RELIABILITY ANALYSIS OF FMECA THRESHING AND CLEANING SYSTEM BASED ON FUZZY COMPREHENSIVE EVALUATION
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基于模糊综合评判的 FMECA 脱粒清选系统可靠性分析

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ABSTRACT
Aiming at the traditional FMECA (Failure Modes, Effect and Criticality Analysis) results of the threshing and cleaning system, which are strongly influenced by subjective factors, imprecise and easy to repeat, the fuzzy comprehensive evaluation method is introduced to quantify the results of the expert evaluation and reduce the subjective influence. Analytic Hierarchy Process (AHP) is used to assign weights to each influencing factor, and by calculating the comprehensive hazard level index, the hazard ranking of each failure mode is carried out, from which the critical failure modes are identified as the focus of improvement, so as to improve the reliability of the system. Comparison shows that the improved method effectively makes up for the shortcomings of the traditional FMECA analysis method, and it is easier to find out the critical failure modes, which provides a theoretical basis for practical application.

摘要
针对脱粒清选系统传统 FMECA(Failure Modes, Effect and Criticality Analysis)分析结果受主观因素影响强烈、取值不精确且易重复等问题，引入模糊综合评判方法，量化专家评价的结果，降低主观影响；采用层次分析法（AHP）对各个影响因素进行权重分配，并通过计算综合危害度等级指数，对各个故障模式进行危害度排序，从中找出关键故障模式作为改进的重点，以此来提高系统的可靠性。通过对比表明，改进后的方法有效弥补了传统 FMECA 分析方法的不足，更易找出关键故障模式，为实际应用提供理论依据。

INTRODUCTION
The reliability of agricultural machinery has an important impact on the quality of agricultural operations, production efficiency, maintenance costs, and user benefits. With the increasing degree of digitisation, automation and intelligence of agricultural machinery, the system structure tends to be complex, resulting in the possibility of potential failures be also increasing, and the reliability of agricultural machinery products has also attracted attention *(Yang et al., 2021)*. In 2022, the Department of Agricultural Mechanisation Management of the Ministry of Agriculture and Rural Development organised a quality survey of some in-use grain combine harvesters for harvesting wheat, and the results of the survey showed that fatal failures and serious failures of these implements in the course of their work mainly occurred in the threshing and clearing system, the engine system, and the travelling undercarriage system, with the highest frequency of failures occurring in the threshing and clearing system.

Threshing and cleaning system is the key part of combine harvester to complete crop harvesting, and its working stability and working effect directly affect the quality of crop harvesting. With the improvement of agricultural production level, people's threshing performance requirements for combine harvester is also higher and higher, its structure is more and more complex, the reliability is more unstable. Therefore, it is of great significance to analyse the reliability of the threshing and cleaning system, grasp its working status, analyse its weak links and optimise it to improve the working quality of the whole machine.

Failure Mode, Effects and Criticality Analysis (FMECA) is a common method of product reliability analysis, by analysing all potential failure modes and their possible impact on the system of each constituent unit of the product (components, assemblies, sub-systems, systems) and classifying each failure mode according to its severity, detection difficulty and probability of occurrence. The weak links and key components in the design can be identified, and the corresponding measures can be taken to prevent or improve them, in order to reduce or eliminate the probability of failures, and thus improve the reliability of the product *(Zhu, 2022; Zhang et al., 2019)*.

Currently, the FMECA analysis method is widely used in aerospace, automotive, machinery and other fields. Shao Weigui draws the hazard matrix diagram of the failure modes of the aircraft front landing gear system through the FMECA analysis method, combines with fuzzy mathematical theory, determines the hazard degree level of each failure mode, finds the weakness of the system, and proposes the corresponding maintenance measures in order to reduce the failure rate *(Shao, 2019)*. Brahim I.B. et al constructs the Bayesian network structure through the FMECA method, and the automobile industry Example analysis is carried out to verify the applicability of the method in the industrial environment *(Brahim et al., 2020)*. Zou Jinglian carried out failure mode impact and hazard analysis of diesel engine subsystems through FMECA analysis method, effectively identified the weak links in the process of diesel engine use, and proposed corresponding optimization methods *(Zou, 2011)*. Hu Qiguo et al analysed the reliability of the hydraulic system of amphibious armoured vehicle by improving the FMECA method, and the analysis results show that the reasonable use of FMECA method can effectively find out the key failure modes of the hydraulic system *(Hu et al., 2017)*.

