

Research on R&D Risk Management of Projects Based on Extended FMEA

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Abstract: In the contemporary era, smartphone research and development is characterized by substantial R&D investment, high confidentiality requirements, diverse influencing factors, and elevated technical risks. It is imperative to implement effective risk management in project R&D, identify potential risk influencing factors in advance, accurately assess the risk levels of each factor, and deploy limited human and material resources to prevent and improve key risk factors. Taking the smartphone NPI project of Company L as a case study, this paper proposes a fuzzy comprehensive evaluation method for failure modes extended from FMEA. By integrating subjective and objective analyses as well as qualitative and quantitative methods, the proposed approach achieves a more precise assessment of risks in smartphone NPI R&D projects.

1. Introduction

Smartphone NPI projects are characterized by high technical risks, large investment, strict confidentiality requirements, and numerous influencing factors throughout the R&D process. Against the backdrop of corporate requirements to reduce operational and R&D costs, coupled with frequent recent trade frictions and rising tariffs, the R&D risks of smartphone NPI projects have been continuously escalating. Therefore, it is necessary to propose an extended failure mode and effect analysis evaluation method based on FMEA, which integrates subjective and objective perspectives to quantitatively analyze potential failure risks of the project, accurately identify a small number of key influencing factors, and arrange countermeasures in advance.

2. Related Concepts

2.1. Project Risk Management

All projects inevitably face a variety of risks; risk-free projects do not exist [1]. Peter, the father of modern management, stated that “risk management is not about predicting the future, but preparing for it” [2]. Jim Collins, author of Good to Great, pointed out that “the survival of an enterprise depends not only on its ability to adapt to and predict the future, but also on its capacity

to manage risks and uncertainties” [3]. Some scholars also define project risk management as a process that converts uncertain events in a project into definite deliverables [4].

2.2. Failure Mode and Effect Analysis

Failure Mode and Effect Analysis (FMEA) is an analytical method for identifying potential risks in products or projects, as well as a proactive risk management technique for eliminating potential failure modes [5]. This method enables a comprehensive analysis of possible failure modes in product design and production, along with their causes and consequences, and assesses the severity of potential risks, so that corresponding solutions can be formulated and implemented [6]. However, traditional FMEA has shortcomings such as excessive reliance on subjective expert judgment and failure to consider the weight differences among Severity (S), Occurrence (O), and Detection (D) [7–10].

2.3. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP), proposed by Satty [11], is a widely used multi-criteria decision-making method and one of the most common risk assessment approaches. It integrates quantitative and qualitative analyses, which significantly improves the reliability of evaluation results [12].

3. Model Construction and Implementation

This paper improves the traditional FMEA model by combining triangular fuzzy numbers, the analytic hierarchy process (AHP), and the entropy weight method, and applies it to the R&D risk assessment of the smartphone NPI project at Company L. The model consists of four stages, as shown in Figure 1.

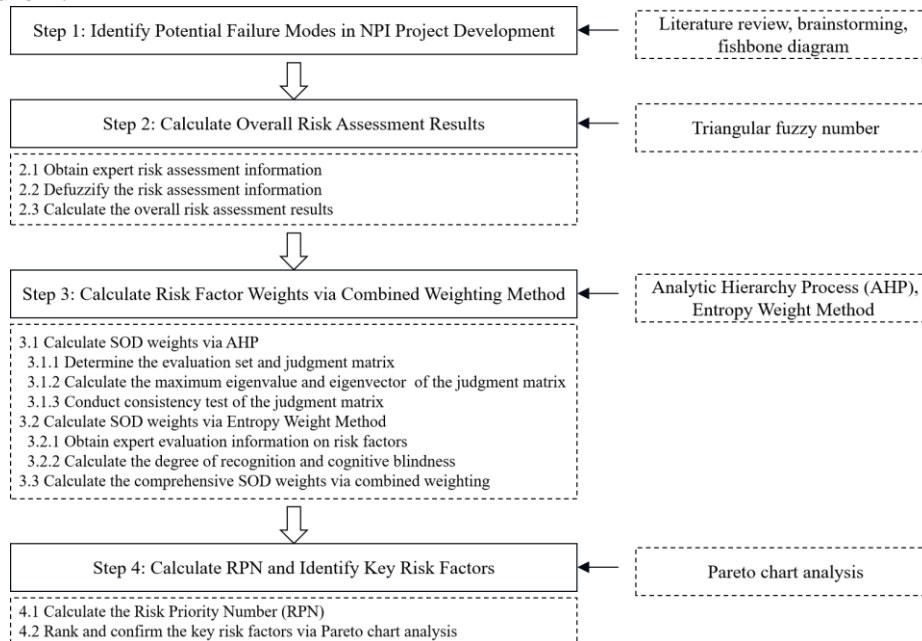


Figure 1: R&D Risk Assessment Model for Smartphone NPI Projects.

