Evaluation of the technical condition of road transport means

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Abstract. The paper presents the methodology for determining the procedures of the condition and fault location test, using logical relations (0,1) between diagnostic parameters and technical conditions of the means of transport in the form of a binary observation matrix, determination of the status control and fault location test and use of diagnostic information received during use of means of transport. Implementation of the proposals included in the study should increase the efficiency of diagnosing means of transport, and thus contribute to activities that rationalize their exploitation.

1 Introduction

Physical processes occurring in systems and sets of means of transport have a significant impact on the change of their state and are related to their use and handling. These processes are the source of emission of diagnostic signals, the analysis of which allows to generate information on the technical condition of means of transport.

The automation of the system of monitoring the condition of means of transport, in which it stands out, the assessment of their technical condition requires, among other things, the determination of the condition and fault location test, while the problems associated with it come down to determining the relationship between diagnostic parameters and technical conditions of the means of transport, determining the test the condition and location of damage and the use of diagnostic information received during the use and operation of means of transport.

The term "best" used above means the adoption of appropriate criteria and consideration of these problems in terms of seeking an optimal solution to the above problems. This requires the development of a methodology and algorithm for determining the status and fault location test, and formulating assumptions for the implementation of the algorithm. Implementation of the proposals included in the study should increase the efficiency of diagnosing means of transport, and thus contribute to activities that rationalize their exploitation.

2 Characteristics of the problem

Determination of the technical condition of means of transport is connected with the examination of relations between diagnostic parameters - the condition of the means of transport. Based on the findings made in [1,2,4,8,9], it is believed that the use of appropriate procedures should take into account the appropriate level of decomposition (means of transport, arrangement of the means of transport, assembly of arrangements, element of the assembly) and the appropriate scope of the condition assessment (condition/state control , location of damage, condition control and location of damage to the means of transport). The complexity of transport systems as well as the complexity of processes occurring in them cause that the existing relationships between diagnostic parameters and states are usually stochastic relationships. These dependencies in the practice of diagnosing means of transport, according to the theory of technical diagnostics, depending on the degree of disturbance of

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diagnostic signals can be determined by a boolean observation matrix - with a small degree of disturbance of diagnostic parameter values or probability matrix with a high degree of disturbance of diagnostic parameters values. It is believed, however, that due to limitations resulting from the passive or passive experimental mode, it is sufficient to analyze the boolean matrix and determine the condition control and fault location test. In order to distinguish possible solutions for the construction of tests, the criterion of state discrimination and the procedure for building the test using the boolean matrix method should be used. As a result of this method, a T_{KS} status control test and a T_{LU} damage location test are obtained.

In the first case, based on the binary matrix M_b^d (condition/state table), a boolean matrix M_b^{KS} should be created for the fitness control, in which a subset of pairs of distinguishable S_o, S_i, $i = \overline{1,k}$ states are introduced in place of the states.

$$M_{bij}^{KS} = \begin{cases} 0 & \text{when } \left(1 - M_{bij}^d\right) = 0 \\ 1 & \text{when } \left(1 - M_{bij}^d\right) = 1 \end{cases} \tag{1}$$

Ones which occur in the elements of matrix $M_{bij}^{KS} \in M_b^{KS}$ stand for state discrimination $S_i \in S$ using the parameter $y_j \in Y$, and zero - indistinguishable. Analyzing the matrix M_b^{KS}, for the test T_{KS} parameter $y_j \in Y$ is chosen, which has a maximum number of ones in the column. In the case when the jth column does not contain only ones, the missing ones in the nth column are searched for, and if they occur, then the nth parameter where $y_n \in Y$ is appended to the T_{KS} test. Then the T_{KS} test takes the form:

$$T_{KS} = \{y_j, y_n\} \tag{2}$$

When specifying T_{LU} test elements, we create a boolean matrix M_b^{LU} to damage location, in which a subset of state pairs is introduced instead of states S_l, S_i; $1 = \overline{1,k}$; $i = \overline{1,k}$; $i \neq L$.

$$M_{blij}^{LU} = \begin{cases} 0 & \text{when } \left| M_{blj}^d - M_{bij}^d \right| = 0 \\ 1 & \text{when } \left| M_{blj}^d - M_{bij}^d \right| = 1 \end{cases} \tag{3}$$

