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A METHOD OF COMPARATIVE STUDIES ON CHECKUP SETS TO EVALUATE THE TECHNICAL CONDITION OF TRACTORS

METODA BADAŃ PORÓWNAWCZYCH ZBIORÓW SPRAWDZEŃ DO OCENY STANU TECHNICZNEGO CIĄGNIKÓW*

In this paper the authors propose an original method of the numerical evaluation of checkup sets for the technical condition of an agricultural tractor. Information entropy required in diagnostic tests for a specific checkup set was used as the evaluation criterion. A formal description is given for the technical condition diagnostics of a tractor in its operation period, which is characterised by a high rate of average damage. The structural model was constructed using information entropy. This model accumulates the number of checkups, probability of specific damage types and assigns them a common numerical measure. The conducted logic analysis of the proposed method and the results obtained in experiments on its practical applicability in service stations indicate that the method adequately describes this area of machine operation and thus may be a measure of information effectiveness for checkup sets determining the machine technical condition.

Keywords: *agricultural tractor, technical condition, checkup set, information entropy.*

W pracy zaproponowano oryginalną metodę liczbowej oceny zbiorów sprawdzeń stanu technicznego ciągnika rolniczego. Jako kryterium oceny wykorzystano entropię informacyjną, konieczną do uzyskania w badaniach diagnostycznych dla odpowiedniego zbioru sprawdzeń. Wykonano formalny opis procesu oceny stanu technicznego ciągnika w systemie eksploatacji, który charakteryzuje duży udział uszkodzeń awaryjnych. Do budowy modelu strukturalnego wykorzystano entropię informacyjną, Model ten kumuluje w sobie liczbę sprawdzeń, prawdopodobieństwo wystąpienia określonych uszkodzeń i nadaje im wspólną miarę liczbową. Przeprowadzona logiczna analiza proponowanej metody oraz wyniki uzyskane w badaniach z jej praktycznego zastosowania w zakładach serwisowych wskazują, że opisuje adekwatnie ten obszar eksploatacji maszyn i może być miarą efektywności informacyjnej zbiorów sprawdzeń stanu technicznego maszyn.

Słowa kluczowe: *ciągnik rolniczy, stan techniczny, zbiór sprawdzeń, entropia informacyjna.*

1. Introduction

In order to ensure efficient machine operation processes various decisions need to be made on an on-going basis and their accuracy is a function of the amount and quality of available information on the process itself and on its environment. Generally the efficiency of performance in the case of technical objects is defined as the degree, to which they meet reliability, economic, quality requirements, etc., within a specific period of time in relation to incurred outlays or inputs [7]. Based on these requirements specific operation strategies are implemented, covering machine use and servicing processes as well as their interdependencies evaluated according to specific criteria [10].

Physical aging of machines, understood as a deterioration of their technical condition, is an objectively existing reality during their use. Current information on the technical condition of machine is crucial in production maintenance. We obtain such information e.g. based on measurements of specific parameters in operation processes as well as assisting processes.

Machine operation and the related processes are investigated in the analyses performed in the economic system, with economic efficiency used as the primary evaluation criterion. This also pertains to the collection and analysis of information on the technical condition of machines. Thanks to advances in measurement methods provided e.g. by the application of electronics and IT tools, the collection of information is an increasingly simple process [1, 17]. In turn, a greater role is played by planning and efficiency of taken measurements as well as analytical methods applied for the resulting information. A combination of these two areas makes it possible to obtain valuable information, which effectively supports management of machine operation processes [7].

Structural formal models are constructed for diagnostic processes in order to conduct simulation studies and evaluate their efficiency based on various criteria. These problems include the theory of construction of diagnostic tests [13], using e.g. the matrix method, the deletion method, etc. [19].

In this respect an essential role is attributed to checkup sets (measurement sets), which are used to determine the machine technical condition, as well as their number and types, sequence, labour intensity and generated costs.

This paper presents a method to evaluate checkup sets in order to diagnose the technical condition of a tractor, after the occurrence of a specific signal (symptom) using information entropy. Examples of checkup sets are given, which results will be used to evaluate their information effectiveness and indicate areas of practical applications for the developed method.

