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OPTIMIZING PRODUCT DEVELOPMENT AND PRODUCTION BY USING FMEA METHODOLOGIES IN AUTOMOTIVE INDUSTRY

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Abstract: *This paper delves into the significance of Failure Mode and Effects Analysis (FMEA) in the design and production phases of new products. Specifically, it focuses on Design Failure Mode and Effects Analysis (DFMEA) for product design and Process Failure Mode and Effects Analysis (PFMEA) for production processes. The authors' team systematically reviews the methodologies and steps involved in executing robust design and production processes, leveraging FMEA techniques that have been developed over time and are continually refined.*

Keywords: *FMEA, Design FMEA, Process FMEA.*

INTRODUCTION

Failure Mode and Effects Analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, in a manufacturing or assembly process in automotive industry during the project phase. It was originally created and developed in USA in the 1960s, by the aerospace industry, during the Apollo mission, to preliminary assess the impact of system failure on the mission success and personnel safety [3]. FMEA was one of the earliest structured reliability improvement methods. Today it is still a highly effective method of lowering the possibility of failure, by improving the safety and reliability in a big range of industries, as automotive, electronics, mechanical, etc.

FMEA serves as a proactive tool to identify potential failure modes and their associated effects early in the product development lifecycle. In the realm of product design, DFMEA enables engineers to anticipate and mitigate risks by systematically analysing the potential failure modes of individual components or subsystems. By identifying failure modes, their causes, and effects, design teams can implement preventive measures to enhance product reliability and performance. The purpose of the analysis is to prioritize the failure modes of a design, process, and product in order to assign the limited resource to the highest risk items.

EXPOSITION

"Failure modes" means the ways, or modes, in which something in a production process might fail. Failures are any errors or defects, especially ones that affect the customer, and can be potential or actual.

"Effects analysis" refers to studying the consequences of those failures. Effects are the ways that these failures can lead to waste, defects or harmful outcomes for the customer. Failure Mode and Effects Analysis is designed to identify, these failure modes.

There are numerous high-profile examples of product recalls resulting from poorly designed products and/or processes.

Failure Mode and Effects Analysis, or FMEA, is a methodology aimed at allowing organizations to anticipate failure during the design stage by identifying and limit all of the possible failures in a design or manufacturing process.

Failures are prioritized according to how *serious* their consequences are, how *frequently* they occur, and how easily they can be *detected.* The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones.

Failure modes and effects analysis also document current knowledge and actions about the risks of failures, for use in continuous improvement.

FMEA begins during the earliest conceptual stages of design – Design FMEA (DFMEA) to anticipate failure during the design stage by identifying all of the possible failures, (Fig.1). It explores the possibility of product malfunctions, reduced product life, and safety and regulatory concerns derived from the material properties, geometry, tolerances, interfaces, etc.

Later, it's used for control, before and during ongoing operation of the manufacturing process – Process FMEA (PFMEA) and continues throughout the life of the product or service. PFMEA (Fig.2) discovers failure that impacts product quality, reduced reliability of the process, customer dissatisfaction, and safety or environmental hazards derived from human factors, methods followed while processing, materials used, machines utilized, measurement systems, environment factors, etc.

FMEA is not a substitute for good engineering. Rather, it enhances good engineering by applying the knowledge and experience of a Cross Functional Team (CFT) to review the design progress of a product or process by assessing its risk of failure.

Potential
Failure Mode and Effects Analysis
(Design FMEA)

System
Subsystems
Component — FMEA number:
Model Year/Vehicle(s) — Design resposibility: — Prepared by:
Core Team — Key Date: — FMEA Date (Orig): — (Rev.):

Item/Functions	Requirements	Potential Failure Mode	Potential efects of Failure	SEV	CLASS	Potential causes / Mechanismes to Failure	Current design Controls Prevetion	OCC	Current design Controls Detection	DET	RPN	Recommended Actions	Responsibility & Targer Completion date	Action Results				
														Actions taken	SEV	OCC	DET	RPN

