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A New Hybrid Fermatean Fuzzy Set and Entropy Method for Risk Assessment

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Abstract: Risk evaluation is an important part of the product design and product manufacturing process; it entails the pursuit of the highest product quality and preventing failure under the constraints of limited resources. The failure mode and effects analysis approach is one of the most widely applied risk evaluation tools that uses the product of the three risk elements of product failure items, severity, occurrence probability, and detection probability, to calculate the risk priority number, the priority of failure risk. However, the typical failure mode and effects analysis method ignores the consideration of objective weights, which may lead to incorrect evaluation results. Moreover, the method of expressing information about product failure provided by experts also directly affects the results of risk assessment. To comprehensively assess the risk of product failure, in this study, the hybrid of the Fermatean fuzzy set and entropy method was used to prioritize product failure items risk. This study used a service failure mode and effects analysis numerical example of self-service electric vehicles to illustrate and test the correctness of the proposed new hybrid Fermatean fuzzy set and entropy method. The mathematical operation results were also compared with the listing of different calculation methods. The test results prove that the proposed new hybrid Fermatean fuzzy set and entropy method can fully consider the cognitive information provided by experts to provide more accurate risk ranking results of failure items.

Keywords: Fermatean fuzzy set; multi-criteria decision-making; entropy method; failure mode and effects analysis; risk assessment

MSC: 94D05; 94A17; 90B50

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1. Introduction

Accurate risk prediction and risk assessment in advance ensures the reduction of possible personal injury and economic loss caused by product failure. The failure mode and effects analysis (FMEA) is one of the most often applied risk evaluation methods. The FMEA method was first used in the aerospace industry in the 1960s, and through the years, a large number of studies have used the FMEA method to explore risk assessment issues in different fields [1–6]. The FMEA method contains several different types, such as design FMEA, service FMEA, software FMEA, manufacturing FMEA, process FMEA, etc. The main purpose of FMEA is to reallocate resources to reduce the impact of possible failure items, thereby reducing the loss of personnel and materials.

The typical FMEA approach uses three different risk elements, including severity (S), occurrence (O), and detection (D), to compute the risk priority number (RPN) value. The higher RPN value expresses a higher failure risk and must be given a higher priority; using limited resources is prioritized to prevent this failure item from occurring. However, due to the different professional backgrounds, experiences, and personal preferences of experts, experts may provide some uncertain or incomplete information when evaluating the different risk elements *S*, *O*, and *D* level of failure items. In terms of uncertain information processing, the fuzzy set (FS) method is the first to propose the approach to deal with the fuzzy information (FI) problems that exist in daily life of a human. The FS method [7] uses the membership degree (MD) and non-membership degree (NMD) to describe the phenomenon of the event occurrence. However, the FS method does not consider the indeterminacy degree (ID) of expert decision-making [8]. Since then, the FS approach has been extended and used to solve many different decision-making fields, such as medical diagnosis [9,10], thin film transistor liquid crystal display [11,12], water resource planning [13], military simulation training systems [14], cloud manufacturing [15], hydrogen energy technology [16], and supplier selection [17], and so on.

To overcome the limitation that traditional FS does not consider the ID, Atanassov [18] extended the concept of FS to propose an intuitionistic fuzzy set (IFS) to deal with the intuitionistic FI of human cognition. The IFS uses the MD, NMD, and ID to describe the phenomenon of the event occurrence. The values of MD, NMD, and ID are all between 0 and 1, and the total sum of the three values is 1. When the ID value is 0, IFS degenerates into the traditional FS. Since IFS reflects the thinking of experts more comprehensively than traditional FS in considering the information, many studies use IFS to handle multi-criteria decision-making (MCDM) issues. For example, Dymova et al. [19] combined the IFS and the Dempster–Shafer theory of evidence to propose the new rule-based evidential reasoning of interval-valued IFS and applied this method to the medical diagnosis of diabetes. Chen and Xue [20] combined the concept of IFS and the technique for order of preference by similarity to the ideal solution (TOPSIS) to propose the new intuitionistic fuzzy TOPSIS method and applied it to the performance evaluation of network recruitment enterprises. Kumari and Mishra [21] combined the complex proportional assessment method and the IFS to solve the problem of green supplier selection under intuitionistic FI. Until today, many researchers have used the IFS method to process group decision-making problems [22–27].

In the actual implementation of risk assessment, sometimes the total sum of the three values of MD, NMD, and ID is >1. This situation violates the definition of FS and IFS and cannot be efficiently solved by FS and IFS. In order to overcome the limitations of traditional FS and IFS, Senapati and Yager [28] proposed the Fermatean fuzzy set (FFS) to expand the consideration mode of information to get closer to the real ideas of experts. The FFS uses the MD, NMD, and ID to describe the phenomenon of the event occurrence and limits the cube sum of MD and NMD to be less than or equal to 1. Since FS and IFS are only special cases of FFS; FFS is more suitable for dealing with risk assessment problems with unclear information. Up to this point, FFS has been applied by many studies to deal with decision-making problems in different fields (such as [29–35]).

The weight consideration of three different risk elements, *S*, *O*, and *D*, is also an important issue in risk evaluation that will directly affect the results of the assessment. Many studies [36–39] have ignored the objective weight of three different risk elements when performing FMEA, which may lead to biased risk assessment results. To fully and effectively overcome the limitations of the conventional risk evaluation approach, in this study, the hybrid of the FFS and entropy methods were used to correctly prioritize product failure items. In information processing, the proposed method used FFS to simultaneously process FI, intuitionistic FI, and Fermatean FI. In the weighting processing of three different risk elements, *S*, *O*, and *D*, the proposed approach uses the entropy approach to compute the objective weights of risk elements, and then the integrated weights were used to correctly prioritize product failure items.

The remaining section organization of this article is as follows: Section 2 briefly reviews the basic knowledge, related definition, and basic calculation rules related to the typical FMEA method and typical IFS and FFS methods. In Section 3, a novel risk assessment method that hybrid FFS and entropy technique is proposed. In Section 4, a numerical example of service FMEA for a self-service electric vehicle is presented to illustrate and verify the feasibility and correctness of the proposed method. At last, we summarize the conclusions and provide possible future research directions in Section 5.

