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FMEA Risk Analysis on the Basis of Action Priorities

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Abstract—The risk assessment system based on action priorities proposed in the recent AIAG/VDA FMEA handbook is analyzed in detail; this system is used in the auto industry. The structure of the action priority (AP) matrix is considered, along with the principles used in its formulation. Problematic aspects of the approach in assessing design risks (as regards the materials employed and the production processes for auto components) are identified and discussed. A method is proposed for assessing the contribution of each element in the risk assessment to the final action priority.

Keywords: risk analysis, FMEA (failure mode and effects analysis), risk priority, priority matrix, action priority (AP), problem analysis

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To eliminate inadequacies in total risk assessment on the basis of risk priorities and in deciding on the need for risk reduction, the first edition of the AIAG/VDA FMEA handbook proposed a different approach to assigning priorities in risk management [1]. The use of risk priorities is now regarded as a very speculative basis for decision making [2]. However, the FMEA manual mentions its use, under certain conditions in determining priorities on the basis of the scores S and O or risk matrices employing the score combinations S and O, S and D, and also O and D. (The use of a limiting priority value is not recommended here, but is not forbidden.)

Instead of risk priorities, the handbook recommends a conversion table directly from the combination of significance (S), occurrence (O), and detection (D) ratings to a three-level action priority (AP); the three levels are H (high), M (medium), and L (low). This is a three-dimensional matrix or risk table.

The method based on action priorities takes account of all possible combinations of the scores S, O, and D. This approach eliminates quantitative estimation of the risk, which cannot be accurate, but still prioritizes some ranks over others. The weight is greatest for the seriousness of the consequences (S), followed by the probability of occurrence (O) and finally the probability of detection (D). These weights appear in the three-dimensional matrix of action priorities, which is represented as a plane table, successively filtering the values of the scores S, O, and D until a specific level of the action priority is determined.

When the combination of scores S, O, and D leads to an action priority of level H, the cause of the failure must be addressed by appropriate actions so as to reduce the risk. In other words, actions are taken to eliminate the cause (by changing the product geometry or the material selected, for example). When the action priority is of level M, action to address the cause of the failure is only recommended. For level L, remedial action is at the discretion of management. Table 1 presents responses of the expert team to different levels of the action priority.

If the potential consequences of the failure are of significance $S = 9–10$, while the action priority is high (H) or medium (M), the AIAG/VDA FMEA handbook recommends that management pay attention to these failures and any actions that have been recommended or taken. (In Table 2, the scores O and D corresponding to this situation are shown in bold.) For a low priority, the enterprise may choose to write “No further actions required” in the FMEA protocol in the space for the causes of the failure. Table 2 presents the responses of the specialist team for different action priorities. (This is a fragment of the action priority matrix.)

As is evident from Table 2, the manual recommends that management be informed when the probability of detection is very high ($D = 1$, almost certain detection), but the probability of observation is moderate or high ($O = 4–7$) and the significance is very high ($S = 9–10$), since such failures may affect the user, pose safety hazards, and violate legal standards.

Table 1

Level of action priority (AP)	Responses
High (*H*)	The team is required either to determine the corresponding improvements in management measures or preventive and/or detection measures; or to establish and document why the existing management methods may be regarded as adequate
Medium (*M*)	The team is recommended either to determine the corresponding improvements in management measures or preventive and/or detection measures; or to establish and document why the existing management methods may be regarded as adequate
Low (*L*)	The team may determine the corresponding improvements in preventive and/or detection measures

Table 2

Significance of consequences for product or enterprise	Score *S*	Probability of occurrence	Score *O*	Probability of detection	Score *D*	Action priority (AP)
Very high	9–10	Very high	8–10	Low/very low	7–10	*H*
				Medium	5–6	*H*
				High	2–4	*H*
				Very high	1	*H*
		High	6–7	Low/very low	7–10	*H*
				Medium	5–6	*H*
				High	2–4	*H*
				Very high	1	*H*
		Medium	4–5	Low/very low	7–10	*H*
				Medium	5–6	*H*
				High	2–4	*H*
				Very high	1	*M*
		Low	2–3	Low/very low	7–10	*H*
				Medium	5–6	*M*
				High	2–4	*L*
				Very high	1	*L*
		Very low	1	Very high to very low	1–10	*L*

