Improving Productivity and Quality of Medium Voltage Cable Production

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Abstract. A cable manufacturer has produced varieties of products, such as low voltage cables, medium voltage cables, telephone cable, and fiber-optic cables. The main goal this company is to achieve ultimate customers satisfaction through timely delivery, consistency in product quality, and best service. The company faces a problem where daily production cannot reach 6,000 meters/day as requested by management. Moreover, defects have been found in certain processes. A method of countering those problems is proposed by integrating OEE, SMED, and HFACS. Based on the analysis results, the OEE from insulation and screening machines are not meet the company target which is below 60%. In addition, visual defect shown as the most frequent type of defect that occurred in the medium voltage cable production process with 56%. SMED has been utilized to separate the internal task and external task, then the daily production can achieve 6,165 meters/day by reducing the setup time based on the simulation result. In addition, HFACS has been used to analyze the main problem due to human factor aspects, then it is recommended to add extra operator, extra material handling for lifting/moving products, and a re-data checking procedure in the business process.

Keywords: cable manufacture, OEE, SMED, HFACS, defects, productivity

1. Introduction
A cable manufacturer was established in 1973, located in Tangerang, has produced varieties of products, such as low voltage cables, medium voltage cables, telephone cable, and fiber-optic cables. The main goal this company is to achieve ultimate customers satisfaction through timely delivery, consistency in product quality, and best service. In achieving this goal, the company always upholds national and international standards. The division experts regularly carry out accurate examinations and control that supported by state of the art at the technology, product engineering, and quality control. Supervision and quality control are implemented at every product stage. The supervision and quality control starts from customer order, raw material, inspection, production process, final product inspection, product delivery, until after-sales service.

The cable manufacturer encounters production problem for medium voltage cable which has not to be able to work optimally. This company shows the production output cannot meet the demand target, and the production in the current condition has a defect that is only found in certain process. Since there is long time on the setup time, the daily demand of 6,000 meters is hard to be achieved. In addition, the company has reached some defect rates in certain months with a percentage of 1-2%. The defect product...
obstructs the production process since it needs time to locate the defect area and repair the defect. Then, the estimated time for the customer receives the finish products can be missed from the target that has been set by production planning department.

Several literatures have explained OEE (Overall Equipment Effectives) assessment that has been used to increase productivity of a production line and focused only on the developing maintenance program. OEE is one method that used to measure the success of Total Productive Maintenance (TPM) program. OEE is procedure used to determine the effectives of machine that consists of availability (A), performance (P), and Quality (Q) [1]. OEE has been used to identify maintenance improvement potential at the croissant production line by analysing failure data that cover a period of 15 months. The evaluation of OEE provide a useful guide to the aspects of production process, which identifies the critical points of the line that require further improvement through effective maintenance strategy [2]. By combining OEE and Fuzzy FMEA (Failure Mode Effect Analysis), the main root cause that often-occurred damage to the machine can be identified, then how to solve the problems to increase machine productivity can be prescribed [3].

The objectives of this paper are to identify the factors and improve the productivity of medium voltage cables by increasing the Overall Equipment Effectiveness rate of each machine to exceed than 60%. Moreover, the cause of the defect in medium voltage cable production will be analyzed to improve the quality of the current production state. This paper provides several considerable impacts to the company that by considering the implementation of OEE method, the higher efficiency of production line can be increase by reducing the setup time. Moreover, the source of defect due to human error can be identified, then the quality of product can be improved.

2. Method

Overall Equipment Effectiveness (OEE) concept is very useful for analyzing the availability, performance and quality of machines in production plants. OEE measurement tool was developed from the TPM concept [4]. The goal of TPM is to achieve zero breakdown and zero defects related to equipment. The TPM concepts puts much attention on productivity equipment, since they have a high influence on quality, productivity, cost, inventory, safety and health, and production output [4]. OEE can be defined as a measure of total equipment performance, that is, the degree to which the equipment is doing what is supposed to do [5]. OEE is a three-part analysis tool for equipment performance based on its availability, performance, and quality rate of the output. OEE can points to hidden capacity in a manufacturing process and lead to balanced flow. OEE can be used to track and trace improvements or decline in equipment effectiveness over a period of time [6]. In this paper, data is acquired through direct observation, interviews, and time study. The data is in the form of path description of the production line, production method, production process, and others. Stopwatch is used to retrieve the preparation time, loading time, unloading time, installation time, and other activities that needed to complete the process. In addition, the data is also collected from company record such as: data of medium voltage cable production, defect, quality, and maintenance activities in 2017 and 2018. The value of OEE can be measured based on the company record through calculation of ratio on Availability, Performance, and Quality on each machine.