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

2. Characteristics of tractor operation processes in agriculture

Analyses of machine operation processes need to include their relationships with the environment [2]. Tractors as energy converting machines have found numerous applications in many sectors of the economy (agriculture, transport, construction industry, etc.). They are highly complex and costly technical objects, being sources of mechanical energy for many other machines. Maintenance of cooperating machines depends on their design characteristics and the role they serve in the production process. Their operation strategy needs to be adapted to specific conditions, applying adequate criteria for its evaluation [4, 10, 12]. Agricultural tractors cooperate with many machines, perform a variety of jobs depending on the season, most frequently in difficult terrain and under harsh weather conditions. Together with the cooperating machines they form series reliability systems, with failure causing downtime of the entire line. Such an environment of the system of their operation generates numerous cases of average damage, which are random in character and this fact needs to be considered in the strategy of their maintenance assurance. As in the case of most machines a major role in the maintenance of tractors is played by preventive maintenance in the form of preventive maintenance inspections. The inspections are performed following generally applied guidelines. In view of the high share of average damage in the operation of agricultural tractors reactive maintenance needs to be executed simultaneously. This strategy reduces efficiency of machine operation, at the same time generating additional costs and losses. They result from multiple problems in this area [6].

In the case of failure it is necessary to identify its cause promptly and to restore the tractor to operating condition after its random loss, which is a pre-requisite for its further operation and minimisation of economic losses.

In decision making processes it is essential to have information on the current technical condition of the tractor, its assemblies and parts. Machine operation practice has provided numerous methods to identify, record and measure signals on the technical condition of machines, based on which diagnostic information is obtained [2, 17].

This task is performed by service mechanics, most frequently on site, since they can use a mobile workshop truck offering limited, but increasingly advanced servicing equipment. Firstly an adequate checkup set needs to be performed, typically measurements to obtain precise information on the damaged/faulty element. In such a case a binary evaluation of the technical condition for the machine and its parts is sufficient, equation (1):

$$I(c_i) = \begin{cases} 1, \; gdy \; c_i \in \{C_1\} \\ 0, \; gdy \; c_i \in \{C_2\} \end{cases} \tag{1}$$

where:

$I(c_i)$ – information on the technical condition of the i-th part,
$\{C_1\}$ – a set of parts in working order,
$\{C_2\}$ – a set of faulty/damaged parts.

Thus we obtain information whether an object (tractor, assembly, part) is in working order (function value 1) or damaged/faulty (function value 0).

The structure of the process evaluating the technical condition (diagnostics) as a subsystem of machine operation is presented in Fig. 1.

The technical condition of a tractor may deteriorate due to specific wear of its part(s) or assembly, which in terms of machine reliability is referred to as damage/fault. A machine which is inoperative emits a specific signal (symptom), which is a set of information and accompanies specific types of wear. A diagnostic signal in a tractor may be manifested as a loss of engine power, increased fuel consumption, elevated temperature, vibrations, excessive smoke from the exhaust, loss of specific work features, etc. For example, a reduced engine power (signal) may indicate an excessive piston to cylinder wall clearance, valve wear, a blown head gasket, etc.

Fig. 1. A flow chart for the process evaluating the technical condition of tractors

After the signal has been identified, specific checkups or their sets need to be performed in order to obtain information on damage. Thus provided information will be used in order to undertake an adequate service decision as well as a machine operation decision. The minimal checkup set is considered to be of greatest merit, as it makes it possible to determine the technical condition of a machine at the lowest number of checkups, lowest costs and labour consumption, etc. It is the primary requirement for efficient diagnostics [14]. In exceptional cases the signal will be diagnostic information, if it is emitted by only one worn part. Relationships between the diagnostic signal and information on the type of wear are complex. The following assumptions were adopted within this study:

- Every part or assembly of a tractor may be operational or faulty/damaged and binary logics will be used in their theoretical description,
- A deterioration of the technical condition or the fault of a tractor or its assemblies is caused by damage to only one of its parts, which is partly confirmed by servicing practice,
- We diagnose random average damage.