2. Preliminaries

This section briefly introduces the basic concepts and calculation rules related to the typical FMEA method and typical IFS and FFS methods.

2.1. Typical FMEA Method

To satisfy the needs of the aviation industry, the FMEA method was first introduced by NASA in the 1960s. FMEA methods are mostly used in the initial stages of product design and manufacturing to improve the quality and safety of design and manufacturing. Since then, the FMEA method has been widely used and discussed by the military (MIL-STD-1629A and MIL-STD-1629), industry (ISO-9000, QS-9000, ISO/TS 16949, and IEC 60812), and academia [40–44].

The typical FMEA method was applied the RPN to rank the possible risk levels of failed items. The RPN value used the three different risk elements, *S*, *O*, and *D*, to compute the RPN value. The evaluation of three risk elements is based on the severity of the failure item, the probability of occurrence, and the probability of not being detected on a sequential scale from 1 to 10. The typical rating scales of three risk elements are mentioned in Table 1.

Table 1. The typical rating scales of severity (*S*), occurrence (*O*), and detection (*D*).

Rating Scales	*S*	*O*	*D*
10	Exceptionally high	Exceptionally high	Exceptionally low
9	Very high	Very high	Very low
8	Moderate high	Moderate high	Low
7	High	High	Slightly low
6	Slightly high	Slightly high	Average
5	Average	Average	Slightly high
4	Slightly low	Slightly low	High
3	Low	Low	Moderate high
2	Very low	Very low	Very high
1	Exceptionally low	Exceptionally low	Exceptionally high

The value of RPN is the product of three risk elements, as expressed in Equation (1). A higher RPN value expresses that a possible failure item has a higher failure risk and must be given a higher failure risk level.

$$\text{RPN} = S \times O \times D \tag{1}$$

2.2. Typical Intuitionistic Fuzzy Set and Fermatean Fuzzy Set Methods

Since the traditional FS cannot handle the ID when expert decisions, Atanassov [18] introduced the concept of IFS to handle intuitionistic FI and imprecise information. The definition of IFS is detailed as follows:

Definition 1 ([31]). Assuming that the IFS (*I*) in the universe of discourse, *X* is expressed as

$$I = \{\langle x,\ \mu_I(x),\ \nu_I(x)\rangle | x \in X\} \tag{2}$$

where $\mu_I(x)$ is the MD and $\nu_I(x)$ is the NMD, $0 \le \mu_I(x) \le 1$, $0 \le \nu_I(x) \le 1$, and $0 \le \mu_I(x) + \nu_I(x) \le 1$.

The ID $\pi_I(x)$ is expressed as $\pi_I(x) = 1 - \mu_I(x) - \nu_I(x)$. It is worth noting that when $\mu_I(x) = 1 - \nu_I(x)$, the IFS (*I*) degenerates to traditional FS.

Definition 2 ([45]). Assuming that $I = (\mu_I(x),\ \nu_I(x))$ is an intuitionistic fuzzy number and $w = (w_1, w_2, \ldots, w_k)^T$ is the corresponding weight vector of F, satisfying the $\sum_{k=1}^{l} w_k = 1$, then the intuitionistic fuzzy weighted geometric (*IFWG*) operators is defined as follows:

$$IFWG(I_1, I_2, \ldots, I_l) = \left(\prod_{k=1}^{l} (\mu_{I_k}(x))^{w_k}, \prod_{k=1}^{l} (\nu_{I_k}(x))^{w_k} \right) \tag{3}$$

To overcome the limitations of traditional FS and IFS, the range of feasible solutions is further expanded: Senapati and Yager [28] proposed the FFS to deal with the Fermatean FI problem in human life. In terms of information processing, Fermatean's FI is closer to the human thinking mode than FI and intuitionistic FI. The definition and calculation rules of the FFS are detailed as follows:

Definition 3 ([46]). Assuming that the FFS (F) in the universe of discourse, X is expressed as

$$F = \{\langle x,\ \mu_F(x),\ \nu_F(x)\rangle | x \in X\} \tag{4}$$

where $\mu_F(x)$ is the MD and $\nu_F(x)$ is the NMD, $0 \le \mu_F(x) \le 1$, $0 \le \nu_F(x) \le 1$, and $0 \le (\mu_F(x))^3 + (\nu_F(x))^3 \le 1$.

The ID $\pi_F(x)$ of x to F is defined as:

$$\pi_F(x) = \sqrt[3]{1 - (\mu_F(x))^3 - (\nu_F(x))^3} \tag{5}$$

Definition 4 ([28]). Assuming that the $F = (\mu_F(x),\ \nu_F(x))$ is a Fermatean fuzzy number and $w = (w_1, w_2, \ldots, w_k)^T$ is the corresponding weight vector of F, satisfying $\sum_{k=1}^{l} w_k = 1$, then the Fermatean fuzzy weighted average (*FFWA*) and the Fermatean fuzzy weighted geometric (*FFWG*) operators are defined as follows:

$$FFWA(F_1, F_2, \ldots, F_l) = \left(\sum_{k=1}^{l} w_k \cdot \mu_{F_k}(x), \sum_{k=1}^{l} w_k \nu_{F_k}(x) \right) \tag{6}$$

$$FFWG(F_1, F_2, \ldots, F_l) = \left(\prod_{k=1}^{l} (\mu_{F_k}(x))^{w_k}, \prod_{k=1}^{l} (\nu_{F_k}(x))^{w_k} \right) \tag{7}$$

