CHAPTER 2
LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1. Literature Review

2.1.1. Previous research

In the literature review and theoretical background will continue the last chapter by explain how other researchers perform with the same method and explain more about specifically using FMEA method. There are some previous research which are being the references in this research. This research about Failure Mode and Effect Analysis (FMEA) was executed in PT. Hyundai Indonesia Motor (PT.HIM). Furthermore this research will identify mode, effect, and causes of failure which focuses on designing and processing. Object of this research is Identification Number Plate (ID Plate). ID Plate is one of the important parts in PT. HIM. Selection of the FMEA method was done by (Vinodh & Santhosh, 2012). That research objectives are to know the improvement of quality in an automotive leaf spring organization and to explain about FMEA which is a decision making tool for prioritizing corrective action to enhance product/system performance by eliminating or reducing failure rate, while (Paciarotti, Mazzuto, & D'Ettorre, 2014) told about the history of FMEA in 1949 when the US Army used it in the aeronautic sector in order to solve reliability and safety problems during the design and production phases. Over the years, the FMEA tool has become standard practice in Japanese, American, and European manufacturing companies from aerospace (NASA) to the automotive and electronics sectors, from the food industry to the energy sector and the medical and pharmaceutical arenas. FMEA provides qualitative and quantitative information about reliability and safety for both simple products and complex systems.

A Failure mode and effect analysis (FMEA) is a procedure for analysis of potential failure modes within a system for the classification by severity or determination of the failure's effect upon the system. It is the process whereby organization methodically address the risks attached to their activities with the goal of achieving sustained benefit within each activity and across the portfolio of all activities. (Namdari, Sh, & Jafari, 2011).

A research about Failure Mode and Effect Analysis was also conducted by (Margineanu, Prostean, & Popa, 2015) told that this method can reduce disaster errors which cause severe damage to the organization; though maybe that there are not tangible. When applying FMEA, each component is examined to identify

possible failures. Following recognition, all possible causes and effects should be classified to the related failure modes. After this practice, priority of failures due to their disaster effects should be ranked by a Risk Priority Number (RPN), which is the multiplication of severity of failures (S), their portability of occurrence (O), and the possibility or detection (D). (Feili, Akar, Lotfizadeh, Bairampour, & Nasiri, 2013).

In the (Estorilio & Posso, 2010) FMEA should be applied as a key element of quality planning in companies' processes. Besides that, in (Dietz, 2014) they combine authors such as Stamatis (1995), Palady (1995), Reid (2005) and Teng et al. (2006) converge on the idea that organizations which use FMEA correctly save resources and reach high levels of customer satisfaction. FMEA can be a very powerful tool when applied accurately. Like any other quality tool, before being used, it must be understood and, once this understanding is obtained, and added to the commitment of the team involved, it becomes possible to identify the financial benefits which will result from improvements to their products and processes.

2.1.2 Present Research

This research is about identify the root-cause of Identification Number Plate (ID Plate) that was in the part of cars which are produced to foreign country (Thailand). Unfortunately, this part does not apply for local product. The function of ID Plate is consisting many important information like identification number (VIN), engine type, manufacturing plant code, year of produce, etc. Based on that, crucial things are shown in ID Plate in this research conducted. This research will apply Failure Mode and Effect Analysis (FMEA) specifically in the process, and design. However, there are still no papers discussing about the reduction potential failure modes occur in part ID Plate. So this paper will create innovation by using the FMEA technique in ID Plate part process and design limitation that can identify and priority critical defects before these defects cause damage. As a result, improvement programs and preventive actions can be done before starting the project using FMEA to avoid wasting resources and time and prevent accidents and risks to employees and employers execute the process efficient and effective.

2.2. Gap Analysis

Gap analysis is used to show the contribution of this research by comparing the previous research with this research based on several aspects which can be seen on the **Table 2.1**. The gap analysis shows that there is previous research considering FMEA method and other researches considering FMEA method but in different objects. Actually, there were many research using FMEA with different objects and adding some methods to complete the FMEA. Therefore, the contribution of this research is the application of the use of FMEA method in the automotive industry especially in the part ID Plate.

Table 2.1. Critical Review for Comparing Previous and Current Research

No.	Year	Writer	Problem Background	Objective	Methods	Result	Gap
1.	2012	Bahrami, M., Bazzaz, D. H., & Sajjadi, S. M.	Based on business performance which increase the success of projects became decisive and increase global competition	Using FMEA technique in various stage of project implementation in order to systematically improvement of processes and reduces project costs	**Implementation FMEA Analysis**	In order to better utilization, contractors and civil engineers can save time and money through proposed preventive and corrective actions, quantization delay factors and finally calculate and compare obtained RPN numbers.	Focus on identifies errors, defects, and failures which exist in the system, process, and project.
2.	2009	Crites, J. W., Kittinger, S. W., Des, C., & Drive, V. P.	Based on changing process system in following electron-beam evaporation of an interconnect-metal film where the liftoff is usually accomplished by one or more solvent, tape, or high-pressure spray methods.	Using FMEA technique in Evaluation off Process transfer of osmic liftoff from low-pressure-solvent to high-pressure-amp liftoff		FMEA successfully identify the most significant risks associated with a change to the manufacturing process, like was applied to evaluate and implementation an improvement process for liftoff with particular concern regarding long-term reliability of the product.	Focus on improve and proven the problem without risks, and without many of manufacturability problems inherent in the old process.
3.	2013	Feili, H. R., Akar, N., Lotfizadeh, H., Bairampour, M., & Nasiri, S.	Since some Geothermal Power Plants face various failure, the requirements of technique to eliminate or decrease potential failures is considerable.	Using FMEA technique in finding risk analysis of geothermal power plants		FMEA successfully finding a top failure depending on frequencies is corrosion.	Focus on the prediction of possible failure modes and eliminate potential failures during the design and the operation of GPPs

No.	Year	Writer	Problem Background	Objective	Methods	Result	Gap
4.	2014	Vinodh, S., & Santhosh, D.	Based on potential areas where failures are expected to be occurring in high frequencies that are scrutinized. These are the areas that directly influence the reliability of product and indirectly support the success of the organization.	To report the application of failure mode and effect analysis (FMEA) to an automotive leaf spring manufacturing organization		FMEA has been used to a decision making tool to prioritize the corrective actions so as to enhance product/system performance.	Focus on developed PFMEA and provide FMEA in maximizing production and minimizing cost.

