Generate troubleshooting strategies based on knowledge modeling

V Dimitrov, I Borisova and K Khubiian
Don State Technical University, 1, Gagarin sq, Rostov-on-Don, 344000, Russia

E-mail: kaf-qm@donstu.ru

Abstract. The article discusses the issues of modeling knowledge of troubleshooting in units and systems of a combine harvester. Based on the approach using tables of fault functions, the analysis of the subject area is carried out. As an illustration of the application of the proposed strategy for finding the causes of a malfunction, one of the subsystems of electrical equipment of a modern combine harvester is considered, for which a diagram has been formed to build a structural-logical model. As a result of the analysis of the table of malfunction functions, sets of elementary checks are determined. To find the optimal sequence of elementary checks by the method of analysis of hierarchies, the analysis of the weight of these checks was carried out on the basis of four evaluation criteria. As a result of the calculation, the optimal sequence of checks was determined and a decision tree was built to find the cause of the malfunction in the considered subsystem of electrical equipment. The decision tree is the basis for the formation of the knowledge base of an intelligent information system. A fragment of the developed knowledge base is given.

1. Introduction

The use of information technology on modern combine harvesters is carried out mainly in the direction of:

- Control and regulation of operating modes of the engine and working bodies;
- Measurement and registration of indicators of the harvesting process (the number of harvested areas, moisture and the amount of bunker grain; "operating time" of the engine and other units, etc.;
- Indication of the intensity of losses behind the threshing-separating device (MSU);
- Automatic adjustment of the combine for harvesting a certain crop, automatic regulation of the threshing load, automatic driving (for later models), etc.

However, the diagnosis is implemented in fragments and is performed mainly in the form:

- Standard diagnostics of the engine-power plant. That is, the measurement of the current values of the diagnostic parameters and the fixation of their limit states in the form of messages about non-conformities. In this case, the diagnosis is formed "manually" by a decision-maker (DM), an operator;
- Indication of fault codes (mainly for electrical systems and electronics), which in its essence is just a visualization of an external sign, without converting it into a verbal description. In this case, the decision maker also performs the search for the cause in the "manual" [1-6].

Management of the technical state of modern agricultural machines as mechatronic systems is inextricably linked with the implementation of a large number of diagnostic procedures. Making a diagnosis presupposes the need to process a significant amount of heuristic knowledge. The effectiveness of the implementation of diagnostics is determined by the strategy adopted by the decision maker, and depends on his competence. Consequently, the incompetence of the decision maker can be leveled by the presence of a ready-to-use set of ranked solution search strategies [7-10].

One of the ways to describe the subject area "search for the causes of failures", that is, the formation of a set of strategies, is based on knowledge modeling methods. Therefore, one of the important tasks of building a model is the choice of a formal description of the semantic spaces of the subject area.

Further, when analyzing the subject area, the electrical equipment system of the ACROS 550 combine harvester was considered as the object of diagnostics. The schematic diagram of the subsystem "vertical movement of the reel" is shown in figure 1.

Applying the principle of decomposition, let us single out the final subsystem “vertical movement of the reel” of the electrical equipment of the combine harvester by its functional purpose.

2. Materials and methods

In accordance with [11-12], the state space of the subsystem under study can be represented as a table of fault functions (TFF) (table 1).

It is assumed that: \( \pi_i \) - designation of elementary checks; \( e_i \) - binary value characterizing the technical state of the studied elements of the subsystem (0 or 1); \( R_{ij} \) - test results, the values of which are presented at the intersection of rows \( \pi_i \) and columns \( e_i \).

The structural-logical model describing the cause-and-effect relationships of the elements of the subsystem "vertical movement of the reel" and necessary for constructing the TFF is shown in figure 2. Conditional designations of the subsystem elements correspond to figure 1.

