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## METHOD OF ASSESSMENT OF TECHNICAL OBJECT APTITUDE IN ENVIRONMENT OF EXPLOITATION AND SERVICE CONDITIONS

### METODA OCENY STANU ZDATNOŚCI OBIEKTU TECHNICZNEGO W OTOCZENIU WARUNKÓW UŻYTKOWANIA I JAKOŚCI OBSŁUGI\*

*In the article, results of exploitation research of three various technical objects (public transportation bus engines) are presented. Gathered data is presented in three sets (1 – concerning object, 2 – concerning driving conditions, 3 – concerning driver; where sets 2 and 3 are object environment) in form of points (expert number assessments). Relation between point information on object and point information on environment was described using coupled state interaction equations. Such approach allowed to determine the following for each moment of exploitation: technical condition parameter  $a_T$  and operating condition parameter  $a_R$ , therefore in each moment of exploitation data regarding operating and technical condition of exploited object (bus) is available. This data allows for identification of object aptitude condition and thus optimally control processes of exploitation and service of particular objects as element of set of objects and set of objects.*

**Keywords:** diagnostics, regulation, aptitude.

*W artykule przedstawiono wyniki badań eksploatacyjnych trzech różnych obiektów technicznych (silników autobusów komunikacji miejskiej). Zebrana informacja została przedstawiona w 3 zbiorach (1 – dotyczy obiektu, 2 – dotyczy warunków jazdy, 3 – dotyczy kierowcy; przy czym zbiory 2 i 3 stanowią otoczenie obiektu) w postaci umownych punktów (eksperskich liczbowych ocen). Relację między punktową informacją o obiekcie i punktową informacją o otoczeniu opisano za pomocą sprzężonych równań stanu. Takie podejście pozwoliło wyznaczyć dla każdej chwili eksploatacji: parametr stanu technicznego  $a_T$  i parametr stanu działania  $a_R$ . Zatem w każdej chwili eksploatacji może być dostępna informacja o stanie technicznym i stanie działania każdego eksploatowanego obiektu (autobusu). Informacja ta pozwala identyfikować w każdej chwili stan zdatności obiektu, a zatem pozwala optymalnie sterować procesami użytkowania i obsługi poszczególnych obiektów jako elementu zbioru obiektów i zbiorem obiektów.*

**Słowa kluczowe:** diagnostyka, regulacja, zdatność.

#### 1. Introduction

Long term exploitation of machine leads to its gradual damage caused by decrease in its material properties and mechanical wear. Technical service is therefore tasked with constant (current) assessment of object technical condition and ability of proper operation of technical objects based on measured diagnostic signals, exploitation signals and conditions in which the object is exploited. This allows to observe changes of operating and technical condition and, subsequently, changes of technical object reliability state [2, 7, 15, 19, 23].

A concept of new exploitation research method is presented based on the assumption that all data (diagnostic signals, exploitation signals, exploitation condition signals) are expressed (presented) in form of points and thus may be easily processed.

Diagnostic signals in form of points were first applied in diagnostics of SH-2G onboard-based helicopter (USA) [22]. In this method, object aptitude is analyzed only by summing all of the points. Subsequently, assessment is made whether the obtained number of points characterizing serviced object is lower than acceptable threshold specified by manufacturer (USA).

Innovative method of using exploitation data (in form of points) proposed in the article is based on fact that each change of diagnostic signals, signals concerning exploitation quality and signals concerning exploitation conditions (depending on their value and time of occurrence) is correlated with number of points determined by the

experts. Subsequently, basing on the aforementioned, parameters of operating condition  $a_R$  and technical condition  $a_T$  are determined using coupled interaction equations [3, 12, 13, 15, 21] for each moment of object exploitation.

The described method may prove very useful, as global exploitation condition of the object is unequivocally presented by unequivocal values of  $a_R$  and  $a_T$  parameters (where  $a_R$  – operating condition parameter,  $a_T$  – technical condition parameter). This allows to predict how the object should be used in future and when the object should be serviced (repaired, overhauled).

#### 2. Diagnostic research of technical object and its environment

Exploited technical object (e.g. bus engine) should be properly used and serviced in conditions according to its destination [4, 5, 8, 9, 16–18, 24–26, 29].

Particular role in exploitation system is fulfilled by expert-driver and expert-diagnostician (expert being a specialist assessing system and its environment). Experts are the main source of knowledge that should be used to increase probability of elaborating comprehensive and reliable assessment of technical object aptitude condition during the process of its service and use including exploitation costs [2, 7, 10, 11, 27, 28].