Reliability analysis through the traditional FMECA method can find the weak links in product design or use in a timely manner, but with the continuous development of reliability analysis methods, people would like to get quantitative assessment results through the analysis, and then the traditional FMECA method would show its shortcomings.

Traditional FMECA analysis defines the risk level of each failure mode by using the Risk Priority Number (RPN), where the higher the RPN value, the higher the risk level of the failure (*Singh et al., 2019*). The RPN of a particular failure mode is equal to the product of the Effect Severity Rating (ESR) of the failure, the Occurrence Probability Rating (OPR) of the failure, and the Difficulty of Detection Rating (DDR) of the failure, that is:

$$RPN = ESR \times OPR \times DDR \tag{1}$$

ESR, OPR, and DDR are classified according to levels, and their levels are usually described qualitatively using fuzzy language such as high, low, size, and difficulty, and the assignment of levels is not fuzzified, so it is highly subjective. In addition, traditional FMECA has the following problems *(Liu et al., 2013; Yu & Zhang, 2022; Hu et al., 2018)*.

(1) There is no consideration of the relative importance between the severity of the fault, the probability of occurrence, and the difficulty of detection.
(2) Different combinations of ESR, OPR, and DDR may produce exactly the same RPN value, at which point the risk priority number is the same, but the potential risk posed by the different combinations will vary.

In order to overcome the above problems of traditional FMECA, scholars at home and abroad adopt various methods such as Fuzzy Mathematics, Grey Theory, Analytic Hierarchy Process (AHP) and so on to improve traditional FMECA *(Xu et al., 2022)*. Dai Chengguo et al. cited the fuzzy comprehensive evaluation method to improve the traditional FMECA, and analysed it by establishing the factor set, evaluation set, and weight set to give more relevant assessment results *(Dai et al., 2011)*. Taking into account the interactions between different factors, Chen Yuan used AHP to determine the distribution of weights among factors based on the citation of fuzzy comprehensive evaluation. Wang Hao et al. based on the FMECA analysis method, combined with the third-order conversion function, and modified on the traditional hazard degree calculation method *(Wang et al., 2017)*. Zhang Haoran et al. introduced "Trapezoidal Fuzzy Number" to transform the evaluation language into fuzzy probability, and the fuzzy probability was homogenised, defuzzified and normalised to obtain specific values, and then ranked the hazards of each failure mode *(Zhang et al., 2020)*. Zhu Xiaocui Application of gray theory to comprehensive cluster assessment of reliability and repairability of CNC machine tools as a way to reduce the subjectivity of expert assessment results *(Zhu, 2013)*. HA Khorshidi aggregates subjective data on failure modes and causes through the system to develop an Overall Failure Index (OFI), which is used to represent the reliability behaviour of the system and prioritize the adoption of corrective actions (*Khorshidi et al., 2016*). Shoaib Ahmed et al. developed a fuzzy logic system using a rule-based fuzzy set approach, which was modelled and tested using different types of membership function in order to compute the corresponding risk values for assessing their potential failure impact *(Ahmed, 2020)*.

Fuzzy comprehensive evaluation method is a comprehensive evaluation method based on fuzzy mathematics, which transforms qualitative evaluation into quantitative evaluation according to the relevant theories of fuzzy mathematics.

It is characterised by clear and systematic results and can effectively solve problems that are difficult to quantify *(Zhang & Wang, 2016; Chai et al., 2011)*. Therefore, combining the two methods to form the FMECA analysis method based on fuzzy comprehensive evaluation can quantify the evaluation opinions of experts, reduce the subjectivity of personal evaluation, and determine the weights between the factors through AHP, so as to make the evaluation results more objective and practical, and effectively improve the shortcomings of the traditional FMECA method.

This paper mainly focuses on the reliability analysis of corn harvester threshing and cleaning system by introducing the fuzzy comprehensive evaluation method on the basis of the traditional FMECA method, and effectively identifies the weak links in the design by calculating the hazard level coefficient to rank the hazard degree of each failure mode. The results show that this method effectively makes up for the shortcomings of the traditional FMECA method. In practical application, it has practical application value for the design and maintenance of the components of combine harvester threshing and cleaning system, and provides theoretical reference for improving the reliability of combine harvester.

