Using ME-OWA approach to modify prioritization of failures in the IPM system

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Abstract

This paper proposed a novel technique, based on Maximal Entropy Ordered Weighted Averaging (ME-OWA), for prioritizing failures for corrective actions in a Criticality Analysis (CA). Most current CA methods use the Risk Priority Number (RPN) value to evaluate the risk of failure. However, conventional RPN methodology has been criticized to have four main shortcomings as below: (1) problem of the measurement scale; (2) severity, occurrence, and detection do not consider weighted with respect to one another in terms of risk; (3) the RPN scale itself has some non-intuitive statistical properties; (4) the RPN elements have many duplicate numbers. Therefore, an efficient, simplified algorithm to evaluate the orderings of risk for failure problems is needed. This paper proposed ME-OWA approach for reprioritization of failures in a system CA. The proposed methodology resolves some of the shortcomings of the conventional RPN method. In numerical verification, a CA of the Intelligent Power Module (IPM) is presented to further illustrate the proposed approach. After comparing the result that was obtained from the proposed method with the conventional RPN method, the result shows that the proposed approach can reduce more duplicated RPN numbers and get a more discriminative, reasonable risk assessment. As a result, the stability of product and process can be assured.

Keywords: Risk priority number; Criticality analysis; Maximal entropy ordered weighted averaging

運用 ME-OWA 手法修正 IPM 系統失效風險的排序

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摘　　要

目前大部分的關鍵性分析方法(criticality analysis，CA)使用風險優先數(risk priority number，RPN)來評估失效風險，然而傳統的 RPN 方法有四個缺點：(1)測量尺度的問題；(2)未考慮權重；(3) RPN 值範圍違反統計假設；(4) RPN 值有許多的重複數。爲克服上述缺點，我們需要一個有效簡單的運算方法重新評估系統失效風險，因此，爲修正

傳統的 RPN 方法用於評估失效風險的缺點，本研究提出新的失效風險排序技巧，以最大熵順序加權平均法(maximal entropy ordered weighted averaging，ME-OWA)重新排定關鍵性分析中失效風險的排序。在案例論證方面，使用智慧型電力模組(intelligent power module，IPM)的例子進一步論證本研究所提之方法。結果證明使用本研究所提之方法可有效減少 RPN 值的重複數，並能得到更正確合理的風險評估結果。

關鍵詞： 風險優先數，關鍵性分析，最大熵順序加權平均

1. Introduction

Risk assessment is a preventive analysis task of product design and the production planning process. It is utilized to find the weaknesses of product design and production process in early stages before going into mass production, to allow the product to have better quality and reliability, which in turn increase the market competitiveness.

Failure Mode, Effects, and Criticality Analysis (FMECA) is a widely used risk assessment tool to identify the potential failure modes of a product. Most current FMECA methods use the Risk Priority Number (RPN) value to evaluate the risk level of a component or process. However, conventional RPN methodology has been criticized to have several shortcomings. These shortcomings are addressed in this paper. Therefore, it is necessary to develop an efficient and simplified algorithm for priority of failures in a system FMECA.

FMECA was first developed as a formal design methodology in the 1960s by the aerospace industry with their obvious reliability and safety requirements. The American army began using FMECA in the 1970's, and in 1974 produced the army standard "MIL-STD-1629: Procedures for performing a failure mode effects and criticality analysis". In 1980, there was also a second print MIL-STD-1629A. Today, FMECA has been adopted in many places, such as the aerospace, military, automobile, electricity, mechanical, and semiconductor industries. FMECA combines Failure Mode and Effect Analysis (FMEA) with Criticality Analysis (CA). An FMECA methodology is a systematic way to identify and evaluate the effects of different component failure mode, to determine what could eliminate or reduce the chance of failure, and to document the system for consideration. It is an analysis procedure that identifies all possible failure modes, determines the effect of each failure on the system, and ranks each failure according to a severity classification of failure effect. Conventionally, the prioritization of failures for corrective actions is performed by developing an RPN to help identify the most serious risks for remedial actions. In order to obtain the RPN of a potential failure mode, a rank from 1 to 10 is assigned to the severity of the failure (S), the probability of failure (O), and the probability of not detecting the failure (D), respectively. The RPN of the corresponding failure mode is then calculated as a mathematical product of the three factors (i.e., $S \times O \times D \in [1, 1000]$). A failure mode that has a higher RPN is assumed to be more important and is given a higher priority than those with lower RPN values.

