Quality Improvement Using Six Sigma Method and Cost Evaluation in NFA2XSY-T 3x150 MM² Products at PT. XYZ

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Abstract. An electric cable is a medium that is in the form of a conductor and insulator to deliver electric current from the area of origin to the destination. The quality of a cable is very much determined by the medium of transmission, the delivery material can be copper or aluminum. PT XYZ Tbk is one of the companies engaged in the electrical cable that produces bare conductors. One type of product produced by PT XYZ Tbk is medium voltage cable. Medium voltage cable is a type of cable that can deliver electricity to 35 kV. But among various types of medium voltage cables, NFA2XSY-T products have the highest failure rate among other types of medium voltage cable, which makes the frequency of rework and repair of these products higher. Based on historical data for three months, from June to August 2018, it is 21%, while the company's target is 1%. Therefore, in this study a quality improvement was carried out to minimize the level of defects with the six sigma method with the Define Measure Analyze step. Improve Control.

In the Define stage, it is done by identifying the type of defect, step Measure evaluates the stability of the process and identifies the quality costs associated with defects that occur, in the Analyze stage, by analyzing the causes of the dominant defect, in the Improve phase, improvements are made by making standard operating procedures, then at the control stage, it is attempted to compare between DPMO and Sigma Level before and after implementation. Based on data processing obtained DPMO of 77,585, and Sigma Level of 2.9, with total quality costs of Rp. 21,260,413 / day, after implementation DPMO was obtained at 55,556 and Sigma level of 3.9 with a total cost of Rp. 14,049,757 / day

Keywords: Six Sigma, DMAIC, Cost of Quality

1. Introduction
In order to win the competition in the business world, a company should always maintain the quality of products or services produced, the higher of a product quality, then the demand of product will be find so high, if the demand increases, it automatically increases the company's sales that have an impact on increasing profit. PT XYZ is a company in the cable industry that produces fiber optic cables, low voltage, medium voltage, high voltage. One that is produced by the company is a type of cable with a type of medium voltage that can deliver electricity to 35 kV. The NFA2XSY-T product is one type of medium voltage cable with the highest failure rate among other cable cables such as: NA2XSEYBY, CUXLPECWS, NA2XY, CU / XLPE / CTS / ALT / PVC / SWA / PVC-AT / FR-UV and according to historical data collected in June-August 2018, it has a failure / defects rate of 21%, and the other side targeted of the company is 1%, therefore on improving quality to minimize defects with the Six Sigma. Six Sigma is a method that can be used to improve quality in stages by reducing variations between the specified standards. And according to Montgomery [1] that quality is inversely proportional to its variation, if the variation approaches the predetermined standard / target, the quality will increase, otherwise the quality will be decrease. The stages carried out in this study are Define, Measure, Analyze, Improve and Control.
At the define stage, it is done by identifying the types of defects that occur from the product. While the products that are the focus of this research are NFA2XSY-T, with the following meanings: The NFA states that the conductor is made of Aluminum (Al), 2X states that the insulation process uses XLPE raw material, S states that the screening process uses copper (Cu) wire, Y states that the outer sheathing process uses raw materials PVC and T states that the cable is twisted. The measure phase is to evaluate the current production process, whether the process has been stable or not, and identify quality costs associated with defects and defective. The Analyze stage is a step to analyze the dominant causes of defects using the Pareto diagram, followed by the Ishikawa diagram. Improve phase is the stage of improvement that is used to correct defects that occur while Control is a stage used to evaluate whether the improvements made have succeeded or not.

2. Literature study
Six Sigma as a method of improving business processes that aims to find and reduce the factors that cause defects, reduce cycle times and operating costs, increase productivity, meet customer needs better and get better returns on investment in terms of production and service [2]. The six Sigma business target consists of three fields, namely increasing customer satisfaction, reducing cycle times and reducing defects. Sigma values in quality are interpreted as how often defects might occur. Six Sigma is a method that serves to reduce the number of defective products with statistical and scientific assistance. In an effort to improve the quality associated with Six Sigma, it is done using the DMAIC methodology (Define, Measure, Analyze, Improve, Control). DMAIC function to improve existing processes to produce zero defect performance [2].

