# Enhancing Quality Control in Electronic Component Assembly: Integrating Fault Tree Analysis and Failure Mode and Effect Analysis for the B31 Series

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**Abstract.** PT EX Batam is a manufacturing enterprise situated in Batam, Riau Islands, Indonesia. It specializes in the production of electronic components, including the Series B31. The quality control implementation conducted is inadequate as there are still numerous defective goods identified during the production process. The Series B31 production, in particular, needs further analysis as it has reached the defect tolerance limit. The objective of this study is to categorize the prevalent production defects, ascertain the underlying reasons of defective goods during the manufacturing process, and propose suitable recommendations for improvement. The research suggests utilizing Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA) as quality control methodologies. This study commences by gathering defect data from the company, which is subsequently analyzed to find the underlying causes of defects. Fault tree mapping is employed to uncover failure modes, enabling the determination of the highest Risk Priority Number value. This number is then used to establish the priority of defects that require immediate repair. The analysis of the sources of defects in this study reveals that they are mostly attributed to human, machine, and material factors. Consequently, it is necessary to propose improvements in employee training, enhance machine facilities, and optimize material handling. The recommended enhancements in this study are anticipated to assist enterprises in decreasing the occurrence of defect goods in alignment with company standards by a maximum of 1%, thereby contributing to the advancement of research in the manufacturing industry.

**Keywords:** Defects, Quality, Fault Tree Analysis, Failure Mode and Effect Analysis, Component Assembly.

## 1 Introduction

The development of the manufacturing industry in Indonesia is growing rapidly. This makes the company must be able to compete in terms of quality to maintain its selling and production value. The ability of an item or service to satisfy or exceed the needs and desires of the client is referred to as quality. In addition, very important elements in quality are such as price and service, quality is a determining factor in how well a


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product enters the market. Quality control has been carried out starting from the selection of raw material providers (suppliers, vendors), to the production process, delivery of goods, and sales[1]. Quality is the overall attributes and features of a good or service that can meet clearly stated or implied needs [2]. The purpose of quality control is to ensure that quality control is carried out appropriately and in accordance with applicable standards, quality control is a verification tool that assesses the level of quality of products or services as expected through planning, use of appropriate methods, regular monitoring, and taking corrective action if non-conforming conditions are found [3]. Based on Table 1 on the number of defects, total production and the number of non-defect products (%) obtained by from the production line data during September 2022 to September 2023 in the part B31 series production process, obtained production of 2,640,000 with a total of 39,215 defective products. From the data below, it is found that there are still many defective products produced that exceed the percentage of defective limits set by PT EX Batam, which is 1% of total production, which means that it cannot be less than 99%.

**Table 1.** B31 Series Defects Quantity

| Month | Defect Product | Total Production | % of Defects |
|---|---|---|---|
| Sep-22 | 807 | 22.000 | 3,67% |
| Oct-22 | 1,507 | 55.000 | 2,74% |
| Nov-22 | 2,107 | 77.000 | 2,74% |
| Dec-22 | 7,727 | 253.000 | 3,05% |
| Jan-23 | 4,991 | 385.000 | 1,30% |
| Feb-23 | 3,150 | 319.000 | 0,10% |
| Mar-23 | 2,785 | 264.000 | 1,05% |
| Apr-23 | 992 | 99.000 | 1,00% |
| May-23 | 2,806 | 187.000 | 1,50% |
| Jun-23 | 2,760 | 220.000 | 0,13% |
| Jul-23 | 3,212 | 319.000 | 1,01% |
| Aug-23 | 3,492 | 220.000 | 1,59% |
| Sep-23 | 2,879 | 220.000 | 1,31% |

The impact is that the connector line cannot meet the production targets set by the company and must do overtime so that it affects the company's production costs. Therefore, a quality control method is needed to reduce production defects in B31 Series products. In this research, the Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA) methods are two quality control methods that can be applied. FTA is an analytical instrument that generates a combination of specific system failures. While FMEA is a method to define, find, and eliminate failure problems in the production process, which are problems found or may arise in the system. FMEA can provide recommendations for improving production procedures at different high failure rates.

