RELIABILITY ANALYSIS OF GRAIN COMBINE HARVESTERS BASED ON DATA MINING TECHNOLOGY
/
基于数据挖掘技术的谷物收获机割台可靠性分析

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ABSTRACT
With the rapid development of agricultural modernization, the reliability of agricultural machinery had become the key to improving the development level of agricultural machinery and equipment in China. Aiming at the problems of subjectivity, fuzziness, high test cost and difficult data acquisition in the Failure Mode, Effects and Criticality Analysis of grain harvester, an FMECA analysis method based on Data Mining Technology was proposed in this paper. In this study, Python 3.7.8 is used to collect and process the fault data of the header of the grain harvester. According to the data analysis, it is concluded that the fault rate of the cutter component is the highest in the whole system. Then the agreed hierarchy of header was analyzed by Analytic Hierarchy Process, and it was concluded that the blade part failure mode was the most hazardous. The results show that the grain harvester should strengthen the inspection and maintenance of the blade of the cutter in the working process. The research results showed the feasibility of the FMECA method based on Data Mining Technology in agricultural machinery reliability analysis, which opens up a new idea of grain combine harvesters' reliability analysis and provides the possibility to obtain the reliability level of harvesters with low input.

摘要
农业现代化的快速发展使得农业机械可靠性成为提高我国农机装备发展水平的关键。针对故障模式、影响及危害性分析在谷物收获机可靠性分析中存在的主观性、模糊性、试验成本高以及数据获取困难等问题，本文提出一种基于数据挖掘技术的FMECA分析方法。该研究通过Python3.7.8对谷物收获机割台故障数据进行采集处理，根据数据分析得出割刀部件在整个系统中故障率最高。然后通过层次分析法对割刀部件进行约定层次分析，得出刀片部分故障模式危害性最大。研究结果表明，谷物收获机在工作过程中应加强对割刀的刀片的检修及保养。该研究表明了基于数据挖掘技术的FMECA方法在农业机械可靠性分析的可行性，该分析方法开拓了谷物收获机可靠性分析新思路，为低投入获取收获机可靠性水平提供了可能。

INTRODUCTION
At present, China's agricultural machinery has the phenomenon of low-level replication, homogenization and serious competition. China unveiled its "No. 1 central document" for 2022 on Feb. 22, which pointed out that it is necessary to improve the level of agricultural facilities and equipment, develop agricultural equipment to fill the weak demand directory and action plan. The low reliability of agricultural machinery had also become the main weakness that restricts the development of agricultural machinery. Take grain combine harvesters as an example, they are widely used in the Chinese market and have a complex structure, and their reliability requirements are even more stringent due to the harsh working environment and tight harvesting time. Most Chinese companies only conducted simple industrial assessment tests, and the reliability level was difficult to assess due to the limited test vehicles and test time and the lack of accurate and reliable test data (*Yang et al, 2021*).

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The grain combine harvesters' industry is developing toward intelligence, digitalization and informatization with the Big Data era. The increasing amount of data provides data support for grain combine harvester's reliability analysis and makes data processing a significant part of reliability analysis. Due to the increasing amount of FMECA data for grain combine harvesters, it is laborious to obtain and filter accurate and reliable data by adopting the traditional FMECA list for data output, and the reliability analysis results are single and random due to over-reliance on expert experience. In response to these problems, some scholars *(Pavlyuk R V et al, 2022)* comprehensively assessed the reliability level of machine maintenance by calculating the failure rate of each faulty component of the grain harvester. Some scholars (*Zhou et al, 2015*) used FMECA results as knowledge sources and used Data Mining Technology to extract shallow knowledge and deep knowledge. It was made use of the ontology model by the OWL and the domain rules were established by SWRL.

