



FURTHER CRITERIA FOR FMEA PRIORITIZATION

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Received 03.02.2026.

Revised 27.05.2026.

Accepted 08.06.2026.

Keywords:

FMEA, Action priority, Risk priority number, Criticality

ABSTRACT

Failure Modes and Effects Analysis is performed to identify and mitigate risks in the production and development of products. A Failure Modes and Effects Analysis created according to the AIAG/VDA FMEA Handbook uses Action Priority to prioritize optimization actions to reduce the occurrence of the failure cause, or to detect the failure cause or failure mode. However, there are only three possible categories of Action Priority, consisting of high, medium, and low, in place of the traditional Risk Priority Number, which could complicate prioritization when there are many items with the same Action Priority. This paper evaluates a method for prioritizing within one Action Priority. Three methods were used to evaluate additional prioritization criteria based on prioritizing first by Action Priority, then criticality, consisting of severity times occurrence, and then by occurrence. The highest possible Risk Priority Numbers were compared to the highest possible criticalities and Action Priority. The results were evaluated using three columns consisting of 1,000 simulated randomized values from which a sample was taken to make comparisons. An evaluation was also performed using a real Failure Modes and Effects Analysis. This study found that prioritization based on Action Priority can be supplemented by prioritization based on criticality within the highest Action Priority. This study provides organization with criteria that can reduce a high number items within one Action Priority to a more manageable number for both prioritizing optimization and reporting.



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1. INTRODUCTION

An FMEA (Failure Modes and Effects Analysis) is a risk identification and mitigation method used across industries such as pharmaceuticals (Sangode, 2024), food (Frunza, 2021), and the automotive industry (Plinta et al., 2021), where FMEAs are mandatory according to ISO/TS 16949:2016 (Gueorguiev et al., 2020). The creation of an FMEA was previously governed by the AIAG's (Automotive Industry Action Group) *Potential Failure Modes and Effects Analysis (FMEA): Reference*

Manual (Chrysler LLC et al., 2008), as well as SAE's (Society of Automotive Engineer) *Surface Vehicle Standard J1739: (R) Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA)* (SAE, 2009). Both AIAG and SAE used RPN (Risk Prioritization) for prioritizing improvement actions in FMEAs because an FMEA may have too many potential failures to effectively introduce additional actions for every failure (Faltin & Opitz, 2017).

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An RPN is derived by multiplying severity times occurrence times detection and severity, occurrence, and detection are rated using tables with values from one to ten (Maisano et al., 2020). The tables are used for rating severity, occurrence, and detection with defined criteria for each rating. For example, a severity of ten corresponds to a safety risk, a severity of nine corresponds to a violation of a regulation, a severity of eight corresponds to a loss of a primary function, and a severity of seven is a degradation of a primary function. Occurrence is rated based on both the maturity of the technology and the detection rating is based on the effectiveness of the evaluation method (AIAG/VDA, 2019).

When using RPN for prioritization, failures with the highest RPNs are addressed first (Zhou et al., 2016). The AIAG (Chrysler LLC et al., 2008) recommends against using threshold values when prioritizing based on RPN; however, this guidance is not always followed by organizations and Plinta et al. (2021) give an example of an organization that considered RPNs of 80 or lower to be acceptable, RPNs of 81 to 300 to be potentially acceptable, and anything over 300 to be unacceptable.

A known disadvantage of RPN that is severity, occurrence, and detection all have equal weight (Li et al., 2020) and severity, occurrence, and detection having equal weighting can lead to unrealistic prioritizations (Fabis-Domagala et al., 2021).

To compensate for a failure with a high severity receiving a much lower prioritization than a failure with a low severity, only severity times occurrence is recommended when using RPN (Anackovski et al., 2021). The value resulting from only considering severity times occurrence is called criticality (SAE, 2021).