3.1. Identification of Potential Failure Modes in NPI Project R&D

In this paper, several experts are invited to analyze and identify 40 failure modes as shown in Table 1 from four dimensions: external risk, management risk, technical risk, and security risk.

Table 1: Potential Failure Modes in Smartphone NPI Project R&D.

SN	Failure Mode(FM)	Failure Consequence	Failure Causes
FM1	Unfavorable policy environment	Affect the customer's decision on whether to award the new project to Company L	Force majeure
FM2	Unfavorable economic environment	Affect the resource investment of the customer and Company L in the new project	Force majeure
FM3	Unfavorable social environment	Affect the resource investment of the customer and Company L in the new project	Force majeure
FM4	Technical barriers such as patents	Affect the progress of the project as scheduled	Force majeure
FM5	Increases in import and export tariffs	Affect the resource investment of the customer and Company L in the new project	Force majeure
FM6	Customs clearance barriers in various countries	Affect the customer's decision on whether to award the new project to Company L	Force majeure
FM7	Intensified competition from domestic and foreign rivals	Affect the resource investment of the customer and Company L in the new project	Force majeure
FM8	Risk of customer supply chain restructuring	Affect the customer's decision on whether to award the new project to Company L	Force majeure
FM9	Inadequate waterproof performance and lower-than-expected yield rate	Affect the progress of the project as scheduled	Insufficient design robustness
FM10	Inadequate dustproof performance and below-target yield rate	Affect the progress of the project as scheduled	Insufficient design robustness
FM11	Excessive poor key tactile feel	Hinders project progress as scheduled	Insufficient design robustness
FM12	Excessive screw locking defects	Hinders project progress as scheduled	Insufficient design robustness
FM13	Excessive spring/clip assembly deformation defects	Hinders project progress as scheduled	Insufficient design robustness
FM14	Design unfavorable for automated assembly/testing	Increases production costs	Improper design

FM15	Thin design weakens product reliability	Hinders project progress as scheduled	Constrained design space
FM16	Environmental/mechanical reliability below expectations	Hinders project progress as scheduled	Insufficient design robustness
FM17	Design unfavorable for disassembly/repair	Increases maintenance costs	Improper design
FM18	Key cycle life below expectations	Hinders project progress as scheduled	Insufficient design robustness
FM19	Heat dissipation performance below expectations	Hinders project progress as scheduled	Insufficient design robustness
FM20	New design brings unknown challenges	Hinders project progress as scheduled	New design has unknown risks
FM21	Failure analysis efficiency/quality risks	Hinders project progress as scheduled	Insufficient manpower/capability
FM22	Design/process parameters not optimal	Increases production/operation costs	Insufficient process optimization
FM23	Conflicting component performance requirements	Conflicting component performance requirements	Conflicting design requirements
FM24	Insufficient core talents	Hinders project progress as scheduled	Talent loss
FM25	Long project R&D cycle	Increases R&D costs	Long R&D cycle
FM26	Complex/volatile customer requirements	Increases R&D costs	Unclear customer requirements
FM27	Risk of poor communication	Increases communication costs and reduces customer loyalty	Insufficient English proficiency of R&D personnel
FM28	Supply chain management risk	Risk of material shortage and defective incoming materials	Poor supplier management
FM29	Production quality management risk	Reduces product yield	Poor quality control of incoming materials
FM30	BOM/DRP management risks	Increases production/material costs	Insufficient BOM management experience
FM31	Production process parameter management	Reduces production yield	Insufficient optimization of process parameters
FM32	NPI Build trial production management	Reduces product yield/quality	Insufficient trial production experience
FM33	Poor communication	Increases communication costs	Reduces customer stickiness
FM34	Environmental safety risks	Increases enterprise economic losses	Poor security management