Ontology models and domain rules are combined to build diagnostic reasoning for engine execution, obtaining fault causes and diagnostic decisions. By improving the risk matrix diagram in the FMECA method, some scholars (*Wang et al, 2021*) combined the probability of risk occurrence and severity level into a two-dimensional plane coordinate system to form a matrix diagram. It combines Data Mining Technology and Visualization Technology to quickly identify the problems in the equipment. Some scholars (*Zhou et al, 2010*) improved FMECA by using a fuzzy comprehensive evaluation method for system reliability analysis, which made the evaluation results more scientific and accurate. Some scholars (*Zhao et al, 2021*) incorporated big data into the reliability testing of automotive drive systems and adopted the Markov Chain Monte Carlo method to construct reliability test loading spectrum for the reliability analysis of electric vehicle drive systems. The above research has validity in the reliability analysis of critical components, but there are still problems such as subjectivity, ambiguity, and high economic cost.

In order to solve the problems of subjectivity, ambiguity and high economic cost in the reliability analysis of grain combine harvesters, this paper adopts the Failure Mode, Effects and Criticality Analysis to investigate the reliability of header components. Use Python Programming Language to collect FMECA data list, establish an FMECA risk ring diagram of grain combine harvesters according to the collected fault mode, and make full use of risk data to make the reliability analysis results of grain combine harvesters more objective and accurate.

This study can provide a reference for improving the health management of the grain combine harvesters industry.

MATERIALS AND METHODS

Introduction to relevant theories

Data Mining Technology refers to finding valuable hidden data by data mining tools that are useful information for the analysis and selection of the Objective market. This paper adopted Data Mining Technology for pattern classification and in-depth analysis of data and established mining models according to the needs of grain combine harvesters' reliability analysis, provided data support for agricultural equipment reliability research (*Feng, 2021*). Data Mining Technology is mainly data cleaning and data visualization. Data cleaning includes checking data consistency, dealing with invalid and missing values, removing duplicate data, and performing data integration (*Luo, 2008*). Data visualization uses computer graphics and image processing techniques to present various types of information in the form of visual images to intuitively display the relationship between data.

Reliability is an important indicator of product quality, the reliability of grain harvesters refers to the ability to complete the required work under the specified conditions and within the specified time (*Feng, 2021*). Research shows that the key to improving product reliability lies in reliability design and analysis. Reliability design starts from product failure and includes four parts: fault prevention, detection of failure, correction of failure, and verification of failure. Reliability analysis methods include failure mode and hazard analysis, fault tree analysis, reliability block diagram, and Markov analysis *(Jiang et al., 2019).* Among them, the failure mode and hazard analysis can analyze all possible failures of the grain harvester, summarize the failure modes of each component, and then determine the hazard according to the severity of the failure mode and the probability of occurrence. It is widely used because of the prescribed analytical procedures (*Jiang et al, 2019*).

At present, the research on the reliability of agricultural machinery at domestic and international level mainly focuses on the Production front-end and studies the probability and causes of failure before the product is put on the market.

This paper takes the part of the harvester with the highest failure rate as an example and conducts reliability research in the order of Failure Mode, Effects and Criticality Analysis.

To address the problems of subjectivity, ambiguity, high test cost and difficulty in data acquisition of traditional FMECA, this paper uses Data Mining Technology to make full use of the existing database information. Origin and Matplotlib are used to draw bar graphs to present failure modes and problem lists of grain combine harvesters more visually. The technical roadmap is shown in Fig.1.

