Failure mode effect analysis and fault tree analysis as a combined methodology in risk management

N A Wessiani\textsuperscript{1}, F Yoshio\textsuperscript{2}
\textsuperscript{1}Department of Industrial Engineering, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo-Surabaya 60111, Indonesia
\textsuperscript{*}wessiani@gmail.com

Abstract. There have been many studies reported the implementation of Failure Mode Effect Analysis (FMEA) and Fault Tree Analysis (FTA) as a method in risk management. However, most of the studies usually only choose one of these two methods in their risk management methodology. On the other side, combining these two methods will reduce the drawbacks of each methods when implemented separately. This paper aims to combine the methodology of FMEA and FTA in assessing risk. A case study in the metal company will illustrate how this methodology can be implemented. In the case study, this combined methodology will assess the internal risks that occur in the production process. Further, those internal risks should be mitigated based on their level of risks.

1. Introduction
Failure Mode Effect and Analysis (FMEA) were formally introduced in the mid-1960. It initially focused on safety issues in the aerospace industry [1]. Further development showed that FMEA are widely used across the research under the topic of risk management. It indicates that this methodology robust enough to be applied in managing risk. Moreover, FMEA methodology is also one of the risk analysis techniques recommended by international standards [2].

Many research that used FMEA as the risk analysis technique has demonstrate the successful implementation. Kurt and Ozilgen could found the major risks that occurred in the dairy product manufacturing by utilizing FMEA methodology. Their finding might help large number of dairy product manufacturers in producing safe products since almost all dairy products share common manufacturing stages [3]. Kumru and Kumru also reported a corrective actions recommendation for improving purchasing process in the public hospital after adopting fuzzy FMEA [4]. The corrective actions recommendation was the result of failures identification in the purchasing process using fuzzy FMEA methodology. Kumru and Kumru’s research was the first authentic example of how fuzzy FMEA approach might be helpful to the management processes [4]. There are still many other researches that also adopt the FMEA methodology as the risk analysis technique [5][6][7].

On the other side, Fault Tree Analysis (FTA) has also been reported as an extensively used technique in risk analysis [8]. This technique was formerly developed by Watson in 1962 at Bell Telephone Laboratories in USA for safety evaluation of the Minuteman launch control system. Then, followed by Haasl et. al. that introduced the basic rules for the construction of the fault trees in 1965 [9]. This technique was then widely used in various field of study. Hyun et. al. implemented this technique
combined with Analytical Hierarchy Process (AHP) for identifying potential risk of undesirable events occurring during tunneling with application of a shield tunnel boring machine (TBM) method. The result showed that the proposed method reliable and indicates its applicability to risk management for shield TBM tunneling [10]. Park and Lee published the application of FTA in the field of hygiene management. They applied the FTA method to investigate the causes for faults in handwashing process. They concluded that FTA, with qualitative and quantitative analyses, was a good alternative approach to hazard analysis in HACCP system implementation [11]. Liu et al employed FTA method combined with quantitative analysis to investigate high-speed railway accidents. They reported that the proposed method was effective to be applied since they can give conclusions and suggestions to decrease the occurrence possibilities of similar accidents [12].

The discussions above are shown how both techniques, FMEA and FTA, reliable to be applied for risk management. Each technique has their own advantages. Whiteley et al. mentioned the advantage of FMEA is a comprehensive way to analyses all of the potential component failure modes in a system [13]. A system, design, process, or service may usually have multiple failure modes or causes and effects. In this situation, FMEA methodology enable the analyst to assess each failure mode or cause and prioritized in terms of their risks so that high risky (or most dangerous) failure modes can be corrected with top priority [14]. Moreover, conducting FMEA technique properly and appropriately will provide the practitioner with useful information that can reduce the risk (work) load in the system, design, process, and service. FMEA is one of the most important early preventive actions in system, design, process, or service which will prevent failures and errors from occurring and reaching the customer [15]. On the other hand, FTA also offers its advantages. FTA is a deductive technique that can be used to classify the instrumental relationships leading to a specific failure mode [13]. FTA is a systematic method for analyzing the risks that are sourced from various combinations of failure events [8][10]. This technique also enables to estimate the probability of an accident from both qualitative and quantitative perspectives. Qualitative analysis of a fault tree helps to find out its minimal-cut sets while its quantitative analysis computes the failure probability of top event using its basic events’ exact failure probabilities [8].

