FUZZY FMEA APPLICATION TO IDENTIFICATION RISK IN-PROCESS PRODUCTION OF TOYOTA HI-ACE WIRING HARNESS PRODUCT

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Abstract

In product manufacture, the high failure rate problem of produce product is the number of product defects. Several types of defects have a high enough percentage. To solve this problem, we need to identify the failures and to get the assessment information of the three risk factors. Our research using the traditional FMEA method at the production of Wiring Harness products to shows the current condition of various modes of failure in those areas. This study focuses on implementing fuzzy FMEA to identify the potential risks that may occur along with the assembling of the Wiring Harness process. The fuzzy FMEA approach is preventing product and process problems before they occur, this paper is also expected to result in some mitigation effort that can be applied to improve the Wiring Harness production process. With the Fuzzy FMEA method, we have found the highest FRPN value that shows the highest defect such as damage insulation is 8.5, damage terminal is 8.5, and the damaged part is 8.5 and the highest RPN from the traditional FMEA is damage insulation (324). To solve this problem, we propose to use the fishbone diagram and give suggestions for improvements to the highest failure modes that are damaged insulation.

Keywords*: FMEA; Fuzzy FMEA; Wiring Harness; Risk; Toyota*

1. Introduction

Product quality is determined by customer demand. Furthermore, qualities are determined as a distinctive feature, the nature of goods, and the services that can meet the customer expectation (Kotler & Keller, 2009). However, this quality standard faces serious problems that come from defective products that cause many claims from consumers. If a defective product moves to the consumer and then causes a loss, the company must replace the loss that has been experienced by the consumer. One of the biggest negative effects was the collapse of the company's reputation in the eyes of consumers. If such a situation is not addressed immediately, the company will lose potential customers. Therefore with good and correct quality control, the manufacture of the product can meet consumer desires (Sutiyarno & Chriswahyudi, 2019). That is why the production process is very important and should be improved continuously in wiring harness car spare part company that located in Balaraja district.

The assembly process uses defective cable products that exceed the minimum limit set by the company, namely 5%, in February 2018 was 9.19%, March 2018 was 8.15%, and April 2018 was 8.19%. So that the number of defects in the assembly of the wiring harness needs to be minimized. One way that can be done in increasing productivity and minimizing the level of disability is to approach FMEA. The main objective of FMEA is to discover and correct the potential failure problems during the stages of production and quality assurance.

There have been many approaches available to identify risk. Failure mode and effect analysis (FMEA) is a method to shows potential failure modes at one level and investigates the effect on the next subsystem level (Sharma et al., 2005). Many studies have been used FMEA approach to identify risk in their case. Budi Puspitasari et al., (2017) using FMEA to improve product quality in Toyota Motor Manufacturing Indonesia. Sukwadi et al., (2017) using FMEA method to determine the risk priority of failure mode in a work accident. Kumru & Kumru (2013) using fuzzy FMEA to identify potential failures in the purchasing process of a public hospital. Fuzzy FMEA is applied to overcome the limitation of conventional FMEA such as the subjective and qualitative description, in natural language, the relative importance among the risk ratings, the difference of risk representation among the same ratings, and the knowledge shared among FMEA team members (Kumru & Kumru, 2013). Sharma et al (2005) argue the fuzzy risk assessment methodology based on fuzzy sets theory (propounded by Zadeh (1965) provides a more flexible and meaningful way to assess risk

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associated with component/item failure modes (Sharma et al., 2005).

This study focuses on implementing fuzzy FMEA to identify the potential risks that may occur along with the assembling of the Wiring Harness process. Fuzzy FMEA is adopted to minimize the subjectivity of experts' assessment in the risk factors evaluation stage. There is still no published record that applies the fuzzy FMEA approach for identifying risk in the Wiring Harness production process. It is expected that this study could contribute to share knowledge regarding the risk profile of the Wiring Harness production process. As the purpose of Fuzzy FMEA approach is to prevent product and process problems before they occur, this paper is also expected to result from some mitigation effort that can be applied to improve the Wiring Harness production process. The production company of Wiring Harness product is employed as the case study to implement the fuzzy FMEA methodology.

2. Methods

A. Failure mode and effect analysis (FMEA)

FMEA is an analytical technique that combines the technology and experience of people in identifying foreseeable failure modes of a product or process and planning for its elimination (D. Besterfield, C. Besterfield-M., G.H. Besterfield, 2003). FMEA is one of the tools to help to control the quality of the product would be the Failure Mode and Effect Analysis (FMEA) method. FMEA identifies potential failures by assigning a value or score for each failure mode based on occurrence level, severity level, and detection level (Stamatis, 2005).