Fig. 1. DFMEA Worksheet (Carl S. 2012)

Potential
Failure Mode and Effects Analysis
(Process FMEA)

Items — FMEA number:
Model Year/Vehicle(s) — Process resposibility: — Prepared by:
Core Team — Key Date: — FMEA Date (Orig): — (Rev.):

Process Step / Functions	Requirements	Potential Failure Mode	Potential efects of Failure	SEV	CLASS	Potential Causes / Mechanismes to Failure	Current Process Controls Prevetion	OCC	Current Process Controls Detection	DET	RPN	Recommended Actions	Responsibility & Targer Completion Date	Action Results				
														Actions taken	SEV	OCC	DET	RPN

Fig. 2. PFMEA Worksheet (Carl S. 2012)

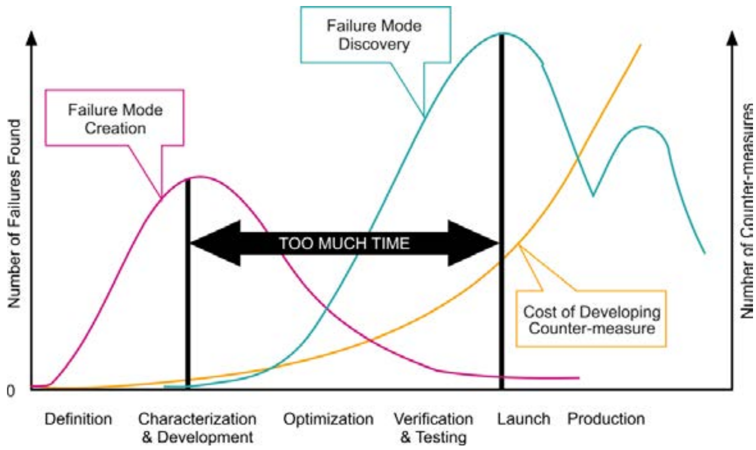

Fig. 3. Late FM Discovery

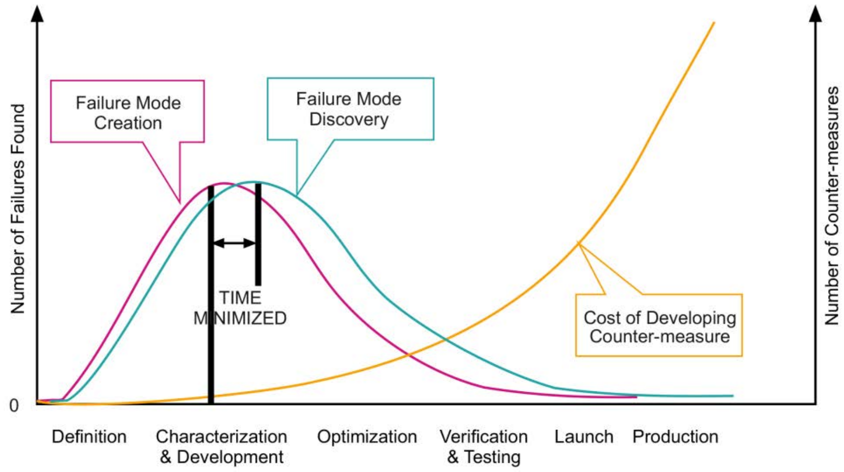

Fig. 4. Early FM discovery (Carl S. 2012)

Historically, the sooner a failure is discovered, the less it will cost. If a failure is discovered late in product development or launch, the impact is exponentially more devastating with nasty consequences of poor performance (Fig. 3). Discovering a failure early in Product Development (PD) using FMEA provides the benefits of multiple choices for mitigating the risk, higher capability of verification and validation of changes, collaboration between design of the product and process, lower cost solution, etc. (Fig. 4).

Performing FMEA starts when you are designing a new product or process, or performing an existing process in a different way, or a quality improvement goals for a specific process exist. Quality and reliability must be consistently examined and improved for optimal results throughout the lifetime of a process.