**Table 1.** TFF subsystem of electrical equipment "vertical movement of the reel"
The checks $\pi_j \in P$ are performed in accordance with the system of equations (1) (figure 2).

$$
\begin{align*}
\pi_1 : & \quad z_1 = e_1 \land x_1 \\
\pi_2 : & \quad z_2 = e_2 \land z_1 \\
\pi_3 : & \quad z_3 = e_3 \land z_2 \land x_2 \\
\pi_4 : & \quad z_4 = e_4 \land z_3 \\
\pi_5 : & \quad z_5 = e_5 \land z_4 \\
\pi_6 : & \quad z_6 = e_6 \land z_5 \\
\pi_7 : & \quad z_7 = e_7 \land z_6 \\
\pi_8 : & \quad z_8 = e_8 \land z_7 \\
\pi_9 : & \quad z_9 = e_9 \land z_8 \\
\pi_{10} : & \quad z_{10} = e_{10} \land z_9 
\end{align*}
$$

The problem of determining the minimum set of elementary checks is solved by analyzing the TFF. Comparing in pairs the column $e_0$ with the columns $e_1$, $e_2$, ..., $e_i$ ($i = 1, 2, ..., 10$), we sequentially select the set of states $U_l \in U$, $l = 1, 2, ..., |U|$ described by the conjunction of disjunctions of parameters $z_j = \pi_j \in P$ (2):
In this case, an expression that adequately describes the technical state of the diagnostic object and contains the minimum set of elementary checks, assuming that only any one element of the diagnostic object can be faulty, has the form:

\[
\bigwedge_{i=1}^{10} z_{ai} = \bigwedge_{i=1}^{10} (z_0 \lor z_1 \lor \ldots \lor z_{ai}) \bigwedge_{i=1}^{10} (z_0 \lor z_1 \lor \ldots \lor z_{ai})
\]

\[
U_1 : P_{01} = (z_1 \lor z_2 \lor z_3 \lor z_4 \lor z_5 \lor z_6 \lor z_7 \lor z_8 \lor z_9 \lor z_{10})
\]

\[
U_2 : P_{02} = (z_2 \lor z_3 \lor z_4 \lor z_5 \lor z_6 \lor z_7 \lor z_8 \lor z_9 \lor z_{10})
\]

\[
U_3 : P_{03} = (z_3 \lor z_4 \lor z_5 \lor z_6 \lor z_7 \lor z_8 \lor z_9 \lor z_{10})
\]

\[
U_{55} : P_{55} = (z_{10})_{55}
\]

(2)

3. Results and Discussion

The diagnostic algorithm presented by expression (3) (in the form of a certain sequence of elementary checks) can be refined using the values of the weight of each check obtained on the basis of the hierarchy analysis method (MAI). The MAI hierarchy diagram is shown in figure 3 [13].

![Hierarchy Diagram](image)

**Figure 3.** Hierarchy diagram: K1 – K4 - respectively: element availability; availability of a tool; blockiness of the element; failure rate; P1 - P10 - respectively: fuse FU8.3 is faulty; defective relay KV23; the SA17 key is faulty; defective switch SB4; unit A11 is faulty; unit A14 is faulty; defective relay KV16; the coil of the YA22 electromagnet is faulty; the coil of the YA23 electromagnet is faulty; defective solenoid coil YA26.

Below are the results of calculating the vector of global priorities (table 2) and the refined, in accordance with the calculated priorities, the sequence of elementary checks (3). The definition of the weight of the criteria K1 - K4 relative to each other and the reasons P1 - P10 relative to each other is not given in this article.

**Table 2. Global Priority Vector Values.**

| Causes | P1   | P2   | P3   | P4   | P5   | P6   | P7   | P8   | P9   | P10  |
|--------|------|------|------|------|------|------|------|------|------|------|
| Global priorities | 0.114 | 0.106 | 0.08  | 0.069 | 0.066 | 0.071 | 0.074 | 0.162 | 0.142 | 0.116 |
A generalization of the above is a description in the form of a conjunction of variables of a healthy state (when you press the SA17 key to control the vertical movement of the reel, the reel moves accordingly) [14]:

\[ Y = X_1 \land X_2 \land Z_9 \land Z_9 \land Z_{10} \land Z_3 \land Z_1 \land Z_2 \land Z_6 \land Z_7 \land Z_4 \land Z_5; \quad (4) \]

