Machinery & Energetics
Vol. 13, No. 1. 2022

Journal homepage:
https://technicalscience.com.ua/en

UDC 631.1.004
DOI: 10.31548/machenergy.13(1).2022.60-66

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Aspects of expert system of engineering management of technical condition of combine harvesters

Abstract. Ensuring the country's food independence is one of the most important tasks, the successful solution of which depends on the effective functioning of the agro-industrial complex. The main condition for solving the issues of technical support of agricultural enterprises is the high quality and competitiveness of Ukrainian agricultural machinery, in particular, combine harvesters. Engineering management plays an important role in improving the efficiency of using combine harvesters, timely detection and prevention of technological and technical failures. In practice, when using complex harvesting equipment, one of the most important tasks is the technological regulation of the machine in the field. This task belongs to the class of time-consuming engineering problems. Basically, the solution of the problem of engineering management of combine harvesters is assigned to the operator and depends on their qualifications. Difficulties in solving the problem of technological regulation are associated with the uncertainty of information about the factors of the external environment in which the combine operates and the complexity and insufficient study of the relationships between harvesting factors, regulatory parameters, and indicators of the quality of the combine. Therefore, special attention should be paid to the development of information support systems for the operator's intellectual activities, which help it during harvesting operations. One of these promising areas is the development of expert systems for the subject area under consideration. The purpose is to substantiate aspects of engineering management of the technical condition of the combine harvester and the functions of practical application in information technology. Methodology – an expert system of engineering management of the technical condition of combine harvesters can operate in two modes: acquiring knowledge and solving problems. The paper presents the results of communication synthesis in the system "combine harvester – combine operator – master diagnostician". According to the results of production tests, failures of hydraulic equipment and electrohydraulics of combine harvesters of the Slavutych model were tabulated. Conclusion – the use of an expert system has reduced the time spent on collecting and analysing information about the technical condition and making decisions – they are more than four times less than the time spent on troubleshooting. Scientific relevance – the validity of existence at the level of significance α=0.05 of the null hypothesis that the duration of technical diagnostics is equal to the duration of repair has been proven, and the competing hypothesis that the duration of diagnostics of a combine harvester is less than the duration of repair

Keywords: intellectual aspect, engineering, diagnostics, combine operation

Article's History: Received: 20.09.2021; Revised: 06.01.2022; Accepted: 23.02.2022

INTRODUCTION

The efficiency of agricultural production is largely determined by the degree of mechanisation of technological operations and the technical level of machines [1]. A means of mechanising the harvesting of grain, sunflower, corn, and other crops is a combine harvester, one of the most complex machines in modern agricultural production [2]. The majority, namely 83%, of grain harvesting equipment in Ukraine is made up of John Deere, Class, New Holland, and Slavutych combines [3].

Management of the technical condition of machines, in particular, combine harvesters, can be considered in

Suggested Citation:
Mozharivskyi, D.M., Titova, L.L., Nadtochiy, O.V., & Dasic, P. (2022). Aspects of expert system of engineering management of technical condition of combine harvesters. *Machinery & Energetics,* 13(1), 60-66.

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three aspects [4]: informational, intellectual, and physical (Fig. 1). In the information aspect, this is the collection and processing of data on the technical condition of the machine. Information about the technical condition can be obtained by the organoleptic method [5] or with the help of technical diagnostic tools – built-in control and measuring devices or standard diagnostics [6], special measuring devices, information and measuring diagnostic complexes [7]. Intellectual aspect – development of a diagnostic algorithm, analysis of information about the technical condition, and making a management decision [8]. Physical aspect – implementation of the control effect of technical service, regulation, and inclusion of backup elements [9].

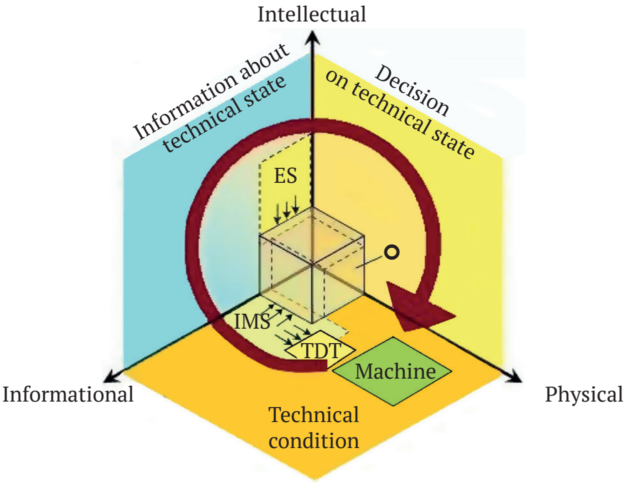

Figure 1. Operator in coordinates:
O – operator; TDT – traditional diagnostic tools; IMS – information and measurement system; ES – expert system