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The research was conducted on three MAN bus engines in Municipal Transport Company of the City of Białystok. The aim of the research was obtaining diagnostic signals concerning object condition  $D_K$  (data from diagnostician) and data on its environment  $U$  (expert data from driver).

Research was conducted in subsequent months of the year, therefore obtaining database for 12 months of the year.

The following was used in order to conduct exploitation analysis:

- opacimeter – measurement of exhaust fumes fogging [1/m],
- acoustimeter – noise measurement [dB],
- diagnostical stand (chassis dynamometer) – fuel consumption measurement [l/100km],
- expert knowledge from driver and diagnostician.
- Obtained data: determined (measurable), probabilistic and heuristic (expert) was divided onto two sets:
- signals concerning technical condition  $D_K$  (Tab. 1)
- signals concerning environment influence condition  $U$  (Tab. 2)

Table 1. Information on diagnostic research of MAN engine:

|           |  |
|-----------|--|
| $D_{M1}$  | average fuel consumption without heating [l/100km]   |
| $D_{M2}$  | average fuel consumption with heating [l/100km]  |
| $D_{M3}$  | fogging value in engine blow [1/m]   |
| $D_{M4}$  | fogging value during engine operation [1/m]  |
| $D_{M5}$  | noise peak value [dB]  |
| $D_{M6}$  | noise average value [dB]   |
| $D_{M7}$  | braking force value on front axis – left wheel [kN]  |
| $D_{M8}$  | braking force value on front axis – right wheel [kN]   |
| $D_{M9}$  | percent value of difference between braking forces of left and right wheel of front axis [%] |
| $D_{M10}$ | braking force value on rear axis – left wheel [kN]   |
| $D_{M11}$ | braking force value on rear axis – right wheel [kN]  |
| $D_{M12}$ | percent value of difference between braking forces of left and right wheel of rear axis [%]  |
| $D_{E1}$  | clatters   |
| $D_{E2}$  | unattended stalls (on neutral gear)  |
| $D_{E3}$  | stalls (during operation)  |
| $D_{E4}$  | bus mileage [km]   |

Table 2. Information on environment research of MAN engine:

|          |  |
|----------|--|
| $U_{K1}$ | job experience [years]                     |
| $U_{K2}$ | number of hours of work in a month [h]     |
| $U_{K3}$ | driving smoothness (braking, accelerating) |
| $U_{D1}$ | number of stops                            |
| $U_{D2}$ | route length [km]                          |
| $U_{D3}$ | surface and lay of the land                |
| $U_{P1}$ | environment temperature [°C]               |
| $U_{P2}$ | wind speed [m/s]                           |
| $U_{P3}$ | atmospheric pressure [hPa]                 |
| $U_{P4}$ | rainfall [mmHg]                            |

Data from Tab. 1 and 2 is of physical nature. Therefore in each case, data is transformed into a point value.

### 3. Special method of consideration of expert knowledge for “weighing” data

In order to obtain knowledge from specialists (experts) and to weigh data with points, specific questionnaires were developed with users – bus drivers. [10, 28]

Research was conducted on group of 20 experts.

Table 3. Expert weight of assessment of condition engine – diagnostic (diagnostician is the expert), driver and environment (driver is the expert)

| Signal   | Signal name                                | Group importance | Importance within group | Ep |
|----------|--|------------------|-------------------------|----|
| $D_{M1}$ | average fuel consumption without heating   | 5                | 3                       | 15 |
| $D_{M2}$ | average fuel consumption with heating      |                  | 3                       | 15 |
| $D_{M3}$ | fogging value in engine blow               |                  | 2                       | 10 |
| $D_{M4}$ | fogging value during engine operation      |                  | 2                       | 10 |
| $D_{M5}$ | noise peak value                           |                  | 1                       | 5  |
| $D_{M6}$ | noise average value                        |                  | 1                       | 5  |
| $D_{E1}$ | clatters                                   | 4                | 2                       | 8  |
| $D_{E2}$ | unattended stalls (on neutral gear)        |                  | 1                       | 4  |
| $D_{E3}$ | stalls                                     |                  | 3                       | 12 |
| $D_{E4}$ | bus mileage                                |                  | 1                       | 4  |
| $U_{K1}$ | job experience                             | 3                | 1                       | 3  |
| $U_{K2}$ | number of hours of work in a month [h]     |                  | 2                       | 6  |
| $U_{K3}$ | driving smoothness (braking, accelerating) |                  | 3                       | 9  |
| $U_{D1}$ | number of stops                            | 2                | 2                       | 4  |
| $U_{D2}$ | route length                               |                  | 1                       | 2  |
| $U_{D3}$ | surface and lay of the land                |                  | 3                       | 6  |
| $U_{P1}$ | environment temperature                    | 1                | 3                       | 3  |
| $U_{P2}$ | wind speed                                 |                  | 1                       | 1  |
| $U_{P3}$ | atmospheric pressure                       |                  | 2                       | 2  |
| $U_{P4}$ | rainfall                                   |                  | 3                       | 3  |