Besides their advantages, both techniques actually also own their disadvantages. Some literatures mention that using FMEA may be difficult and tedious for the case of complex systems that have multiple functions consisting of a number of components so that compound failure effects cannot be analyzed [2][15]. Whitley et al. also states that the main drawback when using only FMEA for reliability analysis, is that the technique is geared towards analyzing individual component failure mode occurrences. Because these failure modes are considered one by one, the interaction of multiple failure mode occurrences are often not listed using this method. Additionally, this type of reliability process is not fully quantitative. Severity and risk rankings can be made, however overall reliability levels cannot be deduced using FMEA [13]. On the other side, the main drawbacks of using FTA is that it cannot take into account dependencies between failure modes. They also don't tend to consider the cause of failure modes, rather just tackling the knock-on effect of the failure's occurrence. Also, a FT must be undertaken individually for each failure mode of interest. The entire range of operating conditions that the system can operate in are not considered in one tree. A tree must be made for each operating condition to be fully accurate [13].

This paper aims to combine FMEA and FTA methodology for managing risks in order to reduce the shortcomings of both methodologies. Risk to be identified are internal risks that occurred in production process. This study uses a production process on a metal company as the case study to implement the combined method. It will choose one product of the metal company to show how this combine method will work to identify the internal risk.

2. Literature Review
2.1. Failure Mode and Effect Analysis (FMEA)
As stated earlier, initially FMEA focuses on safety issues, but further development shows that FMEA becomes one of many other tools in risk management. Applying FMEA as a tool for risk management involving ten steps to be conducted as shown in Table 1 below [1].

| Steps | Description |
|-------|-------------|
| Step 1 | Review the process or product. |
| Step 2 | Brainstorm potential failure modes. |
| Step 3 | List potential effects of each failure mode. |
| Step 4 | Assign a severity ranking for each effect. |
| Step 5 | Assign an occurrence ranking for each failure mode. |
| Step 6 | Assign a detection ranking for each failure mode and/or effect. |
| Step 7 | Calculate the risk priority number for each effect. |
| Step 8 | Prioritize the failure modes for action. |
| Step 9 | Take action to eliminate or reduce the high-risk failure modes. |
| Step 10 | Calculate the resulting RPN as the failure modes are reduced |

Source: [1]

FMEA method defines the level of risk based on the value of risk priority number (RPN) from each risk. The higher the value of RPN will be the higher the risk. The formula for obtaining the RPN can be written as below.

$$RPN = S \times O \times D$$

Where RPN is risk priority number, S is severity ranking for each effect, O is occurrence ranking for each failure mode, and D is detection ranking for each failure mode and/or effect. Each of these three rankings is based on a 10-point scale, with 1 being the lowest ranking and 10 the highest. Based on the RPN, each failure mode could be ranked in order from the highest RPN to the lowest. This prioritization will show which failure mode should be prioritize first to mitigate.

2.2. Fault Tree Analysis (FTA)

Fault tree analysis (FTA) is an analytical technique that performed deductively from the occurrence of undesired event to the identification of root cause. The fault tree itself is a graphic model of the various parallel and sequential combinations of faults that will result in the occurrence of the predefined undesired event [9]. The faults can be events that are associated with component hardware failures, human errors, or any other pertinent events which can lead to the undesired event. A fault tree thus depicts the logical interrelationships of basic events that lead to the undesired event-which is the top event of the fault tree.

Developing fault tree will involve six steps as following [16]:
1. Define undesired event
2. Acquire understanding of system
3. Construct fault tree
4. Collect quantitative data
5. Evaluate fault tree probability
6. Analyze computer results
As fault tree is a graphical representation of the relationship between certain specific events and the ultimate undesired event, constructing the fault tree will need several common symbols as depicted in picture 1 below.