# 2 Literature Review

## 2.1 Quality Control

Quality control refers to the operational strategies and activities employed to ensure that the specified quality requirements are met. According to the definition provided, quality control is an operational approach and activity that is employed to attain, sustain, and enhance the standards for the quality of a product [4]. Quality control is an essential instrument that organizations use to enhance product development, uphold a superior standard of goods, and minimize the occurrence of defective products [5]. Quality control employs seven tools to discover potential improvements: Check Sheet, Control Chart, Cause and Effect Diagram, Pareto Diagram, Histogram, Scatter Diagram, and Stratification [6].

Efficient quality management is essential for promoting economic growth and enhancing competitiveness, particularly for firms aiming to penetrate global markets [7]. Manufacturing organizations have obstacles in their quality control methods, including a lack of awareness of techniques and difficulty in comprehending consumer expectations [8]. Nevertheless, the use of quality control and management systems enables producers to comply with regulatory standards, identify defects, and improve the overall quality of their products [9]. Companies adopt quality control measures in response to internal and external constraints, generally employing techniques such as Statistical Process Control and acceptance sampling [10]. Besides, the implementation of lean production techniques, which have the potential to enhance quality, differs depending on the size and industry of the organization. Larger enterprises are more inclined to utilize these methods on a more regular basis [11].

The assessment of a product's quality can be conducted through multiple methods and is distinguished based on the manner in which variances in quality characteristics are articulated. The quality dimensions consist of eight components that can be utilized for quality analysis [12]. The objective of quality control is to enhance the products by closely monitoring product yields and ensuring that the production process complies with established standards, hence enhancing the quality of the products [13].

## 2.2 Fault Tree Analysis (FTA)

Fault tree analysis is a method used by many different industry sectors. Graphical techniques called fault trees (FTs) are used to simulate how system failures propagate, or how component failures lead to overall failure. Not every component failure results in system failure due to redundancy and backup management. FTAs investigate the degree of dependability of system designs and offer techniques and resources to calculate various attributes and metrics [14].

### 2.3 Failure Modes and Effects Analysis (FMEA).

Failure Mode and Effects Analysis (FMEA) is a systematic procedure aimed at identifying and evaluating potential failure modes in a system, product, or process. It is recommended for identifying the source and fundamental reasons behind quality issues [15]. FMEA is a methodical approach used to anticipate and prevent potential problems with products and processes before they occur [16]. The FMEA process typically follows several essential phases [17].

1. Explain the process in production.
2. Determine the possible failure points in the production procedure.
3. Determine the possible consequences of production failure,
4. Determine the cause of malfunctioning of the production process.
5. Determine the detection mode for the production process.
6. Ensuring the ranking of the production process for Severity, Occurrence, Detection, and RPN (Risk Priority Number).
7. Proposed Improvement.

**Variable FMEA (Failure Mode Effect and Analysis).**

The three process variables Severity, Occurrence, and Detection are the main variables in the Failure Mode and Effects Analysis (FMEA) method. The purpose of these three variables is to calculate the Risk Priority Number (RPN), which indicates the overall risk level of a potential failure mode. Table 2 describes the Severity ratings, where a value of 1 indicates the least serious impact (small risk), and a value of 10 indicates the most serious impact (large risk) [18].

**Table 2.** Severity Rating

| Rating | Criteria |
|---|---|
| 1 | *Negligible Severity. We do not need to think that this consequence will have an impact on product quality. Consumers may not notice* |
| 2-3 | *Mild Severity. The consequences will be mild, consumers will not feel a decrease in quality* |
| 4-6 | *Moderate Severity. Consumers will feel a decrease in quality, but still within the tolerance limit.* |
| 7-8 | *High Severity. Consumers will feel a decrease in quality that is beyond tolerance.* |
| 9-10 | *Potential Severity (Very high adverse effect). The consequences are very influential on quality, consumers will not accept it.* |

Based on Table 3 of the occurrence assessment evaluation a value of 10 indicates a high level of occurrence (often), while a low level of occurrence (not often) ranks first. Based on Table 4 detection Rank 10 represents the level of control that is unable to detect failures, and rank 1 represents the level of control that is able to detect failures [18].