FM35	Environmental safety risks	Increases enterprise operation costs	Poor security management
FM36	Security risks	Increases enterprise economic losses	Poor security management
FM37	Production document leakage	Increases enterprise economic losses	Poor security management
FM38	2D/3D drawing leakage	Increases enterprise economic losses	Poor security management
FM39	Product loss/theft risk	Increases enterprise economic losses	Poor security management
FM40	Insufficient employee security awareness	Increases project information leakage risk	Poor security management

3.2. Calculation of Overall Risk Assessment Results

3.2.1. Acquisition of Expert Risk Assessment Information

Based on the linguistic variable evaluation criteria shown in Table 2, four experts $E_k(k=1,2,3,4)$ conduct risk assessments on the three risk factors—Severity (S), Occurrence (O), and Detection (D)—of the failure modes listed in Table 1.

Table 2: Evaluation Criteria for Linguistic Variables.

Evaluation Semantics	Very Low	Low	Medium	High	Very High
Triangular Fuzzy Number	(0,0,2)	(0,2,4)	(3,5,7)	(6,8,10)	(8,10,10)

The assessment results of Expert E_1 are shown in Table 3.

Table 3: Risk Assessment Results of Expert E_1 .

FM	Fuzzy evaluation values of individual risk factors			FM	Fuzzy evaluation values of individual risk factors		
	S	O	D		S	O	D
FM1	(6,8,10)	(6,8,10)	(0,0,2)	FM21	(0,2,4)	(3,5,7)	(6,8,10)
FM2	(3,5,7)	(6,8,10)	(0,2,4)	FM22	(0,2,4)	(3,5,7)	(6,8,10)
FM3	(0,2,4)	(3,5,7)	(3,5,7)	FM23	(3,5,7)	(0,2,4)	(3,5,7)
FM4	(6,8,10)	(0,2,4)	(0,0,2)	FM24	(3,5,7)	(3,5,7)	(3,5,7)
FM5	(6,8,10)	(6,8,10)	(3,5,7)	FM25	(0,2,4)	(0,2,4)	(0,2,4)
FM6	(3,5,7)	(0,2,4)	(6,8,10)	FM26	(0,2,4)	(6,8,10)	(3,5,7)
FM7	(3,5,7)	(6,8,10)	(3,5,7)	FM27	(3,5,7)	(3,5,7)	(3,5,7)
FM8	(6,8,10)	(6,8,10)	(6,8,10)	FM28	(3,5,7)	(3,5,7)	(3,5,7)
FM9	(3,5,7)	(0,2,4)	(0,0,2)	FM29	(6,8,10)	(0,2,4)	(0,2,4)
FM10	(3,5,7)	(0,2,4)	(0,0,2)	FM30	(6,8,10)	(0,2,4)	(0,2,4)
FM11	(3,5,7)	(0, 2,4)	(0,0,2)	FM31	(6,8,10)	(0,2,4)	(0,2,4)
FM12	(6,8,10)	(0,2,4)	(0,2,4)	FM32	(3,5,7)	(3,5,7)	(0,2,4)

FM13	(6,8,10)	(3,5,7)	(0,2,4)	FM33	(3,5,7)	(8,10,10)	(0,2,4)
FM14	(3,5,7)	(0,2,4)	(3,5,7)	FM34	(3,5,7)	(0,2,4)	(6,8,10)
FM15	(3,5,7)	(3,5,7)	(6,8,10)	FM35	(6,8,10)	(0,0,2)	(3,5,7)
FM16	(3,5,7)	(0,2,4)	(6,8,10)	FM36	(6,8,10)	(0,2,4)	(3,5,7)
FM17	(0,2,4)	(0,2,4)	(0,2,4)	FM37	(6,8,10)	(0,0,2)	(3,5,7)
FM18	(3,5,7)	(0,2,4)	(6,8,10)	FM38	(6,8,10)	(0,2,4)	(3,5,7)
FM19	(3,5,7)	(0,2,4)	(6,8,10)	FM39	(6,8,10)	(0,0,2)	(3,5,7)
FM20	(6,8,10)	(6,8,10)	(6,8,10)	FM40	(3,5,7)	(3,5,7)	(3,5,7)

3.2.2. Defuzzification of Assessment Results

The assessment results of Expert E_k are defuzzified according to Equation (1) to obtain y_{ij}^k , as shown in Table 4.

