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New generation FMEA method in automotive industry: an implementation

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Abstract

In today's production systems, preventing a risk before it occurs is very valuable for companies. In order to do this, various risk analysis methods are used. FMEA, which is the most widely used and mandatory in the automotive industry, is one of these techniques. Failure Mode and Effects Analysis (FMEA) is a risk analysis technique that is a powerful method for identifying and managing potential failures that may arise from products, processes, services and systems. In this study, FMEA method was applied in the coating process of the supplier producing sealing elements in the automotive industry. Three risk evaluation methods which AIAG FMEA Handbook fourth edition 2008, VDA-4 standard and new generation AIAG & VDA FMEA handbook, 2019 were used in FMEA risk analysis in the study. Using these methods, the risks of the coating process were determined and the automation of the processes that were initially carried out manually by the operators was automated. With this improvement, the risk was reduced by 69.8%. In addition, differences and up-to-date information on FMEA assessment methods used in the automotive industry have been brought to the literature.

1. Introduction

Today, it is very important to identify potential failures in manufacturing businesses while the product is still in the design phase and to analyze and manage the risks that these failures will create. Customer's perception and expectation have gained a different dimension with technological developments and have become more complex and difficult to manage. In order to hold on to the market, product and process reliability must be ensured. There are many methods used to achieve this. That led to the emergence of these methods; there are increasing market demands, customer focus, cost, time constraints and intense competitive pressure, laws/regulations that must be fulfilled in product responsibility, technological developments and globalization. Quality management systems that ensure that production activities are standardized; making these methods mandatory is among the reasons for widespread use.

There is a need to increase product reliability in the process from the emergence of the new product to the delivery of the product to the customer and then to the warranty stage. In order to do this, potential risks must be revealed and resolved during the design and process stages. Failure Mode and Effects Analysis (FMEA), which is very powerful in this respect, stands out among the risk analysis methods used to increase the reliability of the product and the customer. FMEA studies are also a requirement according to IATF 16949:2016 Quality Management Systems Standard and customer specific request for automotive companies. In the studies carried out by Luczak and Wolniak, 99% of the automotive industry suppliers determined that FMEA was required from the customer request, 78% from the ISO/TS 16949 requirement, and 62% in terms of the organization's own culture and problem-solving technique (Luczak and Wolniak, 2015).

FMEA can be defined as a systematic set of activities that aim to identify and evaluate the possible failures of a product/process and their effects, causes, identify actions that can eliminate or reduce the likelihood of possible failures, and document the process. It defines what a design or process must do to satisfy the customer (SAE_J1739, 2008). The FMEA was first developed in the US Army and started to be implemented in 1949 with the military standard MILSTD-1629A (Procedures for Performing A Failure Mode Effects and Criticality Analysis) (Narayanagounder and Gurusami, 2009). Afterwards, it started to be applied in the aerospace industry (NASA's Apollo project), nuclear, automotive, aviation, food and many other industries (Bertsche, 2008). First application in the automotive industry in 1977 Ford Motor Company implemented the method followed by the other two major groups of the automotive industry; used by General Motors and Chrysler (Gilchrist,1993).

FMEA; It is a collection of systematic activities established to identify and evaluate the potential defects of a product or process and the effects of these defects, to define actions to reduce or eliminate the possibility of potential failures occurrence, and to document all activities (AIAG, 2008). In the FMEA methodology, there are mainly types of FMEA, which are Design and Process FMEA. FMEA has been applied and continuously developed for more than 40 years in many industries from the first years to the present day. FMEA is a widely used analysis in the manufacturing industry. It is used as an important risk analysis method especially in the automotive industry.

The aim of this study is to diversify the literature by using the action prioritization matrix as well as the RPN evaluation, which is used as a traditional method in FMEA method. In addition, by applying P-FMEA in a new process of the sub-industry, the risks of the process were defined. It has been presented that the risk measure that the business may encounter can also be determined with the traditional risk assessment and the assessment matrix used as a new generation. Considering that this method will become widespread in the coming days, it has been evaluated that the business can make the transition more comfortable. The measures to be taken against the risks of the new process were determined and transferred to the top management. Afterwards, with the support of the top management, the necessary measures were invested in this study. RPN approach is seen as a traditional method in FMEA and has some disadvantages. In this context, other alternative approaches were used instead of RPN in this study. What these approaches can be and how they will be used are among the original points of the study.

We organized the sections of this article as follows: Section 2, we describe FMEA in the literature review and some of the previous studies. Section 3, definitions used in FMEA studies as well as alternative analyzes used in risk assessment are given. In Section 4, the implementation and analysis of the FMEA study is described in detail. Risks were evaluated by considering the manually managed process of a company producing sealing products in the automotive supplier company, and actions that could be developed were defined and implemented. Finally, in Section 5, we present the results and recommendations for future work.

