THE PROBLEMS OF RATIONALIZATION
OF DIAGNOSTIC TEST OF MACHINES

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Abstract. The paper presents the method of rationalization of diagnostic test of machines, using the level of informative entropy about their technical state. According to the theory of information, the larger the differentiation of the probabilities of damage of individual parts of a machine, the smaller the informative entropy. In such a case we need less information from diagnostic tests to qualify the technical state of machine. This fact was used in differentiating the probabilities of damage of parts based on information about their exploitation. A suitable order of checks was proposed, which allows an essential decrease of the expenditures of diagnostic tests of machines.

Key words: agricultural machines, technical diagnostics, quantity of information

INTRODUCTION

Modern agricultural machines are complex technical objects made up of many parts. The component parts are joined in daisy chains, which means that if one of them is damaged some functions of the machine can be disturbed, and sometimes the whole machine cannot operate. At this point it is the task of the technical service team to identify the damaged part and then exchange or repair it.

Technical diagnostics deals with collecting information on the state of a machine as well as identification of its damaged parts. We observe a growing role of diagnostics in modern machines. It results from their complexity, and compact structure, which includes not only mechanical units but also hydraulic, and electronic ones. Little information about the technical state of a machine can been obtained optically by performing the test of movement. To obtain more precise data, appropriate equipment is indispensable.

It is natural to try to do the diagnostic tests in such a way as to get full information about the technical state of a machine at low cost and quickly, with a minimum employment of equipment. Compiling such instruments, which would make it possible to carry out a full diagnosis of the machine, has until lately been a problem. Expenditures of labour and costs of execution were a minor matter. In modern machines this is not

a problem because there are diagnostic computers, which enable a full diagnosis of the electric, electronic and mechanical units. The latter are fitted with suitable sensors [Bocheński and Mruk 1999]. Using such equipment is very convenient, but there is one disadvantage – it is quite expensive for customer. This is often a barrier for the user of the machine, who usually wants to avoid the costs of a full diagnosis with use of a computer and to simple, considerably cheaper ways which are not always successful.

The problem is how to use the diagnostic tests in a successful but not too expensive way.

METHOD

Diagnosis can be understood as a process of obtaining information about the technical state of a machine [Hebda et al. 1980, Rzeźnik 2002]. Formalizing the problem, we can assume that the machine consists of a group of parts n and each part can be in either of the two states: damaged or undamaged. In order to gain information about the technical state of the machine the damaged part must be identified. This is done with the help of a set of checks. If the checks enable us to obtain full information about the technical state of machine, such a set is called a diagnostic test. Because the realization of each check requires some expenditure, therefore there is a need to minimize diagnostic tests: to limit the numbers of checks and unit costs.

If the machine consists of *n* parts and there is a number of checks, where each one identifies the technical state of one component part only, the diagnostic test should include *n* checks. To asses the information on the technical state of the machine, we assume that for each check the probability p_i, i = 1, 2,...,n, of the damage of ith part is known. Probabilities p_i, i = 1, 2,...,n, must satisfy the condition

$$\sum_{i=1}^{n} p_i = 1 \tag{1}$$

This paper assumes that only one part can be damaged. It is a kind of simplification in relation to reality.

If we assume that no information is available on the technical state of the machine prior to the diagnostic tests, then we must also assume that all probabilities p_i, i = 1, 2,..,n, equal $p_i = 1/n$. Then the amount of information on the technical state of the machine, called information entropy, is calculated using the structural theory of information according to the formula:

$$I = \log_2 n. \tag{2}$$

The machine carries some information which should be used for identifying its technical state. This information derives from the knowledge of the structure of the machine, experience in the exploitation of such machines and interview with the operator. The information obtained by the expert can be used for differentiating the probabilities of damage of the component parts of the machine. In this case the informative entropy will be calculated using the theory of statistical information:

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

It can be easy demonstrated [see e.g. Borowkow 1975] that inequality $I > H$ is the case.

From the point of view of the effectiveness of diagnosis the second case, when the different probabilities of damage of each part are known, is more profitable because the amount of information needed in the diagnostic test is smaller, so the expenditures should also be smaller. The problem is how to use this theory in practice.

