Journal of Engineering Management and Systems Engineering
https://www.acadlore.com/journals/JEMSE

Statistical Evaluation of Failure Mode Drivers via the 5M+1E Framework for Enhanced Reliability Control in Automotive Interior Manufacturing

Nikola Banduka[1,2*], Amanda Aljinović Meštrović[1]

[1] Mechanical Engineering and Naval Architecture, Faculty of Electrical Engineering, University of Split, 21000 Split, Croatia
[2] DigitaLLeather LLC, 34000 Kragujevac, Serbia

[*] Correspondence: Nikola Banduka (nikola.banduka@digitalleather.rs)

Received: 05-05-2025 **Revised:** 06-10-2025 **Accepted:** 06-20-2025

Citation: N. Banduka and A. A. Meštrović, "Statistical evaluation of failure mode drivers via the 5M+1E framework for enhanced reliability control in automotive interior manufacturing," *J. Eng. Manag. Syst. Eng.*, vol. 4, no. 3, pp. 176–187, 2025. https://doi.org/10.56578/jemse040302.

Abstract: A comprehensive statistical analysis was conducted to investigate the causes and prioritization of failure modes within a production line manufacturing leather covers for automotive interiors. The study was grounded in a Process Failure Mode and Effects Analysis (PFMEA), with a dual emphasis on evaluating the traditional Risk Priority Number (RPN) approach and the more contemporary Action Priority (AP) methodology, which has been increasingly adopted to enhance risk assessment sensitivity. Failure modes were classified and prioritized using both approaches, revealing notable differences in the ranking outcomes. To further elucidate the underlying contributors to these failure modes, causal factors were systematically categorized in accordance with the 5M+1E framework—Man, Machine, Method, Material, Measurement, and Environment—commonly employed in quality and reliability engineering. A cause-and-effect diagram was constructed to visualize the distribution of root causes across these categories. Descriptive statistics and correlation analyses were employed to quantify the relationship between each category and the prioritized failure modes. Particular attention was paid to examining the interdependencies among the core PFMEA parameters—Severity, Occurrence, and Detection—in order to determine their respective contributions to the variability in failure mode rankings. It was found that Severity exerted the most substantial influence on the prioritization outcomes under the AP model, while Occurrence was more dominant when the RPN method was applied. These findings suggest that the choice of prioritization method significantly alters the interpretation of risk and resource allocation for corrective actions. The integration of 5M+1E categorization with PFMEA metrics offers a structured pathway to enhance the diagnostic capability of reliability assessments and improve decision-making in failure prevention strategies. This approach is proposed as a more robust alternative to traditional analysis, enabling more precise targeting of corrective and preventive measures in high-precision manufacturing environments.

Keywords: Process Failure Mode and Effects Analysis (PFMEA); Production line; Risk Priority Number (RPN); Action Priority (AP); Statistical analysis; 5M+1E framework; Automotive interior manufacturing; Failure mode prioritization; Reliability engineering

1 Introduction

The reliability of a production line, as well as the entire manufacturing process, is of great importance for the business success of manufacturing companies. It is crucial not only for meeting customer requirements but also for many other reasons. The automotive industry, as one of the leading industrial sectors worldwide, recognized the importance of process and product reliability as early as the twentieth century. In order to ensure a high level of process reliability, the automotive industry applies Failure Mode and Effect Analysis (FMEA), specifically its variant adapted to manufacturing processes, known as Process Failure Mode and Effect Analysis (PFMEA).

PFMEA is based on a thorough analysis of each segment of the production process, identification of potential failure modes, as well as their causes and effects. Based on these findings, the PFMEA team within the company evaluates the risk factors: Severity (S), Occurrence (O), and Detection (D). In traditional PFMEA, the final priority of failure modes is determined using the Risk Priority Number (RPN) [1]. According to the prioritization of failure modes, actions are then proposed to reduce the impact of the most critical failure modes to an acceptable level.

Many authors dealing with (P)FMEA analysis have pointed out numerous shortcomings of the traditional RPN approach. These shortcomings are primarily related to the prioritization process, particularly the mathematical methodology used [2, 3]. As practitioners became aware of the seriousness of the issues associated with the existing methodology, efforts were made to develop an approach that would yield more realistic results. Consequently, in 2019, a new FMEA Handbook [4] was published, introducing the Action Priority (AP) approach as a replacement for the traditional RPN method. However, many companies still find it challenging to change their established practices and adopt the new handbook, and often continue to use the traditional approach or apply both in parallel [5]. For this reason, the first objective of this research is to highlight the differences between the two approaches and to present their key characteristics.

In the relevant literature, various methods and techniques have been applied by authors in an attempt to improve the traditional (P)FMEA. For this purpose, Multi-Attribute Decision-Making (MADM) methods have most commonly been used, often extended by the application of fuzzy set theory, as demonstrated in the studies [6–10], as well as certain metaheuristics [11]. However, the number of studies analyzing the new AP approach in the literature remains relatively small [12, 13]. For this reason, the present research includes a comparison of the results obtained by applying these two approaches. It has been determined how the priority of failure modes changes depending on whether RPN or AP is used, along with a statistical comparison of the results.

In addition to the automotive industry [9, 14], (P)FMEA is also frequently applied in other sectors, such as the energy sector [15], information technology [16], the manufacturing industry [17], etc. However, a common feature across all these application domains is that the causes of failure modes can be classified according to the same principle. This paper uses the 5M+1E principle, which recognizes six dimensions of causes: Man, Machine, Method, Material, Measurement, and Environment. This approach has been adopted in numerous studies in the relevant literature [18, 19].

The aim of this paper is to examine which category of causes has the greatest impact on the priority of failure modes, as well as to determine how risk factors influence this priority. To conduct the research, methods of descriptive statistics and correlation analysis were used.