Ep – expert weight points (importance of matter)

Data (signals) connected to object  $\{D_{Mi}\}$ ,  $\{D_{Ei}\}$  and its environment  $\{U_{Ki}\}$ ,  $\{U_{Di}\}$ ,  $\{U_{Pi}\}$  were subjected to expert processing. Experts (Tab. 3) determined importance of signal groups and importance of signal within that group and number of Ep for transforming exploitation fact into point description. The respondents answered the questions by putting points (from range 1–5) in proper section of questionnaire, where 1 was least important data.

Importance of data  $D_i$  and  $U_i$  expressed by proper point weights including knowledge of expert diagnostician is presented in Tab. 4.

Basing on Tab. 4, every situation, phenomenon and exploitation fact may be expressed in form of proper number of points.

Table 4. Expert point weights for assessment of condition of engine, diagnostician and driver (Tab. 3)

| Signal          | Diagnostic signal name                             | Ep | N | N + 5% | N + 10% | N + 15% | N + 20% |
|-----------------|--|----|---|--------|---------|---------|---------|
| D <sub>M1</sub> | average fuel consumption without heating [l/100km] | 15 | 1 | 16     | 31      | 46      | 61      |
| D <sub>M2</sub> | average fuel consumption with heating [l/100km]    | 15 | 1 | 16     | 31      | 46      | 61      |
| D <sub>M3</sub> | fogging value in engine blow [1/m]                 | 10 | 1 | 11     | 21      | 31      | 41      |
| D <sub>M4</sub> | fogging value during engine operation [1/m]        | 10 | 1 | 11     | 21      | 31      | 41      |
| D <sub>M5</sub> | noise peak value [dB]                              | 5  | 1 | 6      | 11      | 16      | 21      |
| D <sub>M6</sub> | noise average value [dB]                           | 5  | 1 | 6      | 11      | 16      | 21      |

| Signal           | Diagnostic signal name                                | Ep | <1% | 1-10% | 10-20% | 20-30% | >30% |
|------------------|---|----|-----|-------|--------|--------|------|
| D <sub>M7</sub>  | braking force value on front axis – left wheel [kN]   | -  | -   | -     | -      | -      | -    |
| D <sub>M8</sub>  | braking force value on front axis – right wheel [kN]  | -  | -   | -     | -      | -      | -    |
| D <sub>M9</sub>  | percentage difference between DM7 and DM8 [%]         | 15 | 1   | 16    | 31     | 46     | 61   |
| D <sub>M10</sub> | braking force value on rear axis – left wheel [kN]    | -  | -   | -     | -      | -      | -    |
| D <sub>M11</sub> | braking force value on rear axis – right wheel [kN]   | -  | -   | -     | -      | -      | -    |
| D <sub>M12</sub> | percentage difference between DM10 and DM11 [%]       | 15 | 1   | 16    | 31     | 46     | 61   |
| D <sub>M13</sub> | braking force value on middle axis – left wheel [kN]  | -  | -   | -     | -      | -      | -    |
| D <sub>M14</sub> | braking force value on middle axis – right wheel [kN] | -  | -   | -     | -      | -      | -    |
| D <sub>M15</sub> | percentage difference between DM13 and DM14 [%]       | 10 | 1   | 11    | 21     | 31     | 41   |

| Signal          | Diagnostic signal name              | Ep | 0-2 | 2-5 | >5 |
|-----------------|-------------------------------------|----|-----|-----|----|
| D <sub>E1</sub> | clatters                            | 8  | 1   | 9   | 17 |
| D <sub>E2</sub> | unattended stalls (on neutral gear) | 4  | 1   | 5   | 9  |
| D <sub>E3</sub> | stalls (during operation)           | 12 | 1   | 13  | 25 |