2.3. Theoretical Background of (FMEA)

2.3.1. Definition of FMEA

There are any four definition which describe what is FMEA

a. FMEA is an approach that helps the thinking process of engineer in identifying the failure mode from its effect, causes and currently detection. Then three of them will multiplied become risk priority number (RPN). (Ford Motor Company, 1992)

b. FMEA is a tool that exists in the larger framework of quality and reliability processes. If one's approach to achieve quality and reliability is sounded, then it will properly guide the use of the FMEA tool (Carlson, 2014)

c. An FMEA is an engineering analysis done by a cross-functional team of subject matter experts that thoroughly analyzes product designs or manufacturing processes early in the product development process. Its objective is finding and correcting weaknesses before the product gets into the hands of customer. (Mikulak, McDermott, & Beauregard, 2011)

d. The FMEA is a method which will identify corrective actions required to prevent failures from reaching the customer, thereby assuring the highest durability, quality, and reliability possible in a product or service. (Stamatis, 2003)

2.3.2. History of FMEA

FMEA was directed in 1949 by the U.S. Armed Forces by introducing the document entitled "Procedures for Performing a Failure Mode Effect and Critically Analysis." (Kolich, 2014). The objective of FMEA is to classify failure according to their impact on mission success and personnel/ equipment safety. The use of FMEA gained momentum during 1960s with the push to put a man on the moon and return him safely to earth. To continue those momentum, FMEA were conducted in the aerospace industry in the mid-1960s and were specifically focused on safety issues. At that time, FMEA became a key tool for improving safety, especially in the chemical process industry. In the late 1970s, an automotive industry, the Ford Motor Company continued to improve FMEA specifically in safety and regulatory consideration after the Pinto affair. They were also used in production and design. Based on (Carlson, 2014) the automotive industry began implementing FMEA by standardizing the structure and methods through the Automotive Industry Action Group (AIAG). Although it was developed by the military, the FMEA method is now extensively used in a variety of industries including semiconductor processing, foodservice, plastics, software,

automotive, and healthcare. Engineers' always analyzed processes and products for potential failure to prevent safety accidents and incident from occurring. Therefore, the automotive industry adapted the FMEA technique for using as a quality improvement tool. The automotive industry uses the International Organization for standardization Technical Specification (ISO/TS 16949-:2009) as the quality standard for its suppliers. This standard specifies the precise quality system requirements for suppliers in the automotive sector. FMEA also plays a central role in the implementation of this standard.

2.3.3. Purposes of FMEA

Preventing process and product problem before they occur is the purposes of Failure Mode and Effect Analysis. They substantially reduce costs by identifying product and process improvement early in the development process when changes are relatively easy and inexpensive to make. So, there are many purposes that are explained by (Jensen et al., n.d.):

a. Focus on problem prevention

In the focus on problem prevention, FMEA became a key to prevent the problems before designs reach testing or processes reach the manufacture plan and can be improvement test and control to make sure that the problem does not tasted by consumers before perform the corrective action.

b. Focus on design and process improvements

When focus on design and process improvements FMEA became strategy improvements specifically in design and process. In FMEA there are many action strategies that can be employed to improve design and processes and also reduce risk to a very low level. Supposed with use both type of FMEA they will make processes are errorless and make part/products are safe, trouble-free and stable.

c. Leverage FMEAs to improve test plans and process controls

FMEAs are influence test plans and process controls by increasing the way to test plan of process controls. FMEA became a link to design verification and process controls.

d. Keep it simple

Simple means effective and efficient. FMEA became effective and efficient when they keep to the essential elements. With the proper aspects FMEAs can make the right choices at each stage and keep the procedure as simple as possible.

FMEA is a vital tool to achieve the objectives above; however it is important to understand the limitations of FMEA. FMEA does not model the interactions between failure modes. FMEAs improve reliability but they do not calculate or predict actual reliability. The occurrence ranking of a given failure mode/cause is a relative ranking and, although it may be based on objective failure frequency ranges, it is still a subjective number. If reliability prediction or calculation is needed, other reliability tools do a better job than FMEA. FMEA should be considered as the overall reliability plan. Based on (Stamatis, 2003) a good FMEA is when they can identify known and potential failure modes, identify the causes and effects of each failure mode, prioritize the identified failure modes according to the risk priority number (RPN) and provide for problem follow up and corrective action.

2.3.4. Type of FMEA

Generally, it is accepted that there are four types of FMEAs based on (Stamatis, 1992) and (Raymond J. Mikulak, 2009) explained below:

a. Design/ Product FMEA

It is used to uncover problems with the product that will result in safety hazards, product multifunction, or a shortened product life. Product FMEA can be conducted at each phase in the design process (preliminary design, prototype, or final design), or they can be used on products that are already in production. They key question asked in design FMEAs is. How can the product fail?. This focuses on product design, typically at the subsystem or component level. The focus is on the design-related deficiencies, with emphasizing on improving the design and ensuring product operation that is safe and reliable during the useful life of the equipment. The scope of the Design FMEA includes the subsystem or component itself, as well as the interfaces between each components. Design FMEA usually assumes the product will be manufactured according to specifications.