The AIAG and a VDA (German association of the Automotive Industry) jointly released *AIAG/VDA Failure Modes and Effects Handbook* in 2019, which introduced AP (Action Priority) in place of RPN (AIAG/VDA, 2019). The SAE released a revision of the SAE standard in 2021 that essentially reverted to the older approach to FMEA using RPN, but with the option of using AP (SAE, 2021). An AP is derived through the use of tables that place the greatest emphasis on severity, some emphasis on occurrence, and the least amount of emphasis on detection (Anackovski et al., 2021). The shift from RPN to AP-based prioritization was due to the possibility of having higher RPNs for failures that realistically did not need optimization actions, such as when prevention and detection ratings are both as low as possible (Ramly & Atan, 2020).

There are three possible APs, consisting of high, medium, and low. An AP of high must have an improvement, an AP of medium can have an improvement or a documented reason explaining why an

improvement is not needed, and an AP of low does not need an improvement (Tague, 2023).

Assessments of prioritization based on AP versus RPN have been made. For example, Sun et al. (2022) used a Monte Carlo analysis to determine the chance of implementing an unneeded optimization when AP is low and the chance of failing to implement a needed optimization when AP is high. The authors found the chance of making such mistakes to be very low when using an RPN threshold value of 100. Barsalou (2022) also investigated the use of AP versus RPN using a threshold value of 100. Statistical software was used to create 10,000 RPN values and found there would be no difference in the number of required optimizations when improving both high and medium APs and there would be less optimizations required when only improving high APs. This paper evaluates the use of criticality, consisting of severity times occurrence, and then detection as supplemental prioritization criteria.

2. LITERATURE REVIEW

The *AIAG/VDA FMEA Handbook* has been discussed in multiple papers since its release. For example, Ramly and Atan (2020) created PFMEAs based on both the older AIAG approach from the 2009 edition of *FMEA Manual* and the *AIAG/VDA FMEA Handbook*. The authors found that the *AIAG/VDA FMEA Handbook* offered superior prioritization due to the use of AP with weighted values in comparison to RPN, but the *AIAG/VDA FMEA Handbook* form sheet was more difficult to use due to additional columns and *AIAG/VDA FMEA Handbook* - style FMEAs should be created in FMEA software programs.

3. METHODOLOGY

To determine the impact of prioritizing within a given AP, three methods were used. First the highest ten percent of criticalities and RPNs were compared to APs of high, medium, and low. Then, the conclusion was evaluated using 1,000 simulated APs, criticalities, and RPNs that were created by generating severities, occurrences, and detections and then randomizing them and taking a sample from the randomized values. Finally, the conclusion was evaluated using a real-world FMEA.

An assessment of the *AIAG/VDA FMEA Handbook* approach was conducted by Kluse (2020), who also found the use of AP to be superior to RPN, but the overall AIAG/VDA FMEA Handbook approach was also found to be much more complex than the older AIAG style FMEA, which necessitates either extensive training or the use of expert users. The use of the *AIAG/VDA FMEA Handbook* has also been explained by Gueorguiev et al. (2020), who describe the methodology and recommend use of external consultants for transitioning from old-style form sheets to AIAG/VDA FMEA Handbook style form sheets.

Kök and Yıldız (2023) compared FMEA prioritization criteria according to AIAG, *AIAG/VDA FMEA Handbook*, and VDA. The AIAG approach to prioritization is RPN, while the *AIAG/VDA FMEA Handbook* uses AP. The VDA approach uses a matrix with three levels of prioritization based only on severity and occurrence, which has the disadvantage of failing to consider detection when prioritizing.

An alternative prioritization system was developed by Salah et al. (2023) for Industry 4.0, who use RPN, but based on severity times occurrence times detection times dependency. The authors describe dependency as rating the impact of a failure on other components using a scale of one to ten. In this system of prioritization, the highest RPNs are identified and addressed first using a Pareto.