Single Minutes Exchange of Dies (SMED) is a method that focuses on the recognition of internal and external activities. This relates primarily by converting and internal activity and an external activity. This relates primarily by converting an internal activity to an external amount as much as possible by also minimizing the internal ones [7]. SMED is characterized as a scientific approach for the reduction of setup times, and which can be applied in any industrial unit and for any machine [8]. In SMED, internal setup time and external setup time are two important operations that involved. Internal setup time can be only carried out when the machine or process has stopped, and external setup time could be performed while the machine or process is still in operating. Based on the OEE result and fishbone diagram, the root cause on long setup time can be solved by increasing Availability ratio through SMED. In the SMED, the external activities during setup time may be done, while the process (internal activity) is still operational.
Human Factor Analysis and Classification System (HFACS) was specifically developed to define the latent and active failures implicated in Reason’s ‘Swiss cheese’ [9]. Meanwhile, [10] explains accident causation with the breakdown of interaction between fundamental elements in an organization; decision makers, line management, preconditions, productive activities, and defences. In Swiss cheese model, elements constitute a production system which receive input and produce some outputs. The human contributions to the breakdown of these elements are separated into two categories active and latent failures. Active failures are errors where the effect can be seen almost immediately, while latent failures refer to the errors whose adverse consequences may lie dormant within the system for a long period of time [10]. One limitation of Reason’s model that respond by HFACS framework is that it does not defines the window of accident opportunity. Human Factor Analysis and Classification System (HFACS) is a framework tool to assist an investigation process to systematically identify active and latent failures within an organization that culminated in the accident. The goal of HFACS is to underlying casual factors that lead to an accident and understand the process framework. HFACS describes four levels of failure, such as: Unsafe Acts, Preconditions for Unsafe Acts, Unsafe Supervision, and Organizational Operations [9]. Based on the fishbone diagram, most of the product defects is affected by human error. Human error is not only from the Man category, but also can be influenced by Management and Method category. In this paper, the HFACS is used to define the cause of visual defect during the process.

3. Result and Discussion
This paper studies in one of the plants owned by the cable manufacturer, which produce medium voltage cable. Medium voltage cable is a power distribution cable with a range from 2,000 to 35,000 volts. The production of medium voltage cable must through eight processes with quality check for each process before continuing to next process. The eight processes flow are Drawing, Stranding, Insulation, Screening, Cabling, Inner Sheath, Armour Sheath, Outer Sheath with Marking, and Final Test. The medium cable production starts from drawing process where the aluminium bought from a producer is stretched by being forcibly pulled to make the diameter from 0.8 mm into the desired dimension. The stretched aluminium then continues to a stranding process, where 35 stretched cables are twisted into one single core, layer by layer. Afterwards, the twisted single core cable is insulated in the insulation process. In insulation process, the previous finished product is coated with 100°C melted Cross-Linked Polyethylene (XLPE). The finished coated cable has three layers of coating, the inner layer called semi-conductive compound, the middle and the thickness layer called XLPE layer, and the outer layer is strippable semi-conductive compound. After being coated, the cable continues to the screening process. In the screening process, there are three stages of screening: semi-conductive water blocking, metallic screen, and non-conductive water blocking. Those process mentioned above are producing single core cable and after the single core has finished the screening process, three finished single cores will be twisted in the cabling process. Then, the twisted cable will be covered with Galvanized Steel Tape in armour process, to protect the cable since medium voltage cables are commonly implemented for underground in streets, so it will not break if passed by heavy load or when exposed to sharp tools during excavation process. The last process is called outer sheath process, where the armour is coated with red extrude 90°C grade PVC and stamped for the product code and company name right after when the PVC still in the hot state. Figure 1 shows the production process flow of medium voltage cable.