EXAMPLE

For a practical verification of the introduced method, the following example was used. The service station of agricultural machines performs on average $N = 1000$ diagnostic tests of identical machines. Identification of their technical states usually results in determining one damaged part out of $n = 8$ parts. The diagnostic test consists of 8 checks, from which each one identifies the technical state of one part of the machine. It is also assumed that the loss of technical state follows from the damage of only one these part, which is close to the real state of matters. Two cases have been considered. In the first case the experience of both the user of the machine and of the person performing the diagnostic test has been left out, which is manifested in assuming equal probabilities of damage of particular parts. In the second case, it is assumed that not all probabilities p_i, $i = 1, 2,...,8$ are equal. Also, the cost k_i, $i = 1, 2,...,8$, performing each of the eight checks is known. The data are shown in table 1.

Table 1. Data of diagnosed machines
Tabela 1. Dane diagnozowanych maszyn

Kind of information Rodzaj informacji	Number of parts or checks Liczba części lub kontroli							
	1	2	3	4	5	6	7	8
Probability of damage of machine Prawdopodobieństwo uszkodzenia maszyny, p_i	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Probability of damage of machine Prawdopodobieństwo uszkodzenia maszyny p_i	0.40	0.20	0.10	0.10	0.05	0.05	0.05	0.05
Costs of check of individual parts Koszty kontroli poszczególnych części, k_i	10	18	20	15	8	12	11	6

Then the implementation of diagnostic tests of machines in five variants was designed.

Variant one concerns a situation when the probability of damage of every part is equal and eight checks for each of the 1000 diagnosed machines are done. We use this procedure when we have a tester or a diagnostic computer at our disposal, which makes it possible to carry out all the checks of the diagnostic test simultaneously.

Table 2. The total cost of diagnostic tests of machines in different variants of the diagnostic process

Tabela 2. Sumaryczny koszt badań diagnostycznych maszyn w poszczególnych wariantach procesu diagnozowania

Variant Wariant	Context Kontekst	Number of Part. check Liczba kontroli części								Total cost of diagnosing Ogólny koszt diagnozy
		1	2	3	4	5	6	7	8	
I	Probability of damage of machine Prawdop. uszkodzenia maszyny, p_i	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	
	The number of machines checked Ilość skontrolowanych maszyn, N_i	1000	1000	1000	1000	1000	1000	1000	1000	
	Costs of carrying out the check of machines Koszty przeprowadzenia kontroli maszyn	10 000	18 000	20 000	15 000	8000	12 000	11 000	6000	100 000
II	Probability of damage of machine Prawdop. uszkodzenia maszyny, p_i	0.40	0.20	0.10	0.10	0.05	0.05	0.05	0.05	
	The number of machines checked Ilość skontrolowanych maszyn, N_i	1000	1000	1000	1000	1000	1000	1000	1000	
	Costs of carrying out the check of machines Koszty przeprowadzenia kontroli maszyn	10 000	18 000	20 000	15 000	8000	12 000	11 000	6000	100 000
III	Probability of damage of machine Prawdop. uszkodzenia maszyny, p_i	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	
	The number of machines checked Ilość skontrolowanych maszyn, N_i	1000	875	750	625	500	375	250	125	
	Costs of carrying out the check of machines Koszty przeprowadzenia kontroli maszyn	10 000	15 750	15 000	9375	4000	4500	2750	750	62 125
IV	Probability of damage of machine Prawdop. uszkodzenia maszyny, p_i	0.40	0.20	0.10	0.10	0.05	0.05	0.05	0.05	
	The number of machines checked Liczba skontrolowanych maszyn, N_i	1000	600	400	300	200	150	100	50	
	Costs of carrying out the check of machines Koszty przeprowadzenia kontroli maszyn	10 000	10 800	8000	4500	1600	1800	1100	300	38 100
V	Probability of damage of machine Prawdop. uszkodzenia maszyny, p_i	0.40	0.20	0.10	0.10	0.05	0.05	0.05	0.05	
	The quantity of information H_i from checks Liczba informacji H_i uzyskanych z kontroli	0.53	0.46	0.33	0.33	0.22	0.22	0.22	0.22	
	Costs of one bit of information, Koszty jednej informacji, K_i	18.87	39.13	60.61	45.45	36.36	54.54	50.00	27.27	
	The number of machines checked Ilość skontrolowanych maszyn, N_i	1000	500	100	300	550	150	200	600	
	Costs of carrying out the check of machines Koszty przeprowadzenia kontroli maszyn	10 000	9000	2000	4500	4400	1800	2200	3600	37 500

Variant two assumes that the probabilities of damage of individual parts of the machine are different. We proceed like in variant one.