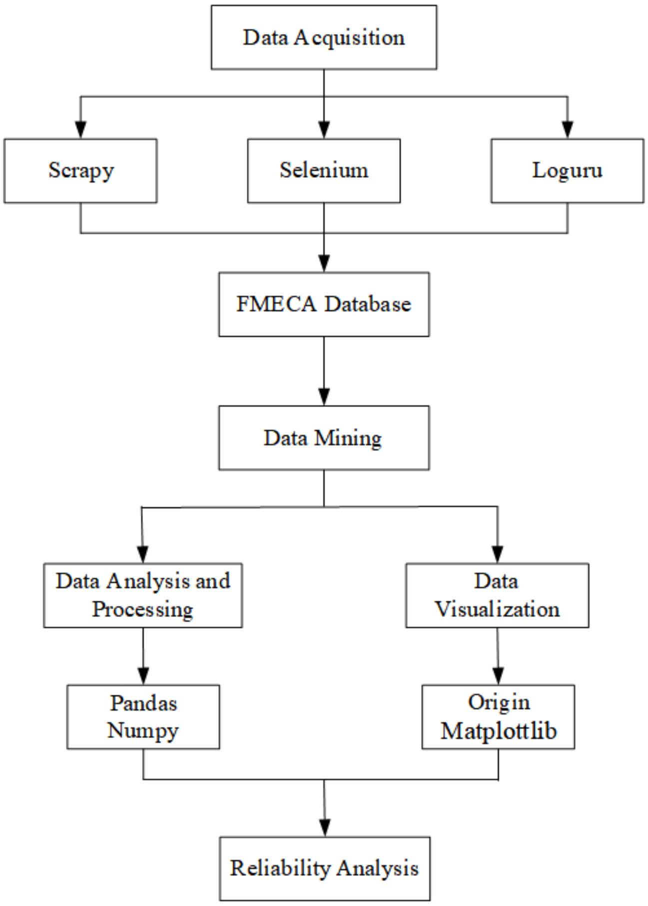

Fig. 1 – Technical route

Firstly, clear header components; Secondly, use Data Mining to collect the list of FMECA faults of the header components and draw the FMECA data ring diagram; Thirdly, use the Risk Assessment Code to calculate the risk index for the header, draw a scatter diagram of the risk assessment level banded classification scatter plot, then conclude that the failure mode of the cutter is the most hazardous. Then use the Analytic Hierarchy Process to analyze the failure mode influence level of the cutter components, and conclude that the blade damage of the cutter components has the most influencing factors.

In order to verify the reliability of the above results, the RiskMatrix is adopted to analyze the header components of the grain harvester again. The study shows that the risk matrix analysis method is consistent with the results obtained from the risk evaluation index and the hierarchical analysis. And the results of the reliability analysis of the grain harvester header components are reasonable.

FMECA data mining and processing of header parts

Header mechanical parts

The header is a crucial working part of the grain combine harvester. Its role is to cut the crop and send it to the threshing device. The header mainly consists of the cutter, the reel, the auger, the frame and the divider, as shown in Fig.2. The articulated shaft connects the header and threshing part, and the hydraulic system controls the lifting of the header (*Geng et al, 2011*).

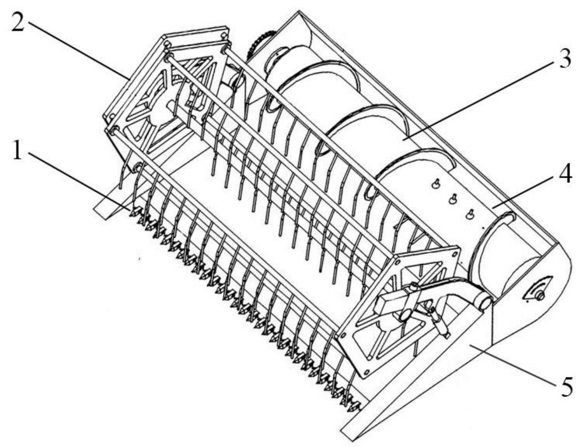

Fig. 2 – Grain harvester cutting table structure

1. Cutter; 2. Reel; 3. Auger; 4. Frame; 5. Divider

Data collection and analysis

Table 1

Data collection information set

Serial number	Data fields
1	Failure mode
2	Cause of failure
3	Effect of failure
4	Severity
5	Failure rate
6	Risk evaluation
7	Basic maintenance measures

Based on clarifying the mechanical structure of the header, the data set was determined based on the data in the FMECA worksheet, as shown in Table 1, and data collection with Python Programming Language. Using Requests to send requests for data acquisition, BeautifulSoup parsing library parses the source code, Xpath for accurate positioning of information, Loguru to achieve data output and save the file as CSV format after data collection.