Most of the literature that confer RPN

related issues and conventional RPN method does not consider the ordered weight, which may cause bias conclusion. The ordered weight is one of the most important factors that are used to evaluate the risk of failure. The concept of Ordered Weighted Average (OWA) operators was proposed by Yager (1988). It is an important aggregation operator within the class of weighted aggregation methods. O'Hagan (1988) developed a procedure to generate OWA weights for given degree of orness α, to maximize entropy. The resulting weights are called the Maximal Entropy Ordered Weighted Averaging (ME-OWA) weights. Many related studies have been published in recent years. For example, Fuller and Majlender (2001) used Lagrange multipliers to derive a polynomial equation, then determine the optimal weighting vector by solving a constrained optimization problem.

The fundamental problem with FMECA is that it attempts to quantify risk without adequately quantifying the factors that contribute to the risk. Bowles (2003) proposed an assessment of RPN prioritization in a FMECA. He pointed out that the conventional RPN method, though well documented and easy to apply, is seriously flawed from a technique perspective. In particular cases, the RPN can be misleading. Sankar and Prabhu (2001) proposed a modified approach for prioritization of failure modes in FMECA called risk priority rank to correct this issue. Their approach extended risk prioritization beyond the conventional RPN method. The ranks 1 through 1000 were used to represent the increasing risk of the 1000 possible S-O-D combinations. An improved FMECA methodology, which utilizes the fuzzy-based rules and grey relation theory to model the entire system, was presented by Pillay and Wang (2003). Wang et al. (1995) proposed an inductive bottom-up risk identification and estimation methodology that combined FMECA and the Boolean representation method. However, it might be difficult to construct Boolean representation tables for some components of a system, especially during early conception and design phases, when the relationships between components are unclear or difficult to precisely represent. However, the above approach does not consider the ordered weight. To solve the above problem, this paper proposes a novel technique, using ME-OWA approach to modified prioritization of failures in the conventional RPN methodology.

The rest of this paper is organized as follows. In Section 2, the conventional RPN method and its shortcomings are discussed. Section 3 introduces the basic definition and some operations of the ME-OWA operators and the methodology that is used to determine ME-OWA weights. In Section 4, we propose a novel methodology that uses the ME-OWA approach for risk assessment. A numerical example of the IPM is adopted and some comparisons with conventional RPN method are discussed in Section 5. The final section makes conclusions.

2. RPN methodology

In this section, we will introduce the components of RPN calculation, severity, occurrence, and detection, with respect to the types of scales on which they are measured. We will also point out the shortcomings of the conventional RPN.

2.1 Conventional RPN method

In the conventional RPN method, three parameters, the severity of the failure (S), the probability of failure (O) and the probability of not detecting the failure (D) are utilized to describe each failure mode by rating them on a numeric scale from 1 to 10. The RPN value is obtained by finding the product of these three factors. Therefore, RPN = $S \times O \times D$. Tables 1, 2, and 3 list the scales that are used to measure the three factors (Ford motor company, 1988). Failure modes with higher RPN values are assumed to be more important and are given higher priorities than those with lower RPN values.

Severity is ranked according to the seriousness of the failure mode effect on the next higher level assembly, the system, or the user. The effects of a failure mode are normally described by the effects on the user of the product or as they would be seen by the user. Table 1 shows the criteria used to rank the severity of a failure effect.

Occurrence is ranked according to the failure probability, which represents the relative number of failures anticipated during the design life of the item. Table 2 lists the occurrence ranking and their associated meanings.