$$y_{ij}^k = \frac{a_{ij}^k + 2b_{ij}^k + c_{ij}^k}{4} \quad i=1,2,\dots,40 \quad j=1,2,3 \quad (1)$$

3.2.3. Calculation of Overall Risk Assessment Results

Assume that the weights of experts E_k in the evaluation team are: $\lambda_1 = 0.3, \lambda_2 = 0.3, \lambda_3 = 0.2, \lambda_4 = 0.2$. According formula(2):

$$z_{ij}^k = \sum_{k=1}^4 \lambda_k y_{ij}^k \quad (2)$$

$z_{ij}^k (i = 1,2,\dots,40 \quad j = 1,2,3)$, the calculation of overall risk assessment results are presented in Table 5,

Table 4: Defuzzified Assessment Results of Expert E1.

FM	Defuzzified evaluation values of individual risk factors			FM	Defuzzified evaluation values of individual risk factors		
	S	O	D		S	O	D
FM1	8	8	0.5	FM21	2	5	8
FM2	5	8	2	FM22	2	5	8
FM3	2	5	5	FM23	5	2	5
FM4	8	2	0.5	FM24	5	5	5
FM5	8	8	5	FM25	2	2	2
FM6	5	2	8	FM26	2	8	5
FM7	5	8	5	FM27	5	5	5
FM8	8	8	8	FM28	5	5	5
FM9	5	2	0.5	FM29	8	2	2
FM10	5	2	0.5	FM30	8	2	2
FM11	5	2	0.5	FM31	8	2	2
FM12	8	2	2	FM32	5	5	2
FM13	8	5	2	FM33	5	9.5	2
FM14	5	2	5	FM34	5	2	8
FM15	5	5	8	FM35	8	0.5	5

FM16	5	2	8	FM36	8	2	5
FM17	2	2	2	FM37	8	0.5	5
FM18	5	2	8	FM38	8	2	5
FM19	5	2	8	FM39	8	0.5	5
FM20	8	8	8	FM40	5	5	5

Table 5: Overall Evaluation Values of Each Risk Factor.

FM	Overall risk assessment values of each risk factor			FM	Overall risk assessment values of each risk factor		
	S	O	D		S	O	D
FM1	3.62	5.15	1.265	FM21	1.61	5	4.37
FM2	3.56	6.47	3.53	FM22	1.61	5	5.81
FM3	2	2.09	5	FM23	5	6.38	5.75
FM4	3.62	1.67	3.785	FM24	5	7.19	3.26
FM5	5.81	8.705	2.105	FM25	0.905	6.38	0.905
FM6	3.47	3.44	5.81	FM26	2	8	2.48
FM7	3.47	8.72	2.09	FM27	2.81	4.25	3.59
FM8	8	8.33	3.62	FM28	5	5	5
FM9	3.47	2.66	1.595	FM29	7.34	2	2
FM10	3.47	1.295	1.265	FM30	8	2	2
FM11	3.56	2.27	2.045	FM31	7.34	2.66	2.66
FM12	4.37	3.41	4.19	FM32	4.34	4.25	3.44
FM13	6.59	4.22	3.41	FM33	5	9.5	2.45
FM14	2.81	2.75	2.48	FM34	5	3.44	6.47
FM15	3.59	4.22	5.81	FM35	4.28	1.265	2.81
FM16	3.56	2.42	5.15	FM36	8	1.67	7.19
FM17	1.61	2	0.905	FM37	7.34	0.5	4.25
FM18	4.34	1.61	4.04	FM38	8.705	1.61	5
FM19	4.34	4.19	4.37	FM39	8	1.595	3.215
FM20	8	8	7.22	FM40	5	5	5

3.3. Calculation of Risk Factor Weights Using Combined Weighting Method

3.3.1. Acquisition of Expert Evaluation Information on Risk Factors

Table 6: Evaluation Results of Risk Factors by Experts Ek.

Experts Ek	Fuzzy evaluation values of risk factors from each expert		
	S	O	D
E ₁	(6,8,10)	(0,2,4)	(3,5,7)
E ₂	(6,8,10)	(3,5,7)	(0,2,4)
E ₃	(6,8,10)	(3,5,7)	(0,2,4)

E ₄	(3,5,7)	(6,8,10)	(0,2,4)
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Experts E_k evaluate each risk factor using triangular fuzzy numbers, and the results are shown in Table 6. The defuzzified results are then presented in Table 7.

Table 7: Defuzzified Results of Risk Factors by Experts.