2. Literature Review

Failure Mode and Effects Analysis (FMEA) is a popular technique used to improve the reliability of products, services and manufacturing processes by analyzing potential failures and causes of failures before they occur them to avoid to customers (Liu et al., 2019a). There are many studies on FMEA both in practice and theory.

Eubanks et al. (1997) applied a different approach to the product behavior model to make the design phase more effective. Advanced Failure Mode Effects Analysis (AFMEA); It is a system that is used to catch failures escaping the traditional FMEA method and captures the failure modes more broadly, which defines the cause-and-effect relationship. Based on the example of an automatic ice machine from a household refrigerator, FMEA has been studied in a non-automotive industry. Cornes and Stockton (1998) emphasized that FMEA is applicable in many industries and must be defined at the beginning of the design. Emphasizing the importance of the timing of FMEA, they revealed that it is a necessity of the design phase. Scipioni et al. (2002) applied the FMEA method in the food industry and revealed its interactions with HACCP (Hazard Analysis at Critical Control Points). By applying FMEA in an industry other than automotive and nuclear, they have led the way that FMEA can be applied to other industries very easily.

Pantazopoulos and Tsinopoulos (2005) applied design and process FMEA in the metal forming industry. They emphasized that it is a potential tool that can be used widely in different sectors as well as the reliability of complex electrical-electronic parts in the automotive and space industry. The aim of this study is to determine the weak points of the system and to determine the studies that will minimize the incidence of failures. Yeh and Hsieh (2007) propose an FMEA for the fuzzy theory approach. They stated that the subjectivity in RPN evaluation can be eliminated with the fuzzy theory approach. Segismundo and Miguel (2008) defined FMEA as a standard that can be used as a technical risk management method for decision-making optimization in the new product development process by applying FMEA work in the automotive industry. As a result of the study, the number of prototypes required was reduced, resulting in a reduction in project and test plans. Zhao (2011) combined SPC (Statistical Process Control) and FMEA methodology and stated the importance of FMEA in the statistical controls of operators.

Chen (2013) revealed the risks of autonomous maintenance by applying FMEA analysis in maintenance activities. It has determined the equipment and operator failure types in autonomous maintenance activities. Shishebori (2015) has worked to reduce production waste in a production facility by using FMEA, DOE and Six-Sigma methods together. As one of the waste reduction methods, the importance of FMEA has contributed to the literature. Vahdani et al. (2015) determined the RPN calculations using the TOPSIS method to improve the risk assessment process. It has added a different dimension by removing RPN calculations from the classical calculation method. According to Jamshidi et al. (2015) uses prioritization with fuzzy FMEA method to decide the best strategy for security standards. They made an application that included medical equipment such as baby incubators, infusion pumps, and computed tomography scanners.

Ristic et al. (2016) developed a dynamic maintenance cost model for the components of a power transformer to save on maintenance costs with a small initial investment. Bao et al. (2017) proposed an approach based on the FMEA method and a modified AHP technique to assess occupational disease risk in the Chinese mining industry. In their approach, the modified AHP method was used to calculate the weights of occupational disease risk factors.

Pazireh et al. (2017) adopted the FMEA approach to design and implement a quality control system in apparel production lines, identify and rank potential challenges, and finally give the right commands to quality control stations. The data were collected from a medium-sized textile factory and implemented by FMEA, and then the improvement of production efficiency was analyzed using simulation-based optimization technique. The results of the simulation showed a significant reduction in product defects, rework and total cost of production. Madzik and Shahin (2020) proposed an approach that could help segment customers more accurately using the FMEA study, they have classified customers by their loyalty priority number (LPN). LPN is designed as the main segmentation criterion consisting of customer loyalty rate, product or service purchase frequency and purchase value. Using the proposed approach allows dividing customers into four broader groups based on their loyalty and values to the organization: random, bronze, silver, and gold.

FMEA is a team work that can be defined as a multi-criteria decision-making problem and carried out by a multidisciplinary team (Carpitella et al., 2018). FMEA is the collaborative effort of a multidisciplinary team to identify potential failure modes, evaluate them, and create corrective actions to reduce risk (Stoll, 1999). However, consensus among experts has been ignored in most of the current research. Therefore, it will be important to introduce the different approaches used in manufacturing sectors to the literature in order to encourage communication between experts and help them reach consensus.