| Signal          | Diagnostic signal name | Ep | < 500 k | 500 k – 1 mln | >1 mln |
|-----------------|------------------------|----|---------|---------------|--------|
| D <sub>E4</sub> | bus mileage            | 4  | 1       | 5             | 9      |

| Signal          | Environment signal name | Ep | < 5 years | 5-12 years | >12 years |
|-----------------|-------------------------|----|-----------|------------|-----------|
| U <sub>K1</sub> | job experience [years]  | 3  | 1         | 4          | 7         |

| Signal          | Environment signal name                | Ep | < 140 h | 140-180 h | >180 h |
|-----------------|--|----|---------|-----------|--------|
| U <sub>K2</sub> | number of hours of work in a month [h] | 6  | 1       | 7         | 13     |

| Signal          | Environment signal name                    | Ep | <10 | 10-15 | >15 |
|-----------------|--|----|-----|-------|-----|
| U <sub>K3</sub> | driving smoothness (braking, accelerating) | 9  | 1   | 10    | 19  |

Table 4. (continued) Expert point weights for assessment of condition of engine, diagnostician and driver (Tab. 3)

| Signal          | Environment signal name | Ep | <15 | 15-30 | >30 |
|-----------------|-------------------------|----|-----|-------|-----|
| U <sub>D1</sub> | number of stops         | 4  | 1   | 5     | 9   |

| Signal          | Environment signal name | Ep | <10 km | 10-15 km | > 15km |
|-----------------|-------------------------|----|--------|----------|--------|
| U <sub>D2</sub> | route length            | 2  | 1      | 3        | 5      |

| Signal          | Environment signal name     | Ep | good surface | mediocre surface | poor surface |
|-----------------|-----------------------------|----|--------------|------------------|--------------|
| U <sub>D3</sub> | surface and lay of the land | 6  | 1            | 7                | 13           |

| Signal          | Environment signal name | Ep | < -10°C | -10-10°C | 10-20°C | 20-30°C | >30°C |
|-----------------|-------------------------|----|---------|----------|---------|---------|-------|
| U <sub>P1</sub> | environment temperature | 3  | 7       | 4        | 1       | 4       | 7     |

| Signal          | Environment signal name | Ep | <28,4 km/h | 28,4-61,56 km/h | >61,56 km/h |
|-----------------|-------------------------|----|------------|-----------------|-------------|
| U <sub>P2</sub> | wind speed              | 1  | 1          | 2               | 3           |

| Signal          | Environment signal name | Ep | <994,66 hPa | 996,66-1020 hPa | >1020 hPa |
|-----------------|-------------------------|----|-------------|-----------------|-----------|
| U <sub>P3</sub> | atmospheric pressure    | 2  | 1           | 3               | 5         |

| Signal          | Environment signal name | Ep | no rainfall | no significant rainfall | small rainfall | rainfall | small snowfall | snowfall |
|-----------------|-------------------------|----|-------------|-------------------------|----------------|----------|----------------|----------|
| U <sub>P3</sub> | rainfall                | 3  | 1           | 4                       | 7              | 10       | 13             | 16       |