A method needs to be developed to rationalise the number and types of checkups required for the evaluation of the technical condition of tractors.

3. Aim of the study

A problem faced within this study is connected with a lack of an objective, numerical valuation of checkup sets (diagnostic tests) based on the criterion of the amount of information required for the determination of the technical condition of tractors using these sets or tests.

This problem may be solved thanks to the construction of an adequate abstract system, the establishment of a database as well as logic verification and practical evaluation of applicability of the developed method. This should result in the development of a universal and objective method, facilitating a comprehensive, numerical evaluation of checkup sets so that diagnostic information may be provided by the signal. The criterion in this evaluation will be based on the amount of required minimal information necessary for the determination of the technical condition of an object after a specific signal is received. This information will be a function of the number and types of required checkups, their complexity and costs, their sequence, etc.

Checkup sets will be used to identify random damage, thus in the developed method probabilistic models were used and the obtained results may be referred to an adequately numerous population of tractors.

In order to achieve the planned objective the following tasks need to be performed:

- identification of the specific character of operation of tractors in agriculture,
- analyses of the evaluation process for the technical condition of tractors in service centres,
- development of an objective valuation and comparison method for checkup sets used in the evaluation of the technical condition of tractors,

- a logic and empirical evaluation of the developed method,
- indication of potential areas for its practical application based on examples.

4. Material and Research Methods

This study is methodological in character and will provide a universal valuation and comparison method for checkup sets determining the technical condition of tractors in their servicing processes. Requirements imposed on the developed method, such as universality, objectivity, comprehensiveness and establishment of a numerical informative evaluation of checkup sets may be met thanks to the construction of a structural model for a deduction process evaluating the technical condition of tractors together with an empirical database.

An inspiration for the development of this method has been provided by the development of basic science, particularly mathematics, which may find further practical applications. An effective combination and utilisation of advances in mathematics and the practical execution of machine operation processes will facilitate development of the new method. Its application will provide in-depth knowledge on machine operation processes and ensure their rationalisation, which is also of practical importance.

The first stage consisted in a description of the formal process of tractor technical condition assessment. The flow chart of the process (Fig. 1) may be described by equation (2):

$$S = \{N_i(p_i)\} \tag{2}$$

where:

S – a signal for the technical condition,
N_i – a set of potential variants of information contained in the signal,
p_i – probability of occurrence of i-th information.

Specific relationships are found between the signal, damage, checkups and information (Fig. 2).

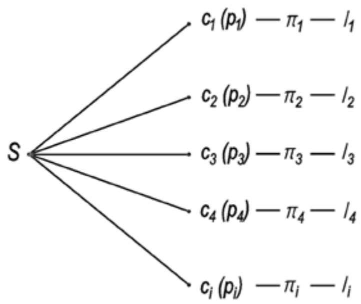

Fig. 2. A diagram for the relationship between the signal – damage/fault – checkup – information.

Each signal S contains a certain set of information variants on damage/fault in part c_i and the probability of occurrence of this damage p_i (Fig. 2). An adequate checkup is required to obtain information from the signal. It was assumed in this study that checkup π_i has to be performed to obtain each item of information 2. The complete evaluation of the technical condition of a tractor requires the execution of checkup set $\{\Pi_i\}$.

Such a process may be described analytically based on the information theory proposed by Shannon [18], with information entropy as the basic concept. This facilitates quantitative valuation of information, which needs to be acquired when investigating a random process; this approach has been successfully used in many areas.

Information entropy has been applied in the formal description of studies on sliding journal bearings at a test stand [20]. As a result a novel and practically useful method was developed for the diagnosis of manufacturing errors in rolling bearings of aircraft engines. In study [15] a method using information entropy was developed to monitor vibrations in the milling process. The value of information entropy was a measure of instability in the work of a machine tool. Information entropy has been applied to valuate the technical condition of machines comprising the system when designing manufacturing systems [9]. Information entropy is a method of modelling random processes in many areas of science and thanks to its clear and logic structure it may be successfully used in practice [8, 11, 16].