FMEA is performed in several steps, with key activities at each step, separated to assure that only the appropriate team members for each step are required to be present.

Step 1. Define the scope of FMEA

Step 2. Gathering the team

Step 3. Understand the system to be analysed.

Step 4. Brainstorm of failure mode for each component and its effect

Step 5. Determine *S*, *O* and *D* for each failure modes. [3]

Each functions, failure modes, effects of failure are ranked by three factors from 1 to 10 – Severity (*S*), Occurrence (*O*) and Detection (*D*). The multiplication of the results, present the Risk Priority Number (RPN) for actions follow-up when counter measures would be taken and are successful at reducing risk or re-design is needed.

There are three steps to ease and improve the FMEA:

Step 1 - Develop a Consistent FM Description – easy to read and understand, using a sample naming:

Part causing failure (object) / 2. Failure mode (adjective) / due to / 3. Failure cause (why)

Ex.: Bearing (object) seized (adj.) due to lack of lubrication (why); Gear (object) worn (adj.) due to the ingress of particles (why)

The use of language in FMEA to describe failure modes is very important to consider the component (what failed), the mode of failure (an adjective) and the cause of the failure (the why) to gain real benefits from an FMEA, otherwise outcomes can be compromised and typically FMEA will not improve the equipment performance as intended.

Step 2 - Development of the Failure Characteristics

Selecting the correct logical decision, by understanding the failure characteristics from a prior failure data or history. This is typically done using statistical distributions.