Table 5. Compilation of diagnostic signals in physical form

| Diagnostic signals |                 |                 |                 |                 |                 |                 |                 |                 |                 |                  |                  |                  |                 |                 |                 |                 |
|--------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|------------------|------------------|-----------------|-----------------|-----------------|-----------------|
| Month              | D <sub>M1</sub> | D <sub>M2</sub> | D <sub>M3</sub> | D <sub>M4</sub> | D <sub>M5</sub> | D <sub>M6</sub> | D <sub>M7</sub> | D <sub>M8</sub> | D <sub>M9</sub> | D <sub>M10</sub> | D <sub>M11</sub> | D <sub>M12</sub> | D <sub>E1</sub> | D <sub>E2</sub> | D <sub>E3</sub> | D <sub>E4</sub> |
| 1                  | 35,7            | 35,7            | 0,37            | 0,02            | 95              | 92              | 12              | 13,2            | 9               | 15,8             | 14,7             | 6                | 0               | 0               | 0               | 215582          |
| 2                  | 35,7            | 35,7            | 0,37            | 0,02            | 95              | 92              | 12              | 13,2            | 9               | 15,8             | 14,7             | 6                | 0               | 1               | 0               | 217982          |
| 3                  | 35,7            | 35,7            | 0,37            | 0,02            | 95              | 92              | 12              | 13,2            | 9               | 15,8             | 14,7             | 6                | 0               | 0               | 0               | 220102          |
| 4                  | 35,7            | 35,7            | 0,37            | 0,02            | 95              | 92              | 12              | 13,2            | 9               | 15,8             | 14,7             | 6                | 0               | 0               | 2               | 222669          |
| 5                  | 35,7            | 35,7            | 0,37            | 0,02            | 95              | 92              | 12              | 13,2            | 9               | 15,8             | 14,7             | 6                | 1               | 0               | 0               | 225125          |
| 6                  | 35,7            | 35,7            | 0,37            | 0,02            | 95              | 92              | 12              | 13,2            | 9               | 15,8             | 14,7             | 6                | 0               | 3               | 0               | 227358          |
| 7                  | 33,7            | 33,7            | 0,45            | 0,03            | 94              | 90              | 11,4            | 12              | 5               | 12,5             | 12,3             | 1                | 0               | 0               | 0               | 229758          |
| 8                  | 33,7            | 33,7            | 0,45            | 0,03            | 94              | 90              | 11,4            | 12              | 5               | 12,5             | 12,3             | 1                | 0               | 0               | 0               | 232273          |
| 9                  | 33,7            | 33,7            | 0,45            | 0,03            | 94              | 90              | 11,4            | 12              | 5               | 12,5             | 12,3             | 1                | 0               | 0               | 0               | 234571          |
| 10                 | 35,1            | 35,1            | 0,42            | 0,03            | 91,9            | 91              | 8,8             | 12,6            | 29              | 11,9             | 13,3             | 10               | 3               | 3               | 0               | 236699          |
| 11                 | 35,1            | 35,1            | 0,42            | 0,03            | 91,9            | 91              | 8,8             | 12,6            | 29              | 11,9             | 14,7             | 10               | 0               | 0               | 0               | 239047          |
| 12                 | 35,1            | 35,1            | 0,42            | 0,03            | 91,9            | 91              | 8,8             | 12,6            | 29              | 11,9             | 14,7             | 10               | 0               | 0               | 0               | 241392          |

Table 6. Compilation of environment signals in physical form

| Environment signals |                 |                 |                 |                 |                 |                 |                 |                 |                 |                         |
|---------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------------------------|
| Month               | U <sub>K1</sub> | U <sub>K2</sub> | U <sub>K3</sub> | U <sub>D1</sub> | U <sub>D2</sub> | U <sub>D3</sub> | U <sub>P1</sub> | U <sub>P2</sub> | U <sub>P3</sub> | U <sub>P4</sub>         |
| 1                   | 4               | 125             | 5               | 33              | 15              | 2               | -0,8            | 15,2            | 995,7           | no significant rainfall |
| 2                   | 24              | 164             | 5               | 21              | 9,4             | 1               | -5,8            | 16,2            | 1002,2          | small rainfall          |
| 3                   | 24              | 160             | 5               | 21              | 9,4             | 1               | 7,7             | 19,4            | 999,3           | no significant rainfall |
| 4                   | 10              | 179             | 5               | 21              | 9,4             | 1               | 14,9            | 16,3            | 987,2           | no significant rainfall |
| 5                   | 10              | 146             | 5               | 40              | 16,9            | 2               | 20,9            | 14,9            | 997,0           | no significant rainfall |
| 6                   | 16              | 187             | 6               | 40              | 16,9            | 2               | 22,1            | 16,4            | 992,2           | small rainfall          |
| 7                   | 16              | 110             | 6               | 40              | 16,9            | 2               | 26,6            | 13,7            | 995,8           | no significant rainfall |
| 8                   | 16              | 144             | 4               | 40              | 16,9            | 2               | 23,8            | 14,6            | 996,7           | no significant rainfall |
| 9                   | 16              | 170             | 4               | 40              | 16,9            | 2               | 20,2            | 16,4            | 995,7           | no rainfall             |
| 10                  | 4               | 144             | 4               | 29              | 14,6            | 2               | 11,8            | 16,0            | 994,0           | no significant rainfall |
| 11                  | 4               | 154             | 7               | 29              | 14,6            | 2               | 6,9             | 15,8            | 995,7           | no rainfall             |
| 12                  | 4               | 185             | 7               | 29              | 14,6            | 2               | -2,3            | 16,3            | 994,5           | no significant rainfall |