Definition 5 ([47]). Assuming that the $F_1 = (\mu_{F_1},\ \nu_{F_1})$ and $F_2 = (\mu_{F_2},\ \nu_{F_2})$ are two Fermatean fuzzy numbers, and $\xi \ge 0$, the operation rules of Fermatean fuzzy numbers are as follows:

$$F_1 \oplus F_2 = \left(\sqrt[3]{\mu_{F_1}^3 + \mu_{F_2}^3 - \mu_{F_1}^3 \cdot \mu_{F_2}^3},\ \nu_{F_1} \cdot \nu_{F_2} \right) \tag{8}$$

$$F_1 \bigotimes F_2 = \left(\mu_{F_1} \cdot \mu_{F_2}, \sqrt[3]{\nu_{F_1}^3 + \nu_{F_2}^3 - \nu_{F_1}^3 \cdot \nu_{F_2}^3} \right) \tag{9}$$

$$\xi \cdot F_1 = \left(\sqrt[3]{1 - \left(1 - \mu_{F_1}^3\right)^{\xi}},\ \nu_{F_1}^{\xi} \right) \tag{10}$$

$$F_1{}^{\xi} = \left(\mu_{F_1}^{\xi}, \sqrt[3]{1 - \left(1 - \nu_{F_1}^3\right)^{\xi}} \right) \tag{11}$$

Definition 6 ([48]). Assuming that the $F_1 = (\mu_{F_1},\ \nu_{F_1})$ is a Fermatean fuzzy number, the score function $S(F_1)$ and the accuracy function $A(F_1)$ of F are expressed as follows:

$$S(F_1) = \mu_{F_1}^3 - \nu_{F_1}^3 \tag{12}$$

$$A(F_1) = \mu_{F_1}^3 + \nu_{F_1}^3 \tag{13}$$

Definition 7 ([49]). Assuming that the $F_1 = (\mu_{F_1}, \nu_{F_1})$ and $F_2 = (\mu_{F_2}, \nu_{F_2})$ are two Fermatean fuzzy numbers, the comparative rules of Fermatean fuzzy numbers are as follows:

(1) If $S(F_1) > S(F_2)$, then $F_1 > F_2$;
(2) If $S(F_1) = S(F_2)$, and
    (i) $A(F_1) > A(F_2)$, then $F_1 > F_2$;
    (ii) $A(F_1) = A(F_2)$, then $F_1 = F_2$.

3. Proposed Hybrid Fermatean Fuzzy Set and Entropy Approach

The FMEA approach is one of the most commonly applied risk evaluation tools. Whether it is the military, industry, or academic units, several studies have used FMEA tools to solve different MCDM problems. However, due to the difference in backgrounds and professional experiences of experts, the information provided may include clear information, FI, intuitionistic FI, and Fermatean FI at the same time. Typical FMEA methods can only deal with clear information issues but not with NMD and ID information in decision-making problems; moreover, it ignores the objective weights among risk elements. To overcome the limitations of typical risk assessment methods, this study proposed a new hybrid of the FFS and entropy methods for risk assessment. The critical elements of the proposed hybrid FFS and entropy approach include information considerations and the integrated weight considerations. In terms of information considerations, the FFS can simultaneously handle clear information, FI, intuitionistic FI, and Fermatean FI. In terms of objective weight considerations, the entropy approach was used herein to compute the objective weight among risk elements. Then, the integrated weight of three risk elements was used, and the S, O, and D linguistic terms of possible failure items was provided by experts to correctly prioritize product failure items.

The proposed hybrid FFS and entropy method is implemented in eight steps (Figure 1), which are detailed as follows:

Step 1: Organizing an FMEA evaluation committee.

An FMEA evaluation committee is formed based on experts with different professional backgrounds and field experience.

Step 2: Determination of the evaluation objective and the possible failure items.

Experts decide possible failure items based on the evaluation objectives.

Step 3: Determination of the *S*, *O*, and *D* values of possible failure items.

Experts determine the *S*, *O*, and *D* values of possible failure items based on their own experience and background, respectively.

Step 4: Aggregation of the assessment information provided by the experts.

The *FFWA* equation is used to aggregate the experts' assessment information.

Step 5: The objective weight and integrated weight of the risk elements is calculated.

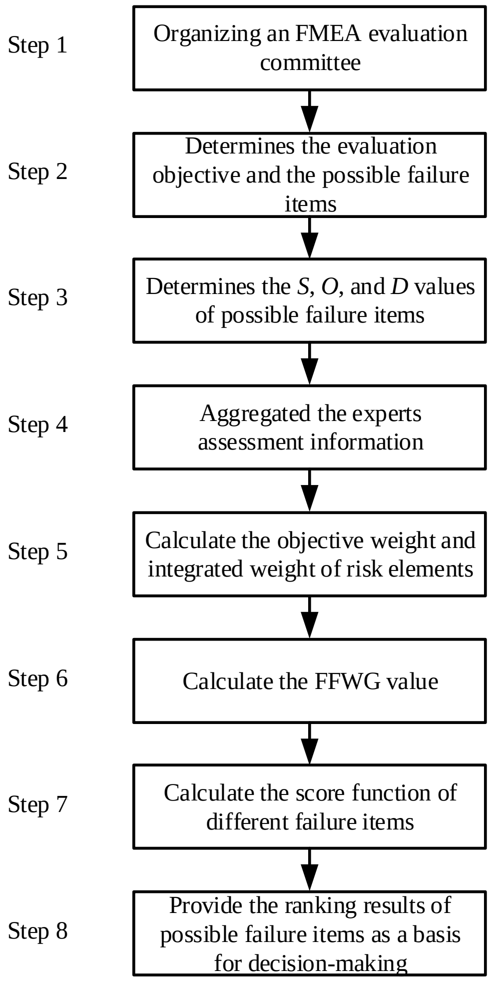

Figure 1. The flow chart of the proposed hybrid FFS and entropy method.

The objective weights of three different risk elements are calculated using the entropy approach, and the calculation equations is as follows [50]:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{14}$$

$$E_j = -\frac{1}{ln(m)} \sum_{i=1}^{m} r_{ij} \cdot ln\left(r_{ij}\right) \tag{15}$$

$$w_j^{ob} = \frac{1 - E_j}{\sum_{j=1}^{n} \left(1 - E_j\right)} \tag{16}$$

where the x_{ij} is the performance value of the i-th possible alternative, the j-th risk elements r_{ij} is the normalized value of the original decision matrix $\left(x_{ij}\right)$, m is the total number of alternatives, and n is the total number of risk elements. E_j is the entropy value of the j-th risk elements, and w_j^{ob} is the objective weight of the j-th risk elements.