The application of the *AIAG/VDA FMEA Handbook* in an automotive organization was explored with a case study by Dumitrascu and Dumitrascu (2024), who found the FMEA lead to a reduction in scrap and an improvement in both product quality and reliability. The FMEA's initial state had 8.7% of the APs rated as high, 78.3% rated as medium, and only 13% rated as low. Once optimizations were implemented, there were no high APs and 56.3% of APs were medium, and the remainder were low.

The use of the *AIAG/VDA FMEA Handbook* in meat processing was assessed by Frunza (2021) using an FMEA with both RPN and AP. The meat processing FMEA had multiple APs of low with an RPN that was greater than the RPN that corresponded to APs of high. An electrical system was also assessed using an FMEA with both AP and RPN (Petrescu et al., 2021). An RPN value of 200 was used as a threshold for improvements, with improvements only required when the threshold was exceeded. The authors found much overlap between RPNs above 200 and an AP of high; however, there were also RPNs below the threshold for improvement that corresponded to AP high and APs that were not high, but had an RPN that was below the threshold for an improvement.

The *AIAG/VDA FMEA Handbook* offers a new approach to FMEAs in addition to the introduction of AP. System elements must be identified and functions are assigned to the system elements. Then, failures are assigned to the function and the resulting worksheet is much larger than previous FMEA form sheets (AIAG/VDA, 2019). An FMEA can still use AP in a more traditional style form sheet when following SAE's *SAE J1739* (SAE, 2021), which offers the possibility of using either AP or RPN.

3.1. Methodology for highest ten percent APs

To determine the impact of prioritizing within a given AP, three methods were used. First the highest ten percent of criticalities and RPNs were compared to APs of high, medium, and low, as shown in Table 1. Then, the conclusion was evaluated using 1,000 simulated APs,

criticalities, and RPNs that were created by generating severities, occurrences, and detections and then randomizing them and taking a sample from the randomized values. Finally, the conclusion was evaluated using a real-world FMEA.

Table 1. Number of high, medium, and low APs for all possible combinations

AP	Number of occurrences	Ten percent
High	318	31.8
Medium	196	19.6
Low	486	48.6

The APs of high, medium, and low were separated into three tables. Each table was sorted first by highest criticalities and then by highest RPN. The highest ten percent of criticalities and RPNs were color-coded to identify them. The amount of overlap between the highest ten percent of criticalities and RPNs were then observed after sorting by RPN and criticality. The severity, occurrence, and detection ratings for the criticalities were also observed. Table 2 lists the highest ten percent of AP high, sorted by criticality. Table 3 lists the highest ten percent of criticalities for AP medium, and Table 4 shows the highest ten percent of criticalities for AP low.

Table 2. Highest ten percent of criticalities for AP high

Severity	Occurrence	Detection	Criticality	RPN
10	10	10	100	1000
10	10	9	100	900
10	10	8	100	800
10	10	7	100	700
10	10	6	100	600
10	10	5	100	500
10	10	4	100	400
10	10	3	100	300
10	10	2	100	200
10	10	1	100	100
10	9	10	90	900
10	9	9	90	810
10	9	8	90	720
10	9	7	90	630
10	9	6	90	540
10	9	5	90	450
10	9	4	90	360
10	9	3	90	270
10	9	2	90	180
10	9	1	90	90
10	8	10	80	800
10	8	9	80	720
10	8	8	80	640
10	8	7	80	560
10	8	6	80	480
10	8	5	80	400
10	8	4	80	320
10	8	3	80	240
10	8	2	80	160
10	8	1	80	80
Note: Gray background indicates value is in top ten percent				

Table 3. Highest ten percent of criticalities for AP medium

Severity	Occurrence	Detection	Criticality	RPN
6	10	4	60	240
6	10	3	60	180
6	10	2	60	120
6	10	1	60	60
8	7	1	56	56
6	9	4	54	216
6	9	3	54	162
6	9	2	54	108
6	9	1	54	54
5	10	4	50	200
5	10	3	50	150
5	10	2	50	100
10	5	1	50	50
5	10	1	50	50
7	7	1	49	49
6	8	4	48	192
6	8	3	48	144
6	8	2	48	96
8	6	1	48	48
6	8	1	48	48