- **Intermediate Events**: An event that happens between two other events
- **Basic Events**: Failure
- **Undeveloped Events**: Event with not enough information
- **External Events**: Event that expected to happen
- **AND gate**: Output happens if both of the branch happens
- **OR gate**: Output happens if one of the branch happens

*Figure 1. Several Common Symbol of FTA [16]*

3. **Combining the FMEA and FTA Methodology for Risk Assessment**
FTA methodology will be used to identify the potential failure mode as stated in the FMEA methodology. Rather than using brainstorming itself, using the FTA methodology for generating the failure mode is expected to have better results. If FMEA is an inductive approach for finding the fault, the FTA itself is a deductive approach. Using FTA for generating the fault, it means attempt to find out what modes of system/component behavior contribute to the failure. Having this deductive approach for identifying the fault (risk), it can be known the root cause of those risks. Mitigation effort that being developed will base on the root cause of the risks hence it would have better results. Recalling the table 1 and modified the steps with the FTA steps, we will have the steps of combining the FMEA and FTA methodology for assessing the risk. The modified methodology can be seen in Table 2 below.

| Steps | Description |
|-------|-------------|
| Step 1 | Review the process or product. |
| Step 2 | Define undesired events |
| Step 3 | Construct the fault tree |
| Step 4 | Collect quantitative data |
| Step 5 | Assign a severity ranking for each fault/failure. |
| Step 6 | Assign an occurrence ranking for each fault/failure. |
| Step 7 | Assign a detection ranking for each fault/failure. |
| Step 8 | Calculate the risk priority number for each fault/failure. |
| Step 9 | Prioritize the fault/failure for action. |
| Step 10 | Take action to eliminate or reduce the high-risk fault/failure. |
| Step 11 | Calculate the resulting RPN as the fault/failure are reduced |

4. **Case Study**
Metal Company is one of metal work and engineering company in Indonesia. This metal company has 3 main business lines. There are, engineering procurement and construction (EPC), industrial tools manufacturing, and foundry. Some products of this metal company are bogie, mill roll, pipeline, road rollers, storage tank, and also ball tank. PT X is a leading bogie supplier in Indonesia with 100% local
demand fulfillment. Moreover, this metal company has been penetrated United States market with 1,500 bogies delivered since 2012. Bogie’s supply both local and worldwide shows a positive trend. This condition forced this metal company to maintain the commitments to give a competitive service in terms of quality, price, and delivery [17].

In this research bogie production process will be the case study for implementing the combining method of FTA and FMEA in assessing the risk.

**Step 1. Review the process or product**

Reviewing the process or product is conducting by making the operation process chart (OPC) of bogie production process. The picture below shows the OPC of bogie production process.

![Operation Process Chart of Bogie Production Process](image)

**Figure 2. Operation Process Chart of Bogie Production Process**

Further the activities involved in each production process are identified to acquire detailed understanding of the system. The example of detailed activities in moulding process can be shown in picture 3 below.

![The Detailed Activities of Moulding Process](image)

**Figure 3. The Detailed Activities of Molding Process**

**Step 2. Define undesired events**

Undesired event is identified through the activities that have been identified in the step 1. Brainstorming is conducted to define undesired events that probably happen through the production process. Those undesired events further will be analyzed by the FTA to find the root cause.

**Step 3. Construct the fault tree**
Fault tree analysis is conducted in order to find the root cause of each undesired events. Those root causes that have identified will be categorize as the internal risks that could occurred in the production process. Picture 4 shows the example of fault tree in the molding process.

**Figure 4. Fault Tree of Molding Process**

**Step 4. Collect quantitative data**
Quantitative data of each internal risk should be collected as much as possible. The frequency of occurrence, the impact, the effort to handle the risk is kinds of data that should be collected. This data is important for the next step that will apply FMEA methodology for defining the severity, occurrence, and detection level of each internal risk.

**Step 5. Assign a severity ranking for each fault/failure**
Severity ranking will show the level of impact that would be happened if the internal risks occurred. The result of severity ranking for each internal risk is shown in Appendix 1.

**Step 6. Assign an occurrence ranking for each fault/failure**
Occurrence ranking reflects how often each fault could occurred in the production process in certain period. Quantitative data that are collected in the previous step could help to determine in which ranking each fault would be fallen. The result of occurrence ranking for each internal risk is shown in Appendix 1.

**Step 7. Assign a detection ranking for each fault/failure**
Detection ranking will show the existence of current control inside the company to detect the failure or effect of failure. If company has no current control, the likelihood of detection will be low and the failure will have high ranking for the detection. The result of detection ranking for each internal risk is shown in Appendix 1.