The w^{ob} is the objective weight of the risk element, and the w^{su} is the subjective weight of the risk element. Then the calculation process of integrated weight (w^{in}) for different risk elements is as follows [51]:

$$w_j^{in} = \lambda \cdot w_j^{ob} + (1 - \lambda) \cdot w_j^{su} \tag{17}$$

where λ is the important coefficient; the value of λ is determined by the preference of experts, usually set to 0.5.

The entropy approach is used to compute the objective weight of the risk elements, and then Equation (17) is used to compute the integrated weight of risk elements.

Step 6: Calculation of the *FFWG* value.

According to the results of Step 4 and Step 5, Equation (7) is used to calculate the *FFWG* value, which indicates the failure risk level of possible failure items.

Step 7: Calculation of the score function of different failure items.

According to the results of Step 6, Equation (12) is used to calculate the score function of different failure items.

Step 8: Provide the ranking results of possible failure items as a basis for decision-making.

4. Numerical Example

4.1. Case Overview

With the rapid development of artificial intelligence and the emphasis on green energy, more and more advanced technologies strive to achieve carbon reduction in electric vehicles. Electric car sharing is a new consumption model to achieve carbon reduction and reduce traffic congestion. There are two types of electric vehicle-sharing models: ride-sharing electric vehicles and self-service electric vehicles. In this section, the service FMEA numerical example of a self-service electric vehicle was applied [52] to illustrate and verify the feasibility and correctness of the proposed hybrid FFS and entropy method. The service life cycle of self-service electric vehicles can be categorized into three phases according to the process of time: the register phase, the application phase, and the account log-out phase. The application phase can be categorized into three parts, start, drive, and stop, according to the application process. The service FMEA evaluation committee consists of four experts (E1, E2, E3, and E4) and the service FMEA of self-service electric vehicles, as shown in Table 2. According to Table 1, the evaluation of three risk elements is based on the S, O, and D on a linguistic level from L1 to L10. The Fermatean fuzzy number for different linguistic levels of S, O, and D as expressed in Table 3.

Table 2. The service failure mode and effects analysis (FMEA) of self-service electric vehicles.

Phases		Basic and Reliable Service	Reason for Service Failure	Failure Item
Register phase		Properly manage user data	Misuse of information	1
Register phase		Equality agreement service	Protocol pitfalls	2
Application phase	Start part	Delivering reliable electric vehicles	Delivering defective electric vehicles	3
Application phase	Start part	High-quality repair service	Low-quality repair service	4
Application phase	Start part	Convenient and hassle-free charging service	Defective charging service	5
Application phase	Start part	Attribution of responsibility is certain	Attribution of responsibility is uncertain	6
Application phase	Drive part	Professional safety certification	Lack of professional safety certification	7
Application phase	Drive part	Reasonable and transparent fees	Unreasonable charges	8
Application phase	Drive part	Adequate safety equipment	Insufficient safety equipment	9
Application phase	Drive part	Sufficient insurance claims	Insufficient insurance claims	10
Application phase	Stop part	Safe and convenient parking service	Parking problem	11
Application phase	Stop part	Complete security alert	Incomplete security alert	12
Application phase	Stop part	Violations resolved quickly	The complexity of dealing with breaches	13
Account log out phase		Efficient deposit refunds	Deposit refunds are troublesome	14
Account log out phase		Resolve disputes fairly	Dealing with arguments is unfair	15
Account log out phase		Excellent customer service	Bad customer service	16

Table 3. The Fermatean fuzzy number for different linguistic levels of severity (*S*), occurrence (*O*), and detection (*D*).

Linguistic Level	*S*	*O*	*D*	FFN
*L*1	Exceptionally low	Exceptionally low	Exceptionally high	(0.10, 0.95)
*L*2	Very low	Very low	Very high	(0.20, 0.90)
*L*3	Low	Low	Moderate high	(0.30, 0.85)
*L*4	Slightly low	Slightly low	High	(0.40, 0.80)
*L*5	Average	Average	Slightly high	(0.50, 0.70)
*L*6	Slightly high	Slightly high	Average	(0.60, 0.60)
*L*7	High	High	Slightly low	(0.70, 0.50)
*L*8	Moderate high	Moderate high	Low	(0.80, 0.40)
*L*9	Very high	Very high	Very low	(0.85, 0.30)
*L*10	Exceptionally high	Exceptionally high	Exceptionally low	(0.95, 0.20)

According to Table 3, each expert determines the linguistic level for the possible failure item is based on their past professional skills and background, respectively; the results are as shown in Table 4. Then, according to Tables 3 and 4, the linguistic level for the possible failure item were converted into Fermatean fuzzy numbers, and the results are expressed in Table 5.

Table 4. The linguistic terms of possible failure items.

Failure Item	*S*				*O*				*D*			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
1	L5	L5	L7	L6	L5	L5	L6	L4	L4	L3	L4	L5
2	L3	L2	L2	L3	L3	L4	L3	L4	L4	L3	L4	L4
3	L4	L5	L6	L6	L6	L6	L6	L7	L7	L8	L7	L6
4	L4	L5	L5	L6	L6	L7	L6	L7	L6	L6	L6	L7
5	L2	L3	L4	L3	L2	L1	L1	L1	L5	L4	L6	L4
6	L3	L5	L4	L4	L7	L6	L7	L7	L1	L1	L2	L1
7	L5	L5	L4	L6	L8	L8	L7	L9	L3	L3	L4	L3
8	L4	L6	L5	L5	L5	L4	L6	L4	L3	L3	L4	L2
9	L4	L2	L2	L4	L7	L6	L7	L8	L4	L5	L4	L3
10	L5	L3	L4	L4	L7	L6	L7	L8	L4	L3	L4	L4
11	L7	L6	L6	L6	L5	L5	L4	L6	L2	L1	L2	L1
12	L4	L3	L3	L5	L3	L4	L4	L3	L3	L4	L2	L2
13	L6	L6	L7	L5	L3	L2	L4	L3	L2	L2	L3	L3
14	L6	L6	L6	L6	L7	L6	L8	L6	L3	L4	L2	L3
15	L7	L6	L7	L7	L6	L6	L7	L5	L2	L4	L3	L2
16	L5	L6	L6	L4	L5	L6	L4	L4	L4	L5	L4	L5

Table 5. The Fermatean fuzzy numbers of possible failure items.

