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FMEA application in production processes and its effects to the manufacturer

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Abstract: The FMEA (Failure Mode and Effects Analysis) method is a systematic approach used to identify potential failure modes in production processes, as well as the associated effects and likelihood of those failures occurring. The FMEA method helps to prioritize potential failure modes based on their potential impact, allowing organizations to address the most critical issues first. This article presents a comprehensive review of the FMEA method, including its history, principles, and steps. The article also discusses the benefits of the FMEA method for companies, including improved product quality, reduced costs, and enhanced customer satisfaction. The FMEA form is an essential component of the FMEA process, as it helps to ensure that all relevant information is captured and organized in a structured manner. This article will introduce the FMEA method and provide an overview of the FMEA form, including its various sections and how it is used in the FMEA process. The aim of this article is to provide a comprehensive analysis of FMEA and the ways in which it is applied, to ensure the applicability of FMEA to manufacturing processes for manufacturers. In this way, manufacturers will benefit in time, budget, energy and profitability. In addition, with FMEA, problems will be prioritized according to their criticality, and errors will be intervened at the right time and in the fastest way. In the article, an FMEA form will be created for the steel rope production process as a study case, and the benefit and profitability it will provide to the manufacturer will be revealed. In this way, the effect of FMEA in a production process will be embodied.

Key words: FMEA, Failure Mode and Effect Analysis, FMEA Form, Steel Rope Manufacturing FMEA

1. Introduction

FMEA, or Failure Modes and Effects Analysis, is a risk management tool that was developed in the late 1940s by the military to identify potential failures in a system and to assess the severity of those failures. It was initially used to analyze complex systems such as aircraft and missiles. FMEA has since been adapted for use in various industries, including manufacturing, healthcare, and service industries. It is used to identify and prioritize potential failures in a process, product, or service, and to develop strategies to mitigate those failures. FMEA can be used during the design phase of a product or process, or it can be used to analyze an existing product or process to identify opportunities for improvement.

Failures are prioritized according to how serious their consequences are, how often they occur, and how easily they can be detected. The purpose of FMEA is to take measures to eliminate or reduce failures, starting with those with the highest priority. FMEA is used during design to prevent failures. It is then used for control before and during the ongoing operation of the process. Ideally, FMEA begins at the earliest conceptual stages of design and continues throughout the life of the product or service [1].

The purpose of the FMEA is to evaluate the risk associated with the identified failure modes, effects and causes, and prioritize issues for corrective action, after identifying possible failure modes and causes and the effects of the failure on the system or end users.

The aim of this article is to enable a company to minimize errors and losses in the manufacturing process and to help the company increase its efficiency by using the FMEA method in a manufacturing process by helping to implement corrective actions to address the most serious concerns in the manufacturing or in any kind of producing processes.

2. Experimental

FMEA was formalized in 1949 by the US Armed Forces by the introduction of Mil-P 1629 Procedure for performing a failure mode effect and criticality analysis.. The objective was to classify failures "according to their impact on mission success and personnel/equipment safety" [2].

In 1950s the increasing attention paid to safety and the need to prevent predictable accidents in aerospace industry led to the development of the FMEA methodology. Later, it was introduced as key tool for increasing quality and efficiency in manufacturing processes [3]. In 1977, Ford Motors introduced FMEA to address the potential problems in the Research and Development (R&D) in the early stage of production and published the Potential Failure Mode and Effects Analysis Handbook in 1984 to promote the method. Later on the automobile manufacturers in America also introduced the FMEA into the management of suppliers, and took it as a key check issue [4].

Find out reasons behind the failure of some subjects of mechanical engineering course and after analyzed the system through FMEA and they suggested recommend to solve the problem [5]. Execute FMEA to develop an effective quality system and to improve the current production processfor the better quality of the products [6]. FMEA a It is a proven tool to reduce lifecycle warranty costs. It is much more economical to fix problems that occur in the early stages of product development than to fix these errors post-launch. FMEAs can identify problems in the production process and provide an opportunity to take action before a potential disaster scenario.