MATERIALS AND METHODS

Traditional FMECA for threshing and cleaning system

Fuzzy FMECA is the introduction of the idea of fuzzy mathematics on the basis of traditional FMECA, so the threshing and cleaning system is first analysed by traditional FMECA. The steps of the traditional FMECA analysis method are shown in Figure 1.

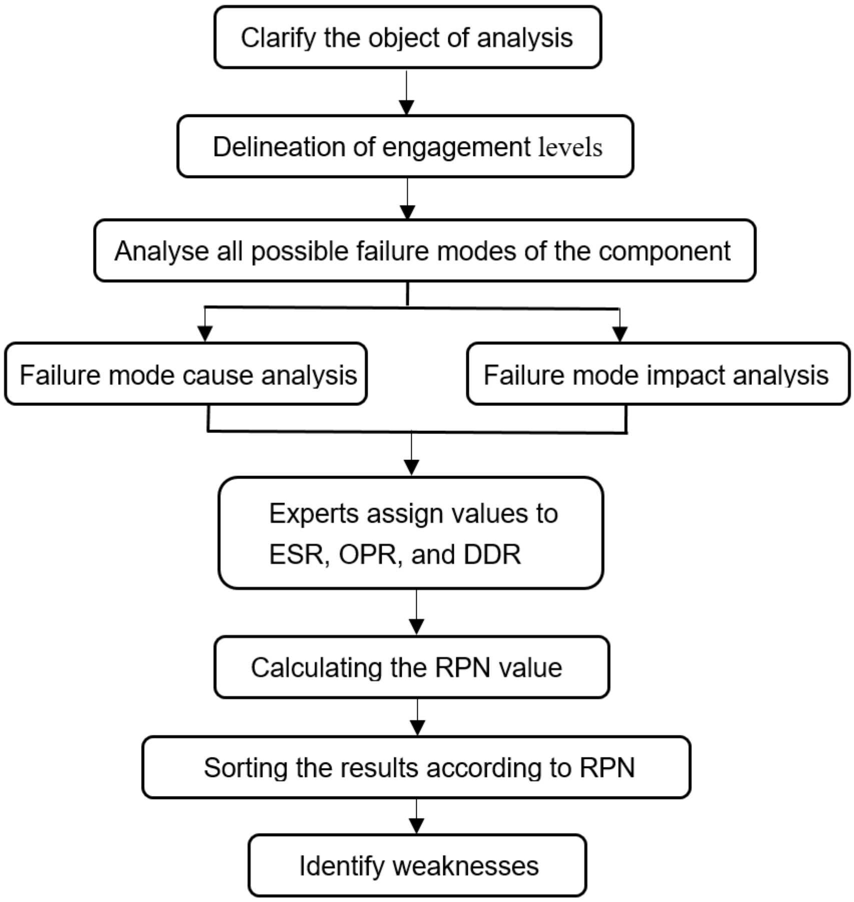

Fig. 1 – The Steps of Traditional FMECA

Wheat combine harvester threshing and sorting system contains threshing separation and sorting two parts, the main components are threshing drum, concave plate sieve, sorting fan, sorting sieve, shaking plate, etc. The FMECA method analysis is based on the smallest unit of the system, bottom up to analyse the potential failure modes of the units and their possible impact on the system, so first of all, the threshing and sorting system is divided into the agreed level, the results of the division are shown in Figure 1. According to the lowest level of agreement in Figure 2, the faults are analysed, the causes and effects of the faults are explored, and the FMECA analysis table is finally obtained, as shown in Table 1.