The security and professional level of machine operators, driver managers and specialists of the engineering and technical service of agricultural enterprises are the most important factors for the effective use of equipment and, unfortunately, current problems of the industry [10]. The most qualified and active specialists left the village in the 1990s [11]. Currently, the situation is not improving [12]. The number of machine operators is reduced by 3-5% annually [13]. The share of machine operators of the first and second classes in their total number decreases and is less than 60% [14]. Young people entering the agricultural sector of the economy are not only not professional machine operators, but also in the vast majority are poorly trained and cannot conduct technological processes in conditions adequate to the environment [15]. Of the total number of employees of the engineering service of agricultural enterprises, 70-75% have professional education, and only 30-35% have higher education [16].

In the absence of a centralised system of training and improving the effectiveness of qualifications, the main means of maintaining the competence of specialists engaged in maintenance is the availability and constant updating of technical documentation at the level of individual agricultural farms [17]. Technical documentation mainly comes with a new machine, or with new equipment [18]. Considering the specifics of the work carried out, methodological manuals, route maps, and user manuals made in the form of printed publications quickly fall into disrepair [19]. This explains the insufficient amount of necessary technical documentation [20]. On the other hand, printed publications (books, posters, etc.) do not provide ease of editing and adding knowledge [21]. At the same time, the technical documentation required for the organisation of maintenance is practically absent for free sale [22].

In this regard, it is necessary to provide support for the operator in information and intellectual aspects, or even exclude it from these areas of technical condition management [23]. That is, it is necessary to automate the process of generating information about the technical condition and provide support for making managerial decisions [24].

In the physical aspect, technical condition management can be carried out by low-skilled personnel [25]. But even in this aspect, the technical condition can be managed automatically, for example, by enabling backup elements [26]. However, this approach is unlikely to be widely used in agricultural machinery.

Thus, it is necessary to "shift" the operator to the origin along the "axes" of the intellectual and information aspects [11], transferring its functions to intelligent and information-measuring systems (Fig. 2). Diagnostics of the technical condition of the combine harvester and its components as objects of technical diagnostics during operation are in various technical conditions [6]. The change in technical condition is characterised by an external feature [21].

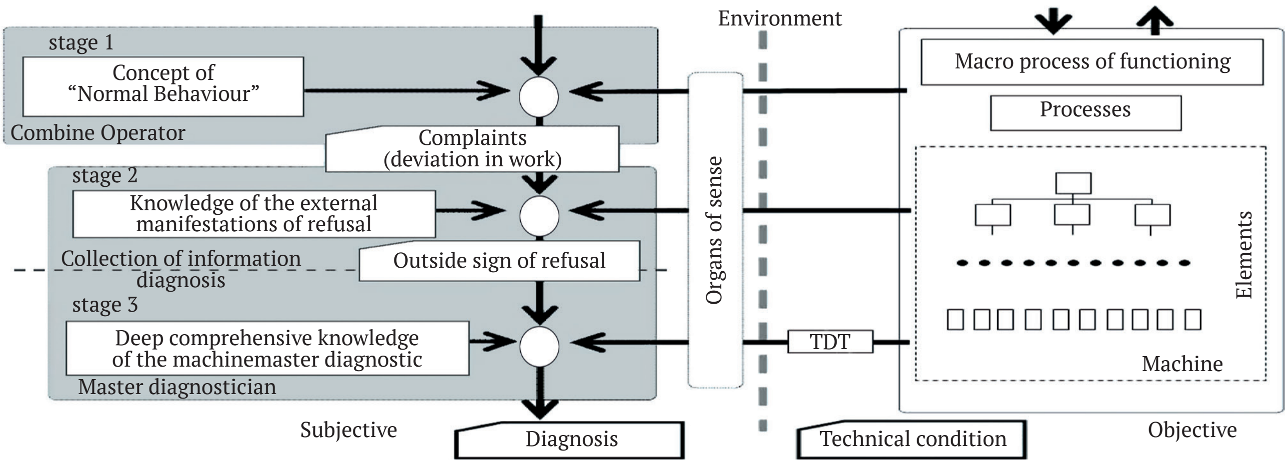

Figure 2. Communication scheme in the system "combine harvester – combine operator – master diagnostician"

Next, the study considers the process of generating information about the technical condition of the combine in the "combine harvester – combine operator – master diagnostician" system. The information generation process can be divided into two parts: collecting a priori information (stages 1 and 2 in Fig. 2) and actually diagnosing it (stage 3 in Fig. 2).