**Step 8. Calculate the risk priority number for each fault/failure**
The calculation of risk priority number for each internal risk will follow equation number 1. The higher the RPN, the higher risk the failure. The failure mode can be ranked based on the RPN further the failure mode that has higher RPN should be prioritized for the mitigation effort. Appendix 1 shows the severity, occurrence, detection and RPN for each internal risk.

**Step 9. Prioritize the fault/failure for action.**
Pareto diagram is used to prioritize which failures should be mitigated first. Pareto diagram shows 80 percent of the total RPN for the FMEA comes from just 20 percent of the potential failures and effects. Picture 5 shows the pareto diagram of internal risks that occurred in the production process.

![Pareto Diagram of Risk Ranking](image)

**Figure 5. Pareto Diagram of Risk Ranking**

**Step 10. Take action to eliminate or reduce the high-risk fault/failure**
Mitigation effort could be the alternative of eliminate the risk, transfer the risk, reduce the severity, reduce the occurrence, and/or accept the risk. Recommendation of mitigation effort for the prioritize risk could be seen in table 3 below.

| Risk                     | Risk Treatment          | Risk Treatment |
|--------------------------|-------------------------|----------------|
| Zone 1 defect discovered | Repair                  | -              | -              | -              |
| Broken Pump in Core Making | Scheduled and preventive maintenance | - | Allocate idle time for machine | Provide spare part | - |
| Broken Pump in Molding   | Scheduled and preventive maintenance | - | Allocate idle time for machine | Provide spare part | - |

**Table 3. Recommendation of Mitigation Effort**

**Step 11. Calculate the resulting RPN as the fault/failure are reduced**
When the recommendation efforts are implemented by the company, further the resulting RPN is calculated. A mitigation effort is effective when it could reduce significant RPN. The resulting RPN could be compared with the initial RPN to analyze how significant the mitigation effort that already done by the company. This research could not provide the resulting RPN since the company does not implement yet the recommendation of mitigation efforts.

5. **Conclusion**
This research tries to combine fault tree analysis (FTA) and failure mode and effect analysis (FMEA) for managing risk that could be occurred inside the company. The result is expected better since by having FTA the company could define the root cause of failure (risk) and further the risk could be prioritized by mapping the risk priority number (RPN) from the FMEA methodology. This prioritization is important since certain costs will exist to take the mitigation efforts. Case study is taken in this research for showing how the combined methodology could be implemented.

6. Reference

[1] McDermott R E, Mikulak R J and Beauregard M R (2009) The Basic of FMEA (2nd ed ) New York: Productivity Press  Taylor and Francis Group
[2] Dyadem Press  (2003) Guidelines for Failure Mode and Effects Analysis for Automotive Aerospace and General Manufacturing Industries  Ontario Canada: CRC Press
[3] Kurt L and Ozilgen S (2013) Failure mode and effect analysis for dairy product manufacturing: Practical safety improvement action plan with cases from Turkey Safety Science(55) 195-206
[4] Kumru M and Kumru P Y (2013) Fuzzy FMEA application to improve purchasing process in a public hospital Applied Soft Computing(13) 721-733
[5] Feili H R, Akar N Lotfizadeh H Bairampour M and Nasiri S (2013) Risk analysis of geothermal power plants using Failure Modes and Effects Analysis (FMEA) technique Energy Conversion and Management(72) 69-76
[6] Wessiani N A and Sarwoko S O (2015) Risk analysis of poultry feed production using fuzzy FMEA Procedia Manufacturing(4) 270-281
[7] Yang Z and Wang J (2015) Use of fuzzy risk assessment in FMEA of offshore engineering systems Ocean Engineering(95) 195-204
[8] Komal (2015) Fuzzy fault tree analysis for patient safety risk modeling in healthcare under uncertainty Applied Soft Computing(37) 942-951
[9] Vesely W E, Goldberg F F Roberts N H and Haasl D F (1981) Fault Tree Handbook Washington D.C: U S Government Printing Office
[10] Hyun K -C, Min S Choi H Park J and Lee I -M (2015) Risk analysis using fault-tree analysis (FTA) and analytic hierarchy process (AHP) applicable to shield TBM tunnels Tunnelling and Underground Space Technology(49) 121-129
[11] Park A and Lee S J (2009) Fault tree analysis on handwashing for hygiene management Food Control(20) 223-229
[12] Liu P, Yang L Gao Z Li S and Gao Y (2015) Fault tree analysis combined with quantitative analysis for high-speed railway accidents Safety Science(79) 344-357
[13] Whiteley M, Dunnett S and Jackson L (2016) Failure Mode and Effect Analysis and Fault Tree Analysis of Polymer Electrolyte Membrane Fuel Cells International Journal of Hydrogen Energy(41) 1187-1202
[14] Wang Y -M, Chin K -S Poon G K and Yang J -B (2009) Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean Expert Systems with Applications(36) 1195-1207
[15] Stamatis D H (2003) Failure mode and effect analysis : FMEA from theory to execution (2nd ed ) Milwaukee: Quality Press
[16] Hixenbaugh A F (1968) *Fault Tree for Safety* Seattle Washington: The Boeing Company
[17] Metal Company in Indonesia (2013) *Metal Company* Retrieved from Metal Company