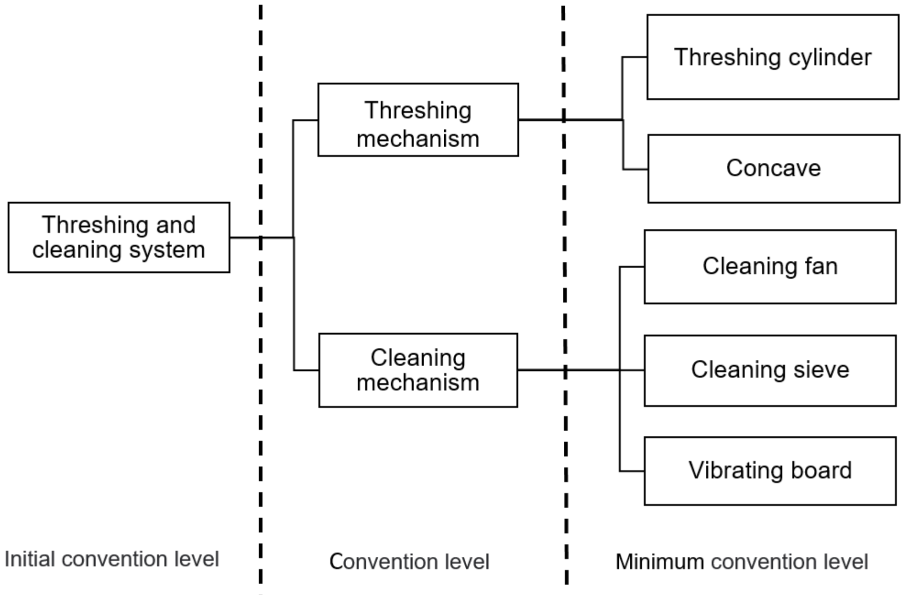

Fig. 2 - Conventional layer classification (Part)

Table 1

FMECA analysis of threshing cleaning system (Part)

Minimum convention level	Serial number	Failure mode	Failure cause	Failure effect		
				Local effect	Higher level influence	Ultimate effect
Threshing cylinder	1	Threshing failure (Threshing is not clean)	The roller speed is low, the grain rod is seriously worn, the grain feeding amount and the threshing gap is too large.	Functional decline	Functional decline	Threshing is not clean
	2	Clogging	The crop moisture content is high, the engine speed is low, the crop feeding amount is too large, the threshing gap is too small, and the transmission belt is slipping.	Loss of function	Loss of function	Cannot work
	3	High seed breakage rate	The roller speed is too high and the threshing gap is too small	Functional decline	Functional decline	Threshing effect descend
	4	Threshing drum abnormal sound	Uneven feeding, bolt loosening or falling off, foreign matter into the roller.	Functional decline	Functional decline	Abnormal work
Concave	5	Abrasion and distortion	Excessive feeding	Functional decline	Functional decline	Abnormal work
Cleaning fan	6	Large fan vibration	Fan and foundation connection is not strong, fan hub wear.	Functional decline	Functional decline	Abnormal work
Cleaning sieve	7	Screen clogging	The opening of the screen is small, the amplitude or inclination does not meet the requirements, and the fan air volume is small.	Loss of function	Loss of function	Cannot work
Vibrating board	8	Breakage	Excessive feeding	Loss of function	Loss of function	Cannot work

Based on ESR, OPR, and DDR scoring guidelines *(Tang et al., 2022)*, combined with the combine harvester threshing and cleaning system failure modes, failure causes and failure impacts in Table 1, 10 relevant experts were invited to assess and assign values to the severity, occurrence probability, and detection difficulty level of each failure mode, and the RPN value was obtained from the product of these three influencing factors, and the calculation results are shown in Table 2.

Table 2

RPN values for each failure mode in traditional FMECA

Minimum convention level	Failure mode	ESR	OPR	DDR	RPN
Threshing cylinder	Threshing failure（Threshing is not clean）	4	3	6	72
	Clogging	6	3	5	90
	High seed breakage rate	5	3	6	90
	Threshing drum abnormal sound	1	5	2	10
Concave	Abrasion and distortion	4	2	6	48
Cleaning fan	Large fan vibration	2	5	3	30
Cleaning sieve	Screen clogging	6	5	6	180
Vibrating board	Breakage	5	1	6	30

As can be seen from Table 2, the traditional FMECA analysis method has a large human subjectivity in the weight allocation of ESR, OPR and DDR, and the calculated RPN values of failure mode 2 and failure mode 3 are both 90, and the RPN values of failure mode 6 and failure mode 8 are both 30, and for such cases with the same RPN values, it is then impossible to correctly rank their specific hazard levels. At this point, the risk priority order of each failure mode cannot be obtained by the traditional FMECA analysis method, which also proves that the traditional FMECA analysis has the problem of low accuracy.

Fuzzy FMECA for threshing and cleaning system

Fuzzy comprehensive evaluation refers to the process of applying fuzzy mathematical ideas to judge complex systems that are not easy to quantify through survey sampling and accumulation of relevant data *(Wang et al., 2021; Zhao et al., 2018)*.

In order to make the evaluation results more scientific and accurate, the fuzzy comprehensive evaluation method is introduced to analyse the reliability of the threshing and cleaning system. On the basis of the traditional FMECA analysis of threshing and cleaning, fuzzy comprehensive evaluation is carried out for each failure mode, and the evaluation results are quantified to rank the hazard level of the failure modes.