At the first stage, the operator informs the master diagnostician of their complaints about the machine [9]. Complaint is a description of a deviation perceived by the operator in the behaviour of the machine, or a clear sign of failure [3]. Examples of complaints: the header does not rise, the harvester valve does not close, instead of turning the discharge screw, the header is lowered, oil leaks along the hydraulic cylinder rod [16]. This is a clear sign of failure.

At the second stage of diagnostics (Fig. 2), the diagnostician analyses the operator's complaint and begins to collect additional information about the condition of the machine [7]. First of all, the diagnostician must make sure that the deviation recorded by the operator is caused by an objective failure of the machine, and not by subjective reasons [1]. For example, a deviation of the unloading device drive that does not turn on has been recorded, in order to recognise it as a manifestation of a combine failure, it is necessary to verify the truth of the following statements:

– the engine is running;

– the inclined discharge screw is in the working position;

– the power button of the discharge device drive is in the ON position.

At this stage of diagnosis, it is also necessary to link the external manifestations of deviations with specific elements of the object [20]. At the same time, object elements are understood as components of the object parts, assembly units, aggregates, the object as a whole and the rules for their installation, adjustment parameters, parameters of the state of components (if in specific conditions it is advisable to separate them from the corresponding parts).

The external failure sign is input information for the third stage (Fig. 2) – determining a non-working element with the required depth [14]. This stage involves the implementation of the traditional diagnostic procedure for elements whose failures may cause the appearance of an external sign.

The purpose of the study – to substantiate aspects of engineering management of the technical condition of the combine harvester and the functions of practical application in information technology.

RESULTS AND DISCUSSION

The authors of this study have developed and are improving an expert system that implements the following functions: description of the design of the combine harvester; preliminary configuration of the working bodies of the machine; adjustment of technological parameters; troubleshooting in the units and systems of the machine; explanation of the results obtained; addition and editing of knowledge; assistance to the user when working with the expert system. The expert system can work in two modes: acquiring knowledge and solving problems. In the knowledge acquisition mode, the knowledge engineer forms a knowledge base together with an expert. In problem solving mode, the user communicates with the expert system. The dialogue box for entering information provides a natural language interface for the user. The interface is one of the most complex components of any software product designed for wide application. The main problem with interface development is related to the user's lack of computer skills. Thus, the organisation of qualified help tips becomes a key issue from an additional service. In addition to traditional static information, the expert system uses multimedia elements that significantly increase visibility and make it easier for users who are not familiar with using computers.

The updated version of the expert bounce search system has a number of features. When used in the expert advisor mode, the expert system provides the maximum amount of information about the technical condition of the combine harvester based on the external features observed by the operator. Moreover, the expert system allows the operator to move from passive observation to setting up "experiments" to obtain new external features. For example, when registering an external feature, the "lifting/lowering of the harvester" button is in the lifting position and the motor is running and the harvester is not in the topmost position and the harvester position relative to the ground has not become higher than it was, the expert system can ask the operator to move the key to rotate the discharge auger to the transfer position to the working position and then ask: "Is the inclined discharge auger being transferred to the working position?". The answer to this question would allow the expert system to adjust the list and sequence of elementary checks, and therefore, increase the effectiveness of diagnostics.

Figure 3 shows the view of the prototype window of the expert system for a situation in which the operator complains about the combine: they chose the interested unit from the list on the left side of the programme window, the unit can be selected by pointing to the corresponding area on the 3D image of the combine: not all combine operators know the names of the units; from the list of deviations proposed by the system, the operator indicated a failure to rise, although the combine lift is a function of the hydraulic system, but many combine operators in the text of the complaint prefer to mention the element that visualises the failure, and such features must be considered when developing the programme interface); after indicating deviations in operation the expert system starts interviewing the operator to establish external manifestations of the technical condition of the combine. As a result of communication with the expert system, the operator will receive a list and sequence of basic checks and necessary explanations.