Maisano et al. (2020) reviews the traditional P-FMEA approach and is intended to allow distributed experts to individually formulate their judgments through Thurstone's Law of Comparative Judgment and Generalized Least Squares method, a new addition technique based on combination with the ZMII technique. The dP-FMEA method is presented as a method that allows many experts to be managed without the need for physical work. Also supported by an application example in a plastic injection molding process

FMEA has some limitations discussed in the literature Liu et al., (2014), The most important among these limitation is that the same RPN (risk priority number) index may arise from different values of severity, occurrence and detection criteria, and in these cases it may become unclear which risk will take priority; RPN comparison alone will not be enough. For this reason, FMEA studies of the AIAG standard operating in the automotive industry and the VDA standard were combined in 2019 and a standard was published (AIAG & VDA FMEA, 2019). What makes this study unique is to solve a current problem of a supplier industry company operating in the automotive sector, as well as to bring to the literature how to use the FMEA method combined in 2019.

3. Method

3.1. Failure Mode and Effect Analysis (FMEA)

Before starting FMEA study it is necessary to have a clear understanding of the concepts. Defining the terms used in a traditional FMEA approach is critical to the FMEA method.

Customer: There are three types of customers in FMEA. Internal customer, assembly line, end user. The severity of a failure mode is defined for these three customers and the highest severity is taken and defined as the severity of the failure mode (Koomsap and Charoenchokdilok, 2018). In FMEA studies, the customer may be the end user the product or service reaches, the assembly line or the next process. The point that the product coming out of a business reaches in the market is the external customer. At the stage where that product circulates between the processes related to the business, each department will be the internal customer of the previous department. In the FMEA study, the customer is considered as the person or department affected by any potential failure that may occur (Stamatis, 2003).

Functions, Requirements, Steps: These are the expected purposes of a process or product. For Process FMEA, the functions that the relevant process step must fulfil are defined in this step. Then the failure types are revealed (Matzler et. Al., 2004). A function is the purpose expected to be achieved by a product or process. It is the desired characteristics of a product or service. A failure that may occur may prevent some features of the product or service from working, as well as cause all features to not work. When the function of the product or process is clearly defined, the detection of failure modes will also become clear. Numerical data and specifications should be specified in this cell when defining the function. The requirements part is the machinery, equipment, materials, etc. needed for the product or service to fulfill this function. Defines the list of in steps, the steps belonging to the flow of the process are expressed (Chemweno et al., 2016).

Potential Failure Modes: All failures that may occur during the use and production of the product must be identified. It is not expected that failures have occurred. Failure can also be considered. A failure occurs when a product or process fails to fulfill the required function and customer expectation. Failure modes are defined as potential failures. Every situation that is likely to happen is taken into account. Failure modes are defined by experiencing from previous failures (Rezaee et al., 2018). FMEA uses the term failure modes to refer to the ways in which something fails to function as required. Failures can be identified either generically or specifically.

Failure Effects: This is the stage where the effects/results of the failure that will occur when the failure modes are not prevented or eliminated, on the product and process are investigated. It is important for the team to be well aware of what failures the customer can accept/tolerate and what they will not.

Potential Root Causes: All possible root causes of the failure should be investigated. There is a direct relationship between the failure and the root causes. The occurrence of the root cause means that the failure mode has occurred. A failure can have more than one root cause. Various problem-solving techniques are used to uncover root causes such as global 8D, 5 Why, Ishikawa etc. (Hekmatpanah, 2011).

Controls: It includes preventive and detection controls. Controls should be accessible to product design and process. Controls should primarily focus on preventive controls to prevent the failure from returning. If preventive controls cannot be provided, detection controls should be defined. All controls that can prevent the failure from escaping to the customer should be evaluated (Stamatis, 2003).

Risk Assessment: The most important step of FMEA is the assessment of the risk. For this, three factors are taken into account; severity, occurrence and detection (Stamatis, 2003). The scores needed for risk assessment may differ from industry to industry.

• **Severity:** Assessing the effect of the failure on the customer. Considering the worst-case scenario, the severity should be given according to that score, which has the most impact on the customer. Severity score can only change with design changes. The severity score cannot be changed by an action taken outside of that. Because severity is the effect on the customer, the effect of a failure is always considered the same.

• **Occurrence**: How often the root cause of the failure and failure may visible. If there is no data on the probability of a failure, a similar score is made using previous experience. Occurrence score in FMEA study can sometimes be for root cause and sometimes for failure mode. Because even if any simulation work is done, root causes for some failures may not be revealed.

• **Detection**: Comprise preventive and detection controls that detect root cause or failure mode (Chao and Ishii, 2007). If there is more than one control, the best case with the lowest detection score is taken into account. Scoring is utilized according to the evaluation tables[1] used in which industry.