Experts E _k	Defuzzified evaluation values of risk factors from experts		
	S	O	D
E ₁	8	2	5
E ₂	8	5	5
E ₃	8	5	5
E ₄	5	8	5

3.3.2. Calculation of SOD Weights Using Analytic Hierarchy Process (AHP)

(1) Construction of the Hierarchical Model for the Problem

The constructed SOD hierarchical model is shown in Figure 2.

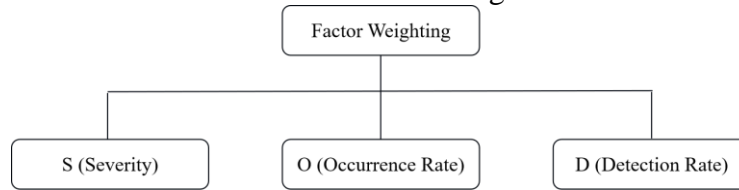


Figure 2: Hierarchical Model of SOD

(2) Construction of Importance Comparison Judgment Matrix for Each Element

The importance pairwise comparison judgment matrix is shown in Table 8.

Table 8: Pairwise Comparison Judgment Matrix of Importance.

Experts E ₁	S	O	D
S	1	3	2
O	0.3333	1	0.5
D	0.5	2	1

(3) Calculation of the Maximum Eigenvalue and Eigenvector of the Judgment Matrix

The Sum column is summed row-wise and normalized to obtain the weights of SOD, as shown in Table 9.

Table 9: Weights of SOD.

Experts E ₁	S	O	D	Sum	W
S	1	3	2	6	0.5294
O	0.3333	1	0.5	1.8333	0.1618
D	0.5	2	1	3.5	0.3088

(4) Consistency Test

a. Calculate the maximum eigenvalue λ_{max}

Calculate AW (where A is the original judgment matrix and W is the weight vector).

$$AW = [1, 3, 2; 0.3333, 1, 0.5; 0.5, 2, 1][0.5294; 0.1618; 0.3088]$$

$$AW_1 = 1 \times 0.5294 + 3 \times 0.1618 + 2 \times 0.3088 = 1.6323$$

$$AW_2 = 0.3333 \times 0.5294 + 1 \times 0.1618 + 0.5 \times 0.3088 = 0.4926$$

$$AW_3=0.5 \times 0.5294+2 \times 0.1618+1 \times 0.3088=0.8971$$

b. Calculate the approximate value λ_{\max}

$$\lambda_{\max} = \frac{1}{n} \times \sum \frac{AW_i}{W_i} \quad (3)$$

$$\lambda_{\max} = \frac{1}{3} \times \left(\frac{1.6323}{0.5294} + \frac{0.4926}{0.1618} + \frac{0.8791}{0.3088} \right) = 3.0111$$

c. Calculate the consistency index CI

$$CI = \frac{\lambda_{\max}-n}{n-1} \quad (4)$$

$$CI = \frac{3.0111-3}{3-1} = 0.00557$$

d. Consult the average random consistency index RI

For a 3-order matrix, RI = 0.58.

e. Calculate the consistency ratio CR.

$$CR = \frac{CI}{RI} = \frac{0.00557}{0.58} \approx 0.0096$$

f. Judge the consistency ratio CR.

CR = 0.0096 < 0.1, indicating that the consistency test is passed. Therefore, for expert E₁, the weight vector of SOD is: W_{E1}=[0.5294,0.1618,0.3088]

The above calculation steps are repeated to obtain:

$$W_{E2}=[0.4286,0.2857,0.2857], W_{E3}=[0.4,0.2,0.4], W_{E4}=[0.5455,0.1818 ,0.2727]$$

Assuming equal weights for all experts, the weights of SOD calculated by the analytic hierarchy process (AHP) are as follows:

$$W_{AHP} = \frac{1}{n} \times [\sum W_{Ei}] \quad (5)$$

$$W_{AHP} = \frac{1}{4} \times [(0.4286 + 0.4 + 0.5455), (0.2857 + 0.2 + 0.1818), (0.2857 + 0.4 + 0.2727)]$$

$$W_{AHP} = [0.4759, 0.2073, 0.3168]$$

That is, W_{AHP_S}=0.4759, W_{AHP_O}=0.2073, W_{AHP_D}=0.3168

3.3.3. Calculation of SOD Weights Using the Entropy Weight Method

Calculate recognition degree and cognitive blindness:

Construct the risk factor ranking matrix P=[P_{kj}]4×3, where P_{kj} denotes the ranking of the evaluation result of risk factor RF_j given by expert E_k. The calculation results are as follows:

$$\begin{bmatrix} 1 & 3 & 2 \\ 1 & 2 & 3 \\ 1 & 2 & 3 \\ 2 & 1 & 3 \end{bmatrix}$$

Let the membership function value of P_{kj} be f_{kj}, the average recognition degree of risk factor RF_j be r_j, the cognitive blindness be q_j, and the overall recognition degree be ρ_j. The formulas for each variable are given as follows:

$$f_{kj} = \frac{\ln(H-p_{kj})}{\ln(H-1)} \quad H = j + 2 \quad (6)$$

$$r_j = \frac{f_{1j} + f_{2j} + \dots + f_{kj}}{k} \quad (7)$$

$$q_j = \frac{|\max(f_{1j}, f_{2j}, \dots, f_{kj}) - r_j + \min(f_{1j}, f_{2j}, \dots, f_{kj}) - r_j|}{2} \quad (8)$$

$$\rho_j = r_j(1 - q_j) \quad (9)$$

The membership matrix F is calculated according to Equation (6):

$$F = [f_{kj}]_{4 \times 3} = \begin{bmatrix} 1 & 0.5 & 0.7925 \\ 1 & 0.7925 & 0.5 \\ 1 & 0.7925 & 0.5 \\ 0.7925 & 1 & 0.5 \end{bmatrix}$$

The average recognition degree of each risk factor is calculated according to Equation (7):

$$\begin{cases} r_S = 0.9481 \\ r_O = 0.7712 \\ r_D = 0.5731 \end{cases}$$

The average cognitive blindness of each risk factor is calculated according to Equation (8):

$$\begin{cases} q_S = 0.0518797 \\ q_O = 0.0212406 \\ q_D = 0.0731203 \end{cases}$$

The overall recognition degree of each risk factor is calculated according to Equation (9):

$$\begin{cases} \rho_S = 0.8989321 \\ \rho_O = 0.754859 \\ \rho_D = 0.5312136 \end{cases}$$

The overall recognition degree is normalized to obtain the weights of each risk factor:

$$\begin{cases} W_{ETP_S} = 0.4114097 \\ W_{ENP_O} = 0.3454725 \\ W_{ENP_D} = 0.2431178 \end{cases}$$

3.3.4. Calculation of the Comprehensive SOD Weights by Combined Weighting

The comprehensive weights of SOD are calculated using the linear weighting method. Assuming equal weights for the analytic hierarchy process and the entropy weight method, we have:

$$W = \frac{1}{2}(W_{AHP} + W_{ETP})$$

$$W_S = \frac{1}{2}(W_{AHP_S} + W_{ETP_S}) = \frac{1}{2}(0.4759 + 0.4114097) = 0.4436$$

$$W_O = \frac{1}{2}(W_{AHP_O} + W_{ETP_O}) = \frac{1}{2}(0.2073 + 0.3454725) = 0.2764$$

$$W_D = \frac{1}{2}(W_{AHP_D} + W_{ETP_D}) = \frac{1}{2}(0.3168 + 0.2431178) = 0.2800$$

3.4. Calculation of Risk Factor Weights Using Combined Weighting Method

3.4.1. Calculation of the Comprehensive RPN Risk Value

The overall risk assessment values of each risk factor in Table 5 are multiplied by the final weights of SOD, and the results are shown in Table 10.

Table 10: Risk Factor Assessment Values Considering SOD Weights.