**Table 3.** Occurrence Rating

| Characteristics | Based on Frequency of Occurrence | Rating |
|---|---|---|
| *Remote* | 0,001 per 1000 *item* | 1 |
| *Low* | 0,5 per 1000 *item* | 3 |
| *Moderate* | 1 per 1000 *item* | 4 |
| | 2 per 1000 *item* | 5 |
| | 5 per 1000 *item* | 6 |
| *High* | 10 per 1000 *item* | 7 |
| | 20 per 1000 *item* | 8 |
| *Very High* | 50 per 1000 *item* | 9 |
| | 100 per 1000 *item* | 10 |

**Table 4.** Detection Rating

| Rating | Based on Frequency Occurrence | Criteria |
|---|---|---|
| 1 | 0,01 Per 1000 item | Prevention methods are very effective. No Chance that a cause may arise |
| 2 | 0,1 Per 1000 item | The probability of a cause occurring is very low. |
| 3 | 0,5 Per 1000 item | |
| 4 | 1 Per 1000 item | The likelihood of the cause occurring is moderate. Prevention methods sometimes allow the cause to occur. |
| 5 | 2 Per 1000 item | |
| 6 | 5 Per 1000 item | |
| 7 | 10 Per 1000 item | The probability of the cause occurring is high. Prevention methods are less effective, cause recurs. |
| 8 | 20 Per 1000 item | |
| 9 | 50 Per 1000 item | The probability of the cause occurring is very high. Prevention methods are ineffective, causes always recur. |
| 10 | 100 Per 1000 item | |

## Risk Priority Number

The number is the product of the incidence rate, detection rate, and severity. RPN Assign the order of failure. Failures are reached using this value then, suggestions are given for potential process improvements to lower the incidence of product faults. The RPN value can be expressed by the following equation [19]:

$$RPN = Severity\ x\ Occurrence\ x\ Detection \quad (1)$$

The result of S x O x D is the Risk Priority Number (RPN) that can be known. For each instrument that successfully completes the fault cause analysis process, a unique Risk Priority Number (RPN) is assigned. That component must be prioritized based on the highest team number (RPN) in order to implement actions or efforts to reduce the quantity of risk through corrective maintenance. The Risk Priority Number (RPN) for each problem cause found throughout the analysis is then compared using this potential. If the (RPN) is generally within the specified range, the risk can be reduced by proposing or implementing corrective actions.

## 3 Research Method

The methodology for analyzing the B31 series production would primarily involve the integration of Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA) to identify, analyze, and address quality control issues in the manufacturing process. The study would likely begin with observational research and interviews to gather initial data on the B31 series production line [20]. FTA would be used to identify root causes of defects or failures specific to the B31 series [21][22], while FMEA would be employed to quantify the risk priority of each failure mode and prioritize improvements in the B31 production process [21][23]. The methodology would culminate in the identification of specific failure modes in the B31 series production and the recommendation of control improvements based on the analyses [22]. The following Fig. 1 show the research approach for analyzing the B31 series production.