After data collection, the collected data are pre-processed, mainly including data cleaning, deduplication, and data integration *(Li et al, 2019*). First, select the subset to be analyzed, hide or delete non-essential information in the collection process and supplement the missing data. Secondly, data sorting, summarization, and initial screening are conducted. Ultimately, carry out the unified processing of the collected data. In the data analysis, were used Pandas to process tabular data, Numpy to process numerical data, and the DataFrame method to populate matrix data. Together, they formed a powerful and efficient data analysis environment in Python, which provides hardware support for grain harvester reliability research, with the database shown in Table 2.

Table 2

Database (local)

Product type	Faulty component	Cause of failure	Maintenance measures	Web link
LOVOL GE80S/GE80S-H	Header	Improper operation and too small space between parts during work	Adjust component spacing and installation position	http://www.sohu.com
Harvester	Auger	Blocking	Stop the engine and remove the obstacles	https://zhidao.baidu.com
Harvester	Cutter	The blade press is too tight and the cutter Clearance is too small	Stop the vehicle for inspection and adjust the cutter spacing	https://zhidao.baidu.com

Table 2
(continuation)

Product type	Faulty component	Cause of failure	Maintenance measures	Web link
Zoomlion 4lz-9l self-propelled full feed grain combine	Pin shaft, Tablet pressing Sleeve and Sizing block	Loose parts	Regular inspection	https://b2b-material.cdn.bcebos.com
Rice wheat wormwood grain harvester	Reel paddle	Reel position is too low, resulting in grass entanglement	Adjust the reel position and remove weeds	https://t10.baidu.com
YISGJ rice wheat combine harvester	Header	Blocking	Reduce the walking speed and remove the blockage	https://t11.baidu.com

By pre-processing the database, list all failure modes of the header. Number the failure modes according to a~n, through the accurate extraction and analysis of regular expression, the failure mode and proportion of the grain harvester header are shown in Table 3.

The most frequent causes of blockage of working parts during operation, are a mismatch between the speed of working parts and the forward speed of the grain harvester's header, and breakage of parts due to external forces occurred.

Table 3

Header failure mode and proportion

Serial number	Cause of failure	Proportion (%)
a	Incorrect installation position of working parts	3.80
b	Excessive clearance between parts	5.90
c	The clearance between parts is too small	4.30
d	Reel position too high	3.50
e	Reel position too low	4.20
f	Blocked working parts	19.10
g	The speed of the working parts does not match the forward speed of the machine	12.10
h	The temperature of working parts is too high	2.50
i	Unstable lifting speed of working parts	7.90
j	Belt slip	5.90
k	Cutter failure	8.40
l	Parts aging	4.20
m	Improper operation of staff	8.00
n	Component fracture	10.20

According to the failure mode, the failure caused by the harvesters can divide into four categories: the failure caused by the normal wear of mechanical parts, accidental failure, the failure caused by improper operation during the working process and the failure caused by the machinery not maintained for a long time. For example, as shown in table 4. All faults cause various failure modes of the header.

Table 4

Causes and proportion of header failure

Cause of failure	Proportion (%)
Failure caused by normal wear of mechanical parts	21.70
Accidental failure	18.50
Failure caused by improper operation during the working process	41.60
Failure caused by the machinery not maintained for a long time	18.20

According to the summary classification of failure modes and causes, the maintenance measures for grain harvester header components are mainly in four categories, namely replacing parts, adjusting the spacing and installation position of components, clearing blockages, and strengthening operator training, as shown in Table 5. Because the first two account for a large proportion, we should prepare enough parts.

Table 5

Header maintenance measures and proportion

Maintenance measures	Proportion (%)
Replace parts	24.80
Adjust component spacing and installation position	33.60
Remove the blockage	22.50
Strengthen staff training	19.10

In order to make the header data more intuitive, use Matplotlib3.0.2 to draw the FMECA data ring diagram of header components, as shown in Fig. 3, to provide an intuitive and visual data display for the following reliability analysis.