Detection is an assessment of the ability of a proposed design verification program to identify a potential weakness before the part or assembly is released for production. Table 3 shows the evaluation criteria used for the detection rankings.

Table 1　Suggested evaluation criteria for the severity of effects for a design FMECA

Effect	Criteria: severity of effect	Rank
Hazardous	Failure is hazardous, and occurs without warning. It suspends operation of the system and/or involves noncompliance with government regulations	10
Serious	Failure involves hazardous outcomes and/or noncompliance with government regulations or standards	9
Extreme	Product is inoperable with loss of primary function. The system is inoperable	8
Major	Product performance is severely affected but functions. The system may not operate	7
Significant	Product performance is degraded. Comfort or convince functions may not operate	6
Moderate	Moderate effect on product performance. The product requires repair	5
Low	Small effect on product performance. The product does not require repair	4
Minor	Minor effect on product or system performance	3
Very minor	Very minor effect on product or system performance	2
None	No effect	1

Table 2 Suggested evaluation criteria for the occurrence of failure in a design FMECA

Probability of failure	Possible failure rates	Rank
Extremely high: Failure almost inevitable	≧1 in 2	10
Very high	1 in 3	9
Repeated failures	1 in 8	8
High	1 in 20	7
Moderately high	1 in 80	6
Moderate	1 in 400	5
Relatively low	1 in 2,000	4
Low	1 in 15,000	3
Remote	1 in 150,000	2
Nearly impossible	≦1 in 1,500,000	1

Table 3 Suggested evaluation criteria for the detection of a cause of failure or failure mode in a design FMECA

Detection	Criteria: likelihood of detection by design control	Rank
Absolute uncertainty	Design control does not detect a potential cause of failure or subsequent failure mode; or there is no design control	10
Very remote	Very remote chance the design control will detect a potential cause of failure or subsequent failure mode	9
Remote	Remote chance the design control will detect a potential cause of failure or subsequent failure mode	8
Very low	Very low chance the design control will detect a potential cause of failure or subsequent failure mode	7
Low	Low chance the design control will detect a potential cause of failure or subsequent failure mode	6
Moderate	Moderate chance the design control will detect a potential cause of failure or subsequent failure mode	5
Moderately high	Moderately high chance the design control will detect a potential cause of failure or subsequent failure mode	4
High	High chance the design control will detect a potential cause of failure or subsequent failure mode	3
Very high	Very high chance the design control will detect a potential cause of failure or subsequent failure mode	2
Almost certain	Design control will almost certainty detect a potential cause of failure or subsequent failure mode	1

2.2 Conventional RPN shortcomings

The conventional RPN method has been widely adopted in safety analysis; however, it has been criticized to have several shortcomings that have been discussed extensively in Sankar et al's (2001) and Bowles's (2003) papers. The four main shortcomings of the conventional RPN method discussed in their papers are summarized below:

(1) Problem of the measurement scale.

Bowles's (2003) and Evie's (2008) papers indicate that ordinal measurement scales are frequently used. But the operations of multiplication and division are not meaningful on ordinal numbers, and addition and subtraction, while sometimes meaningful, must be done carefully because they assume an equal interval between the category labels.

The fundamental problem of the conventional RPN method is that the three parameters *S*, *O*, and D are evaluated according to discrete ordinal scales of measure. But they are treated as if numerical operations on them, most notably multiplication, are meaningful. The results are not only meaningless but in fact misleading.

(2) Severity, occurrence, and detection do not consider weighted with respect to one another in terms of risk.

As a result, some (*S*, *O*, *D*) scenarios produce RPN values that are lower than other combinations but potentially dangerous. For example, the scenario (extreme severity, moderately high occurrence, very high detection) with an RPN of 96 ($8 \times 6 \times 2$) is lower than the scenario (extreme severity, moderate occurrence, high detection), with an RPN of 120 ($8 \times 5 \times 3$), even though it should have a higher priority for a corrective action.

(3) The RPN scale itself has some non-intuitive statistical properties.