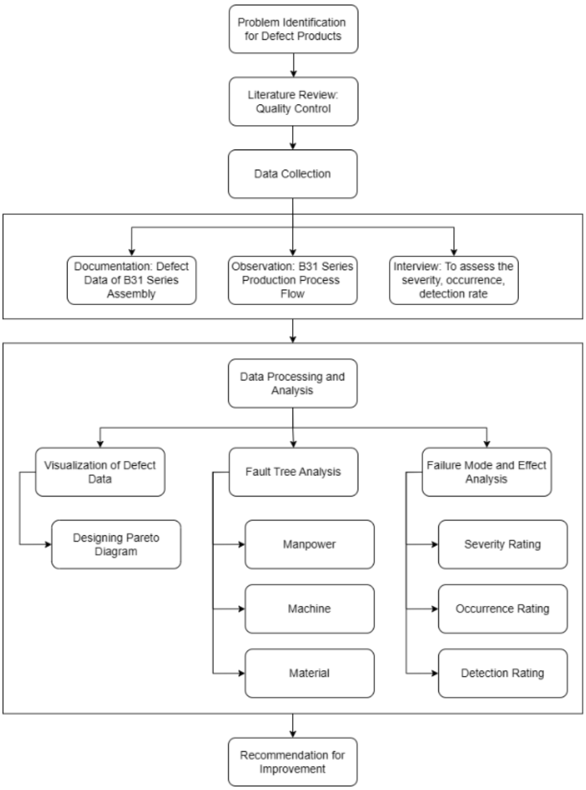


**Fig. 1.** Conceptual Framework

# 4 Results and Discussion

## 4.1 B31 Series Defect

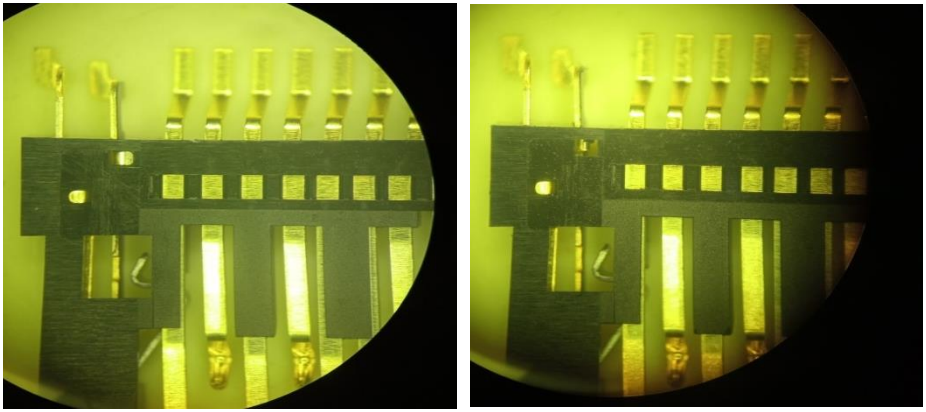

**Fig. 2.** Example *of* tansi *henkei* defect where the *tansi* is twisted

As mentioned earlier, there are 12 categories of defects for the B31 series. An example of one such defect can be seen in Fig. 2. Moreover, Table 5 displays a detailed analysis of the different categories of defects within a production or quality control setting. The most common defect is *tansi henkei*, which accounts for 40.57% of all faults. It is followed by *hontai* Crack and *Tansi* Pitch, which account for 20.91% and 20.39% respectively. These three primary faults account for more than 80% of all problems. Each of the remaining flaws, including Copra and *hontai bondo fuchaku*, accounts for less than 6% of the total. The cumulative percentage indicates that by fixing the top six defect types, more than 93% of all quality concerns would be resolved. A total of 39,215 defects were documented over 12 distinct categories, offering a complete depiction of the quality control difficulties encountered in this specific production or inspection procedure.

**Table 5.** Overall Defect Type Accumulation Data

| No | Type of Defect | Defect Description | Defect number | Percentage (%) | Accumulated (%) |
|---|---|---|---|---|---|
| 1 | *Tansi Henkei* | Henkei is a twisted defect that occurs in the tansi. | 15909 | 40.57% | 40.57% |
| 2 | *Hontai* Crack | Hontai Crack is a crack or fracture defect in the hontai part B31. | 8200 | 20.91% | 61.48% |
| 3 | *Tansi* Pitch | Tansi Pitch is an unnatural distance between *tansi* one to another or does not meet the standard. | 7995 | 20.39% | 81.87% |

| No | Type of Defect | Defect Description | Defect number | Percentage (%) | Accumulated (%) |
|---|---|---|---|---|---|
| 4 | Copra | Defect copra is detected using a camera monitor where the *tansi* does not hit the green line according to the camera standard. | 2113 | 5.39% | 87.25% |
| 5 | Voltage | Defect voltage is when the value generated on the volage machine is not in accordance with the speck or standards that apply in the company. | 1228 | 3.13% | 90.39% |
| 6 | *Hontai Kizu* | Kizu defect is a part scratched due to the machine or material | 1213 | 3.09% | 93.48% |
| 7 | Contact *Bondo Fuchaku* | The condition of this defect is where the bonding liquid is black on the *tansi* | 677 | 1.73% | 95.21% |
| 8 | *Sonyu Guchi Kizu* | The condition of this defect is a scratch located on the metal or the end of the *hontai* part. | 607 | 1.55% | 96.75% |
| 9 | Ohm 2 | This defect is when the resulting value does not match the standard ohm unit, namely HIGH = 500.0 and LOW = 010.0 mΩ. | 473 | 1.21% | 97.96% |
| 10 | Air *Kensa* | This defect occurs due to a cavity, tear, or gap that can cause water to enter the *hontai* that has been bonded. | 321 | 0.82% | 98.78% |
| 11 | *Dabo Kizu* | A condition where the dot mark protruding from the *hontai* is scratched. | 286 | 0.73% | 99.51% |
| 12 | *Hontai Bondo Fuchaku* | This defect is a condition where the bonding liquid hits the *hontai*. | 193 | 0.49% | 100.00% |
| | Total | | 39215 | 100.00% | |