MAFMA (Multi Attribute Failure Mode Analysis)
Multi Attribute Failure Mode Analysis (MAFMA) is a method that integrates conventional Failure Mode and Effect Analysis (FMEA) by considering expected costs. This method can be applied by identifying process functions, identifying potential products and failed processes, analyzing effects, identifying causes of failure and variables in the process, and each ranking failure in determining priorities for corrective action, and documenting results [2].

Cost of Quality
Quality costs are costs arising from poor quality. This definition states that quality costs are associated with two subcategories related to quality-related activities namely control activities and failure activities [3]. The things that cause quality raises costs are all actions included in the category do not carry out activities properly. Quality is measured based on cost of quality, which includes non-conformation costs or failure due to wrong activities. There are four categories of quality costs, namely preventive costs, appraisal costs, internal failure costs, and external failure costs.

3. Methodology
The research methodology carried out in this study, is to take a sample of 30 pieces n = 30≤N, during the month of August 2018, which is examined every single unit of cable. As for the defect obtained is the outer lekop layer, the perforated outer layer of the outer layer, the outer layer is bloated, the outer layer is knotted, the outer layer is pinnate, the outer layer is crusted (see Figure:1)

Figure 1: The kinds of defects
to check whether the production process is stable or not used C charts. Then the level of defects is accumulated. From the most dominant defect level, an Ishikawa diagram is analyzed, then proceed to convert to the Failure Mode and Effect Analysis (FMEA) table along with the calculation of the Risk Priority Number.
Furthermore, RPN sequencing is carried out from the highest to the lowest level accompanied by a mapping of the causes of defects of each RPN calculation. To obtain the most dominant weight in terms of severity, Occurrence, ease of detection and expected cost, used Analytical Hierarchy Process (AHP). Then to find out the most dominant weight of the cause of defects, a comparison is made in pairs with the expected cost, after the highest weight is known, the priority for handling the problem must be obtained, after the consultation process with the production manager is carried out. The proposed improvement is to make an Standard Operating Procedure (SOP), after which Defects per Million Opportunities (DPMO) evaluation, Sigma Level is accompanied by quality costs before and after implementation.

4 Result and discussion

Define Stage

Critical to Quality (CTQ) identification which consists of attribute quality characteristics and variable quality characteristics is carried out. Based on the results of observations and interviews, attribute quality characteristics consist of an outer layer that is bloated, bumped, pinned, twisted, marked with lakop and holes. Variable quality characteristics, namely dimensions, eccentricity and nonstandard resistance conductors. After identifying CTQ, the next step is to make a SIPOC diagram to know input and output processing.

Measure stage

Inspections carried out on NFA2XSEY-T products are carried out on each product produced. So that no sampling is taken of these products. Based on the historical data of the company, the percentage of defects in NFA2XSY-T products in August was 30%. 30% of the cable products are handled by rework and repair. This type of attribute defect consists of an outer layer that is bloated, bumped, pinned, twisted, marked with lakop and holes. Data from product inspection consists of the number of defects and the number of defects with each product inspection. So that in processing the data, a control C charts, is created. Before making a control chart, a pareto diagram was made to find out the focus of defects to be discussed, visuals ranked first as the cause of the defect of NFA2XSY-T products with a percentage of 94.4% with 29 events during June to August. (figure:2)

![Figure 2: Pareto chart](image1)

![Figure 3: C chart](image2)

After calculating the C control map by making a revision once by removing 2 data out of control. The following are the CL, UCL LCL and capillary values of the visual defect data.

\[
\text{C chart} \\
CL = \bar{c} = \frac{\sum ci}{k} = \frac{27}{58} = 0.466 \\
UCL = \bar{c} + 3\sqrt{\bar{c}} = 0.466 + 3\sqrt{0.466} = 2.512 \\
LCL = \bar{c} - 3\sqrt{\bar{c}} = 0.466 - 3\sqrt{0.466} = 0
\]