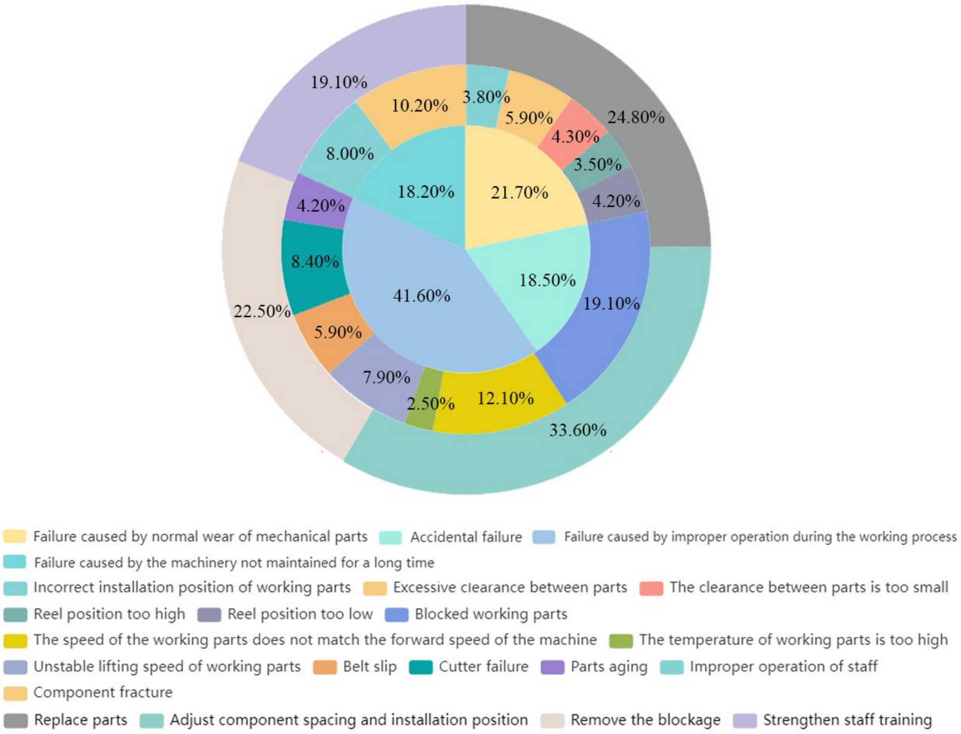

Fig. 3 – Types and percentages of failure modes, causes of failure and repair measures

RESULTS AND ANALYSIS

Failure mode and risk level analysis

The Risk Assessment Code characterizes risk in terms of the possibility of occurrence and the severity of the hazard and allows evaluation of the level of risk and the degree of risk tolerance of the grain harvester header. It is classified according to the possibility and severity of the risk and can be repaired according to the degree of urgency each component has several risk factors, each with different hazard severity and possibility. The formula for calculating the risk level for each risk factor is：

$$C_i = S_i * P_i \tag{1}$$

where: C_i is the risk level of risk factors; S_i - the severity of danger; P_i - the possibility of danger.

Since each risk factor accounts for a different weight (ρ) of its risk, the risk rating of the product is the product of the risk rating and the weight of each risk factor, calculated as:

$$C = \sum_{i=1}^{n} C_i * \rho_i \tag{2}$$

C is the risk assessment index; C_i - risk level of risk factors; ρ_i - weight of risk factors in risk; n - total risk factors of parts.

In order to clarify the hazard index of each component of the grain harvester header, and understand the parts prone to failure and maintenance measures, the risk index refers to the risk index matrix in GJB/Z-1391-2006 "Guide to Failure Mode, Impact and Hazard Analysis" (*Zhao et al, 2022*), as Table 6 shows. Calculate the risk level of each risk component according to Formula (1), determine the risk assessment index C_i with reference to Table 2, and then determine the risk assessment index of the header according to Formula (2), and number the failure modes according to *a~n*, as shown in Table 7.