The initial and correctly assumed observation that the scale starts at 1 and ends at 1000 often leads to incorrect assumptions regarding the middle of the scale. Table 4 contains some common faulty assumptions (Sankar and Prabhu, 2001). The RPN scale is not continuous. It indeed has many "holes" in the scale. That means that many of the numbers in the range of 1 to 1000 cannot be formed from the product of *S*, *O*, and *D*. While it is true that the numbers cover a range from 1 to 1000, 88% of that range is actually empty; only 120 of the 1000 numbers can be generated from the product of *S*, *O*, and *D*. For example, it is impossible to generate all the multiples of 11 (i.e, 11, 22, 33, ... , 990) thus these numbers are excluded. Similarly, all the multiples of 13, 17, 19, etc. are excluded. Moreover, 1000 is the largest number, but 900 is the second largest followed by 810, 800, 729, and 720.

Table 4　RPN scale statistical data

Incorrect assumption	Actual statistical data
The average of all RPN values is roughly 500	The average RPN value is 166
Roughly 50 percent of RPN values are above 500 (The median is near 500)	6 percent of all RPN values are above 500 (The median is 105)
There are 1000 possible RPN values	There are 120 unique RPN values

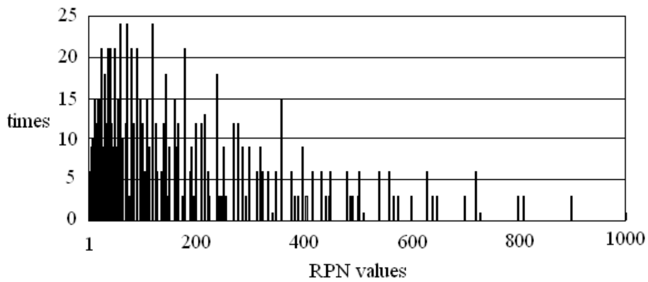

Figure 1 Histogram of RPN values generated from all possible combinations

(4) The RPN elements have many duplicate numbers.

Although 1000 numbers are assumed to be produced from the product of *S*, *O*, and *D*, only 120 of them are unique; there must be many duplicate numbers. In fact, most of the unique numbers can be formed in several different ways (only 6 RPN values are formed by a single, unique combination of *S*, *O*, and *D*). Note that nearly every RPN value is non-unique, some being recycled as many as 24 times. Figure 1 shows the 1000 RPN values that are generated from all possible combinations.

3. ME-OWA operators and its operations

In this section, this paper introduces the basic definition and some operations of the ME-OWA operators, and the methodology that is used to determine ME-OWA weights.

3.1 ME-OWA operators

The concept of OWA operators was first introduced by Yager in 1988. It is an important aggregation operator within the class of weighted aggregation methods. The OWA operator that had the ability to get the optimal weights of the attributes based on the rank of these weighting vectors after an aggregation process (see Definition 1).

Definition 1: An OWA operator of dimension n is a mapping $F: R^n \to R$,
which has an associated n weighting vector $W = [w_1, w_2, \dots, w_n]^T$ that has the properties

$$\sum_i w_i = 1, \qquad \forall w_i \in [0,1], \qquad i = 1, \dots, n,$$

such that

$$f(a_1, a_2, \cdots, a_n) = \sum_{i=1}^{n} w_i b_i \tag{1}$$

where b_i is the ith largest element of the collection of the aggregated objects a_1, a_2, ... a_n. The function value f (a_1, a_2,....., an) determines the aggregated value of arguments, a_1, a_2, ..., an.

A number of special cases of this operator are illustrated in the following instances. If the components in W are such that w_1=1 and $w_j = 0$ for all $j \neq 1$, we get OWA (a_1, a_2, ..., a_n) =Max$_j$ [a_j]. This weighting vector is denoted as W^*. If the weights are w_n=1 and w_j=0 for $j \neq n$, one gets OWA (a_1, a_2, ..., a_n) =Max$_j$ [a_j]. This weighting vector is denoted as W_*. If the weights are $w_j = \frac{1}{\text{n}}$ for all j, denoted as W_n, then

$$\text{OWA}(a_1, a_2, \cdots, a_n) = (\frac{1}{n})\sum_{j=1}^{n} a_j \ .$$

Yager (1988) also introduced two important charactering measures with respect to the weighting vector W of an OWA operator. One of these two measures is orness of the aggregation, which is defined in Definition 2.