Failure Item	*S*				*O*				*D*			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
1	(0.50, 0.70)	(0.50, 0.70)	(0.70, 0.50)	(0.60, 0.06)	(0.50, 0.70)	(0.50, 0.70)	(0.60, 0.60)	(0.40, 0.80)	(0.40, 0.80)	(0.30, 0.85)	(0.40, 0.80)	(0.50, 0.70)
2	(0.30, 0.85)	(0.20, 0.90)	(0.20, 0.90)	(0.30, 0.85)	(0.30, 0.85)	(0.40, 0.80)	(0.30, 0.85)	(0.40, 0.80)	(0.40, 0.80)	(0.30, 0.85)	(0.40, 0.80)	(0.40, 0.80)
3	(0.40, 0.80)	(0.50, 0.70)	(0.60, 0.60)	(0.60, 0.60)	(0.60, 0.60)	(0.60, 0.60)	(0.60, 0.60)	(0.70, 0.50)	(0.70, 0.50)	(0.80, 0.40)	(0.70, 0.50)	(0.60, 0.60)
4	(0.40, 0.80)	(0.50, 0.70)	(0.50, 0.70)	(0.60, 0.60)	(0.60, 0.60)	(0.70, 0.50)	(0.60, 0.60)	(0.70, 0.50)	(0.60, 0.60)	(0.60, 0.60)	(0.60, 0.60)	(0.70, 0.50)

Table 5. *Cont.*

Failure Item	*S*				*O*				*D*			
	E1	**E2**	**E3**	**E4**	**E1**	**E2**	**E3**	**E4**	**E1**	**E2**	**E3**	**E4**
5	(0.20, 0.90)	(0.30, 0.85)	(0.40, 0.80)	(0.30, 0.85)	(0.20, 0.90)	(0.10, 0.95)	(0.10, 0.95)	(0.10, 0.95)	(0.50, 0.70)	(0.40, 0.80)	(0.60, 0.60)	(0.40, 0.80)
6	(0.30, 0.85)	(0.50, 0.70)	(0.40, 0.80)	(0.40, 0.80)	(0.70, 0.50)	(0.60, 0.60)	(0.70, 0.50)	(0.70, 0.50)	(0.10, 0.95)	(0.10, 0.95)	(0.20, 0.90)	(0.10, 0.95)
7	(0.50, 0.70)	(0.50, 0.70)	(0.40, 0.80)	(0.60, 0.60)	(0.80, 0.40)	(0.80, 0.40)	(0.70, 0.50)	(0.85, 0.30)	(0.30, 0.85)	(0.30, 0.85)	(0.40, 0.80)	(0.30, 0.85)
8	(0.40, 0.80)	(0.60, 0.60)	(0.50, 0.70)	(0.50, 0.70)	(0.50, 0.70)	(0.40, 0.80)	(0.60, 0.60)	(0.40, 0.80)	(0.30, 0.85)	(0.30, 0.85)	(0.40, 0.80)	(0.20, 0.90)
9	(0.40, 0.80)	(0.20, 0.90)	(0.20, 0.90)	(0.40, 0.80)	(0.70, 0.50)	(0.60, 0.60)	(0.70, 0.50)	(0.80, 0.40)	(0.40, 0.80)	(0.50, 0.70)	(0.40, 0.80)	(0.30, 0.85)
10	(0.50, 0.70)	(0.30, 0.85)	(0.40, 0.80)	(0.40, 0.80)	(0.70, 0.50)	(0.60, 0.60)	(0.70, 0.50)	(0.80, 0.40)	(0.40, 0.80)	(0.30, 0.85)	(0.40, 0.80)	(0.40, 0.80)
11	(0.70, 0.50)	(0.60, 0.60)	(0.60, 0.60)	(0.60, 0.60)	(0.50, 0.70)	(0.50, 0.70)	(0.40, 0.80)	(0.60, 0.60)	(0.20, 0.90)	(0.10, 0.95)	(0.20, 0.90)	(0.10, 0.95)
12	(0.40, 0.80)	(0.30, 0.85)	(0.30, 0.85)	(0.50, 0.70)	(0.30, 0.85)	(0.40, 0.80)	(0.40, 0.80)	(0.30, 0.85)	(0.30, 0.85)	(0.40, 0.80)	(0.20, 0.90)	(0.20, 0.90)
13	(0.60, 0.60)	(0.60, 0.60)	(0.70, 0.50)	(0.50, 0.70)	(0.30, 0.85)	(0.20, 0.90)	(0.40, 0.80)	(0.30, 0.85)	(0.20, 0.90)	(0.20, 0.90)	(0.30, 0.85)	(0.30, 0.85)
14	(0.60, 0.60)	(0.60, 0.60)	(0.60, 0.60)	(0.60, 0.60)	(0.70, 0.50)	(0.60, 0.60)	(0.80, 0.40)	(0.60, 0.60)	(0.30, 0.85)	(0.40, 0.80)	(0.20, 0.90)	(0.30, 0.85)
15	(0.70, 0.50)	(0.60, 0.60)	(0.70, 0.50)	(0.70, 0.50)	(0.60, 0.60)	(0.60, 0.60)	(0.70, 0.50)	(0.50, 0.70)	(0.20, 0.90)	(0.40, 0.80)	(0.30, 0.85)	(0.20, 0.90)
16	(0.50, 0.70)	(0.60, 0.60)	(0.60, 0.60)	(0.40, 0.80)	(0.50, 0.70)	(0.60, 0.60)	(0.40, 0.80)	(0.40, 0.80)	(0.40, 0.80)	(0.50, 0.70)	(0.40, 0.80)	(0.50, 0.70)

4.2. Typical Risk Priority Number Method Calculation

The typical RPN approach is one of the most widely applied quantitative computing tools for FMEA. The main advantage of the typical RPN approach is that the computation is simple and easy to operate. The RPN value is the product of three different risk elements *S*, *O*, and *D*. The higher the RPN value, representing the higher risk of product failure, should be given a higher priority precaution manner. According to Tables 3 and 5, the aggregated opinions of experts are calculated followed by the RPN value, as presented in Table 6.