Most likely the score $D = 1$ will only be observed when "the cause of the failure or the failure itself cannot occur, since it is ruled out by design choices" (as specified for $D = 1$ in the DFMEA detection table) or "the failure mode is ruled out in this design or in the production process or it has been proven that detection measures ensure the detection of the failure mode or its cause" (as specified for $D = 1$ in the PFMEA detection table). There is some inconsistency here; consequently, it makes no sense to inform management if the failure has essentially already been ruled out. (Rather, the team should review its decisions.)

It is important to understand that using action priorities does not imply selecting three levels of risk priority: high, medium, and low. The action priority relates to risk-reduction measures. Therefore, AP tables should not be referred to as risk matrices: they apply only to action priorities.

Analysis of the AP matrix from the AIAG/VDA FMEA handbook yields the following conclusions.

1. Reviewing the interpretation of the scores *S*, *O*, and *D*, we see that five ranks are provided for the probability of occurrence (*O*), ranging from very low to very high (although elsewhere the table itself uses seven ranks for *O*!); for the significance of the consequences (*S*), five ranks are used (four for the range $S = 2–10$ and one for $S = 1$, which corresponds to the unlikely case with "no marked consequences"); and, finally, for the probability of detection (*D*), only four ranks are provided (although elsewhere in the table five ranks are used!). Table 3 summarizes these ranges of the scores *S*, *O*, and *D* in the AP matrix.

Score D (columns), Score O (rows)

S = 9–10	VL	M	H	VH
VH	H	H	H	H
H	H	H	H	H
M	H	H	H	M
L	H	M	L	L
VL	L	L	L	L

Score D (columns), Score O (rows)

S = 9–10	VL	M	H	VH
VH	H	H	H	H
H	H	H	H	M
M	H	M	M	M
L	M	M	L	L
VL	L	L	L	L

Score D (columns), Score O (rows)

S = 9–10	VL	M	H	VH
VH	H	H	M	M
H	M	M	M	L
M	M	L	L	L
L	L	L	L	L
VL	L	L	L	L

Score D (columns), Score O (rows)

S = 9–10	VL	M	H	VH
VH	M	M	L	L
H	L	L	L	L
M	L	L	L	L
L	L	L	L	L
VL	L	L	L	L

Score D (columns), Score O (rows)

S = 1	VL	M	H	VH
VH	L	L	L	L
H	L	L	L	L
M	L	L	L	L
L	L	L	L	L
VL	L	L	L	L

Score S (columns), Score O (rows)

D = 7–10	VH	H	M	L	VL
VH	H	H	H	M	L
H	H	H	M	L	L
M	H	H	M	L	L
L	H	M	L	L	L
VL	L	L	L	L	L

Score S (columns), Score O (rows)

D = 5–6	VH	H	M	L	VL
VH	H	H	H	M	L
H	H	H	M	L	L
M	H	M	L	L	L
L	M	M	L	L	L
VL	L	L	L	L	L

Score S (columns), Score O (rows)

D = 2–4	VH	H	M	L	VL
VH	H	H	M	L	L
H	H	H	M	L	L
M	H	M	L	L	L
L	L	L	L	L	L
VL	L	L	L	L	L

Score S (columns), Score O (rows)

D = 1	VH	H	M	L	VL
VH	H	H	H	M	L
H	H	M	L	L	L
M	M	M	L	L	L
L	L	L	L	L	L
VL	L	L	L	L	L

Score D (columns), Score O (rows)