3.1.1 AIAG FMEA Methodology

3.1.1.1. Risk priority number (RPN)

In failure modes and effects analysis (FMEA), the failure occurrence, severity and detection scores are used to calculate risk priority number (RPN). The RPN values are utilized to rank failures (Geramian et al., 2019). FMEA assesses each risk factor on three scales – Severity (S), Occurrence (O) and Detection (D) (Shaker et al., 2019). Each of these factors can be assessed on a scale from 1 to 10. Different approaches have been proposed to improve FMEA analysis. (Sankar and Prabhu, 2001). RPN calculation is one of them. The result of the assessment is a list of all the risk factors and their calculated risk priority number (RPN).

Severity x Occurrence x Detection = RPN - Risk Priority Number

The numerical equivalent of each factor (severity, occurrence, detection) varies between 1 and 10. Teams give this score using tables. The RPN value is an integer between 1 and 1000. Preventive actions are planned by sorting the obtained RPN values in descending order (Shi et al., 2019). In the traditional FMEA approach, RPN analysis is used to measure the extent of risk. However, in recent years, such a stand-alone evaluation of RPN is not accepted in the automotive industry. Because the RPN evaluation can sometimes be misunderstanding.

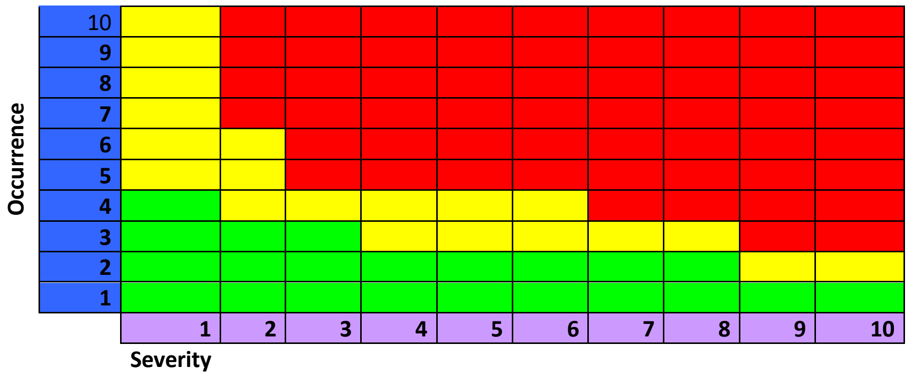
Item	Severity	Occurrence	Detection	RPN
A	9	2	5	90
B	6	3	6	108

Figure 1. Rpn sample

In this example, the RPN is higher for characteristic B, but the priority should be to work on A with the higher severity of 9, although the RPN is 90 which is lower and below the threshold. Especially for this reason, some automotive manufacturers use a matrix rather than RPN. Failure mode severity loses its importance when RPN is evaluated only (Hettiarachchi et al., 2021). In 2019, FMEA was updated and evaluations were made according to action prioritization.

3.1.1.2. VDA FMEA Methodology

This matrix is able to analyze every aspect of the severity, occurrence capability of failures. Automotive manufacturers utilizing VDA (Verband der Automobilindustrie that means that standard rules for Supplier Company) such as BMW, Audi, VW, Mercedes, Daimler. RPN value consist of the severity and occurrence scores are in FMEA study. In this matrix system, the importance of detection does not have a major impact on assessing the magnitude of the risk. Because the important and valuable thing is to prevent the occurrence of failure. The negative effect of this approach is that the detection criterion is not taken into account at all (Kok and Yildiz, 2017a).



(VDA 4, 2012).

Figure 2. Severity & occurrence evaluating matrix

1. Green zone: No action needed. The current risk level of the process is acceptable.
2. Yellow zone: Taking action is not mandatory but recommended. Company decide whether to take action by evaluating its resources.
3. Red zone: Action is mandatory. Action should be taken as resources allow. If action cannot be taken, the reasons should be stated.

Recommended Actions and Results: The trend of actions should be to reduce all risks and reduce the possibility of failure. Actions should be determined in order of priority to reduce severity, then occurrence and, if not, detection. In addition, the risk should be re-evaluated after the action and scoring should be done. (Subriadi and Najwa, 2020).

Table 1. Process FMEA study form

PFMEA Number:
System:
Subsystem:

OEM:
Department:
Group:
Supplier:

PFMEA Prepared by:
PFMEA Key Date:
PFMEA Original Date:
PFMEA Last Revised:

Process Number	Process	Process Function/Requirement	Potential Failure Modes	Max S	Potential Effect(s)of Failure	S	Class	Potential Cause	O	Current Process Controls (Prevention)	Current Process Controls (Detection)	D	RPN	Recommendation	Responsibility	Date	After Actions Taken				
																	S	O	D	RPN	% Reduction

(FMEA software)

FMEA format accepted in the automotive industry is given in Table 1. The columns can be arranged according to the needs, expectations and wishes of the company. Companies manage this format as excel or special package software for FMEA method. The company where the application is made has improved its processes by using a software for FMEA studies. Using a software has benefits in terms of time and effective management.