An example of a Design FMEA is the wheels system of a bicycle. Design FMEA is the design of the whole car-wheels subsystem. The objective is to certify the car-wheels subsystems that accomplishes its intended functions safely and reliably and the risk due to the subsystem design is low.

b. Process FMEA

It is used to analyze manufacturing and assembly processes. A process of FMEA focuses on failure modes caused by process or assembly deficiencies. This

focuses on the manufacturing or assembling process, emphasizing how the manufacturing process can be improved to ensure that a product is built to design requirements in a safe manner, with minimal downtime, scrap, and rework. The scope of a Process FMEA can include manufacturing and assembly operations, shipping, incoming parts, transporting of materials, storage, conveyors, tool maintenance, and labeling.

An example of a Process FMEA is the manufacturing and assembly of a car. In this example, the scope of a car Process FMEA is the entire set of manufacturing and assembly operation of the car. The objective is to ensure that the assembly operations are accomplished as intended in a safe and reliable manner, and ensure the risk due to manufacturing and assembly which is low.

c. System FMEA

It is used to analyze systems and subsystems in the early concept and design stage. A system FMEA focuses on potential failure modes between the functions of the system caused by system deficiencies. This is the highest level analysis of an entire system, made up of various subsystems. The focus is on system-related deficiencies, including safety system, integration system, interfaces or interactions between subsystems or with other systems, interactions with the surrounding environment, human interaction, service, and other issues that could cause the overall system to not work as intended. In the system FMEA, the focus is on functions and relationships that are unique to the system as a whole.

An example of a System FMEA is a car. The scope of a car System FMEA is the entire car subsystems and the integration of the system-level functions. In this example, the purpose is to ensure whether the car will accomplish its intended functions in a safe and reliable manner as well as to ensure the overall risk of the car system which is low.

d. Service FMEA

It is used to analyze services before they reach the customer. A service FMEA focuses on failure modes (tasks, errors, mistakes) caused by system or process deficiencies. This type of FMEA focuses on the installation or service of equipment during operation. Sometimes this type of FMEA is integrated with the FMEA system in which the scope of the System FMEA includes equipment installation and service.

An example is servicing an oil of car system, where the objective is to guarantee the services of oil changes work reliably and safely following service procedures.

Based on the forth type of FMEA in which has already been described, there is a difference in output that makes more understand about the forth type of FMEA except describe about a potential list of errors ranked by the RPN, the table will express in Table 2.2. The differences have already been conducted by (Stamatis, 2003).

2.3.5. Benefit of FMEA

Based on Ford Motor Company (1992), the use of FMA can give a number of benefits for the company. Generally, the benefits of FMEA are:

a. Improving the quality, reliability, security, and accuracy of the products produced by the company,
b. Assisting in improving customer satisfaction,
c. Reducing costs and product development time, and
d. Documenting and tracking measures ever taken to reduce risk.

Specifically, FMEA type provides benefits in more detail as follows:

a. System FMEA
   i. Helps select the optimum system design alternative
   ii. Helps in determining redundancy
   iii. Helps in defining the basis for system level diagnostic procedures
   iv. Increases the likelihood that potential problems which will be considered
   v. Identifies potential system failures and their interaction with other systems or subsystems
b. Design FMEA
   i. Establishes a priority for design improvement actions
   ii. Documents the rationale for changes
   iii. Provides information to help through product design verification and testing
   iv. Helps identify the critical or significant characteristics
   v. Helps identify and eliminate potential safety concerns
   vi. Help identify product failure early in the product development phase
c. Process FMEA
   i. Identifies process deficiencies and offers a corrective action plan
   ii. Identifies the critical and/or significant characteristics and helps in developing control plans
   iii. Establishes a priority of corrective actions
   iv. Assists in the analysis of the manufacturing or assembly process
   v. Documents the rationale for changes

d. Service FMEA

i. Assists in the analysis of job flow

ii. Assists in the analysis of the system and/or process

iii. Identifies task deficiencies

iv. Identifies critical or significant tasks and helps in the development of control plans

v. Establishes a priority for improvement action

2.3.6. Implementation and Procedure of FMEA

The tendency to continuously improve products and processes as much as possible by the industry today led to the implementation of FMEA as a technique to identify and help reduce failure modes which becomes an important thing. Based on the previous explanations regarding definition, history, objectives, type, and benefit then the next is better to know how to apply from the existing procedure. In this analysis, the authors use a 10-step procedure based on (Mikulak et al., 2011). Flow chart of the procedure will be described in Figure 5.1. Specifically based on (Stamatis, 2003) an FMEA should start when:

a. New systems, design, products, processes, or services are designed

b. Existing systems, designs, products, processes, or services are about to change regardless of reason

c. New application are found for the existing condition of the systems, designs, products, process, or service, and

d. Improvements are considered for the existing systems, designs, products, processes, or services.

The best time to start an FMEA is as soon as some information is known, information can be bad report from customers. Then the best time to finish a FMEA is only when the system, design, product, process, or service is considered complete and/or discontinued.