Following the introductory chapter, the second chapter presents the research methodology applied. The third chapter provides a case study based on a PFMEA report originating from a company in the automotive industry operating in the Republic of Serbia. The fourth chapter presents a discussion of the obtained results and conclusions.

2 Methodology

Several analyses were conducted in this study, relying on various statistical and engineering tools and techniques. Fundamentally, the PFMEA analysis carried out on a single production line in an automotive industry company served as the starting point for all subsequent analyses. To assess the priority of failure modes, the RPN parameter, as applied in the observed company, was used, along with the AP methodology, in order to identify the key characteristics of these approaches.

By applying methods of descriptive statistics and correlation analysis, a comparison was made between the results obtained through RPN and AP. Subsequently, the causes of failure modes were classified according to the 5M+1E framework. Additionally, the average influence of each failure mode cause on the RPN value was examined. Finally, an analysis of the interdependence among PFMEA parameters was performed. For clarity, the applied methodology is illustrated in Figure 1.

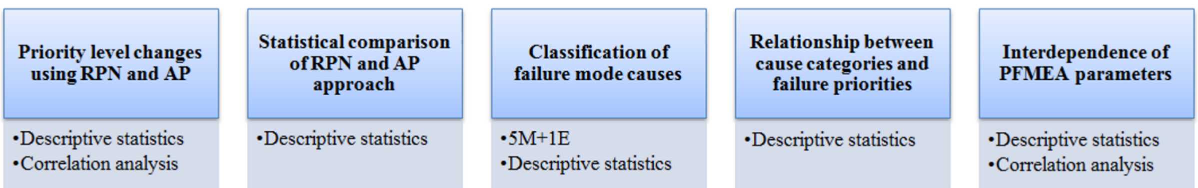

Figure 1. Percentage of priority changes in failure modes when using the AP instead of RPN

The following section of this chapter explains the fundamental methodological concepts used in this research.

2.1 Basics of PFMEA: Determining Priorities using RPN and AP

In the traditional PFMEA (as well as FMEA) approach, the priority of failure modes is determined based on the Risk Priority Number (RPN). The value of this parameter is calculated as the product of three risk factors: Severity (S), Occurrence (O), and Detection (D). These risk factors refer to the seriousness of the consequence that a failure mode may cause (Severity), the expected/estimated frequency of failure mode occurrence (Occurrence), and the likelihood of detecting the failure mode before it materializes (Detection). Therefore, the RPN is calculated using the following expression [1, 20]:

$$RPN = S \cdot O \cdot D \tag{1}$$

The values of the risk factors are assessed by the PFMEA team on a scale from 1 to 10. Therefore, the RPN parameter can range from 1 to 1000. Typically, failure modes with an RPN greater than 100, or with at least one risk factor rated 8 or higher, are considered high-priority [21]. In the case of the analyzed company, the PFMEA team considers failure modes with an RPN value below 60 as low priority (L), those between 60 and 100 as medium priority (M), and those above 100 as high priority (H).

Unlike the traditional RPN parameter, which is interpreted differently depending on the company's needs, the AP methodology provides clear guidelines for determining the priority of failure modes. In the form of a table, the PFMEA team receives specific instructions for each combination of S, O, and D values. The handbook [4] offers a detailed overview and explanation of how to determine failure mode priority using the AP methodology. Since the priority determination table is quite large, a graphical representation of the combinations of S, O, and D values and the resulting priority categories is provided in Figure 2.

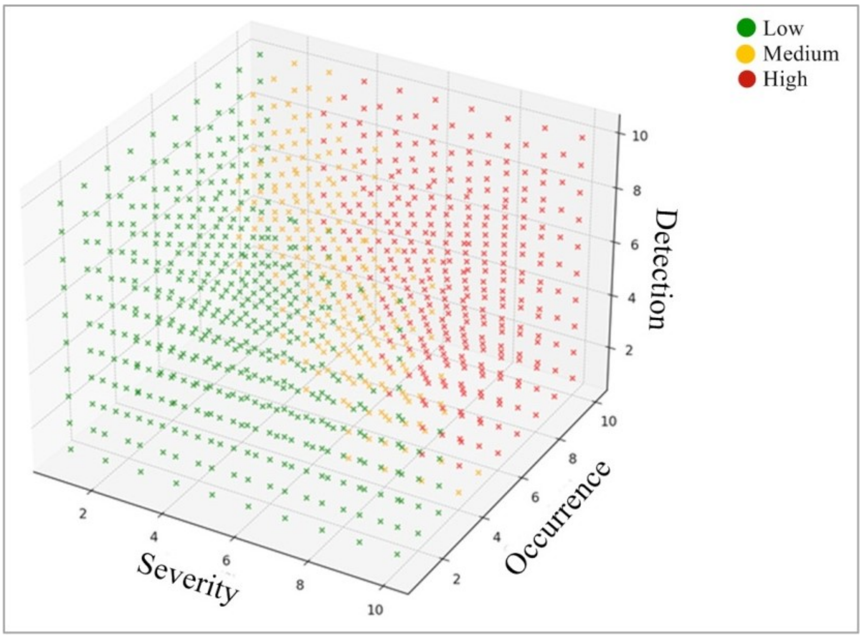

Figure 2. Graphical representation of priority determination according to AP

In Figure 2, it can clearly be seen that the fewest combinations of S, O, and D values lead to the M priority level. From this, it can be concluded that the AP method differentiates relatively well between high- and low-priority failure modes. The medium zone (or M) is very narrow, which significantly assists the PFMEA team in the decision-making process.

2.2 Statistical Analysis

For statistical processing and data analysis in this research, descriptive statistics and correlation analysis were used. In addition to histograms, line and pie charts, the arithmetic mean operator was also applied, which is calculated according to the following expression:

$$\bar{X} = \frac{1}{N} \cdot \sum_{i=1}^{N} x_i \tag{2}$$

where, N denotes the total number of data points in the sample, and x_i is the i-th observed value.