Ones which occur in the elements of matrix $M_{blij}^{LU} \in M_b^{LU}$ stand for state discrimination between $S_l \in S$ and $S_i \in S$ using the parameter $y_j \in Y$, while zero stands for indistinguishable. Then analyzing the matrices M_b^{LU} for the test T_{LU} parameter $y_j \in Y$, which has a maximum number of ones in the column, is beign chosen. In the case when the jth column does not contain only ones, the missing ones in the nth or nth+1 column are searched for. In the event of their occurrence, n and $n + 1$ parameters are included in the test T_{LU}. Then the test T_{LU} takes the form:

$$T_{LU} = \{y_j, y_n, y_{n+1}\} \tag{4}$$

In the case of the T_{KS} state control test for using the presented algorithm, a binary matrix M_d^b should be constructed, that one of its rows correspond to the condition of fitness $S^0 \in S$. The matrix elements in this row should have a value of "0", which means that none of the checks $d_j \in T_D$ give any information about the object's damage.

In the case of a fault location test T_{LU} for using the presented algorithm matrix M_d^b it already contains rows characterizing states from a subset of unfitness:

$$S^l = \{S_i\} \tag{5}$$

3 Methodology for determining the status and fault location test

As shown above, the boolean matrix is determined by means of a set of relations between a set of diagnostic parameters $Y = \{y_n\}; n = \overline{1, N}$ and a set of states $S=\{s_i\}$. The boolean matrix method thus provides for the determination of the state control test T_{KS} and fault location test T_{LU}. In the first case based on a binary matrix M_b^d create a boolean matrix M_b^{KS} to control the state in which a subset of pairs of distinguishability states S_o and incapacity states S_i, $i = \overline{1, k}$ are introduced instead of states. Ones which occur in the elements of matrix $M_{bij}^{KS} \in M_b^{KS}$ stand for state discrimination $s_i \in S$ using the parameter $y_j \in Y$, while zero stands for indistinguishable. Then analyzing the matrices M_b^{KS}, for the test T_{KS} parameter $y_j \in Y$, , which has a maximum number of ones in the column, is being chosen. In the case when the jth column does not contain only ones, the missing ones in the nth or nth+1 column are searched for. In the event of their occurrence, *nth* and *nth + 1* parameters are included in the test T_{KS}, then the test takes form:

$$T_{KS} = \{y_{j,} y_n, y_{n+1}\}, \ T_{KS} = \{d_{j,} d_n, d_{n+1}\} \tag{6}$$

where:

d_j - means checking the jth diagnostic parameter.

In the case determining the elements of the T_{LU} test create boolean matrix, M_b^{LU} to locate faults in which a subset of state pairs S_k, S_i; $k = \overline{1, K}$; $i = \overline{1, I}$; $i \neq k$ is introduced instead of states. Then analyzing the matrix M_b^{LU}, for the test T_{LU} parameter $y_j \in Y$, which has a maximum number of ones in the column, is being chosen. In the case when the jth column does not contain only ones, the missing ones in the nth or nth+1 column are searched for. In the event of their occurrence, *nth* and *nth + 1* parameters are included in the test T_{LU}.

In order to determine the value of the binary elements of the observation matrix, the significance of changes in the values of diagnostic parameters should be performed $\{y_j\}$ depending on the elements of the set of states $\{s_i\}$. Among many possibilities [1,3,4,5,6] the chosen ones that deserve attention are:

    a) method of testing the average value;
    b) the method of testing the distance of confidence intervals of the mean value of the diagnostic parameter;

4 Testing the relationship diagnostic parameter - state using the medium test

The relation of the diagnostic parameter - state test is carried out by means of the procedure of testing the significance of changes in the values of the output parameters with the parametric significance test of the two averages for two sets of parameter values $\{\{y_{jl}\}(\Theta_l)\}$ i $\{\{y_{jl}\}(\Theta_k)\};$. To do this [4,7,8,9]:

1. Calculate the average value:

$$\overline{y} = \frac{1}{N} \sum_{i=1}^{N} y_i \tag{8}$$

2. Calculate the variance of the diagnostic parameter values:

$$\hat{s}^2 = \frac{1}{N-1} \sum_{i=1}^{N} \left(y_i - \overline{y}\right)^2 \tag{9}$$