In elaborating FMEA, the team identified failure modes and measures that can reduce or eliminate the failure occurred equally harmful. Input attempted obtained from a group of experts cover various fields such as design, test, quality, product line, marketing, manufacturing and customer to ensure all identified potential failure modes. Based on SOP described in Appendix 1, it can be explained as to the contents to build FMEA team. The first thing to do in conducting FMEA procedure is to make FMEA Team. Although only one person is usually able to be responsible for coordinating the process FMEA, but making the FMEA team

will bring multiple perspectives to address the issue properly. The size in one FMEA good team is usually four to six people, but the size of this effect on the extent of the problems encountered. While in determining the FMEA leader decided to include people who are able to manage it well. In the (Mikulak et al., 2011) the team leader is responsible for coordinating the FMEA process, including:

a. Setting up and facilitating meetings
b. Ensuring the team has the necessary resources available
c. Making sure the team is progressing toward the completion of the FMEA

In the finishing this thesis, author uses one team FMEA considered by Quality Assurance Dept. Head of PT.HIM. One team is concluding four persons.

a. Brainstorming problem

After finishing the making FMEA team, they will brainstorm the problem. They will see how widespread the problem is happening. The extent of the problem is seen from the effects produced in each process and design. Not only that, with the joint problem brainstorming team, it will facilitate the bringing together of perception as well as objective to resolve the existing problems. In the steps explained (Mikulak et al., 2011) it is stated that focusing of FMEA are on the product and process. Actually, in this analysis author focus on product and process because conducting both type can yield subtstantial benefits. According to (Mikulak et al., 2011) they considerably reduce failure mode by identifying product and process improvement early the the result is tough process and reliable product. FMEA Scope Worksheet will define problem limitation. Figure 2.1 and 2.2 will describe the example of FMEA Scope Worksheet of design and process. Then the result of worksheet will be explained in the next chapter 5. In Figure 2.1 it can be explained on a number of phases to determine how far the problem is obtained. Keyword of any questions is: How will the product failed bias? As for Figure 2.3 it is very helpful in determining what processes are by passed and the influence or not the output of each process to another process.

Based on Mikulak's review there is a worksheet which help the team to identifying the problem by divided into design and process. The principle and steps behind all FMEAs are focused on the product or process. For product/design objectives is to uncover problems with the product that will result in safety hazards, product multifunction, or shortened product life. Figure 2.1 will define the worksheet of design FMEA.

Design FMEA Scope Worksheet		
Product:	Date:	Scope defined by:
Part 1: Who is the customer?		
Part 2: What are the product features and characteristics?		
Part 3: What are the product benefits?		
Part 4: Study the entire product or only components or subassemblies?		
Part 5: Include consideration of raw material failures?		
Part 6: Include packaging, storage, and transit?		
Part 7: What are the operational process requirements and constraints?		

Figure 2.1. Design FMEA Scope Worksheet (Source: Raymond J. Mikulak)

Based on Table 2.2 it can be explained that the worksheet is helpful to conduct a process consisting people, materials, equipment, method, and environment. With the five element and ask how can process failure affect the design of products? Let's answer those simply question each part.

First of all, in the part 1 there is question about the costumer. In this research like already explain before that the costumer for the product of type Hyundai H-1 is foreign costumer. The foreign costumer are Thailand people and they not direct customer who use the vehicle but they are distributor PT.HIM in Thailand.

Next, for the second part, the answer is should describe about the product and characteristics. Object of this research is ID Plate. ID Plate is identification plate that use for vehicle which send abroad. ID plate function is inform customer about the engine number, chasis number and five others components. Because of the customer is from Thailand is out from Indonesia which is means if there is any problems occur with the vehicle machine, ID Plate expected to inform what first aid to cure the vehicle is.

In the third part, the question is about the product benefits. The function of ID Plate is inform or become communication tools for user to know about engine of her/his vehicle. There is any nine components information that consist on one ID Plate. So that, from this a little object able to assist what customer need.

Fourth is asking about the specifically study about the components or subassemblies. In this research, the objective is not the main product but the part of products. In other words, the part is mean the component. The component that become objective is Identification Number Plate (ID Plate). ID Plate is an important part that is needed in order to assists costumer to safe their vehicle. Furthermore, ID Plate has another function, because of ID Plate consist of VIN (Vehicle Identity Number) means that the ID Plate is helpful for identifying the characteristic of vehicle. VIN is comprise 17 numbers. They are serial number of assembly line, manufacturing plant code, model year, check digit, engine type, restraint type, trim level, body type, model/vehicle line, and the last is world manufacturer's code.

Fifth to acquire information about the objective concerning raw material failures or not. And the answer is not. Because of, the part is unable to be created in the PT.HIM environment. Moreover, the part came from the plate is already provided in gravure's area. Then PT.HIM will be printed ID Plate with chassis number, engine number, the number for each process, model of vehicle, and date of making the vehicle. After printing those number, next step is polishing ID Plate and the last step is to install the part into vehicle. Because of this, raw material failures isn't need to be contemplation.

Sixth is including packaging, storage and transit or not. The explanation is not involve packaging and storage. The findings only highlights the incoming process from supplier until ID Plate installed to Hyundai H-1 vehicle. Due to this circumstances, there is no packaging and storage process happened

The last question is the process requirements of ID Plate. The flowchart process production of ID Plate will be shown in Figure 4.14. Starting from raw material plate coming and then move to printing area, polish area, and installation. Consequently, there is four main step along with the whole ID plate process.

Besides that, in the process FMEA which has function to find the failure mode when process performing. It means the failure mode will occur after finishing each process. This elements is different with design of FMEA. Those five element able to ask how process failure can affect the product, processing efficiency, and/or the safety. Figure 2.2 will defining the scope of a process FMEA study.

Process FMEA Scope Worksheet		
Process:	Date:	Scope defined by:
Part 1: What process components are to be included in the investigation?		
Part 2: Who is the customer?		
Part 3: What process support systems are to be included in the study?		
Part 4: To what extent should input materials be studied?		
Part 5: What are the product material requirements and constraints?		
Part 6: Should packaging, storage and transit be considered part of this study?		

Figure 2.2. Process FMEA Scope Worksheet (Source: Raymond J. Mikulak, 2009)

First of all for question part 1 is asking the process component are to be include in this research. The process components are in printing action and installation action. In the printing the component that provide is printing tools. Besides that, for installation action the component are needed is nut and gasses tools.

Secondly asking about the costumer, like already explain before in design FMEA that the costumer is come from abroad specifically from Thailand.