**Process Capability**

\[
S = \sqrt{\bar{c}} = \sqrt{0.466} = 0.683 \\
CP = \frac{UCL - LCL}{6\sigma} = \frac{2.512 - 0}{6(0.683)} = 0.613
\]
CPU = \frac{UCL - \hat{C}}{\hat{C}} = \frac{2.512 - 0.466}{0.683} = 0.998

CPL = \frac{C - LCL}{\hat{C}} = \frac{0.466 - 0}{0.683} = 0.227

CPK = \min (CPU, CPL) = 0.227

Defect per Million Opportunities (DPMO) calculation:

the number of products examined = 58

Total disability (D) = 27

Defect per Unit = \frac{D}{U} = \frac{27}{58} = 0.466

Defect per Opportunity = \frac{U \times CTQ}{D} = \frac{58 \times 6}{27} = 0.077

Defect per Million Opportunities = DPMO x 1000000 = 77586

If DPMO conversion to Sigma level = 3.43 \sigma

Based on the above calculations, obtained DPMO of 77,586 which means there are 77,586 defects in one million possibilities. The DPMO value is then converted into a sigma level which is equal to 3.43 \sigma. After measuring the sigma level, the quality costs incurred in the production process of NFA2XY-S are calculated which consists of preventive costs, appraisal costs, internal failure costs and external failure costs.

### Table 1: Initial cost of quality

| Preventive Cost | Unit | Cost per month | Cost per day |
|-----------------|------|----------------|--------------|
| Salary per month for em-ploy for Medium voltage | 7 employ | Rp 3.800.000 | Rp 26.600.000 | Rp 1.108.333 |
| Oil Gear Box Total Carter EP 220 (2091) | 15 drum | Rp 2.926.000 | Rp 43.890.000 | Rp 1.828.750 |
| Filter | 15 m | Rp 600.000 | Rp 900.000 | Rp 375.000 |
| Subtotal Preventive Cost | | Rp 79,490.000 | Rp 3,312.083 |
| Salary per month for em-ploy for Quality Control | 4 employ | Rp 3.800.000 | Rp 15,200.000 | Rp 633,333 |
| Inspection cost : | | | | |
| Cost determine of tools | 60 x | Rp 26,107 | Rp 1,566,420 | Rp 65,268 |
| Jelly resistor | 60 pcs | Rp 20,000 | Rp 1,200,000 | Rp 50,000 |
| Polypropylene per meter | 10 m | Rp 2,300 | Rp 23,000 | Rp 958 |
| Internal Failure Cost | | | | |
| Sub Total Internal Failure Cost | | Rp 382,196,500 | Rp 15,924,854 |
| External Failure Cost | | | | |
| Service cost | 1 x | Rp 800,000 | Rp 800,000 | Rp 33,333 |
| Copper tape | 500 m | Rp 14,573 | Rp 7,286,500 | Rp 303,604 |
| Non conductive water blocking tape | 500 m | Rp 3,960 | Rp 1,980,000 | Rp 82,500 |
| Semi conductive water blocking tape | 500 m | Rp 5,350 | Rp 2,675,000 | Rp 111,458 |
| PVC | 500 m | Rp 34,585 | Rp 17,292,500 | Rp 720,521 |
| Shipment | 1x | Rp 540,000 | Rp 540,000 | Rp 22,500 |
| Sub Total External Failure Cost | | Rp 30,574,000 | Rp 1,273,917 |
| Total Quality Cost | | Rp 510,249,920 | Rp 21,260,413 |
Can be seen from Table 1, the total cost of quality per month is Rp. 510,249,920 and per day is Rp. 21,260,413. Total preventive costs per month are Rp. 79.49 million, - the total appraisal cost per month is Rp. 17,989,420, -, the total internal failure cost per month is Rp. 382,196,500, - per month and the total external failure costs per month are Rp. 30,754.00, -

![Figure 4: Proportion of quality cost](image)

Based on Figure 4, it can be seen that 85% of quality costs are internal quality failure costs which are costs of failure originating from the production floor. So by minimizing defective products NFA2XSY-T can minimize the cost of internal failure.

**Analyze Stage**

The first step in the analyze stage is identifying the most dominant type of defects using the Pareto Chart.