3.1.1.3. AIAG & VDA FMEA Methodology

The AIAG FMEA Handbook 2008 fourth edition method, which has been used for many years, mainly in the automotive industry, was combined with VDA standards in 2019 and FMEA AIAG & VDA Handbook was published. In the AIAG &VDA new FMEA method, the assessment of risk is provided by a matrix An AP (Action Priority) analysis is performed, which is similar to the VDA standard, but in which the detection factor is also taken into account (AIAG & VDA FMEA, 2019). According to the AIAG VDA FMEA, 2019 standard, there are 7 steps in FMEA (Gueorguiev et.al., 2020, Plinta, et.al., 2021).

System Analysis	Failure Analysis and Risk Mitigation	Risk Communication
Step 1: Planning and Preparation	Step 4: Failure Analysis	Step 7: Results and Documentation
Step 2: Structure Analysis	Step 5: Risk Analysis	
Step 3: Function Analysis	Step 6: Optimization	

Figure 3. AIAG&VDA FMEA 7 step

According to AIAG & VDA FMEA handbook, the biggest change in the risk analysis part applied in step 5 is action priority. The new FMEA handbook contains more specific criteria to be used to rank Severity, Occurrence and detection levels. Verification of the effectiveness of existing prevention and detection controls, product and process experience, and maturity of defect detection methods are additional criteria and will be considered in the FMEA study. In addition, the AP (Action Priority) has replaced the RPN Risk Priority Indicator. S-Severity, O-occurrence and D-Detection ratings can be singular or combined with three factors, and are evaluated as High, Medium and Low to determine the risk reduction action priority (Gueorguiev et.al., 2020). A high priority risk means a request for mitigation action to develop controls to prevent or detect, or an action that justifies why existing controls are deemed appropriate (Subriadi and Najwa, 2020).

4. Implementation

This study was carried out in a company that produces sealing products in the automotive industry. It manufactures sealing products for OEM's called the main industry. It has production locations in various parts of the World. The company, which has a total of 8500 employees, aims to be the leading supplier in its industry. The company's customers include major automotive manufacturers such as VW, Audi, BMW, Mercedes, Ford, Renault, Fiat, Nissan, Toyota and Hyundai. Sealing products are defined as a key part in vehicle manufacturing. The quality of the sealing products is very important in terms of the functional, comfort and visual comfort of the vehicle. It is very difficult for supplier industries to achieve and maintain this quality level. Companies carry out high-level quality activities in order to stay in the market and not to lose their automotive main industry customers.

In order to produce sealing products, first of all, rubber raw materials must be processed with certain formulas and turned into a rubber mixture. Afterwards, this mixture is turned into semi-finished products by molding and vulcanization techniques in extrusion processes. Produced semi-finished products are made ready to be shipped to the customer in processes called finishing. There is a coating as chemically mixed on the surface of the product due to the sealing of the sealing equipment and the minimization of the energy that may occur in the interaction of the part with the case.

The preparation of this chemical coating mixture, which is used in both extrusion and finishing processes, is a serious and critical process. The type of coating varies according to the demands of the customers on the products and the place where the sealing equipment is used. In order to obtain these chemical mixtures separately, five components are mixed with a specific formula. The mixing process is done in the mixture preparation room. After the mixture is prepared, it is supplied to the extrusion and finishing processes and sprayed on the surface of the products by means of guns online-offline. It is applied online in the extrusion process and off-line in the finishing process. In order for the coating on the product surface, not to be scraped and to create a thickness suitable for customer specifications, the preparation of the mixture must be produced in accordance with the defined recipes. Minimizing and eliminating the risks by foreseeing the failures in advance is critical and valuable in terms of the importance of the process. In this process, there is a need to identify potential risks and offer optimum solutions against these risks.

In this study, FMEA methodology was used for the coating preparation process. Scoring is made by evaluating the risks of each step in the coating process. Instead of traditional risk assessment, risk analysis was carried out in accordance with the German VDA method. In addition, specially developed FMEA software was used for risk analysis. There are advantages to using the software in FMEA method. It provides a practical and fast FMEA study for the team. Pareto analysis was used to evaluate the effect of actions against RPN. A multifunctional team participation is required for an effective FMEA study. In this study, responsibilities including all departments were determined and relevant persons were invited as Core Team.