Third, the support system which will consist in this research are the whole process of ID Plate through in the scope of PT.HIM. The process are from incoming part, printing step, polishing step, and the last is installation ID Plate to vehicle. The flow chart of support system will be seen in Figure 4.14.

Fourth, asking about the extent should input in this research. Actually, in the scope of research already told that scope just only in internal of PT.HIM. If there is any external things Fifth, the product material requirement are consisting of printing area that known as graver's component. The tools function is to mark the plate by graphic in the plate by using needle pointer. The needle has an end sharp to make a good gravure's in the plate there is any setting in the pressure of needle pointer. The pressure is helping to positioning the needle in the right force. Then the thickness of gravure's will smooth and understandable.

Finally, the last part question is asking about packaging, storage, and transit are considered in this research or not. The packaging and storage are unavailable in

the process so that there not considered in this research. Whereas, for transit step is considered because of in each step of ID Plate there is any transit starting from incoming. Based on both worksheet can be inferred that those worksheet helpful in defining the problems from general until specific. After finished in the worksheet it's continue on ten steps based on procedure from Mikulak's book.

b. Review the process of product function

The team should review engineering drawings and specific process on the issue of existing parts. This will help ensure that everyone in the team FMEA has the same understanding about the product or process that is being done after obtaining a physical image or an existing process flow chart.

The next step is to find the function of each item and the existing processes. A function is what item or process is intended to do, usually to a given standard of performance or requirement. For process FMEAs, this is the primary purposes of the manufacturing or assembly operation. While, for design FMEAs, this is the primary purpose or design intent of the item.

c. Brainstorm potential failure modes

From the results of the review process and product it can be seen the discovery of the image and function of each process and then next step is looking design failure mode. A failure mode is the way how the goods or operating potentially fail to comply or provide functionality that already exists in the standards or requirements (out of standard). Depending on the existing standards or requirements that have been created by a team such as failure mode analysis may include failure to perform a function, inadequate performance, conduct an unwanted or undesired functions appear. Example of failure modes include described in **Figure 2.3.**

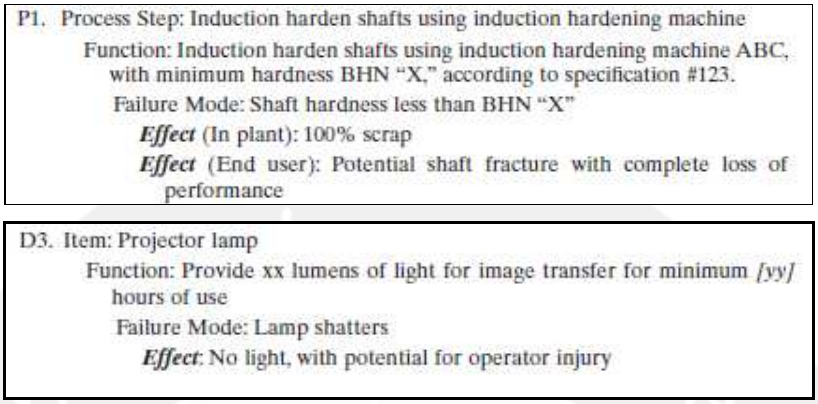
Open circuit	Cracked	Warped	Hole missing
Leak	Brittle	Blistered	Rough
Hot surface	Broken	Corroded	Short/long
Wrong invoice	Dirty	Grounded	Misaligned
Bent	Eccentric	Discolored	Omitted
Over/undersize	Melted	Burred	Binding

Figure 2.3. Example of failure modes (Source: Carl S. Carlton, 2013)

d. List potential effects of each failure mode

After finishing the brainstorm potential failure modes, the next step is list potential effect that will occur. Effects are the results/ outcomes that happen after failure

on the system, design, process, and service. An example of list potential effect will describe in **Figure 2.4.**


P1. Process Step: Induction harden shafts using induction hardening machine
Function: Induction harden shafts using induction hardening machine ABC, with minimum hardness BHN "X," according to specification #123.
Failure Mode: Shaft hardness less than BHN "X"
Effect (In plant): 100% scrap
Effect (End user): Potential shaft fracture with complete loss of performance

D3. Item: Projector lamp
Function: Provide xx lumens of light for image transfer for minimum *[yy]* hours of use
Failure Mode: Lamp shatters
Effect: No light, with potential for operator injury

Figure 2.4. Example of List Potential Effects (Source: Carl S. Carlton, 2013)

Based on the figure, it can be explained that the effects can be for manufacture of end user (customer). Then the potential effect is not limited in one statement if there is so many effects it can be written as much as possible the effects appear.

e. Assign a severity ranking for each effect

Severity is a ranking number associated with the most serious effect for given failure mode, based on the criteria from severity scale. For only severity is define as tha manner of potential failure or in dictionary written as the fact/condition of being deserve.The severity always applies to the effect of a failure mode. There is any correlation between effect and severity, if the effect is critical the severity is high. Otherwise, if the effect is not critical, then the severity is high. Figure 2.5 and Figure 2.6 is a severity scale based on Automotive Industry Action Group (AIAG) 4th Edition, 2008 Manual, "Potential Failure Mode and Effect Analysis (FMEA) in (Carl S. Carlton, 2013)

Effect	Criteria: Severity of Effect on Product (Customer Effect)	Rank
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.	10
	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning.	9
Loss or Degradation of Primary Function	Loss of primary function (vehicle inoperable, does not affect safe vehicle operation).	8
	Degradation of primary function (vehicle operable, but at reduced level of performance).	7
Loss or Degradation of Secondary Function	Loss of secondary function (vehicle operable, but comfort/convenience functions inoperable).	6
	Degradation of secondary function (vehicle operable, but comfort/convenience functions at reduced level of performance).	5
Annoyance	Appearance or audible noise, vehicle operable, item does not conform and noticed by most customers (>75%).	4
	Appearance or audible noise, vehicle operable, item does not conform and noticed by many customers (50%).	3
	Appearance or audible noise, vehicle operable, item does not conform and noticed by discriminating customers (<25%).	2
No Effect	No discernible effect.	1