The steps of fuzzy FMECA are shown in Figure 3, and the steps of fuzzy comprehensive evaluation are shown in Figure 4.

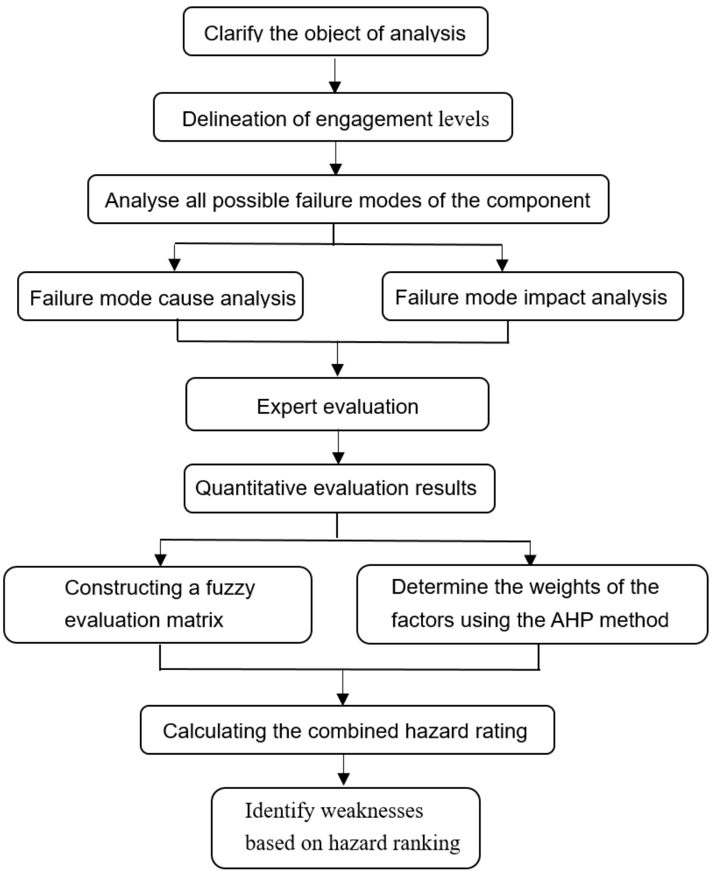

Fig. 3 – The steps of Fuzzy FMECA

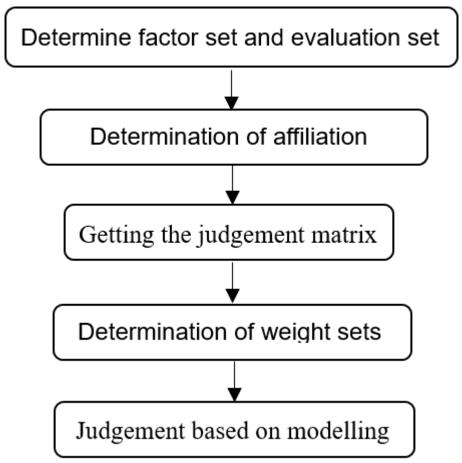

Fig. 4 – The steps of Fuzzy Comprehensive Evaluation

Build a factor set U

A factor set is a collection of factors that affect the object of evaluation, with different elements within the set representing different influences. Factors affecting the reliability of the threshing and cleaning system are the frequency of faults, the degree of fault impact, the difficulty of fault detection, and the difficulty of fault maintenance, so the set of factors U is constructed, that is, U = {Fault frequency (u_1), Fault influence degree (u_2), Fault detection difficulty (u_3), Fault maintenance difficulty (u_4)}.

Create an evaluation set V

The evaluation set is a collection of expert evaluation results, and each element in the set represents the grade of the evaluation results, which is represented by V, that is, $V=\{v_1, v_2, v_3, v_4, v_5\}=\{1,3,5,7,9\}$, and the specific grading and assignment of each influence factor is shown in Table 3.