Table 7. Compilation of diagnostic signals in point form

| Month | D <sub>M1P</sub> | D <sub>M2P</sub> | D <sub>M3P</sub> | D <sub>M4P</sub> | D <sub>M5P</sub> | D <sub>M6P</sub> | D <sub>M9P</sub> | D <sub>M12P</sub> | D <sub>E1P</sub> | D <sub>E2P</sub> | D <sub>E3P</sub> | D <sub>E4P</sub> |
|-------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|-------------------|------------------|------------------|------------------|------------------|
| 1     | 15               | 15               | 10               | 10               | 5                | 5                | 30               | 30                | 0                | 0                | 0                | 4                |
| 2     | 15               | 15               | 10               | 10               | 5                | 5                | 30               | 30                | 0                | 4                | 0                | 4                |
| 3     | 15               | 15               | 10               | 10               | 5                | 5                | 30               | 30                | 0                | 0                | 0                | 4                |
| 4     | 15               | 15               | 10               | 10               | 5                | 5                | 30               | 30                | 0                | 0                | 12               | 4                |
| 5     | 15               | 15               | 10               | 10               | 5                | 5                | 30               | 30                | 8                | 0                | 0                | 4                |
| 6     | 15               | 15               | 10               | 10               | 5                | 5                | 30               | 30                | 0                | 8                | 0                | 4                |
| 7     | 15               | 15               | 10               | 10               | 5                | 5                | 30               | 15                | 0                | 0                | 0                | 4                |
| 8     | 15               | 15               | 10               | 10               | 5                | 5                | 30               | 15                | 0                | 0                | 0                | 4                |
| 9     | 15               | 15               | 10               | 10               | 5                | 5                | 30               | 15                | 0                | 0                | 0                | 4                |
| 10    | 15               | 15               | 10               | 10               | 5                | 5                | 60               | 30                | 16               | 8                | 0                | 4                |
| 11    | 15               | 15               | 10               | 10               | 5                | 5                | 60               | 30                | 0                | 0                | 0                | 4                |
| 12    | 15               | 15               | 10               | 10               | 5                | 5                | 60               | 30                | 0                | 0                | 0                | 4                |

Table 8. Compilation of environment signals in point form

| Month | U <sub>K1P</sub> | U <sub>K2P</sub> | U <sub>K3P</sub> | U <sub>D1P</sub> | U <sub>D2P</sub> | U <sub>D3P</sub> | U <sub>P1P</sub> | U <sub>P2P</sub> | U <sub>P3P</sub> | U <sub>P4P</sub> |
|-------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| 1     | 3,00             | 6,00             | 9,00             | 12,00            | 4,00             | 12,00            | 2,03             | 1,00             | 1,55             | 2,32             |
| 2     | 9,00             | 12,00            | 9,00             | 12,00            | 2,00             | 6,00             | 2,25             | 1,07             | 1,61             | 2,89             |
| 3     | 9,00             | 12,00            | 9,00             | 12,00            | 2,00             | 6,00             | 1,58             | 1,13             | 1,77             | 2,06             |
| 4     | 6,00             | 12,00            | 9,00             | 12,00            | 2,00             | 6,00             | 1,43             | 1,03             | 1,17             | 2,10             |
| 5     | 6,00             | 12,00            | 9,00             | 12,00            | 6,00             | 12,00            | 1,65             | 1,00             | 1,71             | 2,26             |
| 6     | 9,00             | 18,00            | 9,00             | 12,00            | 6,00             | 12,00            | 1,80             | 1,00             | 1,33             | 2,73             |
| 7     | 9,00             | 6,00             | 9,00             | 12,00            | 6,00             | 12,00            | 2,35             | 1,00             | 1,52             | 1,94             |
| 8     | 9,00             | 12,00            | 9,00             | 12,00            | 6,00             | 12,00            | 1,97             | 1,03             | 1,65             | 1,97             |
| 9     | 9,00             | 12,00            | 9,00             | 12,00            | 6,00             | 12,00            | 1,47             | 1,03             | 1,70             | 1,40             |
| 10    | 3,00             | 12,00            | 9,00             | 12,00            | 4,00             | 12,00            | 1,29             | 1,06             | 1,45             | 1,55             |
| 11    | 3,00             | 12,00            | 9,00             | 12,00            | 4,00             | 12,00            | 1,77             | 1,00             | 1,57             | 1,33             |
| 12    | 3,00             | 18,00            | 9,00             | 12,00            | 4,00             | 12,00            | 2,03             | 1,06             | 1,55             | 2,03             |

Values of signals  $U_{p1} \div U_{p3}$  in Tab. 6 are average values from the whole month, whereas  $U_{p4}$  signal value is the most frequently occurring in given month. In Tab. 8 a summed number of points was created through transforming observed signals into point values on daily basis and subsequently summing them in the end of the month and dividing them by number of days in a month.