Figure 2.5 Design FMEA Severity Scale (Source: Carl S. Carlton, 2013)

Effect	Criteria: Severity of Effect on Product (Customer Effect)	Rank
Failure to Meet Safety and/or Regulatory Requirements	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulations without warning.	10
	Potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulations with warning.	9
Loss or Degradation of Primary Function	Loss of primary function (vehicle inoperable, does not affect safe vehicle operation).	8
	Degradation of primary function (vehicle operable, but at reduced level of performance).	7
Loss or Degradation of Secondary Function	Loss of secondary function (vehicle inoperable but comfort/convenience functions inoperable).	6
	Degradation of secondary function (vehicle inoperable but comfort/convenience functions at a reduced level of performance).	5
Annoyance	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by most customers (>75%).	4
	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by many customers (50%).	3
	Appearance or Audible Noise, vehicle operable, item does not conform and noticed by discriminating customers (<25%).	2
No effect	No discemible effect.	1

Figure 2.6 Process FMEA Severity Scale(Source: Carl S. Carlton, 2013)

Rank	Effect	Criteria: Severity of Effect on Process (Manufacturing/Assembly Effect
10	Failure to Meet Safety and/or Regulatory Requirements	May endanger operator (machine or assembly) without warning.
9		May endanger operator (machine or assembly) with warning.
8	Major Disruption	100% of product may have to be scrapped. Line shutdown or stop ship.
7	Significant Disruption	A portion of the production run may have to be scrapped. Deviation from primary process including decreased line speed or added manpower.
6	Moderate Disruption	100% of production run may have to be reworked off line and accepted.
5		A portion of the production run may have to be reworked off line and accepted.
4	Moderate Disruption	100% of production run may have to be reworked in-station before it is processed.
3		A portion of the production run may have to be reworked in-station before it is processed.
2	Minor Disruption	Slight inconvenience to process, operation, or operator
1	No effect	No discernible effect.

Figure 2.7. (Continue) Process FMEA Severity Scale (Source: Carl S. Carlton, 2013)

f. Assign an occurrence ranking for each failure mode

Occurrence is ranked number associated with the possibility that the cause of the failure mode and will be available in the item/ part to be analyzed. So, before finding an occurrence ranking, it should know the causes. A cause is the specific reason for the failure, ideally found by asking “why” until the root cause is determined. The best method for determining the occurrence ranking is to use actual data from the process. When actual failure data are not available, the team must estimate how often a failure mode may occur and at what frequency by knowing the potential cause of failure. Figure 2.8 will execute example of potential causes. Based on the example, it can be described that both of examples are different. In the first example there is only one cause in one effect. But in the second example, there is one effect with four causes. It depends on how the process effect on any process or the next and previous item. In spite of finishing found causes then should find the occurrence ranking based on occurrence scale for design FMEAs. The occurrence scale will be expressed in Figure 2.9 and Figure 2.10. These scales are from the AIAG, 4th Edition, 2008 Manual, “Potential Failure Mode and Effect Analysis (FMEA).

P1. Process Step: Induction harden shafts using induction hardening machine
Function: Induction harden shafts using induction hardening machine ABC, with minimum hardness BHN "X," according to specification #123.
Failure Mode: Shaft hardness less than BHN "X"
Effect (In plant): 100% scrap
Effect (End user): Potential shaft fracture with complete loss of performance
Cause: Induction machine electrical voltage/current settings incorrect for part number

P4. Process Step: Apply primer to part X using primer paint gun
Function: Apply uniform coat of primer, with thickness and evenness to paint specification #XYZ
Failure Mode 1: No primer
Effect: Primer coat operation must be done off-line
Cause 1: Paint gun clogged due to lack of maintenance
Cause 2: No paint in paint holding tank
Failure Mode 2: Primer too thick
Effect: Material must be scrapped
Cause 1: Shut-off switch does not shut off paint flow due to sensor failure
Cause 2: Paint application equipment not calibrated properly

Figure 2.8. Example of Potential Causes of Failure Modes (Source: Carl S. Carlton, 2013)

Likelihood of Failure	Criteria: Occurrence of Cause (Design Life/Reliability of Item/Vehicle)	Criteria: Occurrence of Cause (Incidents per Items/Vehicles)	Rank
Very High	New technology/new design with no history.	≥100 per thousand ≥1 in 10	10
High	Failure is inevitable with new design, new application, or change in duty cycle/operating conditions.	50 per thousand 1 in 20	9
	Failure is likely with new design, new application, or change in duty cycle/operating conditions.	20 per thousand 1 in 50	8
	Failure is uncertain with new design, new application, or change in duty cycle/operating conditions.	10 per thousand 1 in 100	7
Moderate	Frequent failures associated with similar designs or in design simulation and testing.	2 per thousand 1 in 500	6
	Occasional failures associated with similar designs or in design simulation and testing.	0.5 per thousand 1 in 2000	5
	Isolated failures associated with similar design or in design simulation and testing.	0.1 per thousand 1 in 10,000	4
Low	Only isolated failures associated with almost identical design or in design simulation and testing.	0.01 per thousand 1 in 100,000	3
	No observed failures associated with almost identical design or in design simulation and testing.	≤0.001 per thousand 1 in 1,000,000	2
Very Low	Failure is eliminated through preventive control.	Failure is eliminated through preventive control.	1

Figure 2.9. Design FMEA Occurrence Scale (Source: Carl S. Carlton, 2013)