The traditional FMEA uses a risk priority number (RPN) to evaluate the risk level of a component or process. The RPN is obtained by finding the multiplication of three factors, which are the probability/ occurrence of the failure (O), the severity of the failure (S), and the probability of not detecting the failure (D) (Kumru & Kumru, 2013). Traditional FMEA uses a score of 1 and 10 (with 1 being the best and 10 being the worst case) is given for each of the three factors, and a risk-priority-number (RPN). Thus, the RPN value helps the FMEA team to identify the components or subsystems that need priority actions for improvement (Dinmohammadi & Shafiee, 2013).

Below are the steps taken to implement FMEA:

1. Identifying the production and quality control process in Wiring Harness Product
2. Identifying some potential failure modes of the production and quality control process, the effect of failure modes on the production and quality control, and the cause of the failure modes
3. Assessing failure modes on the machine for severity (S), occurrence (O), and detection (D)
4. Calculating the Risk Priority Number (RPN) (Kumru & Kumru, 2013)

It can express mathematically such as:

$$RPN = O \times S \times D \qquad (1)$$

B. Fuzzy approach to FMEA

Fuzzy logic is one method to analyze systems that contain uncertainty (Kusumadewi, 2002). Research using Fuzzy Logic will get more accurate results than using conventional FMEA (Immawan et al., 2018). In the Fuzzy FMEA method, the RPN assessment is not carried out as in conventional FMEA but uses fuzzy numbers for the values of S, O, and D which will then be multiplied by the weight of the importance of each of the S, O, and D factors (Mansur & Ratnasari, 2015). According to (Xu et al., 2002) some weaknesses of Conventional FMEA namely:

1. Statement of the FMEA is often subjective and qualitatively described in natural language.
2. Three levels of severity parameter (S), occurrence (O), and detection (D) are assumed to have similar interests, it turns out in practice the weight of the interests of all three parameters are not the same.
3. The value of risk priority number (RPN) was produced by multiplying the level of S, O and D may imply a representation of risk.

To overcome the weakness - the weakness of the method is based on fuzzy logic is often used to manipulate the linguistic terms used directly in making a critical assessment (Immawan et al., 2018). FMEA fuzzy process stages (Immawan et al., 2018; Mansur & Ratnasari, 2015):

1. Arrange to fuzzification (Define the fuzzy set membership function for three parameters S, O, D as fuzzy input)
2. Create a rule-based fuzzy logic (By using the IF-Then rules obtained from experts and workers. It’s combined into a mapping from fuzzy input to fuzzy inference)
3. Defuzzification/ Perform Fuzzy inference process.

The most popular ones among fuzzy logic systems with fuzzy concepts (fuzzy sets, verbal variables, etc.) are the following: pure fuzzy logic systems, Takagi and Sugeno's fuzzy system, and fuzzy logic systems with fuzzifier and defuzzifier (Mariajayaprakash & Senthilvelan, 2014). One of the most commonly used algorithms in fuzzy logic is the Mamdani algorithm (Rafie & Samimi Namin, 2015). Three input variables (S, O, D) are made fuzzy using the membership function. As a membership function, trimf was used in this study. Trimf (triangular-shaped membership function) is a function of a vector x and depends on three scalar parameters (a, b, and c), as given by (Adar et al., 2017):

$$f(x;a;b;c) = \begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \end{cases} \qquad (2)$$

Perform the Fuzzy inference process is Fuzzy logic output can be converted into a real value that represents the risk (RPN value again).

Table 1. Linguistic, Severity, Occurrence, and Detection Fuzzy Number Detection

No	Severity	Occurrence	Detection	Fuzzy Number
1	Insignificant	Rare	Almost Certain	1,2,3,4,5
2	Moderate	Possible	Moderate	4,5,6,7,8
3	Catastrophic	Almost Certain	Almost Uncertain	7,8,9,10