Definition 2: Assume *F* is an OWA aggregation operator with weighting function

$W=[w_1, w_2, ..., w_n]$. The degree of "*orness*" associated with this operator is defined as

$$orness(W)=\frac{1}{n-1}\sum_{i=1}^{n}(n-i)w_i \tag{2}$$

where $orness(W)=\alpha$ is a situation parameter.

It is clear that $orness(W)\in[0,1]$ holds for any weighting vector.

The second charactering measure introduced by Yager (1988) is a measure of dispersion of the aggregation, which is defined in Definition 3.

Definition 3: Let W be a weighting vector with elements $w_1, \ldots, w_n$. The measure of dispersion of W is defined as

$$dispersion(W)=-\sum_{i=1}^{n}w_i\ln w_i \tag{3}$$

The dispersion measure of W takes into account all of the information in the aggregation. It is really a measure of entropy, which implies the following properties:

(1) if w_1=1 for some i, then the *dispersion* (*W*)=0, a minimum value.

(2) if $w_i=\frac{1}{n}$ for all *i*, then the *dispersion*(*W*) =1n*n*, a maximum value.

O'Hagan [7] combined the principle of maximum entropy and OWA operators to propose a particular ME-OWA weight that has maximum entropy with a given level of *orness*. This approach is based on the solution of the following mathematical programming problem:

Maximize: $-\sum_{i=1}^{n}w_i\ln w_i$

Subject to: $\frac{1}{n-1}\sum_{i=1}^{n}(n-i)w_i=\alpha,\ 0\le\alpha\le1,$

$$\sum_{i=1}^{n}w_i=1,\quad 0\le w_i\le1, i=1,\ldots,n. \tag{4}$$

3.2 Determination of ME-OWA weights

Fuller and Majlender (2001) used the method of Lagrange multipliers to transfer Yager's OWA equation to derive a polynomial equation, which can determine the optimal weighting vector under maximal entropy. By their method, the associated weighting vector is easily obtained by equations (5)-(7).

$$\ln w_j=\frac{j-1}{n-1}\ln w_n+\frac{n-j}{n-1}\ln w_1$$

$$\Rightarrow w_j=\sqrt[n-1]{w_1^{n-j}w_n^{j-1}} \tag{5}$$

and $$w_n=\frac{((n-1)\alpha-n)w_1+1}{(n-1)\alpha+1-nw_1} \tag{6}$$

then

$$w_1[(n-1)\alpha+1-nw_1]^n=((n-1)\alpha)^{n-1}\cdot[((n-1)\alpha-n)w_1+1] \tag{7}$$

where w is a weight vector, n is the number of attributes, and α is the situation parameter.

The optimal value of w_1 should satisfy equation (7). Once w_1 is obtained, then w_n can be determined from equation (6), and the other weights are obtained from equation (5). In a special case, when

$w_1=w_2=\cdots=w_n=\frac{1}{n}$, then

dispersion(*W*)=1n *n*, which is the optimal solution to equation (4) when α=0.5.

4. Proposed ME-OWA approach

The conventional RPN method, as pointed out in section 2.2, has four main shortcomings: (1) problem of the measurement scale; (2) the RPN elements do not consider weighted with respect to one another in terms of risk; (3) the RPN scale itself has some non-intuitive statistical properties; (4) the RPN elements have many duplicate numbers. Therefore, to overcome the above-mentioned shortcomings, this paper proposes an inductive bottom-up risk identification and estimation methodology that uses the ME-OWA technique for priority of failures in a system FMECA.