Note: Gray background indicates value is in top ten percent

Table 4. Highest ten percent of criticalities for AP low

Severity	Occurrence	Detection	Criticality	RPN
6	7	1	42	42
6	6	1	36	36
5	7	1	35	35
6	5	6	30	180
6	5	5	30	150
10	3	4	30	120
6	5	4	30	120
3	10	4	30	120
10	3	3	30	90
6	5	3	30	90
3	10	3	30	90
10	3	2	30	60
6	5	2	30	60
3	10	2	30	60
10	3	1	30	30
6	5	1	30	30
5	6	1	30	30
3	10	1	30	30
4	7	1	28	28
9	3	4	27	108
3	9	4	27	108
9	3	3	27	81
3	9	3	27	81
9	3	2	27	54
3	9	2	27	54
9	3	1	27	27
3	9	1	27	27
5	5	6	25	150
5	5	5	25	125
5	5	4	25	100
5	5	3	25	75
5	5	2	25	50
5	5	1	25	25
6	4	6	24	144
6	4	5	24	120
8	3	4	24	96

6	4	4	24	96
3	8	4	24	96
8	3	3	24	72
6	4	3	24	72
3	8	3	24	72
8	3	2	24	48
6	4	2	24	48
3	8	2	24	48
8	3	1	24	24
6	4	1	24	24
4	6	1	24	24
3	8	1	24	24
3	7	10	21	210

Note: Gray background indicates value is in top ten percent

3.2 Methodology for random combinations

To observe what would happen when criticality is used as an additional prioritization criteria, Minitab Statistical Software was used to generate three columns of one to ten with each value repeated one hundred times to represent severity, occurrence, and detection ratings. Three columns with 1,000 values each were then generated using a random distribution generator. The random values followed the normal distribution and had a mean of 100 and a standard deviation of one. The random values in the first column were sorted from lowest to highest, together with the values representing severity to randomize the position of the severity values. The procedure was then repeated for the simulated prevention and detection values. The AP was then determined for each of the thousand values. There were 327 APs of high, 191 APs of medium, and 482 APs of low, as shown in Table 5.

Table 5. Number of high, medium, and low APs for 1,000 random combinations

AP	Number of occurrences
High	327
Medium	191
Low	482

The simulated severity, occurrence, and detection values were then separated into three tables based on high, medium, and low AP. A new column was then added to each table using a random distribution generator in Minitab Statistical software to generate random normally distributed values with a mean of 100 and a standard deviation of one. This randomization was performed to take a sample of ten values from high, medium, and low APs. The highest ten criticalities for AP high using random combinations are shown in Table 6, the combinations for AP medium are in Table 7, and the combinations for AP low are in Table 8.

Table 6. Number of high, medium, and low APs for 1,000 random combinations

Severity	Occurrence	Detection	Criticality	RPN
9	10	5	90	450
9	10	8	90	720
8	10	7	80	560

10	6	2	60	120
8	7	8	56	448
6	8	10	48	480
6	7	7	42	294
10	4	3	40	120
10	4	2	40	80
8	4	7	32	224

Table 7. Highest ten criticalities for AP medium using random combinations

Severity	Occurrence	Detection	Criticality	RPN
8	6	1	48	48
4	9	4	36	144
5	7	4	35	140
6	5	10	30	300
7	4	2	28	56
4	6	7	24	168
7	3	9	21	189
2	9	9	18	162
2	8	8	16	128
4	4	10	16	160