Based on data acquisition on processing time of each stations, model of existing condition has been developed by using Tecnomatix Plant Simulation®. The simulation of this model shows that the existing capacity for producing medium voltage cable can achieved 5,753 meters/day or still below 6,000 meters/day.

The company has categorized the defect into Visual, Dimension, Electrical, and Construction defect. Based on the secondary data, the most significant influence defect can be analyzed by using Pareto chart as shown in Figure 2.
As can be seen from Figure 2, Insulation and Outer process have the most significant defect influence on the defect percentage by total 88%, where 68% from Insulation process itself. After analyzing and find the most significant influence process to the defect is the Insulation process, the next step is to find which kind of defect that frequently occurs in the Insulation process. From Figure 3, visual defect shown as the most frequent type of defect that occurred in the medium voltage cable production process with 39% and followed by electrical defect with 23%. Electrical defect can be happened because of influenced by visual defect. To explore more in detail the causes of visual defect, this paper uses Fishbone Diagram for further analyzing the root-cause of visual defect. Figure 4 is a Fishbone Diagram that is used to find the root cause of visual defects.
Based on Figure 4, the visual defects are caused by four types of categories, those are: Machine, Man, Method, and Management. In the other hand, from the analysis obtained, most of the damage is affected by human error. Human error is not only from the Man category, but also can be influenced by Management and Method category. Human errors that can cause visual defect in Insulation process can be divided into two categories: Collision and product does not meet the customer request. Collision is a defect caused by errors in material handling because workers ignore procedures. Whereas product does not meet the customer request, are defects that occur because of input data errors or errors in the factory that result in the products produced not in accordance with what is desired by the customer. Table 1 shows the Human Factor Analysis and Classification System (HFACS) to summarize and analyse the human errors that cause collision and product does not meet the customer request.

Table 1. Human Factor Analysis and Classification System

| HFACS Level | Classification | Risk |
|-------------|----------------|------|
|             | Errors         | Violations       |
| 1. Unsafe Acts | Decision Errors | Routine | Exceptional |
|              | Worker does not use tools to move the finished products | Moving item without any moving tools | Human errors |
|              | Worker does not follow instructions | No data checking | Lead to unsafe act |
|              | Worker sets the wrong tools | |
|              | Skill-Based Errors | |
|              | No skill needed | |
|              | Perceptual Errors | |
|              | Worker does not know the effect of not following instructions | |
|              | Worker fills the wrong form from the office | |
|              | 2. Pre-conditions for Unsafe Acts | Conditions of Operators | Personnel Factors | Environmental Factors |
|             | Adverse Mental States | Crew Resource | Physical Environment | Technological Environment |
|             | Careless worker | Failed to coordinate | Manual data transfer |
|             | Loss of situational awareness | Failed to conduct adequate briefing | |
|             | Worker experiences fatigue | Personal Readiness | |
|             | Mental fatigue |  |
|             | Adverse Physiological States | Crew Resource | Physical Environment | Technological Environment |
|             | Medical illness | Failed to coordinate | Manual data transfer |
|             | Unable to lift heavy products | Failed to conduct adequate briefing | |
|             | Physical/Mental Limitation | Crew Resource | Physical Environment | Technological Environment |
|             | Impossible to lift finished products | Crew Resource | Manual data transfer |
|             | Visual limitations | Crew Resource | Manual data transfer |
|             | 3. Unsafe Supervision | Failed to Correct the Problem | Supervisory Violations | |
|             | Inadequate Supervision | Worker continue to violate the instructions | |
|             | Planned of Inappropriate Operations | Cannot to supervise at any time | |
|             | Failed to provide oversight | |
|             | No planned operation | |
|             | Failed to provide correct data | |
|             | Resource Management | Organizational Climate | Organizational Process | |
|             | Lack of supervision | No reward or punishment | Lead to data error |
|             | No daily briefing | No standard procedure for moving finished product | Lead to unsafe act |
|             | Lack of training | |
|             | Limited material handling tools | |
|             | 4. Organizational Operations | Organizational Climate | Organizational Process | |
|             | Lack of supervision | No double checking | Lead to unsafe act |
|             | No daily briefing | |
|             | Lack of training | |
|             | Limited material handling tools | |