3. Testing the hypothesis about equality of variances with the F-Snedecor test:

$$H_o : 6_2^o = 6_i^2 \; ; i = \overline{1, k}$$

$$H_1 : 6_0^2 > 6_i^2 \quad \text{or} \; 6_0^2 \neq 6_i^2 \tag{10}$$

a) the value of F-Snedecor's statistics: $F = \hat{s}_o^2 / \hat{s}_i^2$ gdy $\hat{s}_o^2 > \hat{s}_i^2$; $F = \hat{s}_i^2 / \hat{s}_o^2$

when $\hat{s}_i^2 \leq \hat{s}_o^2$;

b) critical value of the distribution $F_\alpha = F(\alpha, N_o\text{-}1, N_i\text{-}1)$

where: α - the level of significance of the test; $\alpha = 0{,}05$

N_o - number of measurements for the state S_o

N_i - number of measurements for the state S_i

If:

$F > F_\alpha$ - the hypothesis H_o is rejected

$F < F_\alpha$ - there is no reason to reject the hypothesis H_o

4. Testing the hypothesis about the equality of mean values using the variance analysis test

$H_o : m_o = m_i$

$H_o : \neg \, H_o$

a) in case of $6_0^2 > 6_i^2$ the value of the *u* statistics is determined:

$$u = \frac{\left| \overline{y}_{j,o} - \overline{y}_{j,a} \right|}{\sqrt{\dfrac{\hat{s}_{j,o}^z}{N_o} + \dfrac{\hat{s}_{j,a}^z}{N_a}}} \tag{11}$$

and is compared to the critical value of the distribution u_α (distribution $N(0,1)$): $t_\alpha = t(\alpha, N_o + N_i - 2)$; $\alpha = 0{,}05$.

when: $u > u_\alpha$ - H_o hypothesis is rejected,

$u < u_\alpha$ - there is no reason to reject the hypothesis H_o.

b) in case of $6_2^o = 6_i^2$ the value of the *t* statistics is determined:

$$t = \frac{\left| \overline{y}_{j,o} - \overline{y}_{j,a} \right|}{\sqrt{\dfrac{N_o \cdot \hat{s}_{j,o} + N_a \cdot \hat{s}_{j,a}}{N_o + N_a - 2} \cdot \left(\dfrac{1}{N_o} + \dfrac{1}{N_a} \right)}} \tag{12}$$

and is compared to the critical value of the distribution t_α (Students distribution): $t_\alpha = t(\alpha, N_o + N_i - 2)$; $\alpha = 0{,}05$.

when:

$t > t_\alpha$ H_o hypothesis is rejected,

$t < t_\alpha$ there is no reason to reject the hypothesis H_o.

Due to the incomparable measurement conditions, it can be expected that $6_2^o \neq 6_i^2$. This is a premise that in order to determine the significance of changes in diagnostic parameter of the state of transport u statistics should be used and the related application procedure. This

means that as a result of this procedure, the values of the binary matrix are appropriately assumed: 1 - when the test of averages shows that the hypothesis about the equality of mean values of parameters is rejected $\{\{y_{jl}\}(\Theta_1)\}$ and $\{\{y_{jl}\}(\Theta_k)\}$ and 0 when the test of averages shows that there is no reason to reject the equality hypothesis average values of parameters $\{\{y_{jl}\}(\Theta_1)\}$ and $\{\{y_{jl}\}(\Theta_k)\}$.

5 Investigation of the distance of confidence intervals of the mean value of the diagnostic parameter

Investigation of the distance of confidence intervals of the mean value of the diagnostic parameter for two states of the means of transport [1,3,5,7] is carried out using the distance test procedure for two sets of parameter values $\{\{y_{jl}(\Theta_1)\}$ and $\{\{y_{jl}(\Theta_k)\}$. It is assumed that the population has a distribution N($m,\ \sigma$), with both mean value m and standard deviation σ are unknown in the population. Moreover, assuming that a small sample was drawn randomly from the population (n $\geq$ 10), the confidence interval for the average population is obtained by dependence [7,9]:

$$r_{\alpha j} = t_{\alpha j}\frac{S_j}{\sqrt{n-1}} \tag{13}$$

where: $S_j = \sqrt{\dfrac{1}{N}\sum_{l=1}^{N}\left(y_{jl} - \overline{y}_j\right)^2}$ – standard deviation from the sample,

$$\overline{y}_j = \frac{1}{N}\sum_{l=1}^{N}y_{jl}$$ - the arithmetic mean of the results of the trial,

t_α – Student's quantile distribution for N-1 degrees of freedom and significance level α = 0,05.