Table 3

Grade definition of each influencing factor

Factor	Grade				
	1	2	3	4	5
Fault frequency	Very low frequency	Lower frequency	Medium frequency	High frequency	Very high frequency
Fault influence degree	Slight effect	Lower impact	Medium impact	Have a great effect	Influence seriously
Fault detection difficulty	Easy to detect	Easier to detect	Moderate detection difficulty	Harder to detect	Cannot detect
Fault maintenance difficulty	Easy to maintain	Easier to maintain	Moderate maintenance difficulty	Harder to maintain	Cannot repair

The fuzzy evaluation matrix is established

(1) Single factor evaluation

Before carrying out the comprehensive evaluation, a single-factor evaluation is carried out to determine the single-factor evaluation set. In the fuzzy comprehensive evaluation of a certain failure mode, let the i^{th} influencing factor u_i in the factor set have an affiliation degree of r_{ij} to the evaluation level v_j. The single-factor evaluation set of influencing factor u_i is:

$$r_i=\{ r_{i1},r_{i2} ,\cdots,r_{im} \} \tag{2}$$

In carrying out the evaluation, "a" experts are usually invited to form an evaluation group, and each member of the evaluation group evaluates each failure mode separately, and determines the evaluation level v_j of the influence factor u_i. If there are a_{ij} people among the a experts who evaluate u_i to be subordinate to v_j, then the set of experts' evaluations R_i is obtained, that is:

$$R_i=\{\frac{a_{i1}}{a} , \frac{a_{i2}}{a} , \cdots, \frac{a_{ij}}{a} , \cdots, \frac{a_{im}}{a}\}= \{ r_{i1},r_{i2},\cdots,r_{ij},\cdots, r_{im}\} \tag{3}$$

where: $\sum_{j=1}^{m}\frac{a_{ij}}{a} = 1$

(2) Establish a fuzzy comprehensive evaluation matrix

The single-factor evaluation set for each failure mode is used as the rows in the matrix to construct a fuzzy comprehensive evaluation matrix of the influencing factors, denoted by R, that is:

$$R=[R_1R_2, \ \dots, \ R_n]^T = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{4}$$

Taking the drum threshing fault as an example, from equation (3), it can be seen that the evaluation results of the expert group for this fault mode can be obtained after the fuzzification process, and the fuzzy comprehensive evaluation matrix of the fault mode 1 can be obtained as:

$$R_1= \begin{bmatrix} 0.2 & 0.3 & 0.5 & 0 & 0 \\ 0 & 0 & 0.3 & 0.7 & 0 \\ 0 & 0.4 & 0.5 & 0.1 & 0 \\ 0 & 0 & 0.4 & 0.6 & 0 \end{bmatrix}$$

Establishment of factor weight sets W based on AHP

The weights reflect the relative importance of an influencing factor in the overall evaluation, and since the relative importance of each influencing factor is different, it is necessary to assign different weights to each factor in order to establish the factor weight set W.

There are many methods to determine weight distribution, mainly including expert scoring method, entropy weight method, AHP etc. *(Dai et al., 2023)*. This paper uses the AHP method. AHP divides the problem into different factors according to its own knowledge or experience and the overall goal, build a pairwise comparison matrix of different levels for each factor, and make pairwise comparison, and grades the factors according to their importance *(Hu et al., 2021)*, the importance of which is defined in Table 4.

Table 4

Grade definition of each influencing factor

Scale a_{ij}	**Meaning**
1	Equally important
3	Slightly important
5	Obviously important
7	Strongly important
9	Extremely Important
2,4,6,8	Between the above two adjacent scale values

The analysis process of this method is as follows:

(1) Construct the judgement matrix A. The element a_{ij} in the matrix is the value indicating the relative importance of u_i to u_j, namely:

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (5)$$

The judgement matrix A is normalised to obtain the eigenvector ω and the maximum eigenvalue λ_{max} is calculated, that is:

$$\lambda_{max}=\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \quad (6)$$

(2) The consistency test was then performed and the consistency indicator CI value was calculated, that is:

$$CI=\frac{(\lambda_{max}-n)}{(n-1)} \quad (7)$$

The RI value is the average stochastic consistency index of the judgement matrix, which is the standard value, and the RI values of the 1st to 13th order judgement matrices are shown in Table 5.