For determining the Pearson correlation coefficient, the function within Excel was used, under the Data section, Data Analysis, as shown in Figure 3.

All graphical representations used to present the statistical parameters were created in Microsoft Excel.

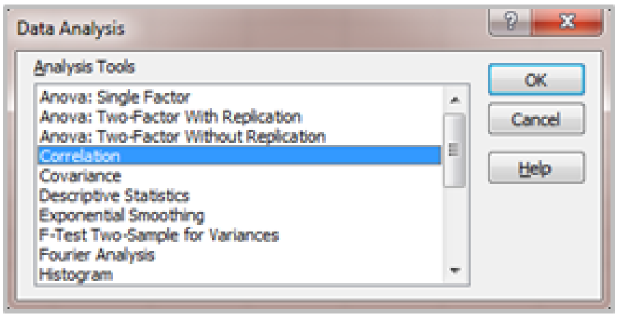

Figure 3. Determining the Pearson correlation coefficient using Excel's Data Analysis tool

2.3 Classification of Failure Mode Causes According to the 5M+1E Framework

The cause-and-effect diagram, also known as a fishbone or Ishikawa diagram, is a highly useful tool for the graphical representation and analysis of problem causes. Various forms of this diagram can be found in the relevant literature, and the 5M+1E variant (sometimes called 5M1E) is very commonly used [19, 22]. For clarity and further explanation, an illustrative example of this diagram is provided in Figure 4.

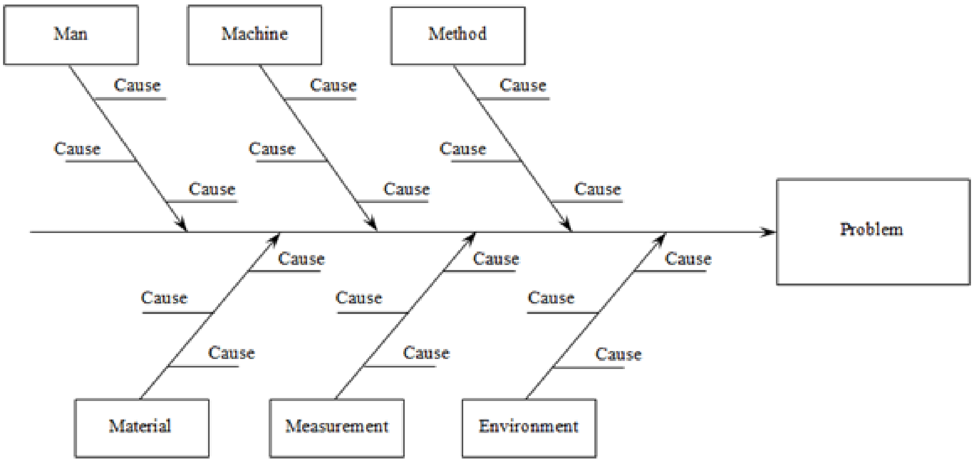

Figure 4. Illustrative example of 5M+1E diagram

As shown in Figure 4, the 5M+1E diagram consists of six dimensions, i.e., six categories of causes that may lead to the occurrence of a problem:

(1M) Man,
(2M) Machine,
(3M) Method,
(4M) Material,
(5M) Measurement, and
(1E) Environment.

In the context of PFMEA analysis, these causes are associated with the emergence of failure modes, while in a broader sense, they can be considered as causes that lead to the occurrence of any kind of problem. This approach enables the PFMEA team and company management to gain a better understanding of why failure modes occur and which factors have the greatest impact on their realization.

3 Case Study

The research presented in this paper was conducted in a company that operates as a Tier 1 supplier within the automotive supply chain. The company is based in the Republic of Serbia and delivers its products to both European and Asian markets. A PFMEA analysis was carried out for the production line manufacturing leather covers for automotive interiors, specifically components integrated into airbags.

The PFMEA team identified a total of 143 potential failure modes associated with the considered production line, from the entry of raw materials to the delivery of the finished product.

According to the analyzed report, the PFMEA team selected 21 failure modes with an RPN value greater than 60. Since no preventive actions are recommended by the PFMEA team for failure modes with an RPN value below 60, this study focuses on the analysis of the 21 identified failure modes. Table 1 presents the failure modes, their causes, and effects.

Table 1. Failure modes, causes, and effects

No.	Failure Mode	Cause	Effect
$f = 1$	Incorrectly distributed parts	Unclear instructions for part allocation	Difficulties during part separation
$f = 2$	Inconsistent appearance and texture of upholstery	Supplier error	Product does not meet customer requirements
$f = 3$	Poor thread quality	Supplier error	Thread breakage
$f = 4$	Object placed between foam and leather	Non-compliance with work procedure	Poor visual appearance of the cover
$f = 5$	Inconsistent stitch length	Stitch roller not properly adjusted	Product does not meet customer requirements
$f = 6$	Backstitch not applied	Backstitch function disabled on machines	Product does not meet customer requirements
$f = 7$	Misplaced sewn part	Technical drawing insufficiently clear	Cover installation impossible
$f = 8$	Visible thread or stitch over 2 mm	Slit too wide	Does not comply with specification
$f = 9$	Misplaced reinforcing stitch	Insufficiently trained operator	Product does not meet customer requirements
$f = 10$	Pleat visible on material	Operator error	Product does not meet customer requirements
$f = 11$	Misplaced plastic on airbag strap	Operator error	Product does not meet customer requirements
$f = 12$	Rework on strap	Operator error	Affects airbag deployment
$f = 13$	Rework on airbag seam	Operator error	Affects airbag deployment
$f = 14$	Overlapping threads	Operator error	Airbag cannot deploy
$f = 15$	Stitch length not per specification	Stitch length not set before starting work	Poor visual appearance of the cover
$f = 16$	Non-glued and loose thread on back side	Operator error	Top stitch may break during installation or use
$f = 17$	Improper position of sewing suspender	Lack of controlled positioning	Product does not meet customer requirements
$f = 18$	Missing or misaligned tuck pin	Operator error	Installation wire may be missing, installation not possible
$f = 19$	Poor visual appearance of cross stitch	Critical point not properly controlled	Product does not meet customer requirements
$f = 20$	Strap lengths do not match drawing	Inaccurate strap sewing	Product does not meet customer requirements
$f = 21$	Missing velcro on the cover	Non-compliance with work procedure	Product does not meet customer requirements

The following sections of this case study address various aspects related to the priority and the causes of occurrence of failure modes. The aim of this analysis is to determine which dimension of the 5M+1E framework has the greatest impact on the occurrence of medium- and high-priority failure modes.