During the period of harvesting grain and leguminous crops in 2021 in the Bilotserkivskyi District of the Kyiv Oblast, data were collected on failures of Slavutych KZS 9-1 (18 vehicles), John Deere (21 vehicles), and Claas (3 vehicles) combine harvesters.

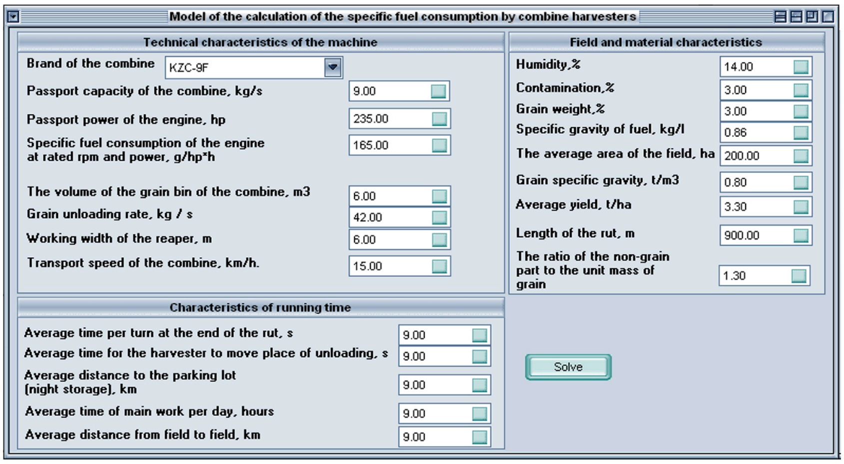

Figure 3. Interface of the expert system window

The following data was registered:
– complaint;
– technical diagnosis;
– duration of diagnosis;
– duration of repairs.

The expert system described above was used for diagnostics and repairs.

The duration of diagnostics was adopted as an indicator of the effectiveness of the technical diagnostics process. Generally speaking, the time spent on completing work can be considered as a complex indicator of its complexity, labour intensity, and responsibility.

In this paper, only failures of hydraulic equipment and electrohydraulics of combine harvesters of the Slavutych model are considered. During the observation period, 21 failures of these systems were recorded (Table 1).

Table 1. Failures of combine harvesters of the Slavutych model

No.	Complaint	Diagnosis	τ_d, hours	τ_r, hours
1	"The entire hydraulic system does not work"	Clogged overflow valve seat	0.12	0.13
2	"The discharge auger is not removed and unloading is not turned on"	No "mass" on HEC	0.10	0.08
3	"The speed of the reel is falling"	Failure of the valve of the shut-off device of the CVT control section of the reel 5PE	0.02	0.17
4	"Steering failure"	Failure of the steering unit AR–125	0.10	2.50
5	"When the header drive is turned on, the electrohydraulic fuse blows"	Closing of the control circuit for switching on the drive of the header part 3PE to "ground"	0.17	0.08
7	"The entire hydraulic system does not work"	Failure of SOV	0.28	1.12
8	"Slow lowering of the header"	The risks on the spindle and the disc mower housing are not combined	0.05	0.02
9	"The threshing drum speed does not increase"	CVT hydraulic cylinder failure	0.18	1.30
10	"Spontaneous lowering of the header"	Failure of the locking device of the lifting/lowering section of the header part 5PM	0.02	3.00
11	"Uploading is not enabled"	DO-13-1 sensor failure blocking switching on of the discharge device drive	0.12	0.08
12	"The header drive does not turn on"	1. Open circuit of the control section for switching on the drive of the header part of 3PE. 2. Mechanical part failure	0.38	0.43
13	"The entire hydraulic system does not work"	Failure of HEC	0.27	0.45
14	"The entire hydraulic system does not work"	NSH-32 pump drive failure	0.22	1.90
15	"The discharge auger cannot be removed"	The hole of the seat of the electromagnet needle of the 3PE discharge screw rotation section is clogged	0.08	0.25
16	"Uploading is not enabled"	Incorrect connection of wires on 2PE	0.18	0.02
17	"The speed of the threshing drum is falling"	Failure of the valve of the shut-off device of the threshing drum speed control section of 3PE	0.03	0.17
18	"Spontaneous lowering of the header"	Failure of the valve of the shut-off device of the lifting/lowering section of the header part of 5PE	0.02	0.17
19	"When lifting the header, the discharge auger is removed"	Worn rubber ring of the seat of the electromagnet of the section of rotation of the discharge screw of 3PE	0.10	0.13
20	"The header and reel do not rise/fall"	5PM failure (worn parts)	0.38	3.05
21	"Uploading is not enabled"	1. DO-13-1 sensor failure blocking the activation of the discharge device drive 2. Mechanical part failure	0.25	0.48