4.1 The reason for using ME-OWA

Most of the literature that confer RPN related issues and conventional RPN method does not consider the ordered weight, which may cause bias conclusion. The ordered weight is one of the most important factors in evaluating the risk of failure. For example, suppose that there are two failure modes: one (referred as scenario 1) has the RPN value 120 (*S, O*, and *D* are 8, 5, and 3, respectively), and the other one (referred as scenario 2) has the RPN value 96 (*S*, *O*, and *D* are 8, 6, and 2, respectively). According to the conventional RPN method, scenario 1 (RPN = 120) is assumed to be more important than scenario 2 (RPN = 96) and is given a higher priority. Actually, the scenario 2 is more important than scenario 1.

4.2 The procedure of the proposed approach

Based on the definitions given in section 3, this paper proposes an ME-OWA approach, consists of seven steps, for risk priority analysis. These seven steps are described as follows.

Step 1 List potential failure modes.

Based on historical data and past experiences, list the potential failure modes of each risk assessment member of the whole system.

Step 2 List all of the possibilities that could cause each potential failure mode.

Discover how systems fail and what caused each type of failure. Arrange failure mode contents to the FMEA table. List the reasons of failure mode occurrence.

Step 3 Define the scales for S, O, and D, respectively.

For each failure mode, experts need to determine the severity of the failure (*S*), the probability of failure (*O*), and the probability of not detecting the failure (*D*), respectively, to establish discrete ordinal scale.

Step 4 Calculate the ME-OWA weights.

From section 3.2, use equations (5)-(7) to calculate the ME-OWA weights.

Step 5 Calculate aggregated value by ME-OWA weights.

According the Step 3 and Step 4, use equation (1) to calculate the aggregated value by ME-OWA weights.

Step 6 Rank the priority for assessing failure risk.

According to the aggregated values by OWA weights from the largest to the smallest, which takes cause of failure out of the risk prioritizing ranking.

Step 7 Analyze the results and provide suggestions.

From Step 6, the results can further analyze their feasible solutions to provide the decision maker.

5. Numerical verification and comparison

In this section, this research uses a real case of an Intelligent Power Module (IPM) in order to demonstrate our proposed approach. The IPM is integrated drive, protection and system control functions that is designed for high performance 3-phase motor driver application like: home appliances application, and inverter drive parts for AC/DC (adaptor) motor driving. The FMECA of this IPM is shown in Table 5 and case data from the mid-sized manufacturing factory located in Hsinchu Science-Based Industrial Park in Taiwan. In table 6, S represents the severity,

O represents the probability of occurrence and D represents the detectability.

Table 5　The FMEA of the IPM

No.	Item	Failure Mode	Cause of failure	S	O	D
1	IC	Burn	Short circuit (burn caused by sudden major electrical surge).	9	5	5
2	IC	Short circuit	Secondary short circuit (not sufficient to cause burn out).	7	1	6
3	IGBT	Burn	Short circuit (burn caused by sudden major electrical surge).	9	3	5
4	IGBT	Short circuit	Secondary short circuit (not sufficient to cause burn out).	7	1	6
5	Lap-joint circuit	Short circuit	Sudden major electrical surge.	9	1	5
6	Lap-joint circuit	Short circuit	Secondary short circuit (not sufficient to cause burn out)	7	1	5
7	Molding	Sufficient conductivity	Insufficient insulation between molding material and components.	8	3	5
8	PCB circuit	Electronic migration	Caused by migration between circuits.	7	2	3
9	Component	Malfunction	Selection of components lack of endurance (current / voltage / temperature).	8	2	5
10	Welding point	Tear	Lack of endurance on welding point.	5	1	3

5.1 Conventional RPN method

Based on the conventional RPN method, the risk of each failure mode is assessed based on its severity, frequency of occurrence, and detection on a numeric scale from 1 to 10. These rankings are then multiplied to construct the RPN. Failure modes that have a higher RPN are assumed to be more important and given a higher priority than those having a lower RPN. The resulting RPN values of the IPM are shown in Table 6.