3.1 Priority of Failure Modes Using RPN and AP

The PFMEA team of the analyzed company uses both the RPN and, in parallel, the AP methodology. However, the RPN parameter is still more closely monitored. Therefore, all failure modes with an RPN < 60 are considered low priority. Those with an RPN between 60 and 100 are treated as medium-priority failure modes, while those with an RPN ≥ 100 are regarded as high-priority and must be addressed.

In contrast to this model, the AP approach proposes a tabular guide for determining the priority of failure modes. Table 2 presents a comparative analysis of the priority levels of failure modes obtained using these two approaches.

It should be noted that the RPN scale can be fine-tuned depending on the company's product range, technological level, and other factors. The classification of failure modes based on RPN as described is applied by the PFMEA team of the analyzed company.

Table 2. Risk factor values and failure mode prioritization

No.	S	0	D	RPN	RPN Priority	AP
$f = 1$	4	6	3	72	M	M
$f = 2$	8	3	4	96	M	L
$f = 3$	9	2	5	90	M	M
$f = 4$	5	3	4	60	M	L
$f = 5$	6	4	3	72	M	L
$f = 6$	7	4	3	84	M	M
$f = 7$	7	2	8	112	H	M
$f = 8$	3	5	8	120	H	L
$f = 9$	10	10	8	800	H	H
$f = 10$	4	3	8	96	M	L
$f = 11$	6	2	8	96	M	L
$f = 12$	9	3	3	81	M	L
$f = 13$	10	2	3	60	M	L
$f = 14$	10	2	3	60	M	L
$f = 15$	6	4	3	72	M	L
$f = 16$	7	4	3	84	M	M
$f = 17$	7	3	3	63	M	L
$f = 18$	2	9	9	162	H	M
$f = 19$	5	4	3	60	M	L
$f = 20$	9	3	3	81	M	L
$f = 21$	8	5	2	80	M	M

As previously stated, this study considers only those failure modes that are classified as medium or high priority according to the RPN approach. However, the presented results indicate that some of these failure modes are categorized as low priority when evaluated using the AP methodology. Figure 5 illustrates the percentage of priority changes in failure modes when transitioning from the traditional RPN approach to the AP method.

The analysis presented in Figure 5 indicates that there are significant discrepancies when comparing the priority levels of failure modes obtained using the traditional RPN approach and the AP method. Out of the 21 failure modes considered, only 6 retained their original priority level. Of these, five were of medium priority and one of high priority, representing approximately 29% of the total. In other words, around 71% of the failure modes experienced a change in priority.

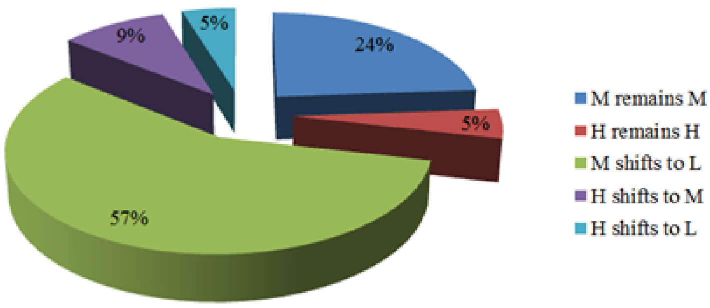

Figure 5. Percentage of priority changes in failure modes when using the AP instead of RPN

The highest percentage of change is observed in the case where failure modes shift from medium to low priority. There are 12 such failure modes, accounting for approximately 57%. Additionally, two failure modes changed from high to medium priority (about 9%), while only one failure mode shifted from high to low. This particular case refers to the failure mode $f = 8$, which had an RPN value of 120. However, since its Severity score was 3, the AP method categorised it as low priority.

For the purpose of further analysis and comparison of the similarity between failure mode priorities based on the RPN and AP approaches, a correlation analysis was conducted. First, the priority levels L, M, and H were transformed into numerical values 1, 2, and 3, respectively. Based on these values, using the correlation function from Excel's Data Analysis Toolpak, the Pearson correlation coefficient was calculated. In this case, the correlation coefficient is $r = 0.48$. This result indicates a moderate and positive correlation between the failure mode priorities obtained through the two approaches. Specifically, there was only one instance in which the priority shifted by two levels (from H to L), while the remaining differences—although notable in number—were limited to a change of just one level.

Based on the overall analysis, it can be concluded that the AP method tends to assign lower priority levels to failure modes compared to the RPN approach. In no case did the priority increase. Therefore, it can be inferred that the AP methodology contributes to a more rational use of resources by adjusting the priority of failure modes that may be overestimated when evaluated solely through RPN. This approach allows focus to be directed toward truly significant and critical failure modes.

3.2 Statistical Comparison of RPN and AP Approach

In the previous section, the changes in failure mode priorities that occur when using the AP approach instead of RPN were presented. Figure 6 shows a comparative chart of the distribution of priority levels for the considered failure modes under these two approaches.