7. Appendix

**Appendix 1** Severity, Occurrence, Detection and RPN for Each Internal Risk

| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN  |
|-----------|-------------------------------------------|----------|------------|-----------|------|
| MOLDING   |                                           |          |            |           |      |
| R1        | Broken Compressor                         | 2        | 2          | 2         | 8    |
| R2        | The pattern is not completely cleaned     | 4        | 2          | 2         | 16   |
| R3        | Broken Pump                               | 8        | 5          | 3         | 120  |
| R4        | Improper mixing                           | 3        | 2          | 1         | 6    |
| R5        | Bad coating                               | 8        | 2          | 2         | 32   |
| R6        | Broken Furnace                            | 3        | 2          | 4         | 24   |
| CORE MAKING |                                      |          |            |           |      |
| R7        | Broken Compressor                         | 2        | 2          | 2         | 8    |
| R8        | The pattern is not completely cleaned     | 3        | 2          | 2         | 12   |
| R9        | Broken Pump                               | 8        | 7          | 3         | 168  |
| R10       | Improper mixing                           | 3        | 2          | 1         | 6    |
| R11       | Broken core box                           | 2        | 6          | 1         | 12   |
| R12       | Broken core                               | 2        | 5          | 1         | 10   |
| R13       | Bad coating                               | 6        | 4          | 2         | 48   |
| SETTING CORE |                                      |          |            |           |      |
| R14       | Incomplete core                           | 2        | 3          | 1         | 6    |
| R15       | Broken core                               | 2        | 5          | 1         | 10   |
| R16       | The core and parting lines is not         | 4        | 2          | 1         | 8    |
|           | completely cleaned                         |          |            |           |      |
| R17       | Loose material left behind                | 6        | 5          | 3         | 90   |
| R18       | Broken core                               | 2        | 2          | 1         | 4    |
| MELTING   |                                           |          |            |           |      |
| R19       | Raw material doesn't meet standard        | 2        | 4          | 1         | 8    |
| R20       | Broken thermocouple                       | 2        | 2          | 1         | 4    |
| R21       | Broken Furnace                            | 8        | 5          | 2         | 80   |
| R22       | Improper chemical composition             | 4        | 2          | 1         | 8    |
| R23       | Improper chemical composition             | 4        | 3          | 2         | 24   |
| R24       | Improper ladle setting                    | 5        | 2          | 2         | 20   |
| R25       | Temperature higher than standard          | 3        | 2          | 1         | 6    |
| POURING   |                                           |          |            |           |      |
| R26       | Temperature higher than standard          | 8        | 2          | 1         | 16   |
| R27       | Pouring time too long                     | 3        | 2          | 1         | 6    |
| SHAKE OUT |                                           |          |            |           |      |
| R28       | Broken Belt Conveyor                      | 8        | 7          | 2         | 112  |
| R29       | The casting was shake when the            | 6        | 2          | 1         | 12   |
|           | temperature is high                       |          |            |           |      |
| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN |
|-----------|-------------------------------------------|----------|------------|-----------|-----|
| R30       | Malfunctioned crane                       | 8        | 6          | 2         | 96  |
| R31       | Casting cannot be pulled out               | 3        | 5          | 2         | 30  |
| R32       | Broken Belt Conveyor                      | 8        | 7          | 2         | 112 |
| R33       | The casting was shake when the temperature is high | 6 | 2 | 1 | 12  |
| R34       | Malfunctioned crane                       | 8        | 6          | 2         | 96  |
| R35       | Casting cannot be pulled out               | 3        | 2          | 2         | 12  |
| R36       | Malfunctioned crane                       | 3        | 5          | 2         | 30  |