And possible faulty (when you press the SA17 button to control the vertical movement of the reel, the corresponding movement of the reel does not occur) states of the subsystem "vertical movement of the reel" of the electrical equipment of the ACROS 550 combine harvester:

\[ \overline{Y} = \overline{X}_1 \land \overline{X}_2 \land Z_9 \land Z_9 \land \overline{Z}_{10} \land Z_3 \land \overline{Z}_1 \land \overline{Z}_2 \land \overline{Z}_6 \land \overline{Z}_7 \land \overline{Z}_4 \land \overline{Z}_5; \]
\[ \overline{Y} = X_1 \land \overline{X}_2 \land Z_9 \land Z_9 \land \overline{Z}_{10} \land \overline{Z}_3 \land \overline{Z}_1 \land \overline{Z}_2 \land \overline{Z}_6 \land \overline{Z}_7 \land \overline{Z}_4 \land \overline{Z}_5; \]
\[ \overline{Y} = X_1 \land X_2 \land \overline{Z}_9 \land Z_9 \land Z_{10} \land Z_3 \land Z_1 \land Z_2 \land Z_6 \land Z_7 \land Z_4 \land \overline{Z}_5; \]
\[ \overline{Y} = X_1 \land X_2 \land Z_9 \land \overline{Z}_9 \land Z_{10} \land Z_3 \land Z_1 \land Z_2 \land \overline{Z}_6 \land \overline{Z}_7 \land Z_4 \land \overline{Z}_5; \]
\[ \overline{Y} = X_1 \land X_2 \land Z_9 \land \overline{Z}_9 \land \overline{Z}_{10} \land \overline{Z}_3 \land \overline{Z}_1 \land \overline{Z}_2 \land \overline{Z}_6 \land \overline{Z}_7 \land \overline{Z}_4 \land \overline{Z}_5; \]
\[ \overline{Y} = X_1 \land X_2 \land \overline{Z}_9 \land \overline{Z}_9 \land \overline{Z}_{10} \land \overline{Z}_3 \land \overline{Z}_1 \land \overline{Z}_2 \land \overline{Z}_6 \land \overline{Z}_7 \land \overline{Z}_4 \land \overline{Z}_5; \quad (5) \]

Below are given, based on the considered dependencies, a decision tree (figure 4), as well as a fragment of the knowledge model in the form of production rules used to build the knowledge base of the expert system.

IF pressing the vertical reel key
moving up does not occur

... ... ...
Rule 10
And the coil of the YA22 electromagnet is operational,
And the coil of the YA23 electromagnet is working,
And the coil of the YA26 electromagnet is operational,

... ... ...
And the SB4 switch is OK,
THEN unit A11 is faulty.
To troubleshoot
Replace block A11.

Knowledge of the "good" / "bad" attribute is determined by additional diagnostic operations (for example, measuring the voltage at the input of the solenoid coil, measuring the voltage at the output of the switch, etc.).
Figure 4. Troubleshooting decision tree:
Parameters: 1 - fuse FU8.3 is OK ?; 2 - is the KV23 relay OK ?; 3 - is the SA17 key OK ?; 4 - is the SB4 switch OK ?; 5 - block A11 is working properly ?; 6 - is block A14 working properly ?; 7 - is the KV16 relay OK ?; 8 - is the YA22 solenoid coil operational ?; 9 - is the coil of the YA23 electromagnet correct ?; 10 - the coil of the YA26? Electromagnet is serviceable.
Reasons: 1 - fuse FU8.3 is faulty; 2 - the KV23 relay is faulty; 3 - the SA17 key is faulty; 4 - switch SB4 is faulty; 5 - block A11 is faulty; 6 - block A14 is faulty; 7 - the KV16 relay is faulty; 8 - the coil of the YA22 electromagnet is faulty; 9 - the coil of the YA23 electromagnet is faulty; 10 - the coil of the electromagnet YA26 is faulty.

4. Conclusion
The problem of troubleshooting in units and systems of complex agricultural machines is weakly formalized. Its solution in the field mainly depends on the practical experience and competence of the operator or diagnostician. In this regard, the development and implementation of decision support systems when searching for the causes of malfunctions is relevant. When building such systems, it is necessary to have a knowledge model of the decision-making process. On the basis of the considered strategy of troubleshooting in the systems and units of the machine, a method is proposed for structuring knowledge of the subject area. This technique is illustrated by an example of the analysis of the electrical equipment subsystem of the ACROS 550 combine harvester. It is shown that to determine the optimal sequence of elementary checks, it is advisable to use various criteria for assessing the weight of checks.
As a result of the analysis and modeling of the subject area under consideration (electrical equipment of the combine), a knowledge base has been formed that includes more than 1200 production rules.

The use of this approach in the implementation of an intelligent information system will allow to increase the utilization rate of the operational time of the combine, reduce downtime for troubleshooting and, as a result, increase the efficiency of harvesting.

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