Step 3 - Determining the Applicable Maintenance Task

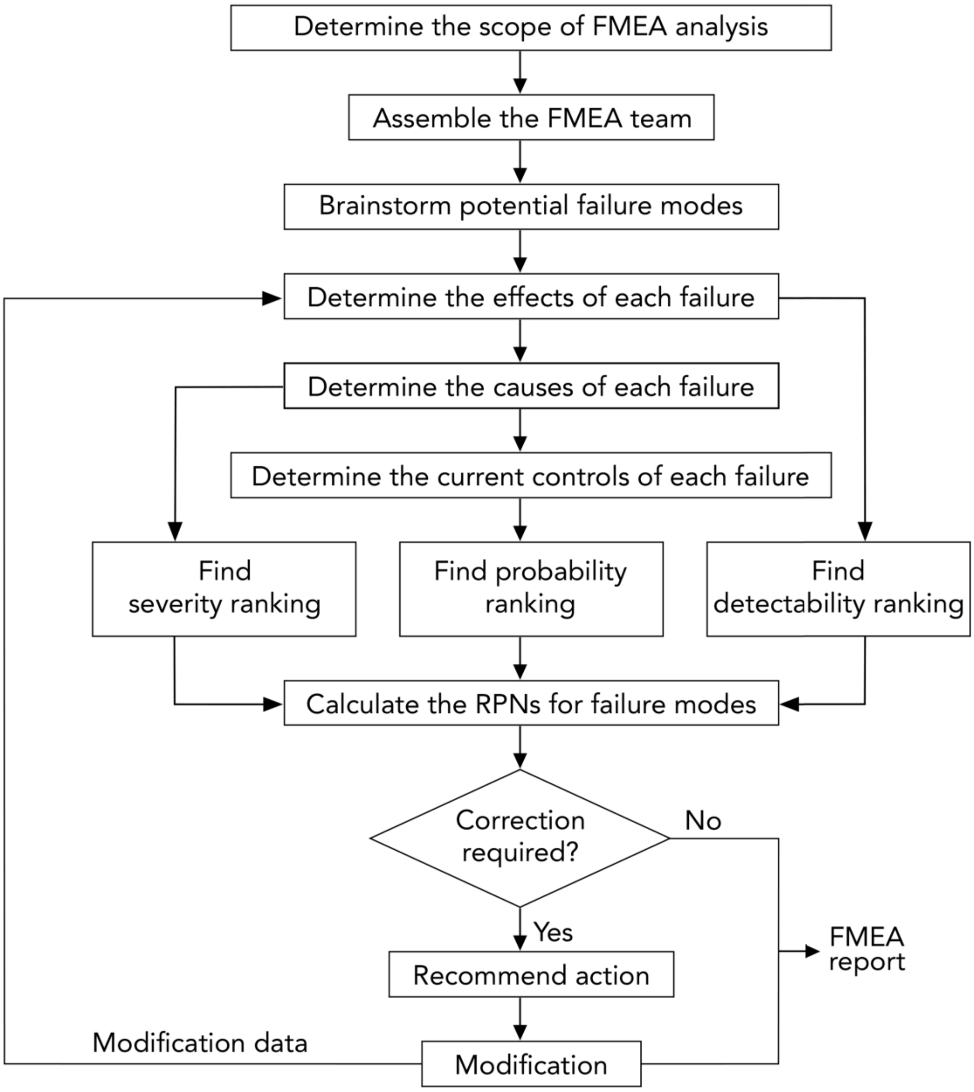

Fig. 5. Main steps of FMEA (Hu-Chen Liu, 2016)

	Evaluation of the Severity Criteria		Evaluation of the Occurrence		Evaluation of the Detection	
10	Very high	Affects safe operation of the vehicle and/or other vehicles, the health of driver or passengers or road users or pedestrians.	Extremely high	First application of a new technology anywhere without operating experience and/or under uncontrolled operating conditions. Not product verification and/or validation experience. Standards do not exist and best practices have not yet beed determined. Prevention controls not able to predict field performance or do not exist.	Very high	Test procedure yet to be developed.
9		Noncompliance with regulations.	Very high	First use of a design with technical innovations or material within the company. New application or change in duty cycle/operating conditions. No product verification and/or validation experience. Prevention cosntrols not targeted to identify performance to specific requirements.		Test method not designed specifically to detect failure mode or cause
8	High	Loss of primary vehicle function necessary for normal driving during expected service life		First use of a design with technical innovations or material within the company. New application or change in duty cycle/operating conditions. No product verification and/or validation experience. Few existing standards and best practices, not directly applicable for this design. Prevention controls not a reliable indicator or field performance.	Low	New test method, not proven
7		Degradation of primary vehicle function necessary for normal driving during expected service life	High	New design based on similar technology and materials. New application or change in duty cycle/operating conditions. No product verification and/or validation experience. Standards, best practices, and design rules appy to the baseline design, but not the innovations. Prevention controls provides limited indication of prformance.		
6	Moderate	Loss of secondary vehicle function		Similar to previous design, using existing technology and materials. Similar application with changes in duty cycle or conditions. Previous testing or field experience. Standards and design rules exist but are insufficient to ensure that the failure cause will not occure. Prevention controls provide some ability to prevent a failure cause.	Moderate	Proven test method for verificatio of functionality or validation of performance, quality, reliability and durability; planned timing is later in the product development cycle such that test failure may result in production delays for re-design and /or re-tooling.
5		Degradation of secondary vehicle function	Moderate	Detail changes to previous design, using proven technology and materials. Similar application, duty cycle or operating conditions. Previous testing or field experience, or new design with some test experience related to the failure. Design adresses lesons learned from previous designs. Best Practices re-evaluated for this design but have not yet been proven. Prevention controls capable of finding deficiencies in the product related to the failure cause and provide some indication of performance.		

Fig. 6. Example of RPN analysis, what to consider

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Design Failure Mode and Effect Analysis V01-09

Description / Beskrivning	Part no. / Artikelnummer	Status - Hardware / Status - Hårdvara	Customer / Kund	
PCB Laila	SXK107110	Rev. A	Samhall	
Function / Funktion	Part name / Artikelbenämning	Issued by / Utfärdad av	Doc.no. / Dok.nr.	Date / Datum
Assembly	PCB	Klaus Mailer	DFMEA:99-001	990521

