product defects to 0.2%
- Reduce waste on low voltage cables

Project Approval

5. Gap Investigation



Problem / Root Cause	Short Cable due to armor piercing insulation	Rough/Torn/Wounded Insulation
Why 1	Tangled steel wire due to supplier error	Cattepillar speed and extruder temperature are unstable due to loosen potential
Why 2	The steel wire is detached and does not enter the clamp	Dies on machine are dirty
Why 3	The eyeplate unit is worn out due to overuse	Dump and dirty materials
Why 4	Steel wire plate is too loose	The operator made a mistake in the settings and was in a hurry to determine the readiness of the cable
Why 5	Operator rush in unrolling steel wire	

Conclus
The steel wire used does not go through a standard process
Operators don't understand SNPP
Machines need to be checked regularly

6. Define and Develop Solutions

Problem / Solution	Short Cable due to armor piercing insulation	Rough/Torn/Wounded Insulation
Solution 1	Rewinding steel wire using a rewinding machine	Paying attention to the engine regulator potentiometer, if it starts to lose, immediately replace the potentiometer so that the temperature and speed do not change by themselves
Solution 2	Conduct a briefing to the operator so that when rewinding the steel wire, the steel wire must actually pass through the steel wire clamp	Dies to be used must also be checked and cleaned so that they are clean before use.
Solution 3	Perform regular eyeplate checks and immediately replace them with new ones if there are worn eyeplates.	Store the material in a place that has good air circulation and lighting so that the humidity can be maintained. For dirty material, mash is used as a filter material
Solution 4	Inspect the clamp and immediately tighten it if it is loose so that the steel wire is not twisted.	Provide in-depth training and knowledge of standard operating procedures and provide supervision to operators
Solution 5	Provide in-depth training and knowledge of standard operating procedures and provide supervision to operators	

7. Validate Solution & create Improvement Plan

Problem / Root Cause	Short Cable due to armor piercing insulation	Rough/Torn/Wounded Insulation
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Why 2	The steel wire is detached and does not enter the clamp	Dies on machine are dirty
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Problem / Solution	Short Cable due to armor piercing insulation	Rough/Torn/Wounded Insulation
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Solution 5	Provide in-depth training and knowledge of standard operating procedures and provide supervision to operators	
Start Date	03-Apr-2021	01-Apr-2021
End Date	17-Apr 2021	15-Apr 2021
PIC	Production Dept. dan QA Dept.	Production Dept. dan QA Dept.

8. Planning Execution

Implement solutions to existing problems. This execution stage has not yet been carried out

9. Upgrade Confirmation

Creating a new defect graph and confirmation of improvement is carried out after the problem solution is implemented

10. Maintain and Replicate

When the solution provided succeeds in providing improvements and succeeds in achieving the desired results, a standard for implementing the solution is made so that it can be carried out continuously

Sponsor Approval | Manager Approval

Figure 7. DMAIC Form

6. Conclusions

The following conclusions can be found after doing this research, namely:

1. Based on the analysis results, 66.67% of the causes of low voltage cable defect products are short cables (leaking), and 33.33% of the cause is rough/ wound/ torn insulation.
2. This type of defect is caused by several factors such as tangled material that punctures the cable and causes leakage, damp material, inaccurate operator factors, incorrect settings, and worn or unstable machine components.
3. The results of the calculation of DPMO for Low Voltage Cables are the sigma level of 4.95. After defining and measuring stages, the analyze stage is carried out to determine the causes, improve for repair, and control the stage. At the Analyze and improve stage, the authors conducted interviews with the production department and quality assurance and direct observations during the production process
4. These are some suggestions that can be given:
    a. Make documentation on how to operate the machine and the things that must be considered so that if there is a change of operator, the new operator can understand the procedure more clearly before doing it directly.
    b. Create a special place for material storage with good air circulation and lighting so that humidity can be maintained.
    c. Placing supervisors in the production department that has the potential to cause defects so that operator negligence and inaccuracy are reduced

d. Mark machines that often cause problems and carry out a thorough inspection of the machine and carry out routine checks on machine components and replace them immediately if they are worn out.
e. Modify the wire steel clamp plate by setting an alarm so that if the steel wire does not pass through the clamp the machine will sound so that the steel wire must completely pass the clamp so that there is no tangled material that could potentially cause the cable to leak.

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Biographies

Felita Yulianti is an Industrial Engineering student at Tarumanagara University. She was born in Jakarta July 12th 2000. She is the second of three daughters. She was graduated from Saint Vincentius Elementary School and Saint Vincentius Junior High School with the fifth highest national exam score. She studied science in Fons Vitae 1 High School and was graduated with the highest national exam score. She was a participant in 2017 National Mathematics Olympiad in chemistry and managed to pass the first preliminary. She entered Tarumanagara University in 2018 and dreams to be a manager in a company and to be a researcher in a laboratory.

Lina Gozali is a lecturer at the Industrial Engineering Department of Universitas Tarumangara since 2006 and a freelance lecturer at Universitas Trisakti since 1995. She graduated with her Bachelor's degree at Trisakti University, Jakarta - Indonesia, then she got her Master's Degree at STIE IBII, Jakarta – Indonesia, and she recently got her Ph.D. at Universiti Teknologi Malaysia, Kuala Lumpur – Malaysia in 2018. Her apprentice college experience was in paper industry at Kertas Bekasi Teguh, shoes industry at PT Jaya Harapan Barutama, and automotive chain drive industry at Federal Superior Chain Manufacturing. She teaches Production System and Supply Chain Management Subjects. She did a research about Indonesian Business Incubator for her Ph.D. She has written almost 70 publications since

2008 in the Industrial Engineering research sector, such as Production Scheduling, Plant Layout, Maintenance, Line Balancing, Supply Chain Management, Production Planning, and Inventory Control. She had worked at PT. Astra Otoparts Tbk before she became a lecturer.