Likelihood of Failure	Criteria: Occurrence of Cause—PFMEA (Incidents per Items/Vehicles)	Rank
Very High	≥100 per thousand ≥1 in 10	10
High	50 per thousand 1 in 20	9
	20 per thousand 1 in 50	8
	10 per thousand 1 in 100	7
Moderate	2 per thousand 1 in 500	6
	0.5 per thousand 1 in 2000	5
	0.1 per thousand 1 in 10,000	4
Low	0.01 per thousand 1 in 100,000	3
	≤0.001 per thousand 1 in 1,000,000	2
Very Low	Failure is eliminated through preventive control.	1

Figure 2.10. Process FMEA Occurrence Scale (Source: Carl S. Carlton, 2013)

Based on the occurrence scale, it able to explain that there is need take sampling data to get more accurately occurrence values. Because in the limitation already limit by company that the data only can take 10% from exiting population. So observation only take a little sample size of data. But, there is any journal that 10% able to be observed. As stated by Gay and Diehl (1996) in Saputra, Hari Guntoro Ridha (2010) minimal number of sample acceptable for study is depend on the type of research conducted. For descriptive study, a sample is use 10% of the population for became minimum sample. This research actually is descriptive research because according to (Suharsimi Arikunto: 2005) the descriptive research is intended to gather information concerning the existing issues. The issues mean obstacles occurring during research. The purpose of descriptive research based on his research is explaining in systematic, factual, and accurately on each fact of the existing population. Same as Arikunto, based on Sugiyono (2003) descriptive research is studies which conducted to determine the value of an independent variable, either one or more variables without making comparisons between each variables. In this case, the data collection is done to get occurrence value. Therefore, the data is ID Plate with causes as the variables. So the data retrieved to determine how many causes occur in ID Plate

process and design of the required minimum sample of 10% of the population. Accidentally, the samples was obtained on July 25th 2015 and February 25th 2016 is 300 ID Plate (the data can be seen in Appendix 5). With the result that 30 ID Plate becomes minimum number of samples study. Observation result is able to seen in Appendix 6. After obtaining sample size of population, to make data errorless they tested again on sufficiency test and the outcome data is sufficient. Data tested by used mensuration of each ID Plate variables. The culmination able to seen in Appendix 7.

g. Assign a detection ranking for each failure mode and/or effect

Detection is ranked number numbers associated with the control of the best of the list of the detection is done in the process. It means, we should know the potential of control that happen before seeking value based on the detection of detection criteria scale. Example of potential control will describe in Figure 2.11.

For figure above can be expressd that the control can be divided into two kinds. There are prevention and detection control. prevention - type design controls describe how a cause, failure mode, or effect in the product design is prevented based on current or planned actions; they are intended to reduce the likelihood that the problem will occur, and are used as input to the occurrence ranking. In the other hand, Detection - type design controls describe how a failure mode or cause in the product design is detected , based on current or planned actions, before the product design is released to production, and are used as input to the detection ranking. If both controls already observed, the next step is to find an occurrence ranking by see **Figure** 2.12 and 2.13.

D3. Item: Projector lamp
Function: Provide *[xx]* lumens of light for image transfer for minimum yy hours of use
Failure Mode: Lamp shatters
Effect: No light, with potential for operator injury
Cause: Over pressure due to wrong gas specified
Prevention Control: Design Guideline for projector lamps including gas properties
Detection Control: Lamp pressure test #456

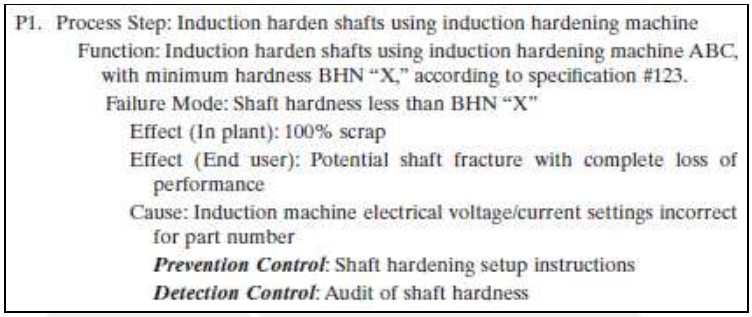


Figure 2.11. Example of Potential of Control (Source: Carl S. Carlton, 2013)

h. Calculate the risk priority number (RPN) for each effect

The RPN is simply calculated by multiplying three primary kind's different ranking, the severity ranking, the occurrence ranking, and the detection ranking. According to (Carl S. Carlton) RPN is the product of each of the three rating scales: severity, occurrence, and detection. If the scale for severitu, occurrence and detection each range from 1 to 10 the the maximum RPN value is range between 1 to 1000.

$$\text{RPN number} = \text{Severity} \times \text{Occurrence} \times \text{Detection} \quad (1.1)$$

i. Prioritize the failure modes for action

The results of RPN value can now be prioritized by ranking them in order based on reviews of those failure modes. Prioritizing can be done from the highest score to the lowest risk. Pareto diagram can be very helpful to describe the difference any failure of the highest and lowest. If the obtained value is very high failure it means that the risk of failure that must be corrected immediately compared to value range of the failure that its value is smaller than the others. So that was step prioritize is very helpful in decline risks which to be handled quickly, prevented and corrected.