Table 5

The standard value of average random consistency index RI

Order of matrix	1	2	3	4	5	6	7	8	9	10	11	12	13
Value of RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54	1.56

Based on the equation (7) and table 5, the consistency ratio CR is calculated, that is:

$$CR=\frac{CI}{RI} \quad (8)$$

Finally, the calculated CR value is compared with 0.1, if CR < 0.1, it proves that the consistency test of the judgement matrix passes, otherwise the judgement matrix should be modified. When the consistency test of the judgement matrix passes, the ω obtained after the normalisation process is used as the weighting coefficient W_k of the factor set, that is:

$$W_k=\{\omega_1, \omega_2, \cdots, \omega_n\} \quad (9)$$

The drum threshing fault is illustrated as an example of the process of determining the weights through AHP. According to the expert group assessment, the relative importance of each influencing factor of the drum threshing fault can be obtained, which is shown in Table 6.

Table 6

Relative importance of each influencing factor

Influence factor	u_1	u_2	u_3	u_4
u_1	1	$\frac{1}{3}$	5	6
u_2	3	1	7	9
u_3	$\frac{1}{5}$	$\frac{1}{7}$	1	1
u_4	$\frac{1}{6}$	$\frac{1}{9}$	1	1

After normalisation, the final fuzzy judgement matrix and weights can be obtained, as shown in Table 7.

Table 7

Relative importance and weight of each influencing factor

Influence factor	u_1	u_2	u_3	u_4	w_i	Aw_i
u_1	0.23	0.21	0.36	0.35	0.2873	1.1777
u_2	0.68	0.63	0.50	0.53	0.5849	2.4561
u_3	0.05	0.09	0.07	0.06	0.0676	0.2682
u_4	0.04	0.07	0.07	0.06	0.0596	0.2400

The maximum eigenvalue λ_{max} can be calculated from equation (6) as 4.07, and the consistency index CI is 0.02 from equation (7), and by checking table 5, it can be seen that the RI is 0.89 in this paper.

Finally, the consistency ratio CR is calculated as 0.0276 by equation (8), and this value is less than 0.1 and the consistency test is passed. Therefore, the set of factor weights for drum threshing failure is as follows:

$$W_1 = \{0.2873,\ 0.5849,\ 0.0676,\ 0.0596\}$$

First-level fuzzy comprehensive evaluation

The fuzzy comprehensive evaluation matrix B_k for failure mode k is the multiplication of the factor weight vector W_k for failure mode k with the level evaluation matrix R_k for failure mode k, that is:

$$B_k = W_k R_k \tag{10}$$

This shows that the first level fuzzy comprehensive evaluation matrix for drum threshing faults is as follows:

$$B_1 = W_1 R_1 = [0.0575,\ 0.1132,\ 0.3768,\ 0.4520,\ 0] \tag{11}$$

Calculation of comprehensive hazard grade index

The comprehensive hazard grade index C_k of failure mode k is equal to its composite fuzzy evaluation matrix B_k multiplied by the evaluation set V^T, namely:

$$C_k = B_k V^T \tag{12}$$

where: V^T is the evaluation matrix.

In the case of drum threshing failure, for example, the combined hazard rating is:

$$C_1 = B_1 V^T = 5.4446 \tag{13}$$

The same procedure was used to determine the fuzzy evaluation matrix for failure modes 2 to 8, respectively:

$$R_2=\begin{bmatrix}0.1 & 0.2 & 0.6 & 0.1 & 0\\ 0 & 0 & 0.1 & 0.6 & 0.3\\ 0 & 0.3 & 0.6 & 0.1 & 0\\ 0 & 0 & 0.3 & 0.7 & 0\end{bmatrix}$$

$$R_3=\begin{bmatrix}0 & 0.2 & 0.5 & 0.3 & 0\\ 0 & 0.1 & 0.3 & 0.6 & 0\\ 0.1 & 0.4 & 0.5 & 0 & 0\\ 0 & 0.1 & 0.4 & 0.5 & 0\end{bmatrix}$$

$$R_4=\begin{bmatrix}0 & 0.1 & 0.3 & 0.5 & 0.1\\ 0 & 0.3 & 0.7 & 0 & 0\\ 0.1 & 0.6 & 0.3 & 0 & 0\\ 0 & 0.2 & 0.4 & 0.4 & 0\end{bmatrix}$$

$$R_5=\begin{bmatrix}0.2 & 0.5 & 0.3 & 0 & 0\\ 0 & 0.2 & 0.5 & 0.3 & 0\\ 0 & 0.2 & 0.5 & 0.3 & 0\\ 0 & 0.4 & 0.4 & 0.2 & 0\end{bmatrix}$$