2.1 *FMEA Standards*

FMEA, or Failure Mode and Effects Analysis, is a systematic method for identifying potential failures in a system or product and assessing the associated risks. It is used to identify and prioritize actions that can be taken to prevent or mitigate those failures. In order to apply this method, there are several specified standards and guidelines that provide guidance on how to conduct an FMEA, including:

- ISO 9001: This international standard provides requirements for a quality management system (QMS) and includes guidance on how to use FMEA as a tool for identifying and mitigating risks in the design and development of products and processes.
- SAE J1739: This standard, developed by the Society of Automotive Engineers (SAE), provides guidance on conducting FMEA for automotive systems.
- MIL-STD-1629A: This military standard provides guidance on conducting FMEA for aerospace and defense systems.
- AIAG FMEA: The Automotive Industry Action Group (AIAG) has developed a set of guidelines for conducting FMEA in the automotive industry.
- Six Sigma: The Six Sigma methodology includes a specific type of FMEA called a "DFMEA" (Design FMEA) that is used to identify and mitigate risks in the design of products and processes.

Regardless of the specific standard or guidelines being followed, the general approach to conducting an FMEA typically involves identifying potential failure modes, determining the effects of those failures, evaluating the likelihood and severity of those effects, and implementing actions to prevent or mitigate the identified risks.

2.2. *Purposes of FMEA*

The primary purpose of conducting an FMEA is to identify and mitigate risks in a system or product. This is typically achieved by identifying potential failure modes and their associated causes, determining the effects of those failures, evaluating the likelihood and severity of those effects, and implementing actions to prevent or mitigate the identified risks. Also, some purposes of conducting an FMEA include:

- Helping to organizations to identify and address potential issues in the supply chain by involving suppliers in the FMEA process
- Helping organizations to identify and prioritize areas for improvement in a product or process.
- Improving communication and collaboration within an organization by involving a diverse group of stakeholders in the FMEA process.
- Documenting the risk assessment process through an FMEA can be useful for demonstrating due diligence and complying with regulatory requirements.
- Helping to improve the overall reliability and safety of a system or product by identifying and addressing potential failure modes,

The main goal of conducting an FMEA is to proactively identify and address potential issues before they occur, which can help to improve the quality, reliability, and safety of a product or system, and reduce the cost and impact of product failures.

2.3 *Types of FMEA*

There are several different types of FMEA that can be used to identify and mitigate risks in a system or product.

Design FMEA (DFMEA): The main aim of a DFMEA is to identify and address potential issues in the design of a product or process especially before it is built or implemented, which can help to improve the overall reliability and safety of the product or process, and reduce the cost and impact of product failures.

The basic implementation process required for effective use of DFMEA can be evaluated as follows: Scope of DFMEA should be defined, including the product or process analyzed and the stakeholders involved in the process, then possible failure modes and their associated causes should be identified. After the effects of each failure mode have been identified, including the potential impact on the customer and the organization, the probabilities and degree of danger of each failure mode and its effects should be determined. Then, the measures to be taken to prevent or reduce the identified risks to an acceptable level should be determined on the basis of regulations. After the identified actions have been implemented, the DFMEA should be reviewed periodically to be current and effective. If the risk situations again rise above the accepted level, a reanalysis should be carried out.

Concept FMEA (CFMEA): It is a type of FMEA used to identify and evaluate potential failure types and associated risks during the conceptual design phase of a product, and to identify the necessary design requirements and features that will enable the product to meet its performance and reliability objectives.

Concept FMEA is often used to evaluate the feasibility and potential risks of different design concepts and to determine the best process plan for moving forward in the development of a product. It is an important tool in the early stages of the design process to identify and address potential problems where they can more easily and cost-effectively intervene and produce solutions.

The concept FMEA execution process follows the same general steps as traditional FMEA, with some customized considerations for the early stages of product development. The main aim is to identify potential failure modes, identify the potential risks and effects of each failure mode, and ensure that appropriate corrective actions are taken to reduce or eliminate these risks.