1- α – coefficient of confidence (probability of coverage by the confidence interval average value m of the population, 1 - α = 0,95),

N – number of objects of the group of means of transport.

Further examination consists in conducting a test for finding common points for the determined confidence intervals for two sets $\{\{y_{jl}(\Theta_1)\}$ and $\{\{y_{jl}(\Theta_k)\}$ according to relation:

a) for $\overline{y}_j(\Theta_1) < \overline{y}_j(\Theta_k)$: $\overline{y}_j(\Theta_k) - r_{\alpha j}(\Theta_k) > \overline{y}_j(\Theta_1) + r_{\alpha j}(\Theta_1)$ ⇒ „1"

$$\tag{14}$$

b) for $\overline{y}_j(\Theta_1) > \overline{y}_j(\Theta_k)$: $\overline{y}_j(\Theta_1) - r_{\alpha j}(\Theta_1) > \overline{y}_j(\Theta_k) + r_{\alpha j}(\Theta_k)$ ⇒ „1"

Correspondingly, the values of the binary matrix are assumed: 1 - when the test shows that the confidence intervals of the mean parameters values $\{\{y_{jl}\}(\Theta_1)\}$ and $\{\{y_{jl}\}(\Theta_k)\}$ they do not have common points (they are significantly dependent on the state s_i) and 0, when the distance test shows that the confidence intervals of the mean parameters $\{\{y_{jl}\}(\Theta_1)\}$ and $\{\{y_{jl}\}(\Theta_k)\}$ they have points in common (they are not significantly dependent on the state s_i).

6 The algorithm for determining the status and fault location test

The algorithm of the methodology for determining the diagnostic test of means of transport includes the following stages [8,9,10]:

1. Data acquisition.
2. Optimization of the set of diagnostic parameter values (only in the case of a large number of elements in Y set, e.g. m>10).
3. Organize a data set by specifying a set $\{s_i\,(\Theta_k),\ i=1,\ldots, 1;\ k=1,\ \ldots, K\}$.

4. The study of the significance of changes in the values of diagnostic parameters $\{y_j(\Theta_k)\}$ depending on the state $\{s_i = f(\Theta_k); \Theta_k \in (\Theta_1, \Theta_b)\}$, ie which of the diagnostic parameters "best" describes the state s_i:

    a)   Using the method of testing the distance between confidence intervals of mean values of diagnostic parameters in the case of testing means of transport (number of objects greater than 10). Correspondingly, the values are: 1 - when the test shows that the confidence intervals of the average parameters $\{\{y_{jl}\}(\Theta_1)\}$ and $\{\{y_{jl}\}(\Theta_k)\}$ they have no common points and 0 if the distance test shows that the confidence intervals of the mean parameters $\{\{y_{jl}\}(\Theta_1)\}$ i $\{\{y_{jl}\}(\Theta_k)\}$ they have common points according to the relations (14);

    b)   In case of set $\{s_i = f(\Theta_k)\}$ is a multi-element set of results of studies on the significance of changes in diagnostic parameter values $\{y_j(\Theta_k)\}$ depending on the state $\{s_i = f(\Theta_k); \Theta_k \in (\Theta_1, \Theta_b)\}$ are identical for all states $\{s_i = f(\Theta_k)\}$.

5. Designation of the boolean matrix:

    a)   1 – when change of state s_i causes significant changes in the value of the diagnostic parameter y_j;

    b)   0 – when change of state s_i does not cause significant changes in the value of the diagnostic parameter y_j;

6. Designation of the T_{KS} state control test based on the boolean matrix - T_{KS} test as a vector of logical values (0, 1) diagnostic parameters and identical to vector: $\{(y_1, \ldots, y_n, \ldots, y_N)\}$ $\Rightarrow S^0 \vee S^1 = \{(s_1, \ldots, s_n, \ldots, s_N)$ for fitness S^0 and the unfittnes of the means of transport S^1.