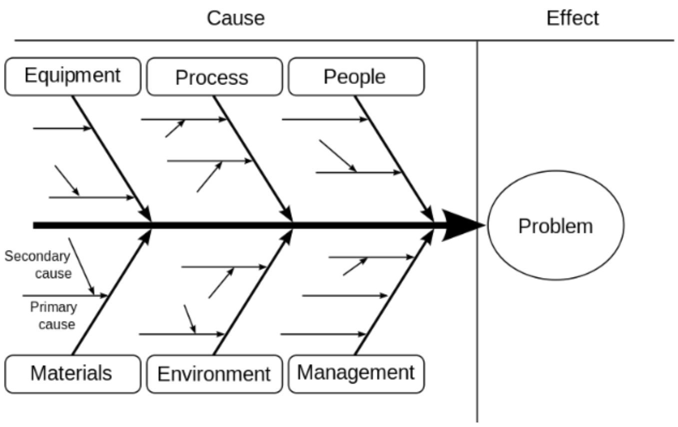

Figure 1. Fishbone Diagram

Table 2. Failure Mode Identification

No.	Process	Potential Failure Mode
1	Sub Assy	TPO (Terminal Push Out), cross circuit, wrong cavity, missing spacer/ retainer
2	Setting	Unlock spacer/ retainer
3	Tapping	Loose tapping, loose band clamp, wrong dimension, wrong tapping, wrong part, missing tapping, missing part, damage terminal, damage insulation
4	Checker	Not click fuse, damage part
5	Visual	Missing tie back
6	Finishing	Unlock lock protector, exposed wire

The defuzzification centroid can be determined by the following equations:

$$y* = y_c = \frac{\int y\mu_{output}\ (y)dy}{\int \mu(y)dy} \qquad (3)$$

Where:
y^* – crisp output
y_c – center of area(COA)
μ – member of function

C. Fishbone Diagram Method

The Fishbone diagram is often called a Cause-and-Effect Diagram or Ishikawa Diagram. Kaoru Ishikawa, a quality control expert from Japan, is one of the seven basic quality tools (7 basic quality tools). Fishbone diagrams are used to identify possible causes of problems and especially when a team tends to go into a routine (Tague, 2005). This tool identifies multiple potential factors that cause overall effect problems (Yazdani & Tavakkoli-Moghaddam, 2012).

In the fishbone diagram each branch represents the "root cause" of the problem is written down or visually by several machine factors (machines or technology), namely methods (methods or processes), materials (including raw materials, consumption, and information), Manpower, Measurement, or inspection), and the Environment.

3. Result and analysis

A. Result of FMEA Application

The result of this study is shown in **Table 1** and **Table 2** with **Figure 1** describing failure mode identification from the wiring harness production process and **Table 2** explaining the results of failure modes, effects, and causes of failure mode. Determine risk identification from the process production of wiring harness using method generates risk factor by identifying any potential negative event occurred on a business process. Identification of negative events could be done by determining sub-system failure and risk drivers that cause failures. After determining the value of severity, occurrence, and detection, then we can calculate the value RPN for each of these failure modes.

Based on the FMEA in **Table 2**, it can be seen the level of risk of each type of failure in each process. Based on **Table 3**, the failure of the damage insulation results in an RPN value of 324 where the highest value is and requires handling/ repair. This failure has a severity score of 9 which means that a rework process can be carried out in the area/ cage rework, rework on

Table 3. Failure Modes, Effect, and Cause, Risk Priority Number (RPN)