Process FMEA (PFMEA): It is similar to traditional Failure Modes and Effects Analysis (FMEA), but is specifically focused on identifying and mitigating potential issues within a process, rather than in a product or system. PFMEA provides continuous improvement for the process with a proactive, systematic, collaborative and risk-based approach.

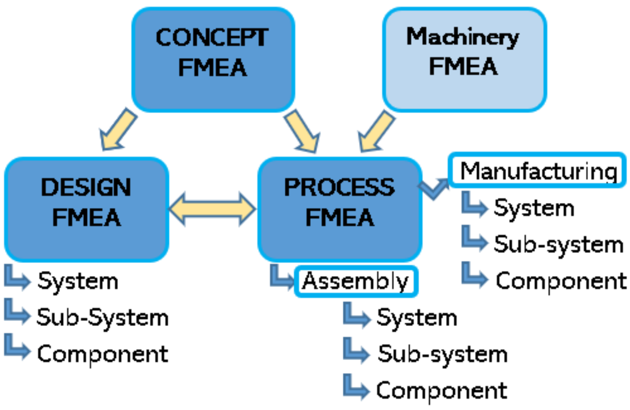

Fig. 1. Types and relations of FMEA

2.3 *Procedures of FMEA*

After a comprehensive understanding of the FMEA process, long meetings and time losses in workplaces will be avoided, and work processes or productions will become more efficient with the quality, loss reduction and savings provided by FMEA.

1. Define the scope of the FMEA by identifying the product or process being analyzed, the potential failure modes, and the potential effects of those failure modes on the product or process.
2. Identify the potential failure modes by identifying all of the ways in which the product or process could fail, as well as the root causes of those failure modes.

3. Evaluate the potential effects of each failure mode by the impact of each failure mode on the product or process, as well as on the customer or end user.
4. Determine the likelihood of each failure mode occurring by estimating the probability of each failure mode occurring, based on historical data, testing, and engineering judgment.
5. Assign a risk priority number (RPN) to each failure mode. The RPN can be calculated by multiplying the severity of the potential effects, the likelihood of the failure mode occurring, and the detectability of the failure mode. The failure modes with the highest RPNs are given the highest priority for corrective action and it represents the highest risks.

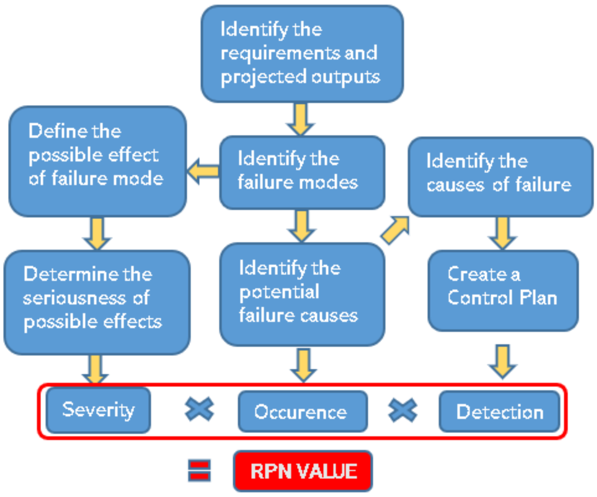

Fig. 2. Identification of the RPN Value

6. Identify potential corrective actions by identifying preventive measures that can be taken to mitigate or eliminate the potential failure modes.
7. Implement the corrective actions by taking the preventive measures identified in the previous step, and by verifying their effectiveness in mitigating or eliminating the potential failure modes.
8. Update the FMEA by revisiting the FMEA periodically to ensure that it is still accurate and effective, and making any necessary updates based on changes to the product or process, or new information that becomes available.

2.4 *FMEA Documentation*

The figures below show the columns in an FMEA form separated. *Figure 3* is shown in the figures from the "SEV" column, *Figure 4* from the "DET" column, the *Figure 5* from the "Target completion date for corrective actions" column, and the *Figure 6* from the "Action Results" column. The numbers under the column headings represent the numbering of the entries that should be written in that box. The explanation for the box corresponding to each number is given below.