Once the entire accumulation is determined, the data is next analyzed using a pareto chart to visually represent the most significant defects occurring between September 2022 and September 2023. The following Fig. 3 shows the number of defects among the twelve sorts of defects mentioned. The pareto diagram is one of the tools employed in this analysis. Based on the pareto principle, 20% of causes are responsible for 80% of issues, and 20% of inputs result in 80% of outputs. Based on the 12 defects mentioned, there are three specific categories of defects: *tansi henkei* with a prevalence of 40.57%, *hontai* crack with a prevalence of 20.91%, and *tansi* pitch with a prevalence of 20.39%. Therefore, the primary focus in defect repair should be on addressing these three types of defects.

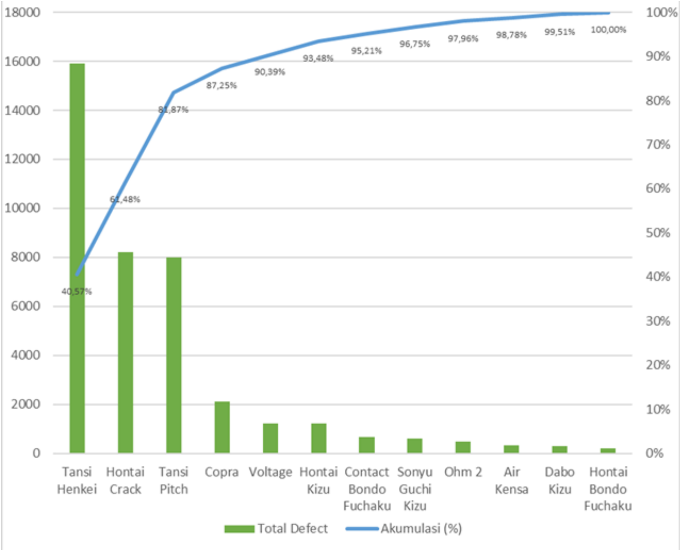


**Fig. 3.** Pareto Chart of Overall Defect Type

### 4.2 Fault Tree Analysis Results

Utilizing the Fault Tree tool for analysis, the objective of the analysis is to identify the reasons responsible for the high rates of defects in *tanshi henkei*, *hontai* crack, and *tanshi* pitch faults. A fault tree can be used to properly illustrate the causes of various issues. Fig. 4, 5, and 6 depict the root causes behind the most significant defects in the B31 series manufacture.