Opportunity for Detection	Criteria: Likelihood of Detection by Design Control	Rank	Likelihood of Detection
No Detection Opportunity	No current design control; cannot detect or is not analyzed.	10	Almost Impossible
Not Likely to Detect at any Stage	Design analysis/detection controls have a weak detection capability; virtual analysis (e.g., CAE, FEA, etc.) is ***not correlated*** to expected actual operating conditions.	9	Very Remote
Postdesign Freeze and Prior to Launch	Product verification/validation after design freeze and prior to launch with ***pass/fail*** testing (subsystem or system testing with acceptance criteria such as ride and handling, shipping evaluation, etc.)	8	Remote
	Product verification/validation after design freeze and prior to launch with ***test to failure*** testing (subsystem or system testing until failure occurs, testing of system interactions, etc.)	7	Very Low
	Product verification/validation after design freeze and prior to launch with ***degradation*** testing (subsystem or system testing after durability test, e.g., function check).	6	Low
Prior to Design Freeze	Product validation (reliability testing, development or validation tests) prior to design freeze using ***pass/fail*** testing (e.g., acceptance criteria for performance, function checks, etc.)	5	Moderate
	Product validation (reliability testing, development or validation tests) prior to design freeze using ***test to failure*** (e.g., until leaks, yields, cracks, etc.).	4	Moderately High
	Product validation (reliability testing, development or validation tests) prior to design freeze using ***degradation*** testing (e.g., data trends, before/after values, etc.)	3	High
Virtual Analysis—Correlated	Design analysis/detection controls have strong detection capability. Virtual analysis (e.g., CAE, FEA, etc.) is ***highly correlated*** with actual and/or expected operating conditions prior to design freeze.	2	Very High
Detection Not Applicable; Failure Prevention	Failure cause or failure mode cannot occur because it is fully prevented through design solutions (e.g. proven design standard, best practice or common material, etc.)	1	Amost Certain

Figure 2.12. Design FMEA Detection Scale (Source: Carl S. Carlton, 2013)

j. Take a recommendation action to eliminate or reduce the high risk failure modes

Recommended actions should consider the existing controls, the relative importance (prioritization) of the issue, and the cost and effectiveness of the corrective action. There can be many recommended actions for each cause. Recommended actions are the tasks recommended by the FMEA team to reduce or eliminate the risk associated with potential causes of failure. An example of recommendation action will be seen in **Figure 2.14.** In the example, it can be explained that the recommendation should be clear enough to be understood. It will be the base of fixing the problem. After thinking about the recommendation it is better to be directly conducted. With the recommendation that is already made, it will reduce the value of the RPN action as soon as possible and change for other failure modes that need to be fixed.

Opportunity for Detection	Criteria: Likelihood of Detection by Process Control	Rank	Likelihood of Detection
No Detection Opportunity	No current process control; cannot detect or is not analyzed.	10	Almost Impossible
Not Likely to Detect at any Stage	Failure Mode and/or Error (Cause) is not easily detected (e.g., random audits).	9	Very Remote
Problem Detection Postprocessing	Failure Mode detection postprocessing by operator through visual/tactile/audible means.	8	Remote
Problem Detection at Source	Failure Mode detection in-station by operator through visual/tactile/audible means or postprocessing through use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc.)	7	Very Low
Problem Detection Postprocessing	Failure Mode detection postprocessing by operator through use of variable gauging or in-station by operator through use of attribute gauging (go/no-go, manual torque check/clicker wrench, etc.)	6	Low
Problem Detection at Source	Failure Mode or Error (Cause) detection in-station by operator through variable gauging or by automated controls in-station will detect discrepant part and notify operator (light, buzzer, etc.). Gauging performed on setup and first-piece check (for setup causes only)	5	Moderate
Problem Detection Post Processing	Failure Mode detection postprocessing by automated controls that will detect discrepant part and lock part to prevent further processing.	4	Moderately High
Problem Detection at Source	Failure Mode detection in-station by automated controls that will detect discrepant part and automatically lock part in station to prevent further processing.	3	High
Error Detection and/or Problem Prevention	Error (Cause) detection in-station by automated controls that will detect, error and prevent discrepant part from being made.	2	Very High
Detection Not Applicable; Error Prevention	Error (Cause) prevention as a result of fixture design, machine design, or part design. Discrepant parts cannot be made because item has been error-proofed by process/product design.	1	Amost Certain

Figure 2.13. Process FMEA DetectionScale (Source: Carl S. Carlton, 2013)

P1. Process Step: Induction harden shafts using induction hardening machine
Function: Induction harden shafts using induction hardening machine ABC, with minimum hardness BHN "X," according to specification #123.
Failure Mode: Shaft hardness less than BHN "X"
Effect (In plant): 100% scrap
Effect (End user): Shaft fractures with complete loss of performance
Effect (Assembly): Not noticeable during assembly
Cause: Induction machine electrical voltage/current settings incorrect for part number
Prevention Control: Shaft hardening setup instructions
Detection Control: Audit of shaft hardness
Recommended Action: Install machine alert light (red) to let operator know when voltage or current is set too high
Recommended Action: Implement Statistical Process Control (SPC) charts on machine voltage and current

Poorly worded example of ***Recommended Action***: Implement Statistical Process Control

Figure 2.14. Example of Recommendation Action (Source: Carl S. Carlton, 2013)

k. Recalculating the resulting RPN as the failure modes are reduces or eliminated

Once action has been taken to improve the product or process, new rankings for severity, occurrence, and detection should be determined, and a resulting RPN calculated. When a failure mode has been eliminated completely, the new risk priority number approaches zero because the occurrence ranking becomes one. So that after get new RPN result succeeding with recomendation action it will be compared with the previous RPN with high RPN. If the RPN number decreasing it mean the recommendation action success, but if opposites it means team should change the recommendation action or it should be waiting for the right moment.

The last is sum of whole data above in one sheet called FMEA Worksheet. An example of FMEA design and process Worksheet can be seen in **Appendix 2 and 3.** With this worksheet, each step of the FMEA analysis should be done with enough clarity and detail to proceed to the next step in the analysis. Too much detail and the analysis bogs down and the team gets frustrated. Too little detail and the team will not get to the root causes and proper corrective actions to reduce risk. As the team proceeds, each step, carefully and properly articulated, makes the subsequent step easier for the team to define.