7. Determination of the fault location test T_{LU} based on the boolean matrix - test T_{LU} as a vector of logical values <0, 1> diagnostic parameters and identical to vector: $\{(y_1, \ldots, y_n, \ldots, y_N)\}$ $\Rightarrow S^1 = \{(s_1, \ldots, s_n, \ldots, s_N)$, while:

    a)   if the logical value of the diagnostic parameter check vector assumes the value "1" - the parameter value is within the limit value range: $y_j = y_{jg}$;

    b)   if the logical value of the diagnostic parameter check vector assumes the value "0" - the parameter value is outside the limit value range: $y_j \neq y_{jg}$.

8. Interpretation of test results:

    a) $T_{KS} = \{y_1, \ldots, y_j, \ldots, y_m\}$:
- $\{0, \ldots, 0, \ldots, 0\}$ – means of transport usable (fit) ("0" means that value $y_j \neq y_{jg}$),
- $\{1, \ldots, 0, \ldots, 0\}$ – means of transport unfit („1" means that value $y_{1} = y_{1g}$),
- $\{1, \ldots, 1, \ldots, 0\}$ - means of transport unfit („1" means that value $y_j = y_{jg}$),
- $\{1, \ldots, 1, \ldots, 1\}$ - means of transport unfit („1" means that value $y_m = y_{mg}$),

    b) $T_{LU} = \{y_1, \ldots, y_j, \ldots, y_m\}$:
- $\{1, \ldots, 0, \ldots, 0\}$ - means of transport unfit, location of fault – state s_i („1" means that value $y_1 = y_{1g}$),
- $\{1, \ldots, 1, \ldots, 0\}$ - means of transport unfit, location of fault – state s_{i+1} („1" means that value $y_j = y_{jg}$),
- $\{1, \ldots, 1, \ldots, 1\}$ - means of transport unfit, location of fault – state s_{i+n} („1" means that value $y_m = y_{mg}$),

7 Implementation of the algorithm for determining the status and fault location test

The scope of the algorithm implementation was formulated on the basis of functional requirements related to the implementation of the methodology of optimization of a set of diagnostic parameters to assess the state of the machine and to determine the technical

condition and fault location test. On the basis of the above scope of implementation, tasks formulated as components of the assessment process of means of transport were formulated. These are [9,10]:

1. Acquisition of measurement and simulation data:
    a) entering data by the end user;
    b) data transfer using the "copy and paste" mechanisms implemented in the Windows system;
    c) data import from other database systems or from text files;
    d) data edition;
    e) saving the entered data to the database;
    f) reduction of the set of diagnostic parameters.
2. Machine condition assesment:
    a) determination of the relation matrix: technical condition - value of the diagnostic parameter;
    b) entering the relation matrix: technical condition - operation time - value of the diagnostic parameter);
    c) to designate a diagnostic test to check the condition and location of damage to the machine.
3. Data reporting and visualization:
    a) visualization of selected series in the form of line and point charts;
    b) defining the parameters of the visualized series (eg color, thickness or type of line);
    c) visualization of the form of the condition and fault location test;
    d) display in a tabular form the results of simulations.

8 Conclusions

To sum up the issues discussed above concerning the methodology of building diagnostic tests of means of transport, the following conclusions can be made:

1. All presented procedures for determining state and location control tests allow to determine optimal diagnostic tests due to the adopted criteria.
2. Due to the preference in the selection of diagnostic parameters of the similarity method and the method of testing the dependence of the diagnostic - state parameter, in order to build a binary diagnostic matrix in the field of logical relations (0, 1), the method of testing the confidence interval distance of the mean value of the diagnostic parameter should be selected.
3. In the case of building a TD diagnostic test, based on the binary analysis of the Boolean matrix, the method of the check vector should be used $T_D = <T_{KS}, T_{LU}>$:

a) T_{KS} test as a vector of logical values (0, 1) of diagnostic parameters and a state vector of states:$\{(y_1, \ldots, y_n, \ldots, y_N)\} \Rightarrow S^0 \vee S^1 = \{(s_1, \ldots, s_n, \ldots, s_N)$ for the state S^0 and state of incapacity of transport S^1.

b) T_{LU} test as a vector of logical values $<0, 1>$ of diagnostic parameters and a state vector of states:$\{(y_1, \ldots, y_n, \ldots, y_N)\} \Rightarrow S^1 = \{(s_1, \ldots, s_n, \ldots, s_N)$.

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