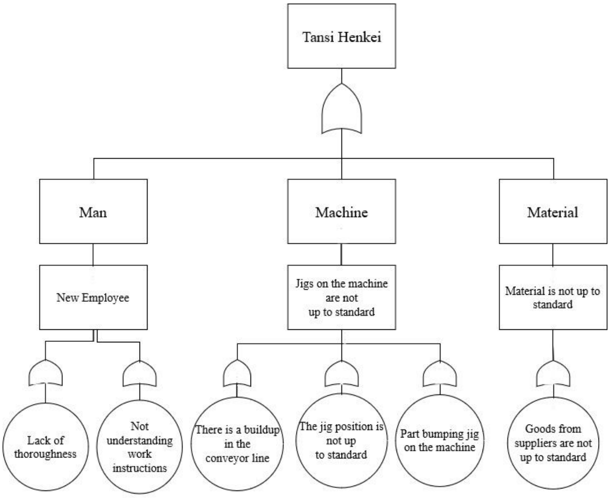


**Fig. 4.** Fault Tree Analysis Defect *Tansi Henkei*

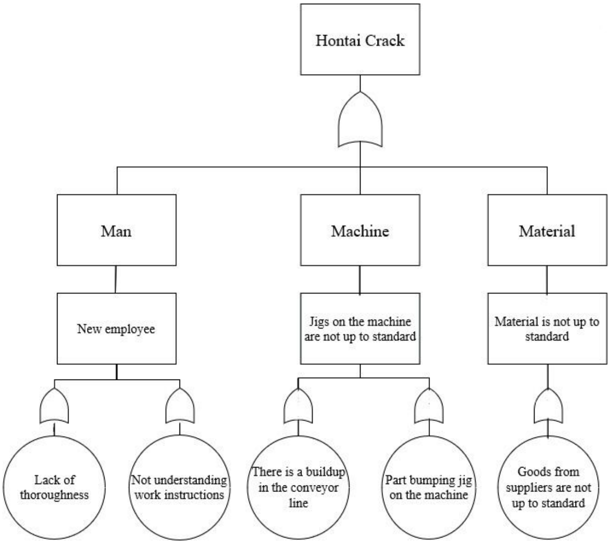


**Fig. 5.** Fault Tree Analysis Defect *Hontai* Crack

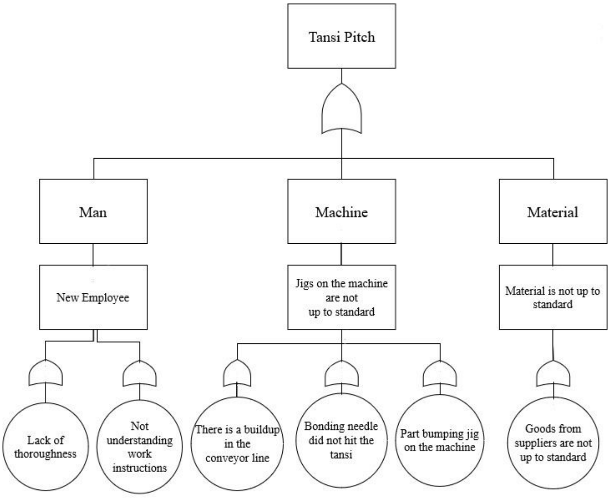


**Fig. 6.** Fault Tree Analysis Defect Tansi Pitch

### 4.3 Failure Mode and Effect Analysis Results

The next step after creating a fault tree or fault tree analysis is to create a table to determine the failure modes of each production stage to ensure the ranking of the severity, occurrence, and detection levels after the failure modes that occur are known. The weighting results used in making (FMEA) Failure mode and effect analysis are obtained through interviews and observations with related parties such as leaders and supervisors.

**Table 6.** Failure Mode and Effect Analysis of *Tansi Henkei* Defect and RPN Value

| Effect Of Failure Mode | Cause Of Failure Mode | S | O | D | RPN |
|---|---|---|---|---|---|
| New Employee | Lack of thoroughness | 6 | 5 | 2 | 60 |
| | Not understanding work instructions | 6 | 5 | 1 | 30 |
| Jigs on the machine are not up to standard | There is a buildup in the conveyor line | 8 | 8 | 2 | 128 |
| | The jig position is not up to standard | 8 | 7 | 2 | 112 |
| | Part bumping jig on the machine | 8 | 8 | 3 | 192 |
| Material is not up to standard | Goods from suppliers are not up to standard | 6 | 4 | 2 | 48 |

From Table 6 above, it is known that the results of the analysis of defects *tansi henkei* using Failure Mode and Effect Analysis (FMEA) on B31 Series products obtained the highest RPN (risk priority number) value, namely the part crashing into the jig on the machine with a value of 192, which is obtained from the value:

$$RPN = S \, x \, O \, x \, D = 8 \, x \, 8 \, x \, 3 = 192 \quad (2)$$

**Table 7.** Analysis of Failure Modes and Effects of *Hontai* Crack Defects and RPN Values

| Effect Of Failure Mode | Cause Of Failure Mode | S | O | D | RPN |
|---|---|---|---|---|---|
| New Employee | Lack of thoroughness | 6 | 3 | 2 | 36 |
| | Not understanding work instructions | 6 | 4 | 2 | 48 |
| Jigs on the machine are not up to standard | There is a buildup in the conveyor line | 9 | 8 | 2 | 144 |
| | Part bumping jig on the machine | 8 | 8 | 2 | 128 |
| Material is not up to standard | Goods from suppliers are not up to standard | 6 | 9 | 2 | 108 |