ITEM	FUNC	Potential Failure Mode	Potential Effect(s) on Failure	SEV
1	2	3	4	5

Fig. 3. FMEA Form Column Headings – 1st Part

Potential Causes of Failure	OCC	Current Design Controls	DET
6	7	8	9

Fig. 4. FMEA Form Column Headings – 2nd Part

RPN	Recommended Action(s)	Target completion date for corrective actions
10	11	12

Fig. 5. FMEA Form Column Headings – 3rd Part

Actual completion date for corrective actions	ACTION RESULTS				
	Actions Taken	SEV	OCC	DET	RPN
13	14	15	16	17	18

Fig. 6. FMEA Form Column Headings – 4th Part

① in *Figure 3* is the manner under the "Item" column represents the process or product being analyzed.

② in *Figure 3* is the manner under the "Function Column" represents the expected function or purpose of a particular product or system within the product or any process being analyzed. In the other words, the requirement that the product or system must meet for the specific task or purpose it is intended to perform.

③ in *Figure 3* is the manner represents the various ways in which a part or system within the product or process being analyzed fails to provide its desired function. In other words, these potential failure modes represent the root cause or underlying mechanism of the failure, with specific symptoms or outputs causing a failure.

④ in *Figure 3* is the manner represents the consequences or effects of a particular failure mode. These effects represent some of the effects that the defect may have on the product or process, as well as any direct or indirect effects that may occur as a result of the defect occurring.

⑤ in *Figure 3* is the manner under the "Severity" column represents the quantitative impact or consequence of a particular failure mode. To assess the severity level of any fault mode, a numerical value is assigned to each fault mode based on a predetermined scale. This scale can range from 1 (low importance) to 10 (high importance). Higher numbers represent higher severity. The severity of each failure mode is then used to prioritize and address the most significant failure modes and implement corrective actions to prevent or mitigate these failures.

Table 1. Severity guidelines for design FMEA [7].

Effect	Rank	Criteria
No	1	No effect
Very Slight	2	Customer not annoyed
Slight	3	Customer slight annoyed
Minor	4	Customer experiences minor nuisance
Moderate	5	Customer experiences some dissatisfaction
Significant	6	Customer experiences discomfort
Major	7	Customor dissatisfied
Extreme	8	Customer very dissatisfied
Serious	9	Potential hazardous effect
Hazardous	10	Hazardous effect

⑥ in *Figure 4* is the manner represents the root cause or underlying mechanism of a particular failure mode. This can be cited as any positive factor or root cause in the product or process that may be more contributing, along with the particular conditions or factors that contributed to the failure.

⑦ in *Figure 4* is the manner under the "Occurrence" column, represents the probability or probability of a particular failure mode occurring. This probability is determined by a joint assessment of each factor that has an impact on the product or process, along with the particular conditions that led to the failure. To identify the quantitative occurrence by 1 to 10 scales. The probability of occurence decreases from 10 to 1.

Table 2. Occurrence guidelines for design FMEA [7].

Effect	Rank	Criteria
Almost never	1	Failure unlikely. History shows no failure
Remote	2	Rare number of failures likely
Very Slight	3	Very few failures likely
Slight	4	Few failures likely
Low	5	Occasional number of failures likely
Medium	6	Medium number of failures likely
Modreately high	7	Moderately high number of failures likely
High	8	High number of failures likely
Very high	9	Very high number of failures likely
Almost certain	10	Failure almost certain

⑧ in *Figure 4* represents inputs that can be used to evaluate the effectiveness of existing design controls in preventing or mitigating the identified failure mode and to identify additional controls that may be necessary to further reduce the risk of failure.

⑨ in *Figure 4* represents the probability of detecting a failure mode before it causes adverse effects, on a numerical scale of 1-10. This column is used to rate the probability that a failure mode can be detected beforehand during the design, development, manufacture or use of a product or system.

Table 3. Detectability guidelines for design FMEA [7].