Basing on data in Tab. 5 and 6 and including expert weights (Tab. 3 and 4), point form of signals were obtained – Tab. 7 and 8 (data for other two buses was filled analogously).

**4. Algorithm of determination parameters of technical condition and operating condition of technical object**

Driver, through his influence on the bus, alters its environment (accelerating, braking, turning). Influence is only effective if bus technical condition is sufficient. Bus performing its daily duties is subjected to wear (increase in noise, fogging, fuel consumption). Intensity of wear depends on varying environment in which the bus operates. Therefore exploitation is an environment for technical condition and technical condition is environment for exploitation. These facts may be expressed by coupled interaction equations [3, 13]:

$$\frac{dD_K}{dt} = a_T D_K + b_T U \tag{1}$$

$$\frac{dU}{dt} = a_R U + b_R D_K \tag{2}$$

where:  $U$  – variable of operating condition (exploitation signal),  $D_K$  – signal of bus technical condition,  $a_R$  – operating condition parameter, depending mostly on object operation and influence of object technical condition,  $b_R$  – parameter of influence of technical condition on operating condition,  $a_T$  – technical condition parameter, depending mostly on diagnostic signals and signals resulting from environment,  $b_T$  – parameter of influence of regulation condition on bus technical condition.

According to rules of static and dynamic identification [20], the following is obtained from equation (1):

$$\hat{a}_T = \frac{\sum \Delta D_K \Delta U}{\sum \Delta U^2} \tag{3}$$

$$a_T = \frac{\Delta D_K}{\frac{\Delta \Theta}{resurs} (D_K + \hat{a}_T U)} \tag{4}$$

Parameter  $a_T$  characterizes technical condition of the system and depends on diagnostic signals as well as signals resulting from actions of driver and environment.

According to rules of static and dynamic identification [20], from equation (2) the following is obtained:

$$\hat{a}_R = \frac{\sum \Delta D_K \Delta U}{\sum \Delta D_K^2} \tag{5}$$

$$a_R = \frac{\Delta U}{\frac{\Delta \Theta}{resurs} (U + \hat{a}_R D_K)} \tag{6}$$

Signals  $D_K$  and  $U$  in homogeneous point form (Tab. 6) were transformed into resultant diagnostic signal ( $D_K$ ) and environment signal ( $U$ ).

$$D_K = \sqrt{D_{M1P}^2 + D_{M2P}^2 + D_{M3P}^2 + D_{M4P}^2 + D_{M5P}^2 + D_{M6P}^2 + D_{M9P}^2 + D_{M12P}^2 + D_{15P}^2 + D_{1EP}^2 + D_{2EP}^2 + D_{3EP}^2 + D_{4EP}^2} \tag{7}$$

$$U = \sqrt{U_{K1P}^2 + U_{K2P}^2 + U_{K3P}^2 + U_{D1P}^2 + U_{D2P}^2 + U_{D3P}^2 + U_{P1P}^2 + U_{P2P}^2 + U_{P3P}^2 + U_{P4P}^2} \tag{8}$$

Table 9. Procedure of calculating of parameters of technical and regulation condition for bus no. 301