**SHOT BLAST**

| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN |
|-----------|-------------------------------------------|----------|------------|-----------|-----|
| R37       | Setting need a longer time to finish      | 4        | 2          | 2         | 16  |
| R38       | Malfunctioned impeller                    | 8        | 7          | 2         | 112 |
| R39       | The casting still has a rough surface     | 3        | 4          | 3         | 36  |

**CUTTING**

| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN |
|-----------|-------------------------------------------|----------|------------|-----------|-----|
| R40       | Setting need a longer time to finish      | 2        | 2          | 1         | 4   |
| R41       | Cutting result doesn't meet standard      | 3        | 4          | 1         | 12  |

**GRINDING**

| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN |
|-----------|-------------------------------------------|----------|------------|-----------|-----|
| R42       | Setting need a longer time to finish      | 2        | 2          | 1         | 4   |
| R43       | Line full                                 | 5        | 5          | 2         | 50  |
| R44       | The casting need a lot of grinding        | 4        | 6          | 2         | 48  |
| R45       | The casting still need to be processed    | 4        | 5          | 2         | 40  |

**MP 1**

| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN |
|-----------|-------------------------------------------|----------|------------|-----------|-----|
| R46       | The fluid is not applied well             | 3        | 4          | 2         | 24  |
| R47       | Improper inspection                       | 6        | 4          | 2         | 48  |
| R48       | Broken MPI tools                          | 6        | 4          | 2         | 48  |
| R49       | Zone 1 defect discovered                  | 8        | 8          | 3         | 192 |

**WELDING**

| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN |
|-----------|-------------------------------------------|----------|------------|-----------|-----|
| R50       | Setting need a longer time to finish      | 2        | 2          | 2         | 8   |
| R51       | Line full                                 | 4        | 5          | 2         | 40  |
| R52       | Casting need a lot of welding             | 4        | 5          | 2         | 40  |
| R53       | The casting still need to be processed    | 4        | 2          | 1         | 8   |

**HEAT TREATMENT**

| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN |
|-----------|-------------------------------------------|----------|------------|-----------|-----|
| R54       | Broken furnace                            | 2        | 4          | 2         | 16  |
| R55       | Undisciplined method                      | 4        | 3          | 1         | 12  |
| R56       | Thermocouple broken                       | 2        | 4          | 2         | 16  |
| R57       | The casting cannot be pulled out from the machine | 2 | 3 | 2 | 12  |
| R58       | The casting need a longer time to cool down | 2 | 2 | 1 | 4   |

**MP 2**

| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN |
|-----------|-------------------------------------------|----------|------------|-----------|-----|
| R59       | Casting need heat treatment process       | 8        | 3          | 2         | 48  |

**MACHINING**

| Risk Code | Risk                                      | Severity | Occurrence | Detection | RPN |
|-----------|-------------------------------------------|----------|------------|-----------|-----|
| R60       | The clamp cannot hold the work piece      | 3        | 2          | 1         | 6   |
| R61       | Line full                                 | 6        | 5          | 2         | 60  |
| Risk Code | Risk                                    | Severity | Occurrence | Detection | RPN |
|-----------|----------------------------------------|----------|------------|-----------|-----|
| R62       | Broken CNC machine                      | 6        | 4          | 2         | 48  |
| R63       | work piece cannot meet the dimensional standard | 4        | 3          | 1         | 12  |
|           | **GAGE INSPECTION**                     |          |            |           |     |
| R64       | Setting need a longer time to finish    | 4        | 2          | 1         | 8   |
| R65       | The casting dimension doesn't meet requirement | 4        | 2          | 1         | 8   |
|           | **FINISHING**                           |          |            |           |     |
| R66       | Nuts and bolts cannot be set            | 4        | 2          | 1         | 8   |
| R67       | Wrong arrangement of product            | 6        | 2          | 1         | 12  |