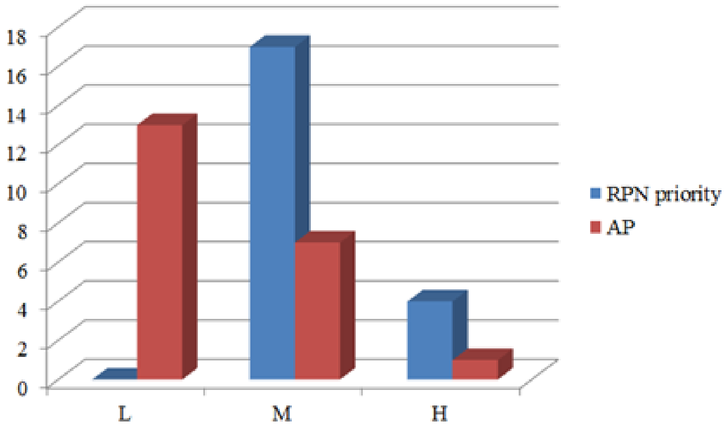

Figure 6. Comparative distribution of failure mode priority levels under RPN and AP approaches

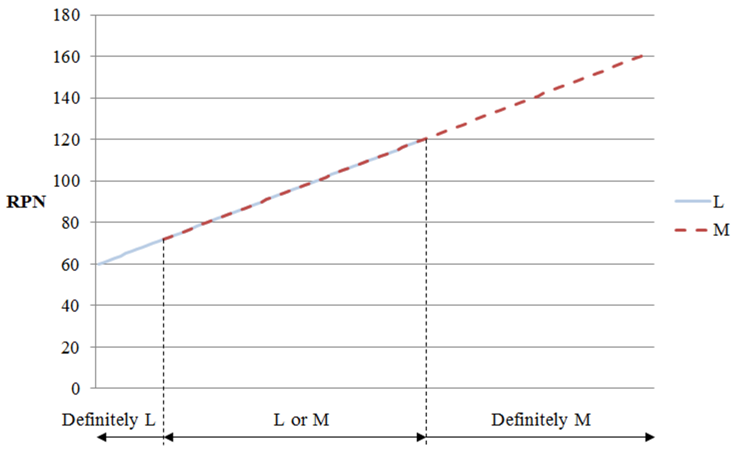

Figure 7. Distribution of RPN values for L and M priority levels according to the AP approach

The RPN parameter values for the L category according to the AP approach in the considered case study range from 60 to 120. The lower limit has already been explained, as only failure modes with an RPN value not lower than 60 were taken into consideration. Failure modes assigned a priority level of M according to the AP approach had RPN values ranging between 72 and 162. Only one failure mode was assigned a priority level of H, which is not sufficient for a deeper analysis. Figure 7 shows the distribution of L and M priorities according to the AP approach, in line with the corresponding RPN parameter values.

When examining the distribution of RPN values for L and M priority levels according to the AP approach, it can be concluded that there is a significant overlap in the range from 72 to 120. This can be described as a kind of "fuzzy" zone. This is yet another indicator that the RPN does not sufficiently distinguish between the priorities of failure modes. This fact can be highlighted as one of the reasons for using mathematical tools, such as MADM methods, for determining the priority and ranking of failure modes.

3.3 Analysis of the Causes of Failure Mode Occurrence

In order to analyze and better understand the causes leading to the occurrence of the identified failure modes, all causes were classified according to the 5M+1E framework, which includes: Man, Machine, Method, Material, Measurement, and Environment. This classification method allows the identification of the dominant source of the problem that leads to the occurrence of failure modes on the considered production line. Table 3 shows which category each cause belongs to.

Table 3. Classification of failure mode causes according to 5M+1E

No.	Cause	Category of Cause (5M+1E)
$f = 1$	Unclear instructions for part allocation	Method
$f = 2$	Supplier error	Environment
$f = 3$	Supplier error	Environment
$f = 4$	Non-compliance with work procedure	Man
$f = 5$	Stitch roller not properly adjusted	Machine
$f = 6$	Backstitch function disabled on machines	Machine
$f = 7$	Technical drawing insufficiently clear	Method
$f = 8$	Slit too wide	Material
$f = 9$	Insufficiently trained operator	Man
$f = 10$	Operator error	Man
$f = 11$	Operator error	Man
$f = 12$	Operator error	Man
$f = 13$	Operator error	Man
$f = 14$	Operator error	Man
$f = 15$	Stitch length not set before starting work	Method
$f = 16$	Operator error	Man
$f = 17$	Lack of controlled positioning	Measurement
$f = 18$	Operator error	Man
$f = 19$	Critical point not properly controlled	Measurement
$f = 20$	Inaccurate strap sewing	Man
$f = 21$	Non-compliance with work procedure	Man

Figure 8 presents a graphical representation of the distribution of failure mode causes according to the 5M+1E framework. Although some failure modes may arise due to multiple causes, the cause with the highest RPN parameter value has been considered.

In Figure 8, it is clearly noticeable that the majority of causes are classified under the "Man" category. Therefore, it can be concluded that the largest number of failure modes can be attributed to human factors (errors, negligence, etc.). The remaining causes are almost evenly distributed, with the "Method" category appearing three times, and "Machine," "Measurement," and "Environment" each appearing twice, while "Material" appears only once in the analyzed sample.

From this, it can be concluded that the most important step is to conduct adequate operator training in order to reduce the number of errors during production operations. Additionally, if possible, it is advisable to implement certain poka-yoke devices that would prevent errors from occurring during work.

If only the causes of those failure modes that are categorized as Medium and High priority according to the AP methodology were considered, the situation would again show the "Man" category as dominant, as illustrated in Figure 9.

When examining the data presented in Figures 8 and 9, it is evident that the human factor is the most significant cause in both cases. Additionally, it is important to note that among the failure modes with high (H) priority according to the RPN approach, two belong to the "Man" category, and one each to the "Method" and "Material" categories. According to the AP approach, only one failure mode is classified as high priority, and it is also influenced by the human factor. In fact, this is a particularly critical failure mode, which occurs due to insufficient operator training and results in the failure to meet customer requirements—ultimately leading to product returns. Such a product is definitively classified as nonconforming.