O = 8–10	VL	M	H	VH
VH	H	H	H	H
H	H	H	H	H
M	H	H	M	M
L	M	M	L	L
VL	L	L	L	L

Score D (columns), Score S (rows)

O = 6–7	VL	M	H	VH
VH	H	H	H	H
H	H	H	H	M
M	M	M	M	L
L	L	L	L	L
VL	L	L	L	L

Score D (columns), Score S (rows)

O = 4–5	VL	M	H	VH
VH	H	H	H	M
H	H	M	M	M
M	M	L	L	L
L	L	L	L	L
VL	L	L	L	L

Score D (columns), Score S (rows)

O = 2–3	VL	M	H	VH
VH	H	M	L	L
H	M	M	L	L
M	L	L	L	L
L	L	L	L	L
VL	L	L	L	L

Score D (columns), Score S (rows)

O = 1	VL	M	H	VH
VH	L	L	L	L
H	L	L	L	L
M	L	L	L	L
L	L	L	L	L
VL	L	L	L	L

Fig. 1. Two-dimensional cross sections of the three-dimensional AP matrix: the first series corresponds to S, the second to D, and the third to O.

2. In all, there are 22 priorities of rank H; 16 of rank M, and 62 of rank L.

3. If we compare the risk priorities for different action priorities, we find the following.

3.1. For priority H, the minimum risk priority is 54; that corresponds to $S = 9$, $O = 6$, and $D = 1$.

3.2. For priority M, the maximum risk priority is 420; that corresponds to $S = 6$, $O = 7$, and $D = 10$. The minimum risk priority is 28; that corresponds to $S = 7$, $O = 4$, and $D = 1$.

3.3. For priority L, the maximum risk priority is 210; that corresponds to $S = 3$, $O = 7$, and $D = 10$.

4. Note that the scores S, O, and D make different contributions to the final action priority (AP). As we see in Fig. 1, the contribution is greatest for the significance of the consequences (S), followed by the probability of occurrence (O), and finally the probability of detection (D).

We now consider these findings in more detail.

1. The use of qualitative scales together with ranges of the scores S, O, and D indicates all ten values of the scores are not necessary to determine the action priority (AP). For example, the AP matrix does not employ all ten possible values of S, O, and D, but only four or five intervals corresponding to specific intervals (Table 3). These categories do not always correspond to those in the initial tables defining the scores S, O, and D. In discussing the AIAG/VDA FMEA handbook, some noted the expediency of ten-point scales for S, O, and D within the FMEA framework [3]. However, the consequences of this choice must be analyzed. It should also be noted that different numbers of qualitative ranks were chosen for the scores: five for S, five for O, and four for D. That results in asymmetry of the matrix for pairs of scores (Fig. 1). It would be logical to create five ranks also for D or to switch to four ranks for all the scores, not least because very low AP scores (VL) always correspond also to the category L.

2. There is an evident imbalance in the AP ranks. Usually the risk matrix is more or less symmetric with respect to the number of ranks appearing, and so their proportions are approximately the same. In the AP matrix, however, the appearances of L considerably outnumber those of M and H. That indicates nonlinearity in determining the AP ranks relative to the ten-point scales of S, O, and D. For the sake of convenience, the three-point AP scale might be replaced by a four-point scale. For example, if the S and O scores are very low, we might add an AP rank signifying that no further action is required (None, N).

3. In determining AP values for the matrix, most weight is given to the significance of the consequences (S). That is consistent with the fourth edition of the

Table 3

S	O	D	Notation	Rank
9–10	8–10	1	VH	Very high
7–8	6–7	2–4	H	High
4–6	4–5	5–6	M	Medium
2–3	2–3	7–10	L	Low
1*	1		VL	Very low