Table 6

Risk index matrix

Risk assessment index		**Hazard severity rating**			
		I	**II**	**III**	**IV**
Possibility of danger	**A**	1	3	7	13
	B	2	5	9	16
	C	4	6	11	18
	D	8	10	14	19
	E	12	15	17	20

Table 7

Risk assessment index of each failure mode

Number / Time	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**
1	19.8	17	19	10.4	7.1	15	1.1	6	15.2	8	--	6.8	17	6
2	16.5	16.5	17.5	2.9	--	11.8	0.8	10.7	18	2	--	--	--	--
3	15.8	13	12.4	8.5	3	10.5	--	11	3.5	7	19	--	18	15
4	12	5.8	11	--	18	9.7	17	8.2	17	--	4.8	6	--	--
5	2.9	7.9	--	17.9	--	12	16.3	11	2.1	--	17.5	10.8	7.2	8
6	9.1	14.2	9.2	9	14	--	18.2	7.2	16	6.1	--	--	--	--
7	16.5	13	8.1	12.8	--	--	--	3.1	15.7	2.3	1.6	7.2	5.9	6.3
8	7.6	8.8	5.9	15.7	--	--	--	2.8	9	3.6	--	16	12	--
9	3.7	7.1	8.2	13.5	2.6	--	1.5	1	3.7	6.2	--	11.7	3.7	--

According to the principle of risk assessment level processing, risk assessment index 1-5 represents the unacceptable degree from large to small. In order to analyze the failure impact of each failure mode visually, the failure mode is combined with the risk assessment level and a risk level assessment banded classification scatter plot is established with Origin, as shown in Fig. 4.

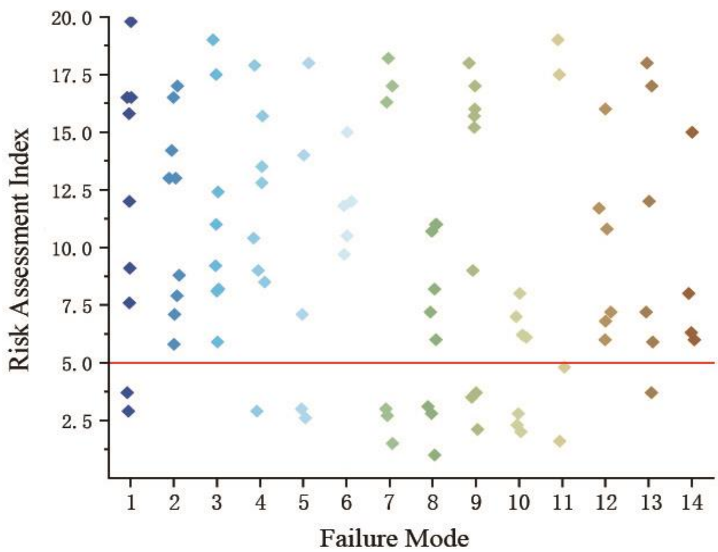

Fig. 4 – Risk assessment level scatter diagram

1. Incorrect component mounting position; 2. Excessive clearance between parts; 3. Too little clearance between parts; 4. Excessively high position of threshing wheel; 5. The position of the threshing wheel is too low; 6. Belt slippage; 7. Blade breakage; 8. Component aging; 9. Clogged working parts; 10. Speed mismatch; 11. Excessive temperature of working parts; 12. Unstable lifting of working parts; 13. Improper operation of staff; 14. Component breakage

As can be seen in Figure 4, most of the risk assessment indices are above 5, but each failure mode has cases with indices below 5, with cutter failures being present most often.

The index of improper adjustment of working parts clearance is above 5, which corresponds to the risk index matrix in Table 6, and it can be concluded that the danger often occurs. The mismatch between the forward speed and the working speed of the header during the working process and the malfunction caused by the improper manual operation is more frequent below 5, which requires timely maintenance or more attention during the working process. The risk indices of many other components are concentrated above 10, and according to Table 6, the possibility of their dangerous occurrence and the danger level is (D, II), which represents the frequent occurrence of failure but low impact of failure. Therefore, the grain harvester should strengthen the optimal design of the cutter components, and pay attention to human-machine cooperation in the harvesting process and timely maintenance.

Fault impact hierarchy analysis

In order to clarify the hazards of harvester cutter failure, firstly, the hierarchy partition of the header was divided using Analytic Hierarchy Process, the influencing elements of each level were analyzed and the weights were calculated, and the factors with greater weights were the factors with greater influence on the problem *(Li,et al,2022).* The convention hierarchy for the grain harvester header is shown in Fig.5.