- Collision
- Delivered product does not meet the customer request
- Unintentional errors/unsafe acts
- Unintentional errors/data input
- Human error
- Uncoordinated
- Human errors
- Lead to unsafe act
- Unprofessional mindset
- Lead to data error
Table 2 shows the current condition, expected condition, and proposed improvement based on two categories of wrong material handling and product does not meet the customer request. The first defect problem caused by human error is wrong material handling due to the current condition where there is limited moving tools and workers moving the finished products by rolling them. The expected conditions are the company provide a more efficient and safe moving tools and also workers to follow the procedure given for material handling. To solve this problem, there is three improvements to be proposed, first is hoist crane can save more time to moving the item and reduce the possibility of defects caused by collisions. Second, the company should give proper training and a presentation about the importance of material handling. Moreover, third is by assigning a person for a specific supervision task in the factory.

| Summary                        | Current Condition                        | Expectation                          | Proposed Improvement                                      |
|-------------------------------|------------------------------------------|--------------------------------------|-----------------------------------------------------------|
| Wrong material handling       | • Limited material handling tools        | • Efficient and safe material handling tools | • Install crane                                        |
|                               |                                          | • Worker follows the procedures for material handling | • Provide training and importance information related to material handling |
|                               |                                          |                                      | • Assign person to supervise                            |
| Product does not meet the customer request | • Move the item by rolling the finished products | • No errors during data transfer | • Add procedure for data checking |

The second defect is an error due to wrong data transfer resulting in a wrong production. The expectation of solving this case is by eliminating the error in data transfer using a computer system. Due to the current situation where all the data transfer is still using a paper form, implementing computer system to all section of the company can take a huge investment. In result, the possible improvement to be proposed to the company is adding a re-data checking procedure in the business process.

Based on the simulation results, the OEE rate has been analysed by utilizing secondary data of each machine. OEE rate calculation depends on three main ratios, such as Availability, Performance, and Quality. The OEE value does not meet the target since the obtained value of OEE is below 60%. Table 3 shows the OEE ratio on overall machines.

| Station | Type of Machine   | Availability | Performance Rate | Quality Production Rate | OEE  |
|---------|-------------------|--------------|------------------|-------------------------|------|
| 1       | Drawing 1         | 84%          | 96%              | 100%                    | 80%  |
|         | Drawing 2         | 84%          | 96%              | 100%                    | 81%  |
| 2       | Stranding ST 54 A | 87%          | 94%              | 99%                     | 82%  |
|         | Stranding ST 54 C | 86%          | 94%              | 99%                     | 81%  |
| 3       | Insulation JR     | 70%          | 86%              | 98%                     | 59%  |
|         | Insulation SUMITOMO | 75%        | 80%              | 98%                     | 59%  |
| 4       | Screening TP-2    | 61%          | 97%              | 100%                    | 59%  |
|         | Screening TP-5    | 61%          | 95%              | 99%                     | 58%  |
|         | Screening TP-6    | 61%          | 95%              | 100%                    | 58%  |
| 5       | Cabling 26 A      | 82%          | 79%              | 100%                    | 65%  |
|         | Cabling 26 B      | 83%          | 80%              | 100%                    | 66%  |
| 6       | Inner             | 71%          | 98%              | 100%                    | 70%  |
| 7       | Armoring TP-4     | 73%          | 95%              | 100%                    | 70%  |
|         | Armoring TP-3     | 76%          | 95%              | 100%                    | 72%  |
| 8       | Other             | 77%          | 91%              | 99%                     | 69%  |

The company has targeted the OEE on each machine must be larger or equal to 60%. The OEE value on the Insulation JR, Insulation SUMITOMO, TP-2 Screening, TP-5 Screening, and TP-6 Screening have not yet reached the targeted of OEE standard values. Based on Table 3, the low availability
especially on Insulation and Screening machines is one factor that makes the OEE value does not reach the target of the company. The low availability rate on those machines was caused by long period of setup time due to lack of supporting operator and material handling tool. The operator waits until the machine stops and then he/she prepares new bobbins. If the supporting operator is present, he/she can prepare new bobbins while the machine is in process. Furthermore, the bobbins are heavy weight, then the operator must wait for the other operator to use the material handling tool for installing/moving the bobbins.