5.2 Proposed method

Sensitivity analysis enables the identification of different α values to evaluate their impact on the risk ranking. Using equations (5)-(7) with n = 3, we calculate the optimal weighting vector under the maximal entropy with respect to different α values. The results are organized in Table 7.

Based on Table 5, Table 7, and equation (1), the aggregated OWA values (α = 0.5, 0.6,..., 1) are calculated and shown in Table 8. When $\alpha = 1$, the

Table 6　The RPN of the IPM

No.	S	O	D	RPN
1	9	5	5	255
2	7	1	6	42
3	9	3	5	135
4	7	1	6	42
5	9	1	5	45
6	7	1	5	35
7	8	3	5	120
8	7	2	3	42
9	8	2	5	80
10	5	1	3	15

$OWA(a_1, a_2, a_3) = Max(a_1, a_2, a_3)$.

Example: Assume $n = 3$ and W=[0.826294, 0.146973, 0.026306] . Find $f(7, 1, 6)$. In this case, we get $b_1 = 7$, $b_2 = 6$, and $b_3 = 1$. The aggregated value is $f(7, 1, 6)=0.826294\times 7+0.146973\times 6+0.026306\times 1=6.69220$

From Table 8, the prioritization of the failure modes for the IPM by the proposed approach is shown in Table 9.

Table 7 The optimal weighting vector under the maximal entropy (n = 3)

α	w_1	w_2	w_3
0.5	0.333333	0.333333	0.333333
0.6	0.438355	0.323242	0.238392
0.7	0.553955	0.291992	0.153999
0.8	0.681854	0.235840	0.081892
0.9	0.826294	0.146973	0.026306
1	1	0	0

Table 8 The aggregated values of the IPM by OWA weights (α = 0.5, 0.6,..., 1)

No.	α = 1 $f(a_1, a_2, a_3)$	α = 0.9 $f(a_1, a_2, a_3)$	α = 0.8 $f(a_1, a_2, a_3)$	α = 0.7 $f(a_1, a_2, a_3)$	α = 0.6 $f(a_1, a_2, a_3)$	α = 0.5 $f(a_1, a_2, a_3)$
1	9	8.30304	7.72535	7.21555	6.75337	6.33333
2	7	6.69220	6.26991	5.78364	5.24633	4.66666
3	9	8.25043	7.56156	6.90755	6.27658	5.66666
4	7	6.69220	6.26991	5.78364	5.24633	4.66666
5	9	8.19782	7.39778	6.59955	5.79980	5.00000
6	7	6.54523	6.03407	5.49164	4.92309	4.33333
7	8	7.42414	6.87971	6.35360	5.83823	5.33333
8	7	6.27759	5.64428	5.06166	4.51500	4.00000
9	8	7.39783	6.79782	6.19960	5.59983	5.00000
10	5	4.59870	4.19868	3.79975	3.39989	3.00000

Table 9 Prioritization by the proposed approach

No.	α = 0.9	α = 0.8	α = 0.7	α = 0.6	α = 0.5	The proposed orderings
1	1	1	1	1	1	1
2	6	6	6	6	6	6
3	2	2	2	2	2	2
4	6	6	6	6	6	6
5	3	3	3	4	4	3
6	8	8	8	8	8	8
7	4	4	4	3	3	4
8	9	9	9	9	9	9
9	5	5	5	5	4	5
10	10	10	10	10	10	10

Note: After ME-OWA operation, the consistent ordering is taken as the proposed ordering.

5.3 Comparisons and discussion

In order to evaluate the proposed method, a case study verification is performed in section 5, which compare the proposed approach with the conventional RPN method. The input data of these methods are shown in Table 5. The results of the two methods are presented in Table 10. From Table 10, we have the following findings.

(1) Sensitivity to small changes.

If D and *O* are both 10, a 1-point difference in the severity ranking results in a 100-point difference in the RPN; at the other extreme, if D and *O* are equal to 1, the same 1-point difference only gives a point difference in the RPN.