Table 6. The results of risk priority number (RPN) values.

Failure Item	*S*	*O*	*D*	RPN
1	5.750	5.000	4.000	115.000
2	2.500	3.500	3.750	32.813
3	5.250	6.250	7.000	229.688
4	5.000	6.500	6.250	203.125
5	3.000	1.250	4.750	17.813
6	4.000	6.750	1.250	33.750
7	5.000	7.875	3.250	127.969
8	5.000	4.750	3.000	71.250
9	3.000	7.000	4.000	84.000
10	4.000	7.000	3.750	105.000
11	6.250	5.000	1.500	46.875
12	3.750	3.500	2.750	36.094
13	6.000	3.000	2.500	45.000
14	6.000	6.750	3.000	121.500
15	6.750	6.000	2.750	111.375
16	5.250	4.750	4.500	112.219

4.3. Fuzzy Set Method Solution Typical Intuitionistic Fuzzy Set Calculation

Extending the concept of FS, Atanassov [18] first introduced the IFS to process the intuitionistic FI for MCDM problems. The IFS used the MD and NMD to be expressed as the intuitionistic fuzzy phenomena that belong or do not belong to the described events in daily life. It is worth noting that IFS requires that the sum of MD and NMD must be less than or equal to 1. According to Table 5, the aggregated opinions of experts is calculated, and then Equation (3) is used to calculate the *IFWG* value; the calculation results are shown in Table 7. The score function of IFS is equal to the value of MD minus NMD.

Table 7. The results of the intuitionistic fuzzy weighted geometric (*IFWG*) values.

Failure Item	*S*	*O*	*D*	*IFWG*	Score Function
1	(0.584, 0.416)	(0.505, 0.495)	(0.404, 0.596)	(0.492, 0.508)	−0.016
2	(0.252, 0.748)	(0.352, 0.648)	(0.376, 0.624)	(0.322, 0.678)	−0.356
3	(0.532, 0.468)	(0.628, 0.372)	(0.709, 0.291)	(0.619, 0.381)	0.237
4	(0.505, 0.495)	(0.654, 0.346)	(0.628, 0.372)	(0.592, 0.408)	0.184
5	(0.304, 0.696)	(0.126, 0.874)	(0.482, 0.518)	(0.264, 0.736)	−0.471
6	(0.404, 0.596)	(0.678, 0.322)	(0.126, 0.874)	(0.326, 0.674)	−0.349
7	(0.505, 0.495)	(0.794, 0.206)	(0.326, 0.674)	(0.508, 0.492)	0.016
8	(0.505, 0.495)	(0.482, 0.518)	(0.304, 0.696)	(0.420, 0.580)	−0.161
9	(0.307, 0.693)	(0.709, 0.291)	(0.404, 0.596)	(0.445, 0.555)	−0.110
10	(0.404, 0.596)	(0.709, 0.291)	(0.376, 0.624)	(0.476, 0.524)	−0.048
11	(0.628, 0.372)	(0.505, 0.495)	(0.151, 0.849)	(0.363, 0.637)	−0.273
12	(0.381, 0.619)	(0.352, 0.648)	(0.280, 0.720)	(0.335, 0.665)	−0.330
13	(0.606, 0.394)	(0.304, 0.696)	(0.252, 0.748)	(0.359, 0.641)	−0.282
14	(0.600, 0.400)	(0.687, 0.313)	(0.304, 0.696)	(0.500, 0.500)	0.000
15	(0.678, 0.322)	(0.606, 0.394)	(0.280, 0.720)	(0.486, 0.514)	−0.027
16	(0.532, 0.468)	(0.482, 0.518)	(0.452, 0.548)	(0.488, 0.512)	−0.025

4.4. Typical Fermatean Fuzzy Set Calculation

Extending the concept of FS and the IFS, Senapati and Yager [28] proposed the FFS and used the MD and NMD to process the Fermatean FI for MCDM problems. The main difference between FFS and IFS is that FFS restricts the sum of the cube of MD and NMD to be less than or equal to 1. According to Table (5), Equation (6) was used to calculate the aggregated opinions of experts, and then Equations (7) and (12) were used to calculate the *FFWG* value and the score function, respectively; the calculation results are expressed in Table 8.

Table 8. The results of Fermatean fuzzy weighted geometric (*FFWG*) values by typical FFS.

Failure Item	*S*	*O*	*D*	*FFWG*	Score Function
1	(0.575, 0.625)	(0.500, 0.700)	(0.400, 0.788)	(0.486, 0.701)	−0.230
2	(0.250, 0.875)	(0.350, 0.825)	(0.375, 0.813)	(0.320, 0.837)	−0.554
3	(0.525, 0.675)	(0.625, 0.575)	(0.700, 0.500)	(0.612, 0.579)	0.036
4	(0.500, 0.700)	(0.650, 0.550)	(0.625, 0.575)	(0.588, 0.605)	−0.018
5	(0.300, 0.850)	(0.125, 0.938)	(0.475, 0.725)	(0.261, 0.833)	−0.560
6	(0.400, 0.788)	(0.675, 0.525)	(0.125, 0.938)	(0.323, 0.729)	−0.354
7	(0.500, 0.700)	(0.788, 0.400)	(0.325, 0.838)	(0.504, 0.617)	−0.107
8	(0.500, 0.700)	(0.475, 0.725)	(0.300, 0.850)	(0.415, 0.756)	−0.360
9	(0.300, 0.850)	(0.700, 0.500)	(0.400, 0.788)	(0.438, 0.694)	−0.251
10	(0.400, 0.788)	(0.700, 0.500)	(0.375, 0.813)	(0.472, 0.684)	−0.215
11	(0.625, 0.575)	(0.500, 0.700)	(0.150, 0.925)	(0.361, 0.719)	−0.325
12	(0.375, 0.800)	(0.350, 0.825)	(0.275, 0.863)	(0.330, 0.829)	−0.533
13	(0.600, 0.600)	(0.300, 0.850)	(0.250, 0.875)	(0.356, 0.764)	−0.401
14	(0.600, 0.600)	(0.675, 0.525)	(0.300, 0.850)	(0.495, 0.645)	−0.146
15	(0.675, 0.525)	(0.600, 0.600)	(0.275, 0.863)	(0.481, 0.648)	−0.160
16	(0.525, 0.675)	(0.475, 0.725)	(0.450, 0.750)	(0.482, 0.716)	−0.255