In Table 1, the following abbreviations are applied: 2PE, 3PE, 4PE, 5PE – electro-hydraulic distributors of 2-, 3-, 4-, and 5-sections; 5PM – muscle distributor; SOV – safety overflow valve (pressure hydraulic valve); HEC – hydraulic valve with electromagnetic control (flow control distributor).

During the observation period, not a single diagnostic error was registered, that is, the effectiveness of diagnostics is maximum.

For clarity, data on the duration of diagnostics and repairs are presented as a diagram in Figure 4.

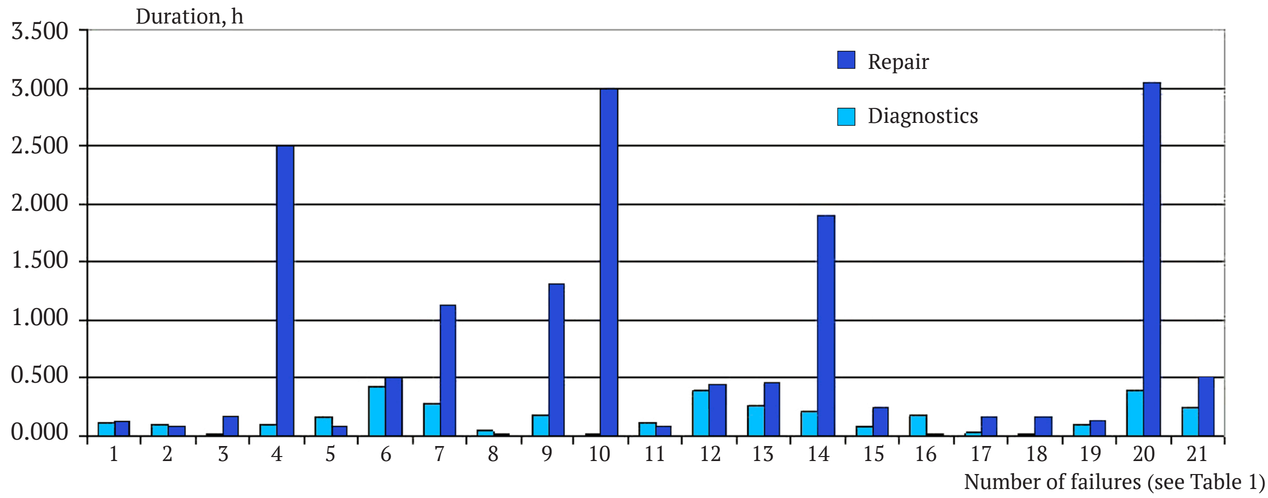

Figure 3. Interface of the expert system window

Based on the obtained data, the average values of the duration of diagnostics and repair of the combine harvester were determined, which amounted to $\bar{\tau}_d$= 0.17 hours and $\bar{\tau}_r$= 0.76 hours.

For a comparative assessment of the duration of diagnosis and repair, a statistical hypothesis about the equality of average normal general populations was tested.

The considered hypothesis has the form:

$$H_0 : M(\bar{\tau}_d) = M(\bar{\tau}_r) H_1 : M(\bar{\tau}_d) < M(\bar{\tau}_r),\ (\alpha=0.05) \quad (1)$$

that is, at the level of significance α=0.05, the null hypothesis that the duration of technical diagnostics is equal to the duration of repairs is considered. A competing hypothesis is that the duration of diagnosis of a combine harvester is less than the duration of repair.

As a criterion for testing the null hypothesis (1), the value of:

$$KI = \frac{\bar{\tau}_d - \bar{\tau}_r}{\sqrt{D(\bar{\tau}_d) + D(\bar{\tau}_r)}}, \quad (2)$$

where $D(\bar{\tau}_d)+D(\bar{\tau}_r)$ – variances of arithmetic mean diagnostic and repair durations, respectively.