Table 8. Highest ten criticalities for AP medium using random combinations

Severity	Occurrence	Detection	Criticality	RPN
6	6	1	36	36
4	5	2	20	40
3	5	3	15	45
6	2	7	12	84
9	1	8	9	72
3	3	9	9	81
8	1	10	8	80
1	6	8	6	48
1	4	10	4	40
1	1	6	1	6

3.3 Methodology for a real-world FMEA

An actual FMEA was used for a final evaluation. The FMEA was for a manufactured product and was created according to the *AIAG/VDA FMEA Handbook*. An FMEA is proprietary; therefore, the organization that owned the FMEA granted permission to use the FMEA, but not to share the content of the FMEA. Therefore, the FMEA will only be described, and not reproduced.

The FMEA had open improvement actions; therefore, there were many high APs that would later be reduced. The high APs were selected and sorted by both criticality and RPN. The different combinations of severity, occurrence, and detection were then observed.

4. RESULTS

4.1 Methodology for highest ten percent of APs

When high APs were sorted from highest to lowest, only 35.5% of the highest ten percent of RPNs overlapped with the highest ten percent of criticalities. For medium APs, none of the highest ten percent of RPNs overlapped with the highest ten percent of criticalities. For low APs,

only 20.4% of the highest ten percent of RPNs overlapped with the highest ten percent of criticalities, as shown in Table 9.

Table 9. Percentage of RPNs overlapping with criticalities

AP	Percent of RPN overlapping with criticality
High	35.5%
Medium	0%
Low	20.4%

For high APs sorted by the highest ten percent of criticalities, the criticalities were all 100, 90, or 80. The corresponding RPNs ranged from 1,000 to 80. There were ten results for each of the three criticalities, whereas the corresponding RPNs always had different values due to each combination of severity and occurrence having ten different detection ratings. Medium APs had a wider range of criticalities and a very wide range of RPNs that were not in the top ten percent of RPNs. For medium APs, the highest ten percent of RPNs that overlapped with the highest ten percent of criticalities tended to be much higher than the RPNs that did not overlap with criticalities and this was due to the impact of higher detection ratings.

Although there was some overlap between criticality and RPN for high and low AP, there was no overlap when AP was medium and the amount of overlap for AP medium and AP low was, limited. The failures prioritized for optimization would be significantly different depending on whether prioritizing was based on AP and then criticality or AP and then RPN. An AP of high has a wide range of possible criticalities due to a highest possible criticality of 100 for severity ten with an occurrence of ten down to a lowest possible criticality of 18 for a severity of nine together with an occurrence of two.

4.2 Results for random combinations

The highest two criticalities in randomly selected high APs were both 90 and the third and fourth highest criticalities were 80 and 60. The highest RPN was 720 and it did correspond to one of the highest two criticalities; however, there was also an RPN of 450 with a criticality of 90, which was lower than two RPNs that corresponded to lower criticalities. In one case, a severity of six, occurrence of eight, and detection of ten would have been prioritized before a severity of nine, occurrence of ten, and detection of five.

For medium APs, the highest criticality was 48 with an RPN of 48. The RPN of 48 was the lowest RPN due to a severity of eight, an occurrence of six, and a detection of one. The highest RPN was 300, and it corresponded to a criticality of 30, which was the fourth highest criticality, due to a severity of six, an occurrence of five, and a detection of ten.

The highest criticality for AP low was 36, which corresponded to an RPN of 36. The RPN of 36 was the second lowest RPN, due to a severity of six, occurrence of six, and detection of one. The second and third lowest RPNs were each 40. One corresponded to a criticality of 20, which was the second-highest criticality, with a severity of four, an occurrence of five, and a detection of two. The other RPN of 40 corresponded to a criticality of four, which was the second lowest criticality, with a severity of one, occurrence of four, and a detection of ten. The highest and fourth-highest RPNs aligned with the two highest criticalities for AP High. However, the lowest criticality was aligned with the fourth lowest RPN. Two of the three highest RPNs within AP medium corresponded to relatively low criticalities when using random combinations, and the highest criticalities corresponded to lower RPNs. For AP low, the highest RPNs corresponded to lower criticalities.