4.5. Proposed Method Calculation

To overcome the limitations of typical risk assessment methods, this study proposed the new hybrid FFS and entropy method for risk assessment. In the numerical example, the service FMEA evaluation committee consists of four experts, and the possible failure items of a self-service electric vehicle include 16 different failure items, as shown in Table 2 (Steps 1 and 2). According to Table 3, experts determine the values of risk elements of different failure items according to their own experience and background, respectively, as expressed in Table 4 (Step 3).

Step 4: Aggregation of the assessment information of the experts.

Equation (6) was used to aggregate the experts' assessment information, and the aggregated information is displayed as Fermatean FI, as expressed in Table 8.

Step 5: Calculation of the objective weight and integrated weight of risk elements.

Equations (14)–(16) were used to calculate the objective weight of three different risk elements; the results are shown in Table 9. Then Equation (17) was used to calculate the integrated weight of risk elements; the results are expressed in Table 9.

Table 9. Subjective weight, objective weight, and integrated weight of three different risk elements.

Weight	*S*		*O*		*D*	
	MD	**NMD**	**MD**	**NMD**	**MD**	**NMD**
Subjective weight	0.333	0.333	0.333	0.333	0.333	0.333
Objective weight	0.197	0.227	0.348	0.546	0.456	0.227
Integrated weight	0.265	0.280	0.340	0.440	0.395	0.280

Step 6: Calculation of the *FFWG* value.

According to the aggregated the assessment information by the experts (Table 8) and the integrated weight of risk elements (Table 9), Equation (7) was used to calculate the *FFWG* value, which indicates the failure risk level of possible failure items, as shown in Table 10.

Table 10. The results of the Fermatean fuzzy weighted geometric (*FFWG*) values by the proposed method.

Failure Item	*S*	*O*	*D*	*FFWG*	Score Function
1	(0.575, 0.625)	(0.500, 0.700)	(0.400, 0.788)	(0.475, 0.701)	−0.237
2	(0.250, 0.875)	(0.350, 0.825)	(0.375, 0.813)	(0.329, 0.835)	−0.547
3	(0.525, 0.675)	(0.625, 0.575)	(0.700, 0.500)	(0.624, 0.578)	0.050
4	(0.500, 0.700)	(0.650, 0.550)	(0.625, 0.575)	(0.597, 0.596)	0.001
5	(0.300, 0.850)	(0.125, 0.938)	(0.475, 0.725)	(0.267, 0.849)	−0.592
6	(0.400, 0.788)	(0.675, 0.525)	(0.125, 0.938)	(0.302, 0.692)	−0.304
7	(0.500, 0.700)	(0.788, 0.400)	(0.325, 0.838)	(0.492, 0.576)	−0.071
8	(0.500, 0.700)	(0.475, 0.725)	(0.300, 0.850)	(0.402, 0.751)	−0.358
9	(0.300, 0.850)	(0.700, 0.500)	(0.400, 0.788)	(0.448, 0.659)	−0.196
10	(0.400, 0.788)	(0.700, 0.500)	(0.375, 0.813)	(0.472, 0.651)	−0.170
11	(0.625, 0.575)	(0.500, 0.700)	(0.150, 0.925)	(0.330, 0.716)	−0.332
12	(0.375, 0.800)	(0.350, 0.825)	(0.275, 0.863)	(0.324, 0.828)	−0.534
13	(0.600, 0.600)	(0.300, 0.850)	(0.250, 0.875)	(0.335, 0.777)	−0.432
14	(0.600, 0.600)	(0.675, 0.525)	(0.300, 0.850)	(0.475, 0.624)	−0.135
15	(0.675, 0.525)	(0.600, 0.600)	(0.275, 0.863)	(0.455, 0.640)	−0.168
16	(0.525, 0.675)	(0.475, 0.725)	(0.450, 0.750)	(0.477, 0.717)	−0.260

Step 7: Calculation of the score function of different failure items.

According to the results of *FFWG* value (Step 6), Equation (12) was used to calculate the score function of different failure items, as shown in Table 10.

Step 8: Providing the ranking results of possible failure items as a basis for decision-making.

The ranking results of possible failure items can provide a reference for limited resource allocation and management decisions.

4.6. Analysis and Discussion

In order to confirm and illustrate the rationality and correctness of the proposed new hybrid FFS and entropy method for risk assessment, in Section 4, this paper used the service improvement of a self-service electric vehicle as an example to test the differences between different calculation methods (the typical RPN method, typical IFS method, typical FFS method, and the proposed method). These four different calculation approaches use the same input data to calculate, as shown in Tables 2–5. The main difference in risk priority ranking, information, and weight considerations between different calculation methods are shown in Tables 11 and 12.

According to Tables 11 and 12, the proposed hybrid FFS and entropy approach has some advantages. First, it is able to consider information provided by experts. The typical RPN approach can only process the crisp information but cannot process the FI, intuitionistic FI, and Fermatean FI provided by experts. Although the typical IFS method can handle the FI and intuitionistic FI provided by experts, it still cannot handle the Fermatean FI provided by experts. Both the typical FFS method and the proposed method can simultaneously process FI, intuitionistic FI, and Fermatean FI provided by experts. Therefore, both the typical FFS method and the proposed method could fully consider the information provided by experts and are closer to the real-world situation.