Process Name	Potential Failure Mode	Potential Effect of Failure	Potential Cause of Failure	S	O	D	RPN
Sub Assy / Housing	TPO (Terminal Push Out)	No Current Found when inspection Process	Operator not using SOP which is 4T (tekan tarik tekan tarik)	5	2	3	30
	Cross Circuit	Checking Process stop in the middle, there is a jumper on checker machine	The operator does not scan the Kanban and does not follow the existing navigation sequence	7	7	1	49
	Wrong Cavity	Checking Process stop in the middle, there is a jumper on checker machine	The operator does not scan the Kanban and does not follow the existing navigation sequence	7	7	1	49
Setting	Missing Spacer/retainer	The connector cannot lock	There is no sorting of the material when it is supplied	5	2	7	70
	Unlock spacer/retainer	The connector cannot be attached to the opponent's connector because the spacer is blocked	Operators do not follow the existing standard sequence of processes	4	3	3	36
Tapping	Loose tapping	Tapping is not tight or loose	The tapping method was not up to standard and the fork spacing was too low causing the tape to hit the jig board	5	7	4	140
	Loose Band Clamp	The clamp/clip cannot be attached to the car body	The operator does not self-check when cutting the clamp band with a gun	4	5	6	120
	Wrong dimension	The size of a certain part exceeds the tolerance limit desired by the customer	Lack of production preparation, lack of approval on the jig board, and the operator did not include the circuit/ wire on the fork in the rapping process	7	8	5	280
	Wrong tapping	The mismatch of the tapping method between the specifications and the actual tapping process results	The operator does not follow a standard sequence of work processes and the operator does not understand drawings	6	2	5	60
Tapping	Wrong part	The wiring harness cannot be attached to the car body	Placement of parts or materials that are not in accordance with the identity of the material, do not carry out activities 7s	7	2	4	56
	Missing Tapping	Wire can be scratched because it is not protected by tappings	Operators do not follow existing process sequences and work standards	6	2	5	60
	Missing part	The wiring harness cannot be attached to the car body	Operators do not follow existing process sequences and work standards	5	5	2	50
	Damage terminal	Difficulty when the joining process is carried out with the opponent's terminal	During the process, the terminal is not inserted into the gutter so that it is trampled on	9	3	8	216
	Damage insulation	Cause sparks when the car is started and cause a fire in the vehicle	During the process, the circuit is not inserted into the gutter, so it is stuck with another part	9	6	6	324
Checker	Not click the fuse	There is no current when simulating the car	The operator did not perform the SOP properly	5	4	2	40
	Damage part	The wiring harness cannot be properly attached to the car body	Operators are not careful when handling	9	4	6	216
Visual	Missing tie back	Difficult to do the bundling wiring harness on the box (not neat)	Operators do not follow existing process sequences and work standards	4	3	3	36
Finishing	Unlock lock protector	Circuit/wire is not neat and visible	The operator does not do a self-check when finished pressing the protective lock	4	9	5	180
	Exposed wire	Circuit/ wire can be seen/ pinched	The operator does not tidy up the circuit/ wire when installing the protector	5	6	6	180

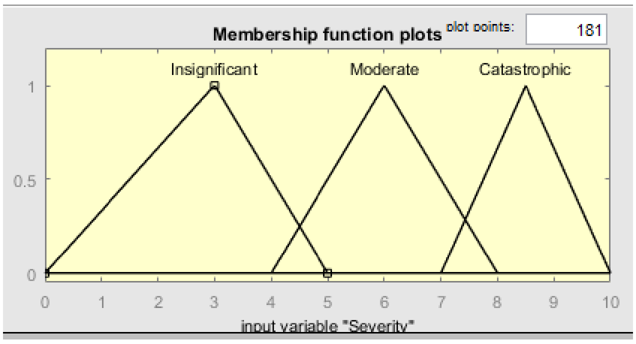

Figure 2. Fuzzy Ratings for Severity Assessment of Failure and Their Membership Function

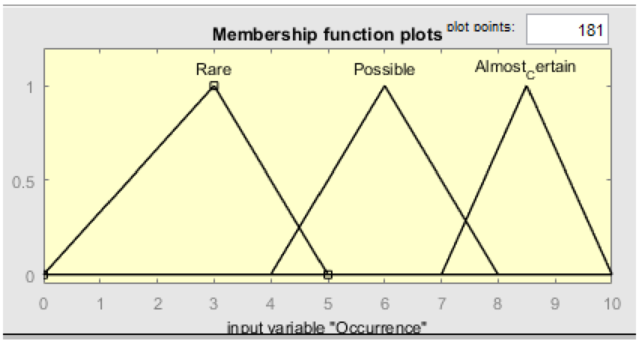

Figure 3. Fuzzy Ratings for Occurrence Assessment of Failure and Their Membership Function

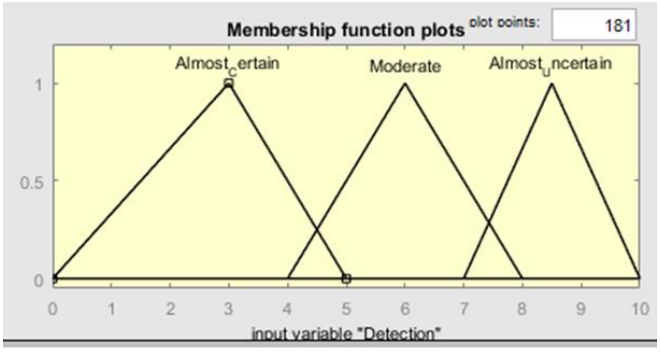

Figure 4. Fuzzy Ratings for Detection Assessment of Failure and Their Membership Function

Table 4. Fuzzy weights for the relative importance of risk factors

Linguistic	Fuzzy Number
Low	1,2,3,4,5
Medium	4,5,6,7,8
High	7,8,9,10

the wiring harness but for the damaged circuit part must be removed and replaced with a new circuit, the occurrence score is 6, which means that the failure occurs on a moderate level and a detection score of 6 which means that this failure has a low probability of being detected.