Effect	Rank	Criteria
Almost Certain	1	Proven detection methods available in concept stage
Very Slight	2	Proven computer analysis available in early design stage
Slight	3	Simulation and/or modeling in early stage
Minor	4	Tests on early prototype system element
Moderate	5	Tests on preproduction system components
Significant	6	Tests on similar system component
Major	7	Tests on product with prototypes and system components installed
Extreme	8	Proving durability tests on products with system components installed
Serious	9	Only unproven or unreliable technique(s) available
Hazardous	10	No known techniques available

⑩ in *Figure 5* represents the Risk Priority Number (RPN) is a quantitative measure of the overall risk associated with a particular failure mode. The RPN is calculated by multiplying the ratings for the likelihood of occurrence, the severity of the effect, and the detectability of the failure mode.

$$RPN = Severity \times Occurence \times Detection$$

⑪ in *Figure 5* represents the actions that can be taken and the course to be followed to reduce or mitigate the detected failure mode and reduce the associated risk.

⑫ in *Figure 5* represents the date by which recommended actions to prevent or mitigate a particular failure mode are expected to be completed. The target completion date should be realistic and achievable, taking into account the resources and constraints available.

⑬ in Figure 6 Represents the date recorded on the FMEA form to monitor the progress of risk reduction efforts after recommended actions have been implemented. The actual completion date should be compared with the targeted completion date to determine whether the proposed actions are completed on schedule. If the actual completion date is later than the targeted completion date, it may reveal delays or obstacles that prevent the proposed actions from being completed on time.

⑭ in Figure 6 represents the actions taken to reduce the identified risk. The actions may be modifications to the design or process, material changes, extra inspection or testing procedures, or any other measure aimed at reducing the severity of their effects.

⑮, ⑯, ⑰, ⑱ in Figure 6 represents current Severity value after actions taken, current Occurence value after actions taken, current Detection value after actions taken and new RPN value after necessary risk reducer actions taken, respectively. After the actions taken, the new severity, occurrence, and detection values gives the new RPN value. If the new RPN value determined is not at the desired level and is still at a dangerous level, it is recommended to take new actions. If the RPN value is at the desired level, it is recommended to repeat the FMEA process periodically to ensure effectiveness.

In *Figure 7* below, FMEA form is created for a steel rope production process. Potential problems that may arise at the stages of the steel rope production process have been identified. Within the framework of FMEA principles and depending on the process flow, starting from critical problems, solutions were offered for functions above the limit value and risks were brought to a reasonable level. In the "heat treatment" step in the steel rope production process, potential failure effects were determined as ductility and durability problems for the potential failure modes. Since ductility problems in steel ropes or cables produced can cause fatigue crack of the material, the "severity" value of this problem is set as 9. The "detectence" value is set to 7, since it takes place inside the fatigue crack material and has low detectability. The "occurence" value of this problem, which has a low potential for realization as it is an important parameter and its controls are provided in many stages, was determined as 3. Accordingly, the RPN value was calculated as 189 and the need for a solution arose because it was above 100, which is considered a risky value. As a solution to this problem, the action was taken to update the machine and give the necessary instructions to the employees. Thanks to that, the new RPN value has been updated to 36 and the risk status has been reduced. This situation enabled the problem to be identified and solved through FMEA without incurring an extra cost for the manufacturer.

Optimizing costs by maximizing the customer satisfaction constitutes the basic principle of creating quality. It is sufficient to produce faultless and complete product and offering it to the clients, the expectations of customers should also be met [8]. In order to create a quality, FMEA is a key application for quality control as it is one of the methods to be applied for cost reduction and quality creation.