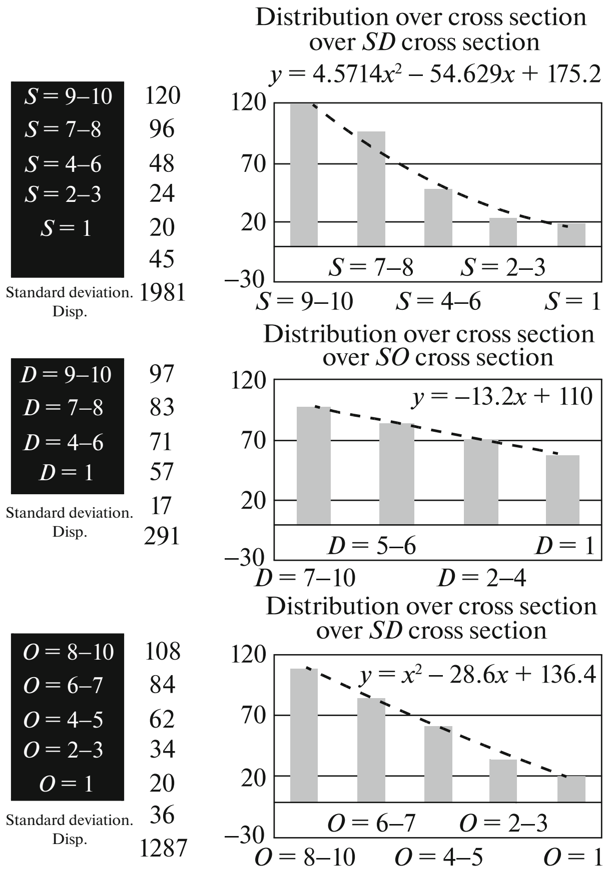

Fig. 2. Distribution of the AP totals over two-dimensional cross sections of the three-dimensional AP matrix: the first series corresponds to *S*, the second to *D*, and the third to *O*.

AIAG FMEA handbook, where the significance of the consequences is given most weight in determining the action priorities. For example, if the team assigns the value *H* to the AP in the presence of high scores *S* and *O*, then it will be difficult to change the AP value by reducing only *D* when assessing risk-reduction measures. On the other hand, if *D* is high, the situation may be regarded as acceptable (AP = *L*) even with some combination of medium or even high *S* and *O*. The different contributions of *S*, *O*, and *D* may be traced visually, by comparing two-dimensional cross sections of the three-dimensional AP matrix on passing from very high to very low scores (Fig. 2). For low and very low *D* (corresponding to rank *VL*), there are four levels of *H* and four levels of *M*. With low *O* (rank *L*), there is one level of *H*, as against three levels of *M*. For *S* of rank *L*, there are only two levels of *M*.

This point is clearer if we convert from qualitative to quantitative AP values, according to the following rule: level *H* corresponds to 9; *M* to 3; and *L* to 1. We may now assess the total priority level for each cross section and observe the variation in priority from one cross section to another—in other words, between levels of *S*, *O*, and *D*. Plotting a polynomial trend in the distribution of the total AP value over the cross sections for scores *S*, *O*, and *D* (Fig. 2), we see that the greatest trend—that is, the greatest nonuniformity in the priority distribution—corresponds to the significance of the consequences (*S*).

The contribution of the significance of ranks *VH* and *H* is considerably greater than for the lower ranks. (This is also evident from the standard deviation of the AP totals between the cross sections.) For *D*, the trend is essentially linear. In other words, the AP total declines slowly and steadily from one cross section to the next (from one rank to the next). For the occurrence score *O*, the trend is also close to linear. We see that the distribution of the AP totals is nonuniform. (Medium and high ranks are slightly favored.) However, the nonuniformity is less pronounced than for *S*. This indicates a clear priority: first *S* and *O* are taken into account, with considerable preference for *S*; then *D* is taken into account, at a significantly lower level. (For *D*, the priority is half of that for *O*, and a quarter of that for *S*.)

It may be necessary to prioritize the significance of the consequences *S* even more over the probability of occurrence *O*. That would require modification of the AP matrix by redistribution of the AP levels between different ranks of *S*, *O*, and *D*.

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