From Table 7 above, the results of the FMEA (Failure Mode and Effect Analysis) *hontai* crack defect analysis on B31 Series products obtained the highest RPN (risk priority number) value, namely the buildup in the machine conveyor line with a value of 144.

**Table 8.** Analysis of Failure Modes and Effects of Tansi Pitch Defects and RPN Values

| Effect Of Failure Mode | Cause Of Failure Mode | S | O | D | RPN |
|---|---|---|---|---|---|
| New Employee | Lack of thoroughness | 6 | 3 | 2 | 36 |
| | Not understanding work instructions | 6 | 4 | 2 | 48 |
| Jigs on the machine are not up to standard | There is a buildup in the conveyor line | 8 | 8 | 2 | 128 |
| | Bonding needle did not hit the *tansi* | 8 | 8 | 2 | 128 |
| | Part bumping jig on the machine | 7 | 8 | 3 | 168 |
| Material is not up to standard | Goods from suppliers are not up to standard | 6 | 4 | 2 | 48 |

From Table 8 above, the results of the FMEA (Failure Mode and Effect Analysis) pitch defect analysis on B31 Series products obtained the highest RPN (risk priority number) value, namely the part crashing into the jig on the machine with a value of 168 obtained from:

$$RPN \;= S\,x\,O\,x\,D \;=\; 7\,x\,8\,x\,3 \;=\; 168 \tag{3}$$

At this stage, the RPN (Risk from Number) value is sorted from the highest to the lowest value based on the FMEA which has been given a weighted value, the following table contains the sorted values:

**Table 9.** Risk Priority Number

| Causes of Failure | S | O | D | RPN |
|---|---|---|---|---|
| Part bumping jig on the machine | 8 | 8 | 3 | 192 |
| Part bumping jig on the machine | 7 | 8 | 3 | 168 |
| There is a buildup in the conveyor line | 9 | 8 | 2 | 144 |

Based on Table 9 above, the highest RPN value is 192 which is caused by parts crashing into the jig on the machine, then the next highest RPN value is 168 which is caused by parts crashing into the machine and the RPN value of the buildup in the conveyor line on the machine with a value of 144. Moreover, improvements will be made based on the causes of failure using information from the results of the Failure Mode and Effect Analysis (FMEA) analysis that has been made previously. The proposed improvements for improvement in the B31 series production process are as following Table 11.

**Table 10.** Proposed Improvement of B31 Series Products

| Type of Defect | Factors Causing Defects | Proposed Improvements |
|---|---|---|
| *Tansi Henkei* | Part bumping jig on the machine | Perform regular maintenance, namely daily check of the machine every day before starting work, checking the reel process at the material level whether there are found *karami* or rolled up in the reel position, repairing the jig according to the company's work instructions, namely if a defective product is found, immediate repair is carried out. |

| Type of Defect | Factors Causing Defects | Proposed Improvements |
|---|---|---|
| *Tansi* Pitch | Part bumping jig on the machine | Perform regular maintenance, namely daily check of the machine every day before starting work, reporting if there is a change in the shape of the jig, grinding, cutting edge to PE because of its relationship with the drawing jig, cleaning the *jidoki* machine, ensuring the position of the *tansi* reel before being placed into the cutting machine. |
| *Hontai* Crack | There is a buildup in the conveyor line | Perform regular maintenance, namely daily check of the machine every day before starting work, mechanic insert *tansi* into the *hontai*, setting the punch insert machine, checking the conveyor line. |

### 4.4 Discussion

The application of Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA) has proven to be an effective approach in identifying and addressing quality control issues in manufacturing processes across various industries, in this research specifically discuss in the electrical component, B31 series. These methods have been successfully employed to analyze defects in automotive components [20], cylinder heads [24], refined sugar production [25], plastic bottles [26], and jumbo roll products [27]. The studies consistently demonstrate that these analytical tools can pinpoint the root causes of defects, which often stem from a combination of human factors, machine issues, and material-related problems. In the automotive components, [20] found that operator errors and method/process issues were primary contributors to defects in the automotive manufacturing process, while other research [26] identified human factors, machine factors, and material factors as the main causes of defects in plastic bottle production.