FAILURE MODE AND EFFECTS ANALYSIS

Item:	Steel Rope	Responsibility:	F. Demirkaya	FMEA number:	123
Model:	Designed for a bridge construction	Prepared by:	F. Demirkaya	Page :	1 of 1
Core Team:	Quality, Production and Engineering responsibles of the manufacturer			FMEA Date (Orig):	11.09.2022 Rev: 1

Function	Potential Failure Mode	Potential Effect(s) of Failure	SEV	Potential Cause(s)/ Mechanism(s) of Failure	OCC	Current Design Controls	DET	RPN	Recommended Action(s)	Target Completion Date for corrective actions	Completion Date for corrective actions	Actions Taken	SEV	OCC	DET	RPN
Heat treatment	Improper heat treatment, Overheating, and Uneven heat distribution	Ductility and Durability problems	9	Human and Machinery Faults	3	None	7	189	Carefully controlling the temperature and time of the heat treatment	12.09.2022	13.09.2022	Machine updates and giving instructions to responsibles	9	2	2	36
Steelmaking	Defects in the steel	Insufficient material ductility	9	Inefficient furnace operation	4	Regularly testing the steel for defects	5	180	Implement strict quality control measures	15.09.2022	15.09.2022	Regularly review and update quality control processes	9	3	1	27
Raw material preparation	Improper mixing of the materials	Problems with the structural integrity	9	Improper quality of the raw material	3	Following a consistent mixing procedure	5	135	Use high-quality raw materials	1.10.2022	1.10.2022	Use pure iron ore and low sulfur coke	9	2	1	18
Hot rolling	Difficulties with the heating and rolling process	Production difficulty	5	Improper operation of machinery	2	None	1	10	None				5	2	1	10
Wire drawing	Equipment malfunction	Insufficient Strength	8	Wrong Machine Setup	4	Operator training and instructions	2	64	None				8	4	2	64
Stranding	Strand misalignment, Strand breakage, Strand Surface defects	Premature Tool or Machine Breakdown	7	Improper machine set up	3	Operator training and instructions	1	21	None				7	3	1	21
Laying	Layering defects, Layering misalignmentand Layering surface defects	More prone to failure	8	Human and Machinery Faults	2	Following the laying procedures carefully	2	32	None				8	2	2	32
Continuous casting	Defects in the slab	Insufficient strength and performance	7	Low quality of the material	2	Using high-quality steel	2	28	None				7	2	2	28

Fig. 7. A FMEA Form Case Study Example Prepared for the Steel Rope Manufacturing Process

3. Results and discussion

The results of the study show that the application of FMEA method has a significant positive effect on the profitability and productivity of the producer.

In terms of profitability, according to case example study made in the study, manufacturers saw a reduction in the number of product defects and malfunctions. This results in fewer warranty claims and customer complaints. This results in increased customer satisfaction and loyalty, as well as reduced costs associated with repairing and replacing defective products, and increasing long-term benefits. The FMEA method also helped the manufacturer identify and prioritize possible types of failures and take corrective action before they happen, leading to a reduction in unplanned downtime and an increase in the overall reliability of production processes. This resulted in increased productivity as the company was able to produce more products with fewer interruptions in a given time frame.

The results of our study demonstrate the value of FMEA in increasing profitability and productivity for manufacturers. By identifying and addressing potential failure modes, the FMEA method helps companies reduce the occurrence of defects and failures, resulting in increased customer satisfaction and loyalty, as well as reduced costs associated with repairing and replacing defective products.

4. Summary and conclusions

The FMEA method helps increase the reliability and uptime of production processes, increasing productivity and efficiency. This is especially important in today's competitive business environment, where companies are under pressure to deliver high-quality products at lower cost and with shorter lead times.

The study showed that one of the main benefits of the FMEA form is that it helps to organize and document the results of the FMEA analysis in a structured and systematic manner. This includes identifying potential failure modes, their potential effects, and the recommended actions for addressing them. By capturing this information in a standardized form, manufacturers are able to easily communicate and share the results of the FMEA analysis with relevant stakeholders, including engineering, quality, and production teams.

Overall, the study shows that the FMEA method is a valuable tool for manufacturers looking to increase their profitability and productivity. By applying FMEA, companies can proactively address potential types of failures and take corrective action, leading to reduced defects and failures, increased customer satisfaction and loyalty, and increased profitability and productivity.

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