FM	Risk factor evaluation values considering SOD weights			
	S	O	D	RPN
FM1	1.6060	1.4235	0.3542	0.8096
FM2	1.5793	1.7883	0.9883	2.7912
FM3	0.8873	0.5777	1.3998	0.7175
FM4	1.6060	0.4616	1.0597	0.7855
FM5	2.5775	2.4060	0.5893	3.6548
FM6	1.5394	0.9508	1.6266	2.3808
FM7	1.5394	2.4102	0.5851	2.1710
FM8	3.5491	2.3024	1.0135	8.2815
FM9	1.5394	0.7352	0.4465	0.5054
FM10	1.5394	0.3579	0.3542	0.1951
FM11	1.5793	0.6274	0.5725	0.5673
FM12	1.9387	0.9425	1.1731	2.1435
FM13	2.9236	1.1664	0.9547	3.2555
FM14	1.2466	0.7601	0.6943	0.6579
FM15	1.5926	1.1664	1.6266	3.0217
FM16	1.5793	0.6689	1.4418	1.5231
FM17	0.7143	0.5528	0.2534	0.1000
FM18	1.9254	0.4450	1.1311	0.9691
FM19	1.9254	1.1581	1.2235	2.7281
FM20	3.5491	2.2112	2.0214	15.8630
FM21	0.7143	1.3820	1.2235	1.2077
FM22	0.7143	1.3820	1.6266	1.6056
FM23	2.2182	1.7634	1.6098	6.2969
FM24	2.2182	1.9873	0.9127	4.0233
FM25	0.4015	1.7634	0.2534	0.1794
FM26	0.8873	2.2112	0.6943	1.3622
FM27	1.2466	1.1747	1.0051	1.4718
FM28	2.2182	1.3820	1.3998	4.2912
FM29	3.2563	0.5528	0.5599	1.0079
FM30	3.5491	0.5528	0.5599	1.0985
FM31	3.2563	0.7352	0.7447	1.7829
FM32	1.9254	1.1747	0.9631	2.1782
FM33	2.2182	2.6258	0.6859	3.9951
FM34	2.2182	0.9508	1.8114	3.8203
FM35	1.8988	0.3496	0.7867	0.5223
FM36	3.5491	0.4616	2.0130	3.2976
FM37	3.2563	0.1382	1.1899	0.5355

FM38	3.8618	0.4450	1.3998	2.4056
FM39	3.5491	0.4409	0.9001	1.4083
FM40	2.2182	1.3820	1.3998	4.2912

3.4.2. Risk Ranking and Identification of Critical Minority Factors

The failure modes are ranked according to the RPN values, as shown in Figure 3:

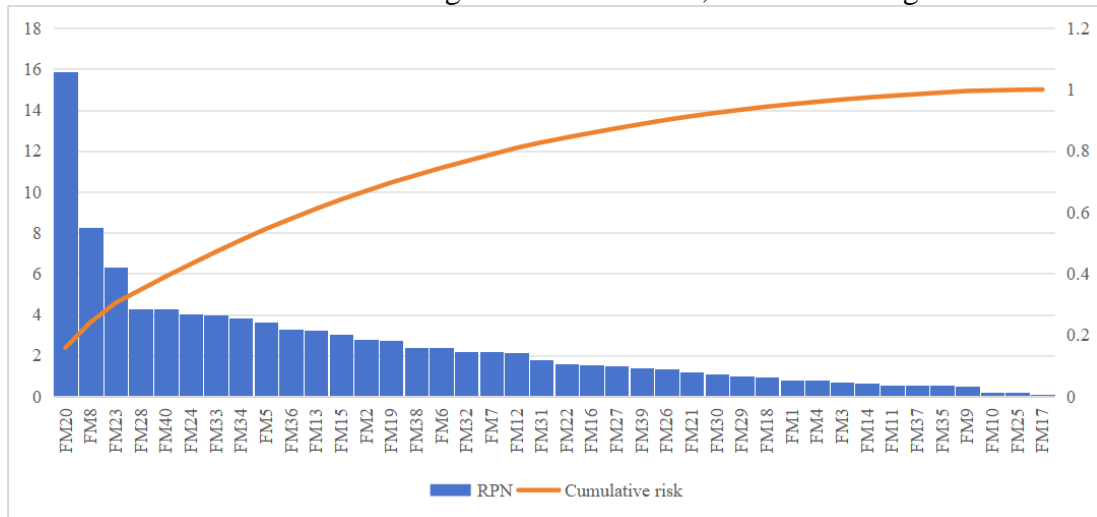


Figure 3: Ranking of Risk Factors.

It can be seen from Figure 3 that the top 8 items contribute more than 50% of the cumulative risk, which are the critical minority factors.

4. Conclusions

The FMEA method established in this paper has the following advantages:

- (1) Linguistic terms are adopted to evaluate failure modes, making the evaluation results more objective and reasonable.
- (2) The combined weighting method takes into account both the subjective and objective weights of risk factors, which reflects the weight distribution of RPN elements more reasonably and improves the practicability of the proposed FMEA method.

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