Since the long period of setup time has significant impact on low availability rate and OEE rate, then Single Minutes Exchange of Die (SMED) was used as method to reduce the setup time. Table 4 shows the setup activities at Insulation JR machine after applying SMED. The setup consists of two activities, internal and external setup. Internal setup is activities that require an inactive (shut down) process, meaning that operator no orders to do set up until the machine stops. External setup activities may be done while the process is operational. From the SMED result on Insulation JR machine, the setup time decreased to 70.12 minutes/day from 109.71 minutes/day.

| No | Work Element             | Task Time (s) | Internal | External |
|----|--------------------------|---------------|----------|----------|
| 1  | Loading input            | 470.30        |          |          |
| 2  | Unloading input          | 461.15        |          |          |
| 3  | Running                  | 18850.00      |          |          |
| 4  | Preparation new loading input | 200.20      |          |          |
| 5  | Preparation new loading output | 181.30     |          |          |
| 6  | Unloading output bobbin  | 503.70        |          |          |
| 7  | Unloading input bobbin   | 372.75        |          |          |
| 8  | Checking cable           | 402.30        |          |          |
| 9  | Checking bobbin          | 385.60        |          |          |
| 10 | Taking and putting tools | 1608.45       |          |          |
| 11 | Cleaning                 | 1997.10       |          |          |
|    | **Total Setup Time**     |               | **Internal (min)** | **External (min)** |
|    |                          |               | 70.12    | 39.59    |

The similar SMED method has been applied for other Insulation and Screening machine and found that significant decrease on setup time. The setup time decreased to 70.24 minutes/day from 109.81 minutes/day on Insulation Sumitomo machine. While, on Screening TP-2, TP-5, and TP-6, the setup time decrease from 170.80 minutes/day to 101.01 minutes/day, from 161.90 minutes/day to 92.21 minutes/day, and from 161.09 minutes/day to 88.34 minutes/day, respectively.

By using the same production model on Figure 2 and modify the setup time in accordance to SMED analysis, the simulation shows that the number of production output has reached 6,165 meters/day from 5,753 meters/day, then it can fulfil the daily customer request.

4. Conclusion and Recommendation
It is necessary to improve productivity so that the output can be maximized. In this case, each operating process must be analyzed for the cause of the problem so that how well the resources are managed and utilized to achieve optimal results. The OEE from insulation and screening machines are not meet the company target which is below 60%. Low availability rate that caused by long period of setup time is the main factor that causes the OEE of the insulation and screening machines does not meet the target of the company. SMED method can be used to reduce the setup time and increase the output daily output of the company.

Meanwhile, the quality of medium voltage cable production in this company gives a significant impact on the product quality, production schedule, waste material, and delivery time. Based on the Pareto chart, Insulation process has the highest defect rate for the past two years. Defects that often occur
in Insulation processes are Visual and Electrical defects, where Electrical defects occur due to Visual defects. Fishbone diagram shows that three categories that inflict Visual defects caused by human errors from various aspects. Human Factor Analysis and Classification System analysis to look for potential errors caused by human errors.

The results of the analysis using Human Factor Analysis and Classification System shows that human error that results in collide is workers who do not comply with the rules and tools that use for material handling. While the occurrence of production errors is due to an error entering the data. Both of these errors can occur due to lack of supervision and professionalism when working.

A new material handling is proposed to be installed in intention to minimize the possibility of Visual defect caused by a collide. The installation of a crane also uses to decrease the setup time. For maximizing the use of cranes, an extra operator is needed for helping the main operator in preparing the material. In addition, regular training is also needed for workers in the factory to know the importance and influence of material handling on products, safety and cost to the company.

Business Process Improvement is a new procedure of re-data checking before all data continues to the manufacturing department. The aim of the data checking is to detect an error in data transfer and to correct any errors that exist to prevent production errors caused by input data errors.

Since this paper shows a proper result in improving the production quality, the future study related to the quality improvement in production will be required. In addition, the company want to increase the daily production of medium voltage cable up to 10,000 meters/day. Then, feasibility study related to the additional machines and operators need to be obtained.

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