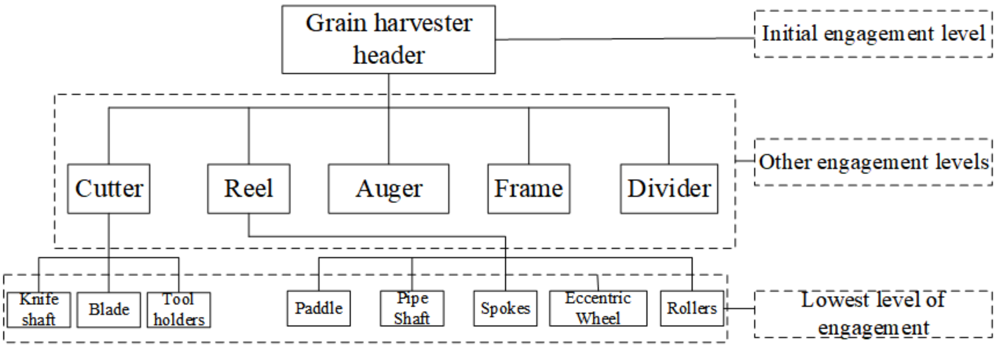

Fig. 5 – Agreed hierarchy diagram of header FMECA analysis

According to the FMECA hierarchy partition diagram of the grain harvester header, the fault influence hierarchy of the cutter components is drawn as shown in Fig.6.

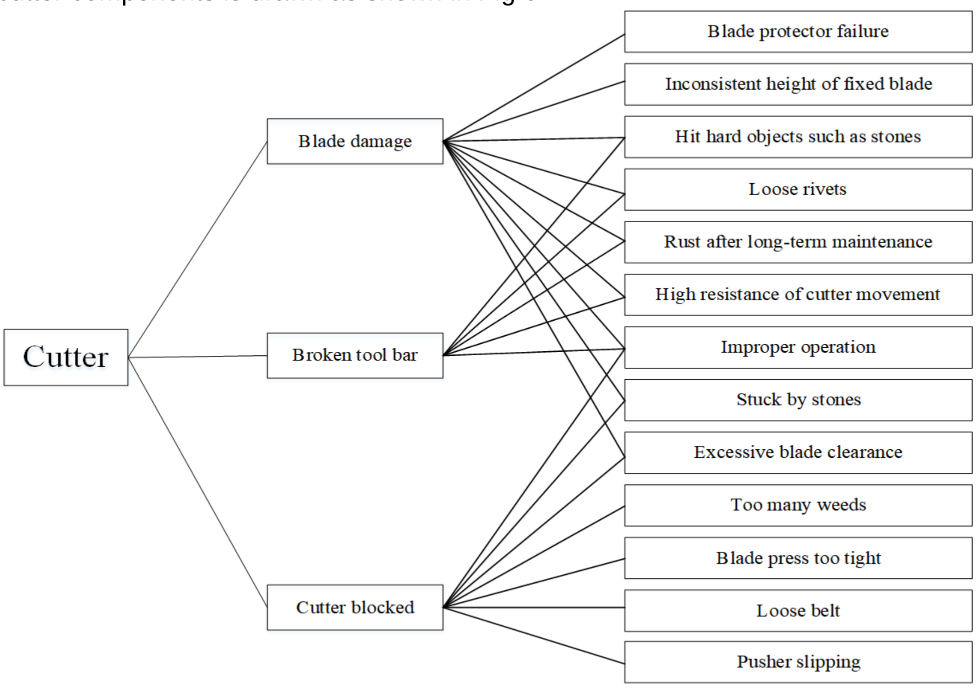

Fig. 6 – Fault influence hierarchy diagram

From the hierarchy diagram of tool module failure, it can be found that the influencing factors leading to blade damage are the most. Combined with the above FMECA ring diagram, it can be seen that the main failure mode leading to failure of the header is cutter failure, and the main manifestation leading to cutter failure is blade damage. Although there are many factors affecting it, it is clear from the risk assessment index scatter diagram that blade damage has a low-risk factor and should be the main target during repair and maintenance.