For the traceability of the FMEA study, the number of the FMEA, by whom it was prepared, when it was updated, is defined as the header. The revised date must be changed with FMEA update. The original date defines when FMEA study is started, and the key date defines when the study is matched to serial conditions. The last revision date indicates the last update date of the study (Wang et.al. 2012). Each FMEA must be tracked with a traceability number. When any change is made in the process, the revision date must be updated. The core team identifies the preventive and detection controls in the current state of the process by identifying the type of failure and root causes that may arise in the related process through brainstorming.

4.1. AIAG FMEA Method

Table 2. PFMEA study

PFMEA Number: 0001 PFMEA Prepared by: Nesimi KÖK PFMEA Original Date: 05.05.2019
PFMEA Key Date: 23.09.2019 PFMEA Last Revised: 11.06.2020

Core Team Members:

FMEA Coordinator; Laboratory Responsible; Process Engineer; Quality Engineer; Production Responsible

Process	Process Function/Requirement	Potential Failure Modes	Max S	Potential Effect(s) of Failure	S	Class	Potential Cause/ Mechanism of Failure	O	Current Process Controls (Prevention)	Current Process Controls (Detection)	D	RPN	Recommendation	Responsibility	After Actions Taken				
															S	O	D	RPN	% Reduction
1. Measuring	1. Improper receipt	1.Wrong Material	7	Process Effect: mixture may be unusable.	7		Material selecting is manual by operator	5	None	None	10	350	Control plan was defined	Quality	7	2	6	84	76 %
				Internal Effect: % 100 Scrapped	7								Automatic system was implemented	Process Engineering					
				Customer Effect: Functional Problem	7		Wrong label on raw-material	3	None	None	10	210	Using tracker system	IT	7	3	5	105	50 %
							Wrong labelling for returning material	2		None	8	112	Returning method was defined	Production	7	2	6	84	25 %

Core teams analyzed this study by applying the brainstorming technique. The team's technical assessments were adapted to the FMEA global format, accompanied by a moderator. It was formed by taking into account the experience of the team in the process. AIAG FMEA manual handbook was used for scoring tables.

While giving the severity score, 7 points were given for the effect on the customers as process effect, internal effect, and customer effect. Since there is no special characteristic in this process, the class column is left blank. For the occurrence score, a scoring was made by evaluating the statistical probabilities of the root causes. Failure cards and realization rates of these root causes were kept in the process, and these data were used in the FMEA study. If there is no control in FMEA, it is important to write none so that that column is not skipped. The main problem here is that the operations made in the process depend on the operator, and as a result, failures are constantly experienced during the operations of the operator. Therefore, automation systems were evaluated in the actions column for root causes or failure modes determined by the team. The top management's ability to allocate a budget for the improvement of this system and what the system will cover have been determined in the FMEA study.
In Table 2, the risk assessment was repeated after the actions and scores were evaluated again. When the specified actions are completed, RPN reductions in percentages are shown in the rightmost column of the form as % RPN reduction compared to the classical approach. Process steps are measurement, preparation, packaging and transfer. Failure modes, root causes, controls and RPN values of these four processes were calculated. Table 2 shows only the risk assessment of the first process step. In which activities it is absolutely necessary to take action and when it is desired to reveal risky areas.

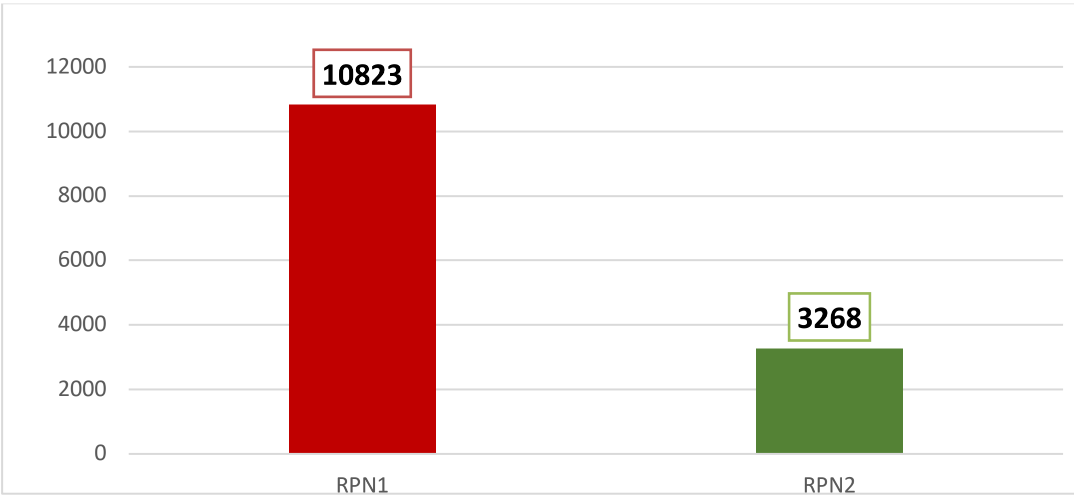


Figure 4. Coating RPN (Before- After)