B. Result of Fuzzy approach to FMEA

After carrying out the identification risk that occurs in the Wiring Harness product process (**Table 1**). Next, determine the priority based on the assessment of risk factors using the conventional FMEA method. These risk factors include the severity (S), the degree of frequent occurrence of risk (O), and whether the risk is easy or difficult to detect (D). Then the risk priority number (RPN) value will be obtained from each risk or mode of failure that occurs (**Table 3**). In the fuzzy logic using Matlab software program has been used in calculating the value of Fuzzy RPN. The input of fuzzy logic has three variables; Severity, Occurrence, and Detection, and one output variable (FuzzyRPN) (Kumru & Kumru, 2013).

In this paper, the 3-class evaluation was used, including linguistic variables: low, moderate, and high. Of the three membership functions are then producing 24 fuzzy rules, which are used as a factor determining the value fuzzy RPN. Determining fuzzy numbers of S, O, and D based on **Table 3**. These linguistic terms are perfectly consistent with those defined by the traditional FMEA, but they are treated as trapezoidal and triangular fuzzy numbers in this paper rather than precise numerical values (Wang et al., 2009). **Figures 2–4** show their membership functions for the sake of visualization.

To overcome the result of FMEA's traditional weakness due to no accounts of the relative importance of the risk factors and treats them equally [16]. Hence in this study considered the relative importance weights of the risk factors, but they are not easy to be precisely determined due to the same reason as S, O, and D. these assessed using the linguistic terms in **Table 4**, whose membership functions are visualized in **Figure 4**.

The result of set fuzzy defuzzification was done using Centroid (center of gravity technique) method. In Centroid, the value is obtained based on the gravity of the decision-making process yield curve (Immawan et al., 2018). In this study, defuzzification is used to find the value of output in the form of FRPN value of the input that has been entered. Inputs come from the

Table 5. Comparison of RPN and Fuzzy RPN

Process Name	Potential Failure Mode	Value			FMEA Results		Fuzzy FMEA results	
		S	O	D	RPN	Priority	FRPN	Priority
Sub Assy / Housing	TPO (Terminal Push Out)	5	2	3	30	19	6.0	16
	Cross Circuit	7	7	1	49	14	6.0	14
	Wrong Cavity	7	7	1	49	15	6.0	13
	Missing Spacer/ retainer	5	2	7	70	9	6.0	8
Setting	Unlock spacer/ retainer	4	3	3	36	17	2.6	18
Tapping	Loose tapping	5	7	4	140	7	6.0	6
	Loose Band Clamp	4	5	6	120	8	6.0	7
	Wrong dimension	7	8	5	280	2	5.0	17
	Wrong tapping	6	2	5	60	10	6.0	10
Tapping	Wrong part	7	2	4	56	12	6.0	11
	Missing Tapping	6	2	5	60	11	6.0	9
	Missing part	5	5	2	50	13	6.0	12
	Damage terminal	9	3	8	216	3	8.5	2
	Damage insulation	9	6	6	324	1	8.5	1
Checker	Not click fuse	5	4	2	40	16	6.0	15
	Damage part	9	4	6	216	4	8.5	3
Visual	Missing tie back	4	3	3	36	18	2.6	19
Shiage	Unlock lock protector	4	9	5	180	5	6.0	4
	Exposed wire	5	6	6	180	6	6.0	5

severity, occurrence, and detection that have been obtained from the results of FMEA risk identification using conventional methods in **Table 5**.

Based on **Table 5** there is a difference between the value and ranking among the RPN and Fuzzy RPN. This is due to calculations using RPN simply done by multiplying the severity, occurrence, and detection alone and irrespective of the degree of importance of each input. While FRPN value obtained from the fuzzification generates value by considering the degree of interest of any given input. In the process of defuzzification, calculations have put the rules that prioritize the handling of the problem over to the cause of the risk. In this study, all the risk factors were based on expert opinion.