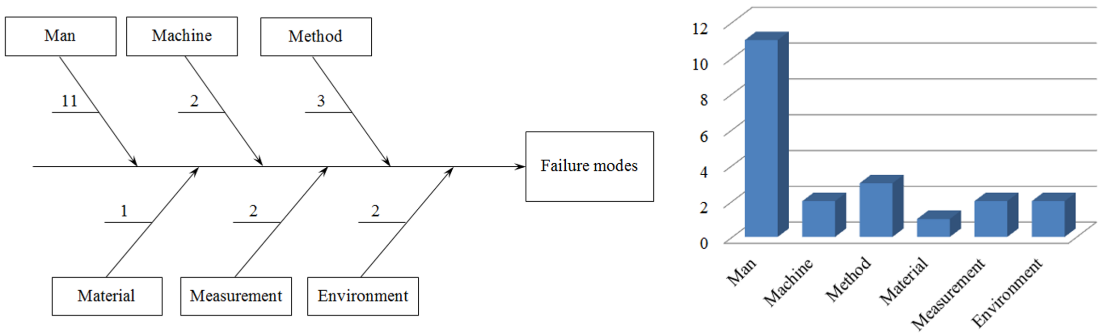

Figure 8. Distribution of failure mode causes according to the 5M+1E framework

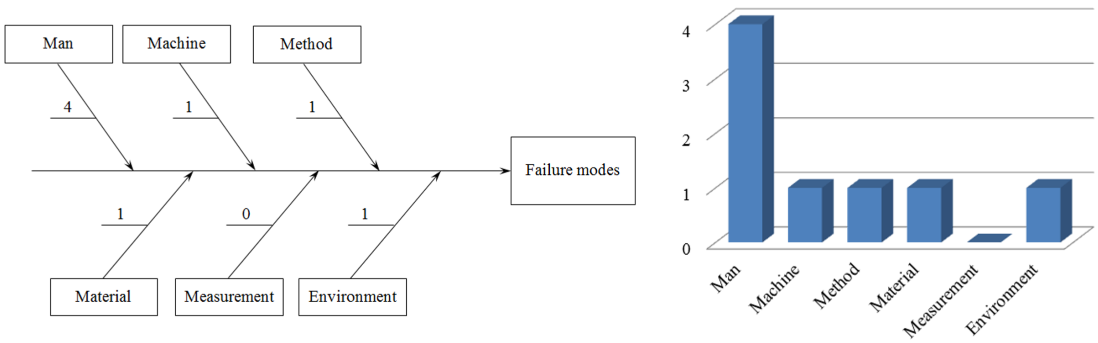

Figure 9. Distribution of failure mode causes according to the 5M+1E framework (for M and H priority according to AP)

3.4 Analysis of the Relationship Between Cause Categories and Failure Priorities

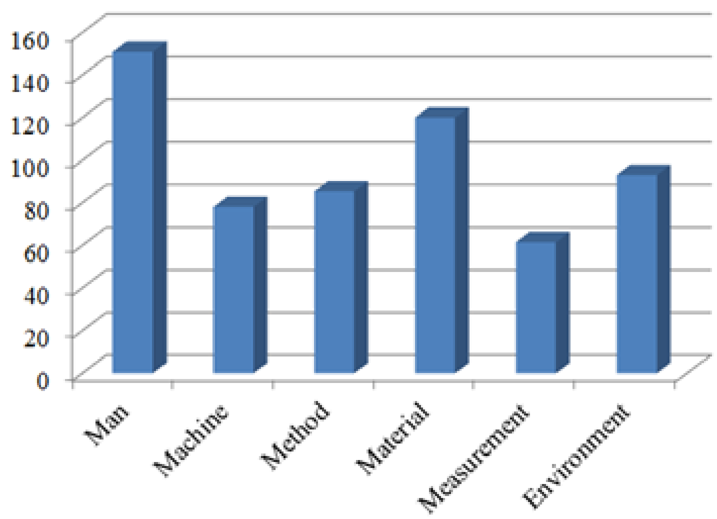

Figure 10. Average RPN values by 5M+1E cause categories

For the purpose of further analyzing potential failure modes, an analysis of average RPN values by 5M+1E cause categories was carried out. The aim of this analysis is to identify the categories considered most critical for the observed production line. The analysis is presented in Figure 10.

As with the previous analyses, in this case, the “Man” category holds the highest importance. However, it should be noted that the RPN value for one failure mode is 800, which significantly affected the average value. Without this “extreme” value, the average RPN value for this category would be 86, which would bring it closer to the average. In second place is the “Material” category; however, this category contains only one failure mode. Therefore, this data cannot be considered conclusive. Moreover, this failure mode had an H priority according to the RPN parameter, but an L priority according to the AP methodology.

It should be noted that failure modes with an RPN value below 60 were not considered. These account for 85% of the total sample, so they would have significantly affected the conduct of this analysis. However, as these failure modes are not significant in any way, the analysis was conducted by considering only those failure modes with an acceptable significance based on their RPN value.

3.5 Interdependence of PFMEA Parameters

In order to examine the interdependence of PFMEA parameters, namely S, O, D, RPN values, and the failure mode priorities determined by the AP methodology, a correlation analysis was conducted. The Pearson correlation coefficients obtained using Excel’s Data Analysis Toolpak are shown in Figure 11.