In the traditional approach, the size of the risk can be seen after the actions in the study by looking at the RPN scores. The reduction in the size of the risk can also be given by the total RPN assessment. The sum of the RPN values determined by the evaluation of the failure modes of the coating process was determined separately as before and after the action. In the analysis of whether the actions were effective or not, it was observed that the RPN value decreased by 69.8%. RPN1 pre-action RPN2 post-action risk assessments in Figure 4. For the 34 failures identified according to the risk assessment criteria, the risk was reduced from RPN1: 10823 to RPN2: 3268. These values were calculated from the full study. To specify how the calculation method is according to Table 2; RPN1: 350+210+112= 672; RPN2: 84+105+84=273. When the action was taken and risk reduced by 69.8 %. It is most appropriate to analyze all the risks separately, but here it is done in this way to see the change in the performance of the total risk of the all process and to present it to the company. It is important to make such a calculation in terms of making the risk numerical and measurable.

4.2. VDA-4 FMEA Method

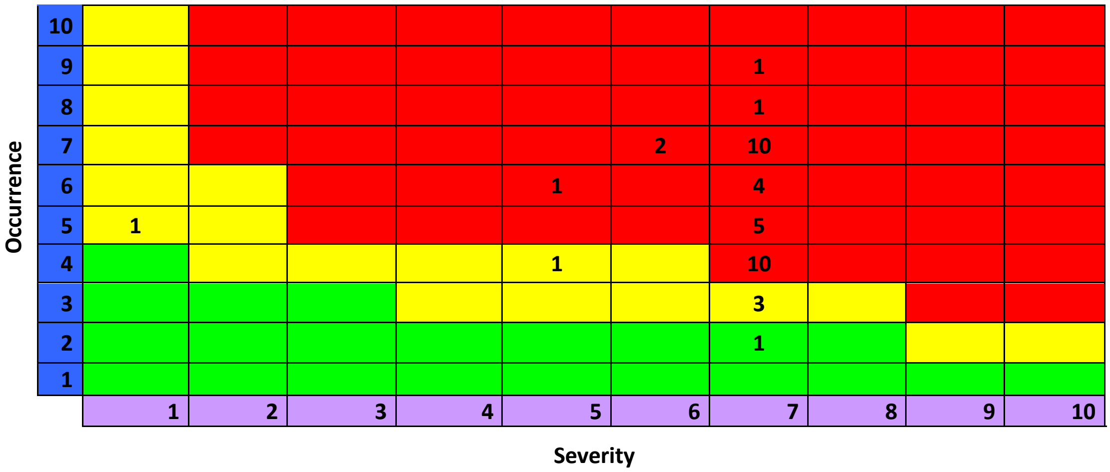


Figure 5. Severity & occurrence evaluating matrix

If the German group is assessed according to the VDA-4 standard, Figure 5. Matrix of severity&occurrence evaluated. The matrix was created by looking at the severity and occurrence scores of all failure types in the Process FMEA Study Form. When using this matrix, severity and occurrence are evaluated. Because the use of the detection factor after the failure occurs is not very valuable for the VDA standard. In order to use and report this approach, after the severity and occurrence scores, it is determined in which region the relevant failure mode falls. Today, it is possible to do this work automatically with a simple excel formulation or FMEA software. In FMEA studies where there are multiple failure modes, it may be difficult to simply determine which failure corresponds to which column. This matrix is very simple to use. The severity score on the horizontal axis is determined by taking into account the occurrence score on the vertical axis. When all risks are evaluated together with the team in the FMEA study, the 1 failure in the green zone, 5 failures in the yellow zone and 34 failures in the red zone. Action requirements for 34 activities should be determined according to the standards. Actions for activities specified in the study are defined in the "Recommendations" column of the Process FMEA Study Form. The risk level of the process has been minimized by taking action for the risks indicated by red.

4.3. AIAG&VDA FMEA Method (Action Priority)

In the FMEA study, the scoring made before and after the action was defined according to the FMEA AIAG&VDA standard. In the evaluation prepared by using the automotive industry AP matrix, the high-risk activity was brought to the medium level after the action. The risk was re-evaluated according to the new method, taking into account the scores in Table 2. It can refer to AIAG&VDA FMEA, 2019 handbook AP table to find out which scores are action prioritized. High risk necessary to take action and reduce risk. In Medium, it is recommended to reduce the risk by taking action (Maisano et al., 2020). When the risk is re-evaluated before and after the action, it is seen that the high risk mitigation into the medium risk. This is a critical improvement for the process and company.