![Figure 5: Pareto chart of defects](image)

Can be seen in Figure 5, Pareto diagram shows that 80% of disability is caused by 4 types of disability, namely the outer layer is bloated, pinnate, stick and crusty. So that the identification of the causes of the 4 types of disabilities is done using the Ishikawa diagram.
Figure 6: Ishikawa diagram for knotted

Figure 7: Ishikawa diagram for the outer layer is crusty

Figure 8: Ishikawa diagram bloated outer layer

Figure 9: Ishikawa diagram pinnate
After identifying the causes of disability using the Ishikawa diagram, the next step is to identify the causes of failure using the FMEA method.

| Failure Mode                  | Potential Causes of Failure          | Severity (S) | Potential Cause of Failure          | Occurrence (O) | Current Control for Prevention | Detection (D) | Risk Priority Number (RPN) |
|-------------------------------|-------------------------------------|--------------|-------------------------------------|----------------|--------------------------------|----------------|----------------------------|
| Bloated outer layer           | Defective product                   | 7            | Water blocking moist white tape     | 9              | Not available                   | 6              | 378                        |
|                               |                                     |              | Vacuum crosshead suction is weak    | 8              | Pressure indicator supervision by the operator | 6              | 336                        |
|                               |                                     |              | Vacuum crosshead clogged            | 7              | Periodic cleaning of the machine | 6              | 294                        |
|                               |                                     |              | Cleaning after the screening process| 9              | Pressure indicator supervision by the operator | 3              | 189                        |
| The outer layer is knotted    | Defective product                   | 7            | There is foreign material trapped   | 6              | Not available                   | 6              | 252                        |
|                               |                                     |              | Water blocking tape concerns in the screening process | 4              | Supervision by supervisor when operating a screening machine | 3              | 84                         |
| Outer Layer pinnate           | Defective product                   | 7            | The pull of the extruder machine is slow | 4              | Periodic cleaning of the machine | 6              | 168                        |
|                               |                                     |              | Size dies too big                   | 5              | Dies arrangement is carried out according to the correct SOP | 3              | 105                        |
| The outer layer is crusty     | Defective product                   | 7            | The melting material is not perfect | 4              | The operator checks the temperature on the heater | 2              | 56                         |
|                               |                                     |              | The temperature on the heater is not standard | 3              | The operator checks the temperature on the heater | 2              | 42                         |
|                               |                                     |              | Moist pvc material                  | 7              | Not available                   | 6              | 294                        |
|                               |                                     |              | Termocouple errors                  | 6              | Periodic cleaning of the machine | 7              | 294                        |

Based on the calculation of the RPN value, the highest value of the RPN is in the cause of failure of the bloated outer layer, namely the moist white waterblocking tape with an RPN of 378. Furthermore, the entire potential causes of failure are identified using the pareto diagram.
Figure 10: Pareto chart for defects

Pareto diagram shows that 80% of the causes of bloated outer layers are A: moist white water blocking tape, B: vacuum crosshead suction power is weak, C: moist PVC material, D: thermocouple error, E: vacuum crosshead clogged, F: foreign material trapped and G: cleaning after the screening process is not clean. So that the seven causes of failure will be the focus in solving problems using the MAFMA method with priority selection using the AHP (Analytical Hierarchy Process) method to compile the Criteria, interviews with production managers of medium voltage cables and work station operators were conducted.

Table 3: Matrix interviews

| Severity | Occurrence | Detection | Expected cost |
|----------|------------|-----------|---------------|
| Severity | 1          |           |               |
| Occurrence | 1          |           |               |
| Detection | A little more important | Equally important |
| Expected cost | Obviously more important | Obviously more important | A little more important |

Table 4: Expert judgment is converted in numeric value and calculates its priority

| Severity | Occurrence | Detection | Expected cost | Total | Priority |
|----------|------------|-----------|---------------|-------|----------|
| Severity | 1          | 1         | 0.333         | 0.2   | 0.5081   | 0.0992 |
| Occurrence | 1          | 1         | 0.333         | 0.2   | 0.6687   | 0.1306 |
| Detection | 3          | 1         | 1             | 0.333 | 1        | 0.1953 |
| Expected | 5          | 5         | 3             | 0.333 | 2.9428   | 0.5748 |