When α =0.5, if *D* and *O* are both 10, a 1-point difference in the severity ranking results in a 0.333-point difference in the proposed method; at the other extreme, if *D* and *O* are equal to 1, the same 1-point difference still results in the same 0.333-point difference in the proposed method.

(2) The proposed approach can reduce the occurrence of duplicated RPN numbers.

The No. 2 and No. 8 have the same RPN of 42 (based on the conventional RPN method), thus they have the same priority. However, the different ratings combinations might imply different risks. In The proposed method, using the ME-OWA approach, the rankings of the No. 2 and No. 8 are 6 and 9, respectively. Therefore, we can see that the proposed approach is more effective in differentiating the risk representations of the failures that have the same RPN.

(3) The proposed approach get a more discriminative risk ranking.

From Table 10, we can see that the No. 9 has the RPN value 80 (*S*, *O*, and *D* are 8, 2, and 5, respectively) and No. 5 has the RPN value 45 (*S*, *O*, and *D* are 9, 1, and 5, respectively). It shows that according to the conventional RPN method, the No. 9 has a higher priority compared with the No. 5. However, conventional RPN method does not consider the ordered weight, thus the conclusion may be bias. The results of our proposed method show that the No. 5 has a higher priority compared with the No. 9. This shows that a more accurate ranking can be achieved by applying our proposed ME-OWA approach to FMECA.

The prioritization of failure modes on the IPM that was obtained from the ME-OWA technique in terms of criteria is:

No.1 > No.3 > No.5 > No.7 > No.9 > No.2, No.4 > No.6 > No.8 > No.10,

which is different from the conventional RPN prioritization; i.e.,

No.1 > No.3 > No.7 > No.9 > No.5 > No.2, No.4, No.8 > No.6 > No.10,

The analysis of the results that were produced by the conventional RPN and the ME-OWA methods shows that a more accurate, reasonable ranking can be achieved by applying ME-OWA method.

Table 10　The ranking comparison of the conventional RPN method and the proposed method

No.	RPN	Ranking RPN	Ranking OWA-based
1	255	1	1
2	42	6	6
3	135	2	2
4	42	6	6
5	45	5	3
6	35	9	8
7	120	3	4
8	42	6	9
9	80	4	5
10	15	10	10

6. Conclusion

In this paper, we propose a novel technique to assess the risk of the IPM. It is useful, when conducting FMEA, to apply the ME-OWA approach to assess the risk of potential failure modes. This approach provides a more flexible structure for combining severity, occurrence, and detection parameters. In order to further illustrate the proposed method and compare with the traditional RPN method, an IPM example is adopted. The results showed that the proposed approach can resolve some of the inherent shortcomings of conventional RPN method. It is more convenient to differentiate the risk representations among the failure modes having the same RPN. The analysis results provided a more accurate, reasonable risk ranking to help the decision makers find the most critical causes of failure and assign limited resources to the most serious risk items.

The advantages of the proposed ME-OWA approach are as follows.

(1) The proposed method can reduce the occurrence of RPN duplicate numbers.

(2) The proposed method has to consider the ordered weight.

(3) The proposed method provides more accurate and effective information to assist the decision making process.

7. Applications on national defense

With the defense organization restructuring, and limited nation defense budget, how to arrange limited national defense resource efficiently becoming a very important issues. The usefulness of the proposed method as a design tool and in the decision making process is dependent upon the effectiveness with which problem information is communicated for early design attention. It can be used on new weapon development researches, resource management, and weapon system reliability evaluations. According the American army print "MIL-STD-1629A" indicates: although the FMECA is an essential reliability task, it also provides information for other purposes. The use of the FMECA is called for in maintainability, safety analysis, survivability and vulnerability, logistics support analysis, maintenance plan analysis, and for failure detection and isolation subsystem design. This standard applies to the acquisition of all designated DoD systems and equipment. It primarily applies to the program activity phases of demonstration and validation and full-scale engineering development; e.g., design, research and development, and test and evaluation.

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