Available literature lacks examples of applications for information entropy in processes of technical condition evaluation for agricultural tractors. Due to the random character of the occurrence of damage/fault information entropy may prove to be useful in modelling of the evaluation process for the machine technical condition using checkup sets identifying damage.

An empirical system composed of a set of damage/fault variants and the probability of their occurrence, constituting missing information in the evaluation of the technical condition of tractors, may be described using the statistical information theory with equation (3) of information entropy [18]:

$$H = -\sum_{i=1}^{n} p_i \log_2 p_i , \tag{3}$$

where:

n_i – the number of variants of information on damage/fault,
H – the amount of needed information (bit),
p_i – probability of occurrence of the i-th variant of damage/fault in the signal.

If in equation (3) we apply a logarithm with the base of 2, then the amount of information entropy is obtained in bits. It results from equation (3) that the value of information entropy H is a function of the number of possible damage/fault variants n_i contained in the signal and probability of their occurrence p_i. In the case of clustered probability distribution, in which it is easy to predict which part is faulty/damaged, the value of entropy decreases. Then the checkup set required to obtain information on the technical condition of a tractor will be optimal. Particularly when the signal contains only one variant of fault/damage, with the probability of distribution of 1, the value of entropy will be 0. This is equivalent to complete information on the machine technical condition and thus results in no need for checkups. If the diagnostic signal contains a numerous set of fault/damage variants with a small and uniform probability of their occurrence ($p_i = 1/n$), information entropy takes the maximum value. It may be calculated from equation (4) of the structural information theory:

$$\mathrm{I} = log_2\, n_i \tag{4}$$

where:

I – the amount of information according to the structural information theory (bit),
n_i – the number of information variants on fault/damage.

Then a numerous checkup set needs to be executed to obtain information on the machine technical condition.

In the practical execution of processes evaluating the machine technical condition the probability of occurrence of a specific type of wear and information on that wear may be differentiated based on studies on machine operation, experience of service mechanics and information obtained from machine operators.

From the point of view of diagnostics the case described by equation (3) is more advantageous in comparison to that described by equation (4), since the amount of information, which needs to be obtained in tests - and as a result also the incurred outlays - will be smaller.

Knowing the diagnostic signal and potential information it contains we may construct adequate checkup sets to evaluate the machine technical condition. These sets will differ in the number and type of checkups as well as the sequence of their execution. From equations (3) and (4) we may calculate the numerical value of the information, which needs to be obtained and the required adequate checkup set, which makes it possible to acquire complete information on the technical condition of a tractor. Such a checkup set will be characterised by the smallest information entropy. As a result equations (3) and (4) provide a numerical valuation and comparison of checkup sets based on the criterion of their information entropy and in this respect constitute an abstract model, which logic accuracy and practical applicability need to be verified. It constitutes a subsystem of the general model of the machine operation process [3, 5].

It results from the logic analysis of equations (3) and (4), as well as the actual evaluation of the tractor technical condition that information entropy of a checkup set verifying the technical condition:

- reaches the value of zero when the signal contains information on only one specific damage, i.e. the signal is then diagnostic information,
- reaches the maximum value when each checkup from a checkup set identifies a specific fault/damage type with equal probability,
- decreases when each checkup from a checkup set identifies specific information variants with different (clustered) probability,
- increases with an increase in the size of the checkup set required for a complete identification of the machine technical condition.

The presented dynamics of changes in information entropy is fully adequate for the informative description of checkup sets in the evaluation of the tractor technical condition. In terms of logics equations (3) and (4) may be used to calculate the amount of information (information entropy) generated by respective checkup sets to evaluate the tractor technical condition.

The practical utilisation of the developed method needs to be verified. For this purpose empirical studies have been performed concerning tractor servicing.

5. An example application for the method

Analyses were conducted on agricultural tractors, in which a specific fault occurred. A signal on the fault was displayed on the onboard computer as the fault code or after an external computer with software compatible with the tested tractor was connected. The fault code or message is a signal, which generates a series of potential damage types. Typically one signal denotes several variants of damage. In such a situation the person verifying the technical condition has to make a decision what checkups to perform and in what sequence.