Initial matrices

| Priority | Result | Result | Priority | Eigen |
|----------|--------|--------|----------|-------|
| 0.099    | 0.4099 | 0.4099 | 0.0992   | 4.132 |
| 0.131    | 0.5401 | 0.5401 | 0.1306   | 4.136 |
| 0.195    | 0.8151 | 0.8151 | 0.1953   | 4.174 |
| 0.575    | 2.3097 | 2.3097 | 0.5748   | 4.018 |

Amount of eigenvalues

\[= 4.132 + 4.136 + 4.174 + 4.018 = 16.46\]

Average eigenvalue
After calculating the eigenvalues of each factor by multiplying the initial matrix with priority values, then dividing the results with priority values, consistency index (CI) will be calculated. Based on calculations, the CI value obtained is 0.0383, then the CR (Consistency Ratio) value obtained from dividing the CR with the RI value (Ratio Index) is 0.04, which means that CR <0.1 means that the value of the pairwise comparison matrix is consistent.

Next, we calculate the alternative criteria weight for the expected cost criteria. The calculation of the consistency of the alternative matrix is based on criteria by compiling an assessment of criteria with numerical values based on interviews and then calculating the priorities of each cause.

| Cause | Causes | Expected cost | Priority |
|-------|--------|---------------|----------|
| A     | 1      | 1             | 0.33     |
| B     | 1      | 1             | 0.33     |
| C     | 0.33   | 1             | 0.3      |
| D     | 1      | 0.33          | 0.33     |
| E     | 3      | 1             | 3        |
| F     | 0.33   | 0.33          | 0.33     |
| G     | 0.33   | 0.33          | 0.33     |

Table 5: pairwise comparison matrix

= 4.115
\[ CI = \frac{\text{initial eigen} - n}{4 - 1} = 0.0383 \]
\[ CR = \frac{CI}{RI} = 0.04 \]

Total eigenvalue = 8.2164 + 7.4519 + 7.4443 + 7.4631 + 8.3844 + 7.4631 + 7.443 = 53.8675

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Next, we calculate the alternative criteria weight for the expected cost criteria. The calculation of the consistency of the alternative matrix is based on criteria by compiling an assessment of criteria with numerical values based on interviews and then calculating the priorities of each cause.

| Initial matrices | Priority | Result | Result | Priority | Eigen |
|------------------|----------|--------|--------|----------|-------|
| 1 1 3 1 0.3 3 3 | 0.1881   | 1.5455 | 1.5455 | 0.1881   | 8.2164|
| 1 1 3 1 3 1 1   | 0.1881   | 1.4017 | 1.4017 | 0.1881   | 7.4519|
| 0.3 1 1 1 1 1 1  | 0.1175   | 0.8747 | 0.8747 | 0.1175   | 7.4443|
| 1 0.3 1 1 0.3 1 1| 0.1004   | 0.7493 | 0.7493 | 0.1004   | 7.4631|
| 3 1 1 3 1 1 1 1  | 0.1881   | 1.5771 | 1.5771 | 0.1881   | 8.3844|
| 0.3 0.3 1 1 1 1 1 | 0.1004   | 0.7493 | 0.7493 | 0.1004   | 7.4631|
| 0.3 1 1 1 1 1 1 1 | 0.1175   | 0.8747 | 0.8747 | 0.1175   | 7.4443|
The CI value obtained is 0.1158, then the CR (Consistency Ratio) value obtained from dividing the CR with the RI value (Ratio Index) is 0.087, which means that CR < 0.1 means that the value of the pairwise comparison matrix between criteria is consistent. After calculating the criteria and weights of alternative criteria for the expected cost criteria, then proceed by calculating the value of local priority for each criterion obtained from the FMEA calculation for severity, occurrences, detection and calculation calculations using paired comparisons for the expected cost criteria. After getting the local priority value, then do the calculation to get the total priority value obtained from the multiplication between the priority weights with the local priority of each cause of failure. In the final stage of MAFMA calculation, the total priority value of each failure is summed so that the final result of the MAFMA method is obtained.