Second, it is able to consider the weight of three different risk elements S, O, and D. For the weight consideration of three different risk elements S, O, and D, the typical RPN method, typical IFS method, and typical FFS method only consider subjective weights of three different risk elements and ignore objective weights consideration, which will lead to incorrect evaluation results. The proposed method fully considered the subjective and objective weights of risk elements, and the assessment results more reasonably and correctly reflected the real results of risk assessment.

Finally, we consider the risk priority ranking of the self-service electric vehicle. For the typical RPN method [33], the risk priority ranking of the self-service electric vehicle was Item3 $\succ$ Item4 $\succ$ Item7 $\succ$ Item14 $\succ$ Item1 $\succ$ Item16 $\succ$ Item15 $\succ$ Item10 $\succ$ Item9 $\succ$ Item8 $\succ$ Item11 $\succ$ Item13 $\succ$ Item12 $\succ$ Item6 $\succ$ Item2 $\succ$ Item5. For the typical IFS method [41], the risk priority ranking of the self-service electric vehicle was Item3 $\succ$ Item4 $\succ$ Item7 $\succ$ Item14 $\succ$ Item1 $\succ$ Item16 $\succ$ Item15 $\succ$ Item10 $\succ$ Item9 $\succ$ Item8 $\succ$ Item11 $\succ$ Item13 $\succ$ Item12 $\succ$ Item6 $\succ$ Item2 $\succ$ Item5. For the FFS method [26], the risk priority ranking of the self-service electric vehicle was Item3 $\succ$ Item4 $\succ$ Item7 $\succ$ Item14 $\succ$ Item15 $\succ$ Item10 $\succ$ Item1 $\succ$ Item9 $\succ$ Item16 $\succ$ Item11 $\succ$ Item6 $\succ$ Item8 $\succ$ Item13 $\succ$ Item12 $\succ$ Item2 $\succ$ Item5. For the proposed method, the risk priority ranking of the self-service electric vehicle was Item3 $\succ$ Item4 $\succ$ Item7 $\succ$ Item14 $\succ$ Item15 $\succ$ Item10 $\succ$ Item9 $\succ$ Item1 $\succ$ Item16 $\succ$ Item6 $\succ$ Item11 $\succ$ Item8 $\succ$ Item13 $\succ$ Item12 $\succ$ Item2 $\succ$ Item5.

Table 11. The main difference of risk priority ranking between different calculation methods.

Failure Item	Typical RPN Method [36]		Typical IFS Method [45]		Typical FFS Method [28]		Proposed Method	
	RPN	Ranking	Score Function	Ranking	Score Function	Ranking	Score Function	Ranking
1	115.000	5	−0.016	5	−0.230	7	−0.237	8
2	32.813	15	−0.356	15	−0.554	15	−0.547	15
3	229.688	1	0.237	1	0.036	1	0.050	1
4	203.125	2	0.184	2	−0.018	2	0.001	2
5	17.813	16	−0.471	16	−0.560	16	−0.592	16
6	33.750	14	−0.349	14	−0.354	11	−0.304	10
7	127.969	3	0.016	3	−0.107	3	−0.071	3
8	71.250	10	−0.161	10	−0.360	12	−0.358	12
9	84.000	9	−0.110	9	−0.251	8	−0.196	7
10	105.000	8	−0.048	8	−0.215	6	−0.170	6
11	46.875	11	−0.273	11	−0.325	10	−0.332	11
12	36.094	13	−0.330	13	−0.533	14	−0.534	14
13	45.000	12	−0.282	12	−0.401	13	−0.432	13
14	121.500	4	0.000	4	−0.146	4	−0.135	4
15	111.375	7	−0.027	7	−0.160	5	−0.168	5
16	112.219	6	−0.025	6	−0.255	9	−0.260	9

Table 12. The main differences in information and weight considerations for different calculation methods.

Information and Weight Considerations	Typical RPN Method [36]	Typical IFS Method [45]	Typical FFS Method [28]	Proposed Method
Considerations for FI	No	Yes	Yes	Yes
Considerations for intuitionistic FI	No	Yes	Yes	Yes
Considerations for Fermatean FI	No	No	Yes	Yes
Subjective weight	Yes	Yes	Yes	Yes
Objective weight	No	No	No	Yes

5. Conclusions

Risk evaluation is a crucial aspect of the product design and manufacturing process. The correctness of the risk assessment results directly affect the quality of the product and the profit of the company. Most risk assessment approaches use the RPN approach to assess the level of product failure risk. The typical RPN approach uses the product of three different risk elements to calculate the RPN value. Failed items with high RPN values express a higher system failure risk, and a higher priority must be given to prevent the occurrence of possible risks. However, the typical RPN approach cannot handle the intuitionistic FI and Fermatean FI provided by experts during the risk evaluation process. Moreover, the typical RPN approach does not consider the objective weights of the three different risk elements, which leads to biased assessment results. To fully and correctly assess the product failure risk, a hybrid of the FFS and entropy methods was used in this study to correctly prioritize product failure items.

The advantages of the proposed hybrid of the FFS and entropy methods are the following:

(1) The proposed approach is able to deal with both FI and intuitionistic FI provided by experts.
(2) The proposed approach is able to deal with Fermatean FI provided by experts.
(3) The proposed approach fully considers the subjective weights of three different risk elements.

(4) The proposed approach fully considers the objective weights of three different risk elements.
(5) The typical RPN approach, typical IFS method, and typical FFS method are only special cases of the proposed approach.

Although the proposed hybrid FFS and entropy approach is able to deal with FI, intuitionistic FI, and Fermatean FI provided by experts during the risk evaluation process, the proposed approach still has some limitations that do not consider the differences between different combinations of subjective weights and objective weights. Subsequent researchers can discuss the differences between different subjective weight calculation methods and objective weight calculation methods on the topic of risk assessment. Follow-up researchers can also extend the concept of the proposed approach to solve different MCDM problems, such as talent selection, resource allocation, supplier selection, material selection, site selection, and reliability allocation.

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