Current Status				**After actions**			
Severity	Occurrence	Detection	AP	Severity	Occurrence	Detection	AP
7	5	10	High	7	2	6	Medium
7	3	10	Medium	7	3	5	Medium
7	2	8	Medium	7	2	6	Medium

Figure 6. AP evaluation

Integration of the automation system performed manually by the operators in the coating process has changed the magnitude of the risk from high to medium. Figure 6 shows the scoring and AP of the activities defined in the Table 2.When the operator's failure in using the wrong material is analyzed, it is seen that the root causes are manual material selection by the operator, wrong labelling on the raw material, wrong labelling for the returned material.. Scores of these three root causes are given in Figure 6.

5. Conclusion

FMEA is the pre-detection and analysis of potential failures. Although it is widely used in the automotive industry, many industries carry out FMEA studies. FMEA is a risk assessment method. The assessment of risk varies from industry to industry and from customer to customer. By determining and analyzing the risks of both designs and processes, many risks will be eliminated and reliable products will be produced. FMEA is a very powerful tool as it can detect potential failures in advance. After identifying and analyzing the risk, there are different approaches to determine the magnitude of the risk. Following and applying the up-to-date ones of these approaches gives businesses an advantage over customers.

In the beginning, relying on the operators, the manually operated coating was converted to a system for automatic process with this FMEA study. With this application, companies will reduce both operating costs and contribute to the country's economy in the context of continuous improvement. In addition, such studies within the scope of innovation will provide competitive advantage to businesses by providing serious positive contributions to the future point of industrial systems. The new system has allowed the operator to be managed completely automatically with a closed system without handling. The operator only selects the recipe and the system carries out all other operations (measurement and preparation) within the recipe itself. Images for automation are available in the Figure 7. Coating process before – after.

In the traditional risk analysis approach, RPN is used, but in recent years, RPN has been replaced by different methods and different matrix evaluations. With this study, the evaluation matrix used by the automotive German group and AIAG& VDA FMEA, 2019 version were used as a different approach for a problem in an automotive supplier company. The intended method specific to the industry and company can be preferred.

When the analysis was made according to the potential failures that may occur in the process, there was a 69.8% decrease in the total RPN values before and after the actions. In the coating process, it was observed that the risk was reduced by 69.8% by enabling the operator to perform the manual operations with automation. Analyzes were performed using traditional RPN evaluation as well as new methods. After the improvements made, all failures that were in the red area according to the VDA standard are now in the green and yellow areas. According to the AIAG VDA FMEA, 2019 version standard, high-risk activities have been reduced to medium or low. With this improvement, Industry 4.0 studies were also leaded and communication between machines (prescription-based preparation, mixing, measuring) was ensured.

As a result, Failure Mode and Effects Analysis (FMEA) has a structure that evaluates risk. It requires a certain experience and knowledge for businesses to determine and manage possible risks in advance. In order to obtain maximum benefit from FMEA studies, determining the scope of the study, following the suggested actions and supporting the management are among the important elements. Companies that systematically implement FMEA; It gains a competitive advantage in the industry by designing high reliability and quality products with low costs and producing them in a short time. It is possible to give priority to the efforts to reduce the risk by informing the Senior Management about the extent of the risk. In FMEA studies, new technology and innovation studies are brought to the fore. FMEA and digitalization can be considered together for the new studies to be done in the coming years.

Before **After**

Figure 7. Coating process before -after

6. Limitations and Further Research

FMEA types are available as process FMEA, design FMEA, system FMEA, machine FMEA, service FMEA, logistics FMEA. In this study, only the process FMEA was evaluated. Other FMEA types have not been evaluated within the scope of this study. FMEA study was prepared for the sub-process of the supplier company which is operating in the automotive sector. These risks may change in other companies. As well as the risk assessment criteria of different OEM's vary as indicated in the literature section of the study. The VDA standard used by the German group and AIAG&VDA standard were used in this study. It appears as customer requests in automotive and other sectors where FMEA studies must now be managed with software. Therefore, studies can be made by integrating with software and the relation of digitalization with FMEA.

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Please contact the author for the full FMEA report.

Contribution of Authors

Both Nesimi Kök and Mehmet Selami Yıldız contributed to literature review, data collection, problem definition, data analysis, and conclusion.

Conflicts of Interest

The authors declared that there is no conflict of interest.

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