C. Risk Evaluation and Mitigation

Based on **Table 5**, that, the value of each FRPN failure mode is sorted, which is the largest FRPN value top rank. FRPN value got the highest priority to low priority. The highest FRPN value that shows the highest defect such as damage insulation is 8.5, damage terminal is 8.5, and the damaged part is 8.5. The highest priority FRPN value same with RPN value is damage insulation in the tapping process. The potential failure of damage insulation got value RPN is 324 and FRPN is 8.5. This research found 19 risks are classified as corrective risks from 7 processes in the production of Wiring Harness.

Damage insulation defects are the largest part that affects the defect rate above 5%. Damage insulation defect is damaged or scratched to reveal the insulation (copper inside the circuit/ wire). Mitigation efforts are proposed to identify the root cause of the problem using a fishbone diagram. After we finish finding the root cause of the problem, we will be given suggestions for improvement for the failure mode that has the highest FRPN score. **Figure 3** shows root cause analysis using a fishbone diagram for damaged insulation. Based on the Fishbone Diagram which can be seen in **Figure 5** and the proposed improvements to the failure of damaged insulation can be seen in **Table 6**.

4. Conclusion

This study is applying fuzzy FMEA methodology to identify and evaluate the risk that happens in-process production of Toyota Hi-Ace Wiring Harness Product. To improve the effectiveness of the traditional FMEA, develop a fuzzy-FMEA approach for risk and failure mode analysis in Wiring Harness Product. The fuzzy approach is used the Fuzzy Risk Priority Number (FRPN). The fuzzy FMEA approach is preventing product and process problems before they occur, this paper is also expected to result in some mitigation effort that can be applied to improve the Wiring Harness production process. This study found 19 risks are classified as corrective risks from 7 processes in the production of Wiring Harness. Using the fishbone diagram, we have found the root analysis and then suggest how to solve the problem.

The failure mode such as damage insulation, we suggest providing SWCT (Standard Work Combination Table) training to each operator to better understand the job. We believe it is necessary to

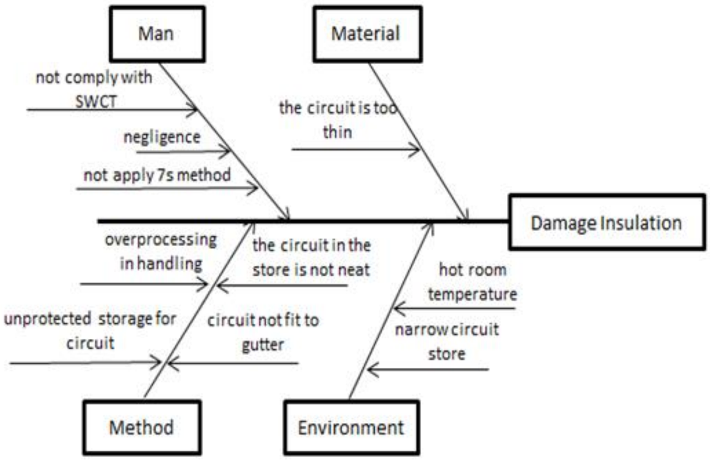

Figure 5. Root Cause Analysis Using Fish Bone Diagram for Damage Insulation

Table. 6. Mitigation Was Proposed Using The Fishbone Diagram

Failure Mode	Factor	Proposed Improvement
Damage Insulation	Man	Providing training and supervision to operators, both new employees, and old employees
		Reaffirm the SWCT and 7s method for the tapping part
		Provide sanctions for operators who do not participate in SWCT and 7s method
	Material	Changing the size of the circuit with a larger diameter than before
	Method	Reducing the handling process by reducing the ready-to-hand hanger
		Change the process layout to make it easier to do the hand to hand method
		Inserting a circuit on the gutter so that it does not hit the floor then you are stepped on or pinched by the conveyor
		Wrap the end of the terminal with a special plastic so that it is protected and does not scratch other circuits when placing it in the circuit store
	Environment	Converting area wider space for the operator when placing the circuit in the circuit store
		Provide air conditioning such as a blower or fan in the circuit store area so that the operator does not rush when placing the circuit

change the layout to facilitate the moving process without hanger, insert a circuit in the gutter so that the circuit is not trampled by the operator or conveyor, and provide air conditioning such as a blower or fan so that the operator does not rush to work.

This study has not calculated the implementation costs from suggestions for future improvements. However, the benefit is to get that can be applied to improve the Wiring Harness production process.

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