In order to analyze the rationality of the Risk Assessment Code and the Analytic Hierarchy Process for the reliability study of grain harvester header components, the RiskMatrix was used for validation *(Chen,2021)*. The probability and severity levels of risk occurrence were fused and input into the two-dimensional coordinates to form a risk matrix diagram. In order to make the data more intuitive, use the Matplotlib in the Python library to visualize the data. The axes are divided into two, the horizontal axis is the hazard severity level, and the vertical axis is the possibility of hazard occurrence. Then the number of failure points of risk factors in each failure mode is put into the matrix diagram, and the magnitude of the failure mode hazard is judged according to the color change and the density of the failure point, and the risk matrix diagram is shown in Fig. 7.

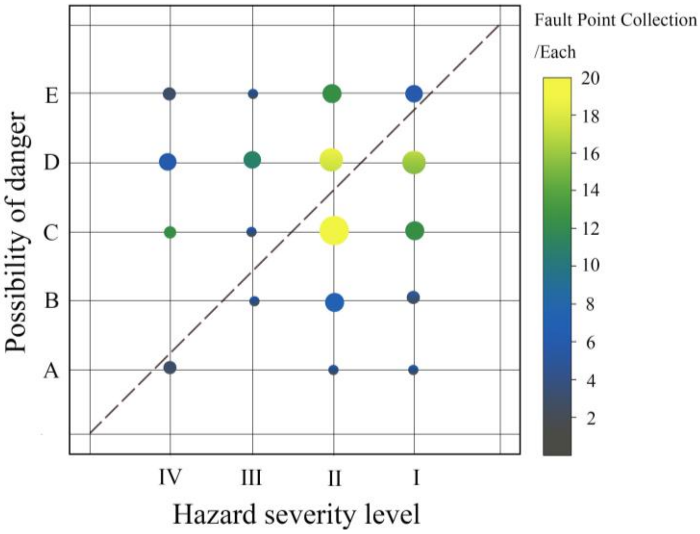

Fig. 7 – Improved risk assessment matrix

According to the matrix diagram, there are three failure modes with hazard occurrence possibility A, in Ⅰ, Ⅱ and Ⅳ respectively. There are a few failure modes with hazard occurrence possibility B. The possibility of hazard occurrence is mainly concentrated in C and D. Among them, the failure modes with severity level Ⅱ and possibility C are the most among all failure modes, and the corresponding risk assessment level is 6. Although the number of fault points in the upper left corner of the dotted line is more than that in the lower right corner, the hazard severity level is concentrated in Ⅰ and Ⅱ, and the possibility of hazard occurrence is concentrated in C, D and E. However, most of the risks are acceptable during the operation of the grain harvester, which is in line with the above analysis results.

CONCLUSIONS

Aiming at the problems existing in the failure mode, influence and hazard analysis of grain harvester reliability analysis, and FMECA analysis method based on data mining techniques are proposed. The method adopted data mining technology to collect the FMECA risk list and used Python for data analysis as well as data visualization to provide ideas for low-cost and high-efficiency analysis of grain harvester reliability.

According to the collected FMECA data, the reliability study of the grain harvester header components was carried out using the Risk Assessment Code and the Analytic Hierarchy Process. By creating a banded scatter plot of the risk assessment levels, it was concluded that the failure modes of the header components were the most hazardous. Using the Analytic Hierarchy Process to complete the fault influence hierarchy diagram of the cutter components, we obtained that blade damage is the main failure cause of header failure. In order to verify the reasonableness of the analysis results, the FMECA data were analyzed using RiskMatrix. It was verified to be generally consistent with the above results.

The reliability analysis method based on Data Mining Technology is in line with the trend of equipment informatization, digitalization and intelligence, and the analysis results are accurate, which greatly improves the efficiency and lays a solid foundation for equipment reliability and safety analysis. This study will follow the development of the grain harvester era and integrate intelligent monitoring and early warning of agricultural machinery into the reliability analysis of agricultural machinery to promote the health management and development of the grain harvester industry while ensuring its efficiency.

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