Table 6: Total Value and Rank

| No | Causes of failure                      | Total   | Rank |
|----|----------------------------------------|---------|------|
| A  | Moist white water blocking             | 0.1702  | 1    |
| B  | Vacuum crosshead suction weak          | 0.1675  | 2    |
| C  | Vacuum crosshead clogged               | 0.1243  | 3    |
| D  | Moist pvc material                     | 0.1145  | 4    |
| E  | Termocouple error                      | 0.1662  | 5    |
| F  | There is foreign material trapped      | 0.1118  | 6    |
| G  | Screen cleaning process is not clean   | 0.1177  | 7    |

The first sequence of causes of failure based on the total value of MAFMA is occupied by the cause of the white water blocking tape which is moist. Therefore, problem solving will focus on the causes of failure. To explore the causes of moist white water blocking tape, the cause of failure will be identified using the Ishikawa diagram.

Figure 11: Ishikawa diagram for water blocking moist white tape
Based on Ishikawa diagram the cause of moist water blocking tape, found 3 causes, namely white water blocking tape coating in the screening process is prone to moisture, operators put water blocking tape carelessly and the operator does not use gloves when touching cables that have been coated with water blocking tape.

**Improve step**

As explained in Table 6, it turns out that there are three causes that must be corrected. The first is the white blocking tape that is moist, the second is the weak vacuum crosshead power and the third is the thermocouple error, and after analyzing with the Ishkawa diagram, what needs to be improved is as follows:

a. The human factor for water blocking tape is that it is moist.

This is due to the negligence of operators who put cables that have been coated in water blocking tape carelessly and do not use gloves, the proposal used is to make changes to the standardization of more informative work.

b. Environmental factors for dirt buildup in vacuum motors

The accumulation of dirt on the vacuum motor so that the suction power of the weak crosshead vacuum is to add a cyclone filter that functions to filter out the sucked dirt. As for the cyclone filter chosen by the company is the brand Super Dust Deputy XL 6’Cyclone

c. Proposal made on thermocouple error

The cause of the thermocouple error is that there is no work instruction for the thermocouple calibration process, because it is necessary to conduct a calibration process, among others, by cleaning the thermo couple regularly and visually checking the thermocouple before calibration.

**Control stage**

The control phase carried out in this study is to compare the sigma six metrics before and after implementation. Implementation is carried out from January 14 to January 31, 2019, with data collection as many as 31 observations. The results obtained are as follows:

| Indicators       | Before implementation | After implementation | (%)  | Remarks   |
|------------------|-----------------------|----------------------|------|-----------|
| DPMO             | 77.585                | 55.558               | 28.39 | Decrease  |
| Sigma Level      | 2.92                  | 3.09                 | 5.82 | Increase  |
| Cost of quality  | Rp 21,260,413         | Rp 14,049,757        | 33.91| Decrease  |

5. **Conclusion**

The conclusions that can be drawn from this study are:

1. The type of disability in cable products is a visual defect that consists of an outer layer that is bloated, bumped, pinnate, marked lacop, berbolong - hollow and crusty.
2. The production process of NFA2XSY-T cables has a DPMO value of 77586 which is equivalent to 3.43 sigma, and the total cost of quality is Rp. 510,249,920 per month or Rp. 21,260,413 per day.
3. Proposed improvements to improve quality and reduce product quality costs. Make changes to work instructions that are more informative, add cyclone filters to the vacuum motor and make work instructions for the calibration process.
4. After implementation of the company, it turns out that DPMO has decreased by 28.39%, Sigma level has increased by 5.82% and Cost of Quality has decreased by 33.91%

**References**

[1] Montgomery,D.C. *Introduction to Statistical Quality Control*, 5th edition, Wiley, New York, 2005
[2] E.R. James, W.M. Lindsay, *An Introduction to Six Sigma & Process Improvement*, South Western, Singapore: Thomson, 2005
[3] Braglia, Marcello, *MAFMA: Multi-Attribute Failure Mode Analysis*. (International Journal of Quality & Reliability Management). University of Pisa, Italy, 2000.
[4] H. Mowen, *Cost Management, Accounting & Control. 5th Edition*, Stamford: Thompson Corp, 2006.