In variant three, the probabilities of damage of every part are equal, and it is assumed that the checks are done individually in random order. The technical state is identified after each check has been performed in 125 machines. Thus, after every check the number of machines which must undergo the next check decreases by 125.

Variant four has different probabilities of the damage of parts, like in the second variant. We carry out checks individually, beginning from the part for which the probability of damage is the largest and proceed in the order of decreasing probability. The realization of every check results in identifying the technical state of such a number of machines which is equal to the overall number of the diagnosed machines multiplied by the probability of damage of the checked part.

In the fifth and last variant, the probabilities of damage of parts are also different and checked individually. Additionally, a parameter called "unit cost of obtaining information in individual checks" was introduced. The quantity of information from every check is calculated according to the equation below:

$$H_i = - p_i \log_2 p_i \tag{4}$$

Unit cost of information obtained from an individual check it was calculated dependence:

$$K_i = k_i/H_i \tag{5}$$

where k_i denotes the cost of checking part i. The check were done in the following order: first the one in which the cost of obtaining one bit of information is the lowest and subsequent ones according to increasing costs.

For each of the five variants the total cost of diagnostic tests of 1000 machines was calculated and it is presented in table 2. From the table we can see how the cost of diagnostic tests differs for particular variants.

CONCLUSIONS

Technical diagnostics, which is the part of the technical service of agricultural machines, is estimated by customers first of all according to economic criteria. The service stations, apart from care about equipment and the effectiveness of tests should also take into account the results of this study.

1. During complex diagnostic tests, which enable a simultaneous checking of many units and parts, the costs should be maintained on a level that would not prevent machine owners from having them done.

2. The users of agricultural machines are now better prepared to their exploitation. They have the adequate knowledge and experience, which should be used in diagnostic tests. Consequently, we diagnose in e single check only one part or unit, for which the probability of damage is the largest. This will lower considerably the costs of the tests.

3. When assembling the diagnostic equipment and developing technologies of its use, the service stations of the agricultural machines should pay attention to costs which the

customer will have to pay. The method presented in this study can prove very helpful in reducing the costs of diagnostic tests.

REFERENCES

Bocheński C., Mruk R., 1999. Technologie informacyjne w diagnostyce bezpieczeństwa ciągni-
ków i maszyn rolniczych. Inżynieria Rolnicza. PAN Warszawa.
Borowkow A. A., 1975. Rachunek prawdopodobieństwa. PWN Warszawa.
Hebda M., Niziński S., Pelc H., 1980. Podstawy diagnostyki pojazdów mechanicznych. WKŁ
Warszawa.
Rzeźnik C., 2002. Podstawy obsługi technicznej maszyn rolniczych. Wyd. AR Poznań.

PROBLEMY RACJONALIZACJI DIAGNOSTYCZNYCH BADAŃ MASZYN

Streszczenie. W pracy przedstawiono metodę racjonalizacji diagnostycznych badań ma-
szyn, w której wykorzystano poziom entropii informacyjnej o ich stanie technicznym.
Z teorii informacji wiadomo, że im większe zróżnicowanie prawdopodobieństw uszko-
dzenia poszczególnych części maszyny, tym entropia informacyjna jest mniejsza. W ta-
kim przypadku mniej informacji musimy uzyskać z badań diagnostycznych, aby określić
stan techniczny maszyny. Fakt ten wykorzystano, różnicując prawdopodobieństwa uszko-
dzenia części na podstawie informacji z ich eksploatacji. Następnie zaproponowano od-
powiednią kolejność wykonywania sprawdzeń. Wszystko to pozwala na istotne zmniej-
szenie nakładów na diagnostyczne badania maszyn.

Słowa kluczowe: maszyny rolnicze, diagnostyka techniczna, liczba informacji

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