$$R_6=\begin{bmatrix}0 & 0.1 & 0.4 & 0.5 & 0\\ 0 & 0.3 & 0.6 & 0.1 & 0\\ 0.1 & 0.5 & 0.4 & 0 & 0\\ 0 & 0.3 & 0.4 & 0.3 & 0\end{bmatrix}$$

$$R_7=\begin{bmatrix}0 & 0 & 0.2 & 0.7 & 0.1\\ 0 & 0 & 0.2 & 0.7 & 0.1\\ 0 & 0.3 & 0.5 & 0.2 & 0\\ 0 & 0 & 0.3 & 0.6 & 0.1\end{bmatrix}$$

$$R_8=\begin{bmatrix}0.1 & 0.6 & 0.3 & 0 & 0\\ 0 & 0.2 & 0.4 & 0.4 & 0\\ 0 & 0.2 & 0.4 & 0.4 & 0\\ 0 & 0.1 & 0.5 & 0.4 & 0\end{bmatrix}$$

In this paper, since the relative importance of the factors affecting each failure mode is the same, the same set of weights W is used, that is:

$$W=\{0.2873,0.5849, 0.0676,0.0596\}$$

According to formula (10) and formula (12), the fuzzy comprehensive evaluation matrix B_k and the comprehensive hazard coefficient C_k can be calculated for failure modes 2 to 8, respectively:

$$B_2=[0.0287 \quad 0.0777 \quad 0.2893 \quad 0.4282 \quad 0.1755]$$

$$C_2=6.2848$$

$$B_3=[0.0068 \quad 0.1490 \quad 0.3768 \quad 0.4669 \quad 0]$$

$$C_3=5.6059$$

$$B_4=[0.0068 \quad 0.2567 \quad 0.5397 \quad 0.1675 \quad 0.0287]$$

$$C_4=4.9065$$

$$B_5=[0.0575 \quad 0.2980 \quad 0.4363 \quad 0.2077 \quad 0]$$

$$C_5=4.5865$$

$$B_6=[0.0068 \quad 0.2559 \quad 0.5167 \quad 0.2200 \quad 0]$$

$$C_6=4.8982$$

$$B_7=[0 \quad 0.0203 \quad 0.2261 \quad 0.6598 \quad 0.0932]$$

$$C_7=6.65$$

$$B_8=[0.0287 \quad 0.3088 \quad 0.3770 \quad 0.2848 \quad 0]$$

$$C_8=4.8340$$

According to the comprehensive hazard index, the hazards of failure modes 1 to 8 are, in descending order, as follows: failure mode 5, failure mode 8, failure mode 6, failure mode 4, failure mode 1, failure mode 3, failure mode 2, and failure mode 7. By analysing the historical failure data, it is found that the results of this judgement are in line with the situation in actual use.

RESULTS

By comparing the results of traditional FMECA analysis with the results of fuzzy FMECA analysis, it can be seen that in the traditional FMECA analysis method, the relative importance of the three influencing factors of ESR, OPR and DDR is not considered, and the assignment of the value is not fuzzy, so that different failure modes get the same RPN value, and then it is not possible to rank them in terms of their hazard degree. After the introduction of fuzzy comprehensive evaluation, the weights of each influencing factor are assigned and the expert scores are processed using fuzzy mathematical methods to obtain more accurate hazard level coefficients, which can effectively rank the risk level of each failure mode, so as to find out the weaknesses and make up for the shortcomings in the traditional FMECA analysis.

CONCLUSIONS

(1) In this paper, on the basis of traditional FMECA, the fuzzy comprehensive evaluation method is introduced to quantify and analyse the evaluation results and reduce the influence of subjective evaluation of experts on the results. At the same time, AHP is used for weight allocation, two-by-two comparisons are made between the influencing factors of the failure modes, a judgement matrix is constructed to determine the relative importance of the factors, and the failure modes are ranked by calculating the hazard level index, which effectively compensates for the shortcomings of the traditional FMECA, and makes the evaluation results more scientific and in line with the reality.

(2) This paper takes the threshing and cleaning system of wheat combine harvester as an example, and carries out reliability analysis based on the improved FMECA method, and finally concludes that failure mode 7 has the greatest degree of harm, followed by failure mode 2, which can be used as the focus of reliability improvement and provide a theoretical basis for practical production application. According to the results of reliability analysis, the weak links of the system can be identified, and the system can be checked before operation to reduce the failure rate during operation, thus improving the reliability of the system as well as the service life of the whole machine.

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