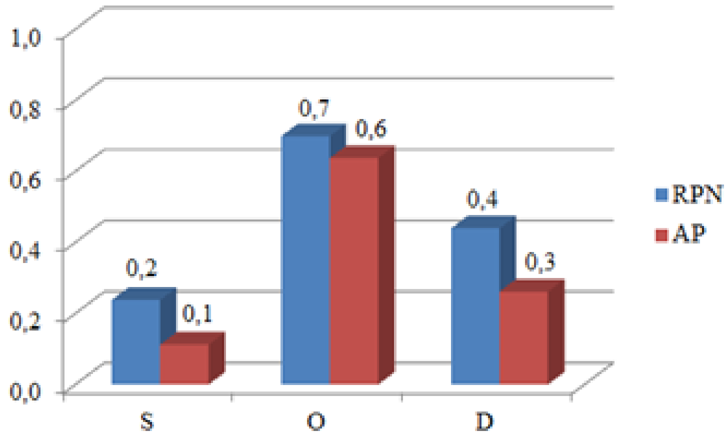

Figure 11. Correlation coefficients of PFMEA parameters

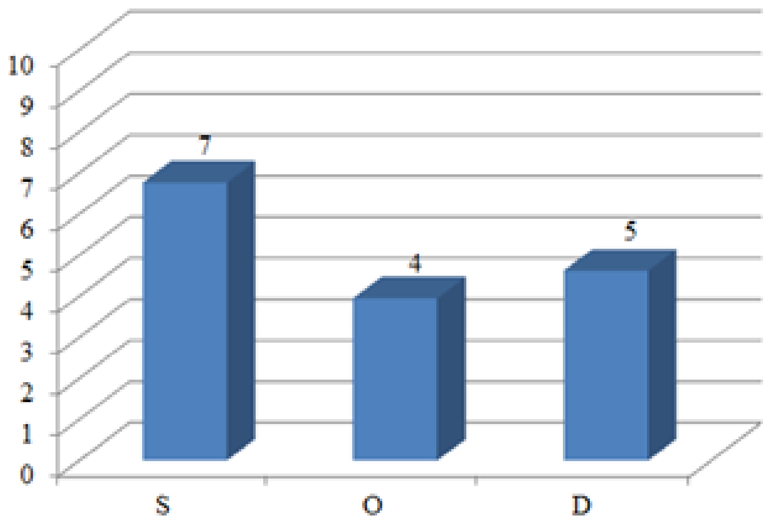

Figure 12. Average values of S, O, and D

Figure 11 illustrates how changes in the risk factors S, O, and D affect the RPN values and AP priorities of failure modes in the PFMEA report. In both the RPN and AP approaches, a moderate to high correlation with the O risk factor is most apparent. In other words, the frequency of occurrence is the primary driver of priority: the more often a failure mode occurs, the higher its assigned priority. Therefore, to improve the reliability of the production line, measures should be taken to reduce the likelihood of these failure modes.

The S risk factor, despite having the highest average value (Figure 12), exhibits the lowest correlation coefficient with the two parameters used to determine failure mode priority.

The S risk factor does not significantly influence changes in failure mode priorities, because its values are already very high for the failure modes under consideration. In contrast, the O risk factor makes the greatest difference in priority assignment. Since O has the lowest average value, any significantly high value of this factor has a large impact on priority.

It is up to the company's management to develop a strategy on whether to target reducing the S risk factor, which theoretically has the greatest impact on priority, or to focus on decreasing the O risk factor, in order to minimize the frequency of potentially high-consequence failure modes.

4 Discussion and Conclusions

Through the presented case study, the importance of differences in determining the priority of failure modes between the traditional RPN approach used in the observed company and the new AP approach was highlighted. It is clearly evident that a relatively high percentage of failure modes, based on RPN values, were classified into the medium or high-priority category. However, the conclusion is that this may lead decision-makers to incorrect conclusions, given that the AP approach produces significantly different results. Primarily, AP reduces the priority of failure modes, allowing decision-makers to focus on those failure modes that are truly significant and may have an undesirable effect on the observed production line, as well as on the company's overall operations. The application of the AP approach has shown that it provides a more consistent and accurate classification of failure modes, especially in cases where the values of risk factors and the RPN are very similar.

The second and very important aspect of the conducted analysis lies in the classification of failure mode causes according to the 5M+1E framework. In this way, a systematic categorization of causes was performed, contributing to the identification of the root of the observed problem-the failure modes. The research results showed that, for the specific production line, the most important and most critical cause of problems is "Man". Therefore, human factors such as negligence, inadvertent errors, and insufficient operator training have the greatest impact on the reliability of the production line. It can be concluded that operational management needs to make considerable efforts to standardize work processes and to improve the education and training of operators.

The key scientific contributions of this research are: (1) a clear comparison between the RPN and AP approaches using real-world data from practice, (2) it was demonstrated how the AP method enables a more consistent assessment of the priority of failure modes, (3) a systematic classification of failure mode causes was carried out using the 5M+1E framework, (4) it was identified which causes are the most significant for the analyzed problem, and (5) based on the obtained results, specific guidelines were proposed for improving the implementation of the PFMEA analysis.

In addition to these contributions, the research also has certain limitations: (1) the case study is limited to a single company and one production line, (2) the sample size, i.e., the number of analyzed failure modes, is relatively small, (3) the subjectivity in the evaluation of S, O, and D values may significantly affect the reliability of the obtained results, and (4) the analysis is based on existing data and does not account for possible future changes.

Regarding directions for future research, the main focus will be on the quantitative validation of the conducted analysis by examining a larger sample, i.e., a greater number of failure modes. The analysis will be carried out in various companies within the automotive industry, whose production lines differ in technological level and complexity. In addition, the development of a software tool that integrates this type of analysis would represent one of the key practical contributions of the future work.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] D. H. Stamatis, *Failure mode and effect analysis*. Quality Press, 2003.

[2] C. Liu, Heng, L. Liu, and N. Liu, "Risk evaluation approaches in failure mode and effects analysis: A literature review," *Expert Syst. Appl.*, vol. 40, no. 2, pp. 828–838, 2013. https://doi.org/10.1016/j.eswa.2012.08.010

[3] H. C. Liu, "Fmea using uncertainty theories and MCDM methods," in *FMEA Using Uncertainty Theories and MCDM Methods*. Springer Singapore, 2016, pp. 13–27. https://doi.org/10.1007/978-981-10-1466-6_2

[4] Automotive Industry Action Group, *Failure Mode and Effects Analysis - FMEA Handbook: Design FMEA, process FMEA, supplemental FMEA for monitoring & system response*, Southfield, Michigan, 2019.