The criterion value calculated by equation (2) Z_{obs}=-2,72, a critical point Z_{cr}=1,64, that is Z_{obs}<-Z_{cr}, therefore, the null hypothesis is rejected. At the significance level of 0.05, it can be argued that the duration of diagnosis is less than the duration of repair. Diagnostics of machines is mostly related to the information and intellectual aspects of managing the technical condition, while repair is related to the physical one. The results obtained indicate that the use of an expert system has reduced the time spent on collecting and analysing information about the technical condition and making decisions – they are more than four times less than the time spent on repairs. Data on the duration of diagnostics of a combine harvester without the use of an expert system are given in [7, 19]. Moreover, as practice shows, combine operators are often not able to independently diagnose the machine at all, especially in terms of electrical equipment and hydraulics.

Therefore, the use of an expert system significantly expands the range of tasks solved by the combine operator, without increasing the information load on them.

CONCLUSIONS

1. The proposed expert system contains aspects of engineering management of the technical condition of the combine harvester and implements the following functions: description of the design of the combine harvester; preliminary configuration of the working bodies of the machine; adjustment of technological parameters; troubleshooting in the units and systems of the machine; explanation of the results obtained; addition and editing of knowledge; assistance to the user when working with the expert system.

2. The expert system can work in two modes: acquiring knowledge and solving problems. In the knowledge acquisition mode, the knowledge engineer forms a knowledge base together with an expert. In problem solving mode, the user communicates with the expert system.

3. It was established empirically that the average values of the duration of diagnostics and repair of a combine harvester of the 2021 season were $\bar{\tau}_d$= 0.17 hours and $\bar{\tau}_r$= 0.76 hours.

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Аспекти експертної системи інженерного менеджменту технічним станом зернозбиральних комбайнів

Анотація. Забезпечення продовольчої незалежності країни – одне з найважливіших завдань, успішне вирішення якого залежить від ефективного функціонування галузей агропромислового комплексу. Основною умовою у вирішенні питань технічного забезпечення аграрних підприємств є висока якість та конкурентоспроможність української сільськогосподарської техніки, зокрема зернозбиральних комбайнів. У підвищенні ефективності використання зернозбиральних комбайнів, своєчасному виявленні та запобіганні технологічним і технічних відмовам велика роль належить інженерному менеджменту. На практиці при використанні складної збиральної техніки одним з найважливіших завдань є технологічне регулювання машини в польових умовах. Це завдання належить до класу трудомістких інженерних завдань. В основному вирішення проблеми інженерного менеджменту зернозбиральних комбайнів покладається на оператора та залежить від його кваліфікації. Труднощі з вирішенням завдання технологічного регулювання пов'язані з невизначеністю інформації про фактори зовнішнього середовища, в якій функціонує зернозбиральний комбайн, а також складністю та недостатньою вивченістю взаємозв'язків між факторами збирання, регулювальними параметрами та показниками якості роботи комбайна. Тому на особливу увагу заслуговують питання розробки систем інформаційної підтримки інтелектуальної діяльності оператора, які допомагають йому при проведенні збиральних робіт. Одним з таких перспективних напрямів є розробка експертних систем для предметної галузі, що розглядається. Мета – обґрунтувати аспекти інженерного менеджменту технічним станом зернозбирального комбайна і функції практичного застосування в інформаційній технології. Методологія – експертна система інженерного менеджменту технічним станом зернозбиральних комбайнів може працювати в двох режимах: набуття знань та рішення задач. В статті представлено результати синтезу спілкування в системі "зернозбиральний комбайн – комбайнер – майстер діагност". За результатами виробничих випробування табульовано відмови гідрообладнання та електрогідравліки комбайнів сімейства Славутич. Висновок - застосування експертної системи дозволило скоротити витрати часу на збір та аналіз інформації про технічний стан і прийняття рішення – вони більш ніж в чотири рази менше витрат часу на усунення несправностей. Наукова значимість – доведена правмірність існування на рівні значущості α=0,05 нульової гіпотези про те, що тривалість технічного діагностування дорівнює тривалості ремонту, та конкуруючої гіпотези – тривалість діагностування зернозбирального комбайна менша тривалості ремонту

Ключові слова: інтелектуальний аспект, інженерія, діагностування, робота комбайна