The implementation of FTA and FMEA not only helps in identifying the causes of defects but also facilitates the development of targeted improvement strategies. Previous research [24] utilized FMEA to determine the severity, occurrence, and detection of potential failure modes, which led to proposed actions for enhancing manufacturing efficiency and customer satisfaction. Similarly, other research [27] employed these methods to identify the root causes of defects in jumbo roll products and suggested improvements such as regular maintenance of refiner parts and adjusting pulp composition. These studies highlight the versatility and effectiveness of FTA and FMEA in quality control across different manufacturing contexts, demonstrating their potential for improving product quality and reducing defect rates in various industrial settings.

# 5 Conclusion

Based on the research that has been conducted on B31 series products at PT EX Batam, the conclusions that can be obtained are as follows: The use of pareto diagrams produces a sequence of defects from largest to smallest, the order of defects from the largest is *tansi henkei*, *hontai* crack, *tansi* pitch, copra, voltage, *hontai kizu*, contact *bondo fuchaku*, *sonyu guchi kizu*, ohm 2, *air kensa*, *dabo kizu*, *hontai bondo fuchaku*. After analyzing using Pareto diagrams, the most dominant defects are obtained, namely, defects *tansi henkei* 40.57%, *hontai* crack 20.91%, *tansi* pitch 20.39% so that the main focus in defect repair is the three types of defects. Based on the analysis that has been done using Fault tree analysis, there are three factors of defects *tansi henkei*, *hontai* crack, *tansi* pitch in the production of B32 series, namely man, machine, and material. From the results of the FMEA (Failure Mode and Effect Analysis) analysis on the B31 Series product, the highest RPN value is 192. which is caused by the part crashing into the jig on the machine, then the next highest RPN value is 168 which is caused by the part crashing into the machine and the RPN value of the buildup in the conveyor line on the machine with a value of 144. The proposed improvements given to the B31 series product defect based on the highest RPN value are:

1. *Tansi Henkei*: Perform regular maintenance, namely daily check of the machine every day before starting work, checking the reel process at the material level whether it is found *karami* or rolled in the reel position, repairing the jig.
2. *Tansi* Pitch: Perform regular maintenance, namely daily check of the machine every day before starting work, reporting if there is a change in the shape of the jig, grinding, cutting edge to PE because of its relationship with the drawing jig, cleaning the *jidoki* machine, ensuring the position of the *tansi* reel before being placed into the cutting machine.
3. *Hontai* Crack: Perform regular maintenance, namely daily check of the machine every day before starting work, mechanic inserting the *tansi* into the *hontai*, set-ting the punch insert machine, checking the conveyor line.

Future study could investigate the potential integration of traditional quality control methods, such as FTA (Fault Tree Analysis) and FMEA (Failure Mode and Effects Analysis), with emerging technology and data-driven approaches in different industrial environments. Researchers could explore the possibility of integrating FTA (Fault Tree Analysis) and FMEA (Failure Mode and Effects Analysis) with machine learning algorithms to improve defect prediction and root cause analysis in real-time production settings. Furthermore, research might prioritize the adaptation of these techniques to tackle quality control obstacles in Industry 4.0 environments, characterized by interconnected systems and the proliferation of IoT devices that produce immense volumes of data. An additional area of research that shows potential is the investigation of the efficacy of fuzzy FMEA, when compared to conventional FMEA in various industries. This research has the potential to enhance the precision of risk evaluations in intricate manufacturing procedures. In addition, conducting longitudinal studies to monitor the enduring effects of FTA and FMEA implementations on overall product quality, manufacturing efficiency, and corporate profitability could offer useful insights to scholars and practitioners in the quality control sector.

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