Operation		Characteristics of failure				Rating				Action - Status						
No.	Step	Failure mode	Causes of failure	Effects of failure on part/system	Testmethod	Po	S	Pd	RPN	Recommendations	Decisions taken	Po	S	Pd	RPN	Respons.
1	Incoming inspection	Material change not notified to Samhall	Deficient information	Goods not released, production delay	None	1	2	1	2							
2		FIFO not followed	Traceability not followed	Incurant material due to age or specifiction	None	2	2	1	4							
3		Interchange of PCB	Erroneous marking	Wrong PCB to production	None	6	8	10	480							
4		ESD damage to PCB	Wrong handeling	PCB will be destroyed	None	4	7	5	140							
5	Spotwelding fuse to precut Ni-strip	Mounted other way round	Lack of information	Further assembly fuse not in use	None	1	4	4	16							
6		Position natt acc to tolerances	Machinery tolerances	Fuse does not fit	None	3	4	5	60							

Fig. 7. Example of real DFMEA (The Elsmar Cove Homepage, 2024)

The analysis could be demonstrated in three paths:

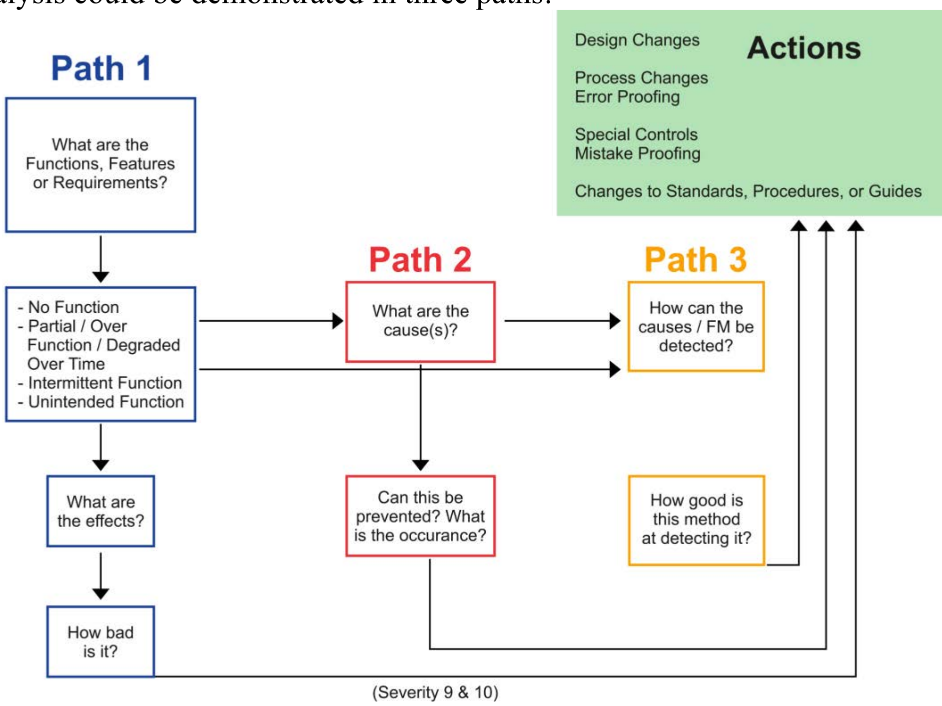

Fig. 8. FMEA - Three Path Model (Quality-One International, 2023)

A maintenance task is said to be *applicable* if, the task is capable of improving on the reliability that would exist if the task was not performed. If an acceptable maintenance task cannot be found to reduce the risk to an acceptable level, then the only way to protect from failure would be to redesign the system.

CONCLUSIONS

The paper emphasizes the iterative nature of FMEA, highlighting the importance of continuous improvement. As technologies evolve and new challenges emerge, FMEA methodologies must adapt accordingly to remain effective. The authors' team underscores the need for organizations to invest in ongoing training and development to ensure that FMEA practices are up to date and aligned with industry best practices. Failure Mode and Effects Analysis (FMEA) is a structured approach to discovering potential failures that may exist within the design of a product till the production process.

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