4.3 Results for a real-world FMEA

Prioritization based on AP followed by criticality, and finally RPN was assessed on a real-world FMEA. High APs were selected and then sorted by criticality. The highest ten criticalities were for severities and occurrences of nine or ten. The highest RPNs were in the top six, but three of the RPNs were lower than RPNs that were associated with the lowest criticalities. When sorted by RPN, the first six RPNs and criticalities were again aligned. However, the next three criticalities were not the highest three criticalities.

Sorting all APs of highest by RPNs in a real-word FMEA resulted in three severities of eight in the top ten, while sorting by criticality resulted in only severity and occurrence combinations of ten and nine. There is a risk of overlooking failure effects involving loss of life, injury, and violation of laws when using RPN to prioritize after selection based on AP. This would be due to the equal weighting between severity, occurrence, and detection, which can result in overlooking potentially severe consequences where the detection rating is very high.

5. DISCUSSION

The highest prioritizations within a given AP differ based on if criticality or RPN is used as an additional prioritization criterion for the top ten percent of APs of high, medium, and low, random combinations, and a real-world FMEA. This is due to only using severity times occurrence for criticality and using severity times occurrence times detection for RPN.

Both the highest criticalities and RPNs occur within AP high. However, a severity of ten and occurrence of 10 will have the highest possible criticality, but could have a much lower RPN than a severity of six, occurrence of seven, and a detection of eight. This means a failure that could result in loss of life and happens often would be

prioritized after a failure that only results in a loss of a secondary function that does not occur as often, if prioritized by AP or RPN instead of AP and criticality. The difference between criticality and RPN was most pronounced within AP medium. This may be due to many possibilities of having a low combination of severity and occurrence, but a possibility of having a detection rating of one to ten. Within AP medium, higher severities can only occur together with a lower occurrence. For example, a severity of seven or eight is the highest possible severity and that can only happen with an occurrence of two or three. This means that the worst possible failure consequences consist of either a loss of a main function or a reduction in a main function.

Within AP low, a severity of nine or ten is possible, but only together with an occurrence of two or three, together with a very low detection rating, or an occurrence of one, which indicates the failure cause cannot occur. Higher RPNs may result within AP low due to severity ratings of five, with occurrence ratings of only three together with a high detection rating. For example, a low AP may have an RPN as high as 150. However, optimization actions for an AP of low are optional and the highlights severity ratings, and therefore the worst failure consequences, only happen within AP low when occurrence and detection are very low. In such circumstances, the RPN will be higher than the criticality value, even though the chance of the failure happening is very low or even non-existent.

6. CONCLUSION

An FMEA is mandatory in the automotive industry, where AP is used in place of RPN in organizations following the *AIAG/VDA Failure Modes and Effects Handbook*. This presents a complication when a limited top risk list is required due to AP only having three options, consisting of high, medium, and low.

This paper evaluated prioritization based on the highest combinations of severity times occurrence, followed by the highest detection rating for the highest AP. This paper found that the highest combinations of severity times occurrence, followed by the highest detection rating for the highest AP can be used to identify a limited list of top items for both reporting and prioritizing for optimization actions.

This study has implications for practitioners, managers, and researchers. Practitioners should use the criteria identified in this paper when confronted with too many high APs to address all at once and then repeat the procedure when the first optimizations have been implemented. Managers requesting reports, such as a top ten list, need to need to understand that there may be more than ten items with an AP of high and should require employees to use the criteria identified here to identify the items that will be reported.

Prioritizing both optimization actions and items for reporting using AP has the advantage of ensuring that the highest combinations of severity, indicating severe consequences, and occurrence, indicating the failure

happens often, are prioritized first. But there are many possible combinations of severity times occurrence within one AP rating, and this paper provides additional prioritization criteria.

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