[5] D. Tadić, N. Banduka, T. Petrović, and N. Komatina, "Application of FMEA in the automotive industry: Present situation and perspectives in the republic of serbia," *Trend. Poslov.*, vol. 12, no. 1, pp. 127–135, 2024. https://doi.org/10.5937/trendpos2401137T

[6] N. Komatina, "A compromise-based MADM approach for prioritizing failures: Integrating the radar method within the fmea framework," *Jurnal Sist. Manaj. Ind.*, vol. 8, no. 2, pp. 73–88, 2024. https://doi.org/10.30656/jsmi.v8i2.9283

[7] N. Komatina, D. Tadić, A. Aleksić, and N. Banduka, "The integrated pfmea approach with interval type-2 fuzzy sets and fbwm: A case study in the automotive industry," *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.*, vol. 236, no. 6, pp. 1201–1212, 2022. https://doi.org/10.1177/09544070211034799

[8] N. Banduka, A. Aleksić, N. Komatina, A. Aljinović, and D. Tadić, "The prioritization of failures within the automotive industry: The two-step failure mode and effect analysis integrated approach," *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, vol. 234, no. 12, pp. 1559–1570, 2020. https://doi.org/10.1177/0954405420926906

[9] D. Tadić and N. Komatina, "A hybrid interval type-2 fuzzy DEMATEL-MABAC approach for strategic failure management in automotive manufacturing," *J. Eng. Manag. Syst. Eng.*, vol. 4, no. 1, pp. 21–38, 2025. https://doi.org/10.56578/jemse040102

[10] N. Afzali Behbahani, M. KhodadadiKarimvand, and A. Ahmadi, "Environmental risk assessment using FMEA and entropy based on topsis method: A case study oil wells drilling," *Big Data Comput. Vis.*, vol. 2, no. 1, 2022. https://doi.org/10.22105/bdcv.2022.331778.1054

[11] N. Komatina, D. Tadić, G. Đurić, and A. Aleksić, "Determination of manufacturing process failures priority under type 2 fuzzy environment: Application of genetic algorithm and variable neighborhood search," *Proc. Inst. Mech. Eng. Part E J. Process Mech. Eng.*, vol. 238, no. 5, p. 1, 2023. https://doi.org/10.1177/09544089231160510

[12] M. Barsalou, "Investigation into a potential reduction of FMEA efforts using action priority," *Manag. Prod. Eng. Rev.*, vol. 13, no. 4, pp. 59–71, 2022. https://doi.org/10.24425/mper.2022.142395

[13] D. I. Panyukov, V. N. Kozlovskii, D. V. Aidarov, and M. V. Shakurskii, "FMEA risk analysis on the basis of action priorities," *Russ. Eng. Res.*, vol. 42, no. 10, pp. 1077–1080, 2022. https://doi.org/10.3103/S1068798X22100227

[14] R. Godina, B. G. R. Silva, and P. Espadinha-Cruz, "A dmaic integrated fuzzy FMEA model: A case study in the automotive industry," *Appl. Sci.*, vol. 11, no. 8, p. 3726, 2021. https://doi.org/10.3390/app11083726

[15] H. Li, A. P. Teixeira, and C. Guedes Soares, "A two-stage failure mode and effect analysis of offshore wind turbines," *Renew. Energy*, vol. 162, pp. 1438–1461, 2020. https://doi.org/10.1016/j.renene.2020.08.001

[16] G. Đurić, Č. Mitrović, N. Komatina, D. Tadić, and G. Vorotović, "The hybrid MCDM model with the interval type-2 fuzzy sets for the software failure analysis," *Int. J. Intell. Fuzzy Syst.*, vol. 37, no. 6, pp. 7747–7759, 2019. https://doi.org/10.3233/JIFS-182541

[17] S. Nestić, R. Gojković, T. Petrović, D. Tadić, and P. Mimović, "Quality performance indicators evaluation and ranking by using TOPSIS with the interval-intuitionistic fuzzy sets in project-oriented manufacturing companies," *Mathematics*, vol. 10, no. 22, p. 4174, 2022. https://doi.org/10.3390/math10224174

[18] D. Jin, D. Ma, Y. Zhang, B. Yang, D. Wang, and L. Guo, "Introduction of '5M1E' mode of quality management in chemical analysis laboratory of special equipment," in *2022 International Conference on Creative Industry and Knowledge Economy (CIKE 2022)*, Qingdao, China, 2022. https://doi.org/10.2991/aebmr.k.220404.001

[19] E. Malinowska, "Using the concept of the weighted Ishikawa Diagram for defining the impact of catering enterprises on the environment," *Equilibrium*, vol. 5, no. 2, pp. 165–177, 2010. https://doi.org/10.12775/EQUIL.2010.033

[20] C. S. Carlson, "Understanding and applying the fundamentals of fmeas," in *Annual Reliability and Maintainability Symposium*, 2014, pp. 1–35.

[21] N. Banduka, I. Veža, and B. Bilić, "An integrated lean approach to Process Failure Mode and Effect Analysis (PFMEA): A case study from automotive industry," *Adv. Prod. Eng. Manag.*, vol. 11, no. 4, pp. 355–365, 2016. https://doi.org/10.14743/apem2016.4.233

[22] E. Goryńska-Goldmann, M. Gazdecki, K. Rejman, S. Łaba, J. Kobus-Cisowska, and K. Szczepański, "Magnitude, causes and scope for reducing food losses in the baking and confectionery industry—a multi-method approach," *Agriculture*, vol. 11, no. 10, p. 936, 2021. https://doi.org/10.3390/agriculture11100936