Tests were performed on 72 agricultural tractors of the same type, in which the signal of fault indicated an excessively high temperature of the engine. For such a signal specific checkup sets were established, which will provide complete information on the technical condition of the tractor engine.

Table 1. Checkup sets for the signal indicating "excessively high temperature of the tractor engine"

item	Type of checkup	Probability of fault/damage occurrence for tested checkup sets		
		1	2	3
1.	Faulty thermostat	0.067	0.053	0.181
2.	Too low coolant level	0.067	0.053	0.151
3.	Too low engine oil level	0.067	0.053	0.102
4.	Oil cooler damage	0.067	0.053	0.079
5.	Loose or broken coolant pump V-belt	0	0.053	0.079
6	Faulty temperature sensor	0.067	0.053	0.134
7.	Fan damage	0.067	0.053	0.031
8.	Faulty fan clutch assembly	0.067	0.053	0.031
9.	Fouled radiator core	0.067	0.053	0.031
10.	Faulty temperature transmitter	0.067	0.053	0.055
11.	Clogged coolant system pipes	0.067	0.053	0
12.	Blown head gasket	0.067	0.053	0
13.	Cracked head	0.067	0.053	0
14.	Cracked engine block	0.067	0.053	0
15.	Coolant pump damage	0.067	0.053	0
16	Broken coolant system pipe	0	0.053	0.031
17.	Engine overload	0.067	0.053	0.063
18.	Radiator drain plug damage	0	0.053	0.031
Values of information entropy for checkup sets (bits)		**3.92**	**4.04**	**3.42**

The first checkup set was developed based on the technical specifications of the manufacturer and data given in the diagnostic computer system for this signal (Table 1). Analysis of data facilitated the construction of a checkup set, but did not make it possible to differentiate the probability of occurrence of individual variants of fault/damage.

The second checkup set was developed using additionally the results of a questionnaire survey conducted among 127 service mechanics, who were performing analyses of the technical condition of these tractors. Based on their experience and machine operation conditions the respondents supplemented the first checkup set with additional checkups (Table 1). They included fault/damage types, which occurrence had not been predicted by the tractor manufacturer.

The third checkup set was created with the use of the survey, in which the respondents indicated damage most commonly diagnosed in their practice. The probability of each damage type, identified by a respective checkup, was calculated on this basis. For each of the three checkup sets, the amount of required information (information entropy) was established using equations (3) and (4). Results of these calculations are presented in Table 1.

It results from data collected in Table 1 that using equation (3) we may calculate the amount of information (information entropy) required to fully identify the technical condition of a tractor applying each checkup set. Having such an assessment we may take a rational decision which checkup set to use in practice. The criterion for this evaluation will be based on the minimum amount of information required for the complete identification of the tractor technical condition. In this case it will be checkup set 3.

The presented example application of this method confirmed that the provided numerical scores for the informative value (information entropy) of checkup sets adequately describe the actual process for the determination of the tractor technical condition. A necessary precondition for an efficient application of the method is to create a set of potential checkups for a given signal as well as determine the probability of occurrence of individual damage/fault types.

6. Final conclusions

1. The method presented in this study provides a numerical evaluation for each of the potentially applicable checkup sets testing the technical condition of a tractor following the occurrence of a specific signal, based on the criterion of the amount of missing information (entropy). The results may be compared and the checkup set efficient in terms of its informative power may be selected, as that characterised by minimal entropy. This set will identify the technical condition of a tractor at the minimum number of checkups performed in an appropriate order.
2. The numerical measure of entropy for the checkup set is global in character and it accumulates information from tractor manufacturers, service stations and tractor operators. The logic verification of the method and an example of its practical application indicate that it describes adequately the actual process generating checkup sets for the evaluation of the tractor technical condition. It is a universal method and may be applied in the case of other machines, provided an appropriate database is available.
3. The amount of missing information is calculated using probabilistic data, thus the recorded results may be referred to an adequately numerous set of tractors and then their practical use is efficient. Having a database on fault/damage and after performing appropriate calculations optimal checkup sets may be constructed, which will accumulate the experience of service mechanics and the specific character of tractor operation in a given region. An example of such a situation is presented in this study.

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