| Determination of technical $a_T$ and regulation $a_R$ potentials |                       |       |       |                 |              |            |           |                  |        |              |         |                |             |             |          |          |
|--|-----------------------|-------|-------|-----------------|--------------|------------|-----------|------------------|--------|--------------|---------|----------------|-------------|-------------|----------|----------|
| Month  | Time of work $\theta$ | $D_K$ | $U$   | $\Delta \Theta$ | $\Delta D_K$ | $\Delta U$ | $D_K * U$ | $\Sigma D_K * U$ | $U^2$  | $\Sigma U^2$ | $D_K^2$ | $\Sigma D_K^2$ | $\hat{a}_T$ | $\hat{a}_R$ | $a_T$    | $a_R$    |
| 1  | 215582                | 50,16 | 21,05 | 2346            | 50,16        | 21,05      | 1055,65   | 1055,65          | 442,92 | 442,92       | 2516    | 2516           | -2,3834     | -0,4196     | 0        | 0        |
| 2  | 217982                | 50,32 | 22,52 | 4746            | 100,48       | 43,57      | 1133,20   | 2188,84          | 507,16 | 950,08       | 2532    | 5048           | -2,3038     | -0,4336     | -0,01354 | 0,01308  |
| 3  | 220102                | 50,16 | 22,39 | 6866            | 150,64       | 65,95      | 1122,93   | 3311,78          | 501,18 | 1451,27      | 2516    | 7564           | -2,2820     | -0,4378     | -0,02366 | 0,02258  |
| 4  | 222669                | 51,58 | 21,30 | 9433            | 202,21       | 87,26      | 1098,80   | 4410,57          | 453,89 | 1905,16      | 2660    | 10224          | -2,3151     | -0,4314     | 0,00951  | -0,00979 |
| 5  | 225125                | 50,79 | 24,43 | 11889           | 253,01       | 111,69     | 1240,79   | 5651,36          | 596,73 | 2501,89      | 2580    | 12804          | -2,2588     | -0,4414     | -0,00485 | 0,00468  |
| 6  | 227358                | 50,79 | 28,70 | 14122           | 303,80       | 140,38     | 1457,60   | 7108,96          | 823,49 | 3325,38      | 2580    | 15384          | -2,1378     | -0,4621     | -0,00204 | 0,00190  |
| 7  | 229758                | 42,91 | 23,12 | 16522           | 346,71       | 163,50     | 992,06    | 8101,02          | 534,59 | 3859,97      | 1841    | 17225          | -2,0987     | -0,4703     | -0,00374 | 0,00336  |
| 8  | 232273                | 42,91 | 25,33 | 19037           | 389,61       | 188,83     | 1086,75   | 9187,78          | 641,52 | 4501,48      | 1841    | 19066          | -2,0411     | -0,4819     | -0,00233 | 0,00213  |
| 9  | 234571                | 42,91 | 25,26 | 21335           | 432,52       | 214,09     | 1083,83   | 10271,60         | 638,07 | 5139,55      | 1841    | 20907          | -1,9985     | -0,4913     | -0,00268 | 0,00240  |
| 10   | 236699                | 74,40 | 23,35 | 23463           | 506,93       | 237,44     | 1737,47   | 12009,07         | 545,30 | 5684,86      | 5536    | 26443          | -2,1125     | -0,4541     | 0,00086  | -0,00097 |
| 11   | 239047                | 72,22 | 23,37 | 25811           | 579,15       | 260,82     | 1688,13   | 13697,20         | 546,35 | 6231,21      | 5216    | 31659          | -2,1982     | -0,4326     | 0,00108  | -0,00128 |
| 12   | 241392                | 72,22 | 27,01 | 28156           | 651,37       | 287,83     | 1951,05   | 15648,25         | 729,79 | 6961,00      | 5216    | 36875          | -2,2480     | -0,4244     | 0,00201  | -0,00281 |

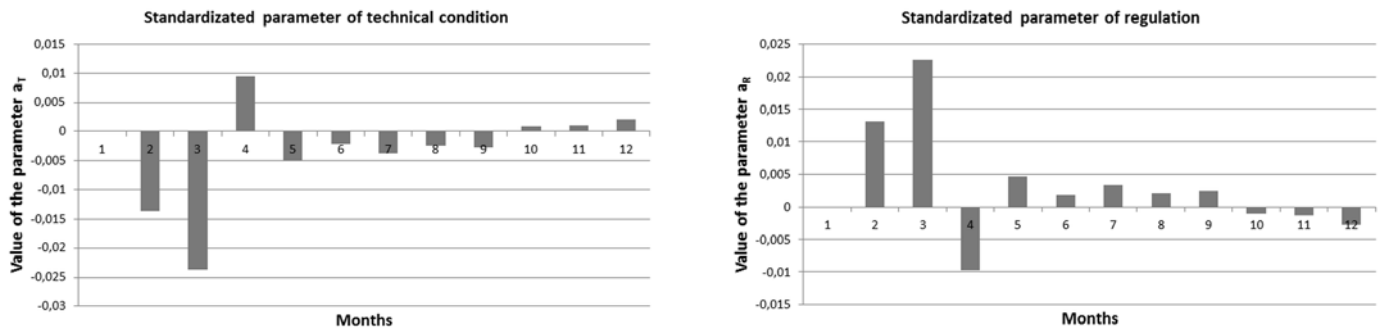


Fig. 1. Changes of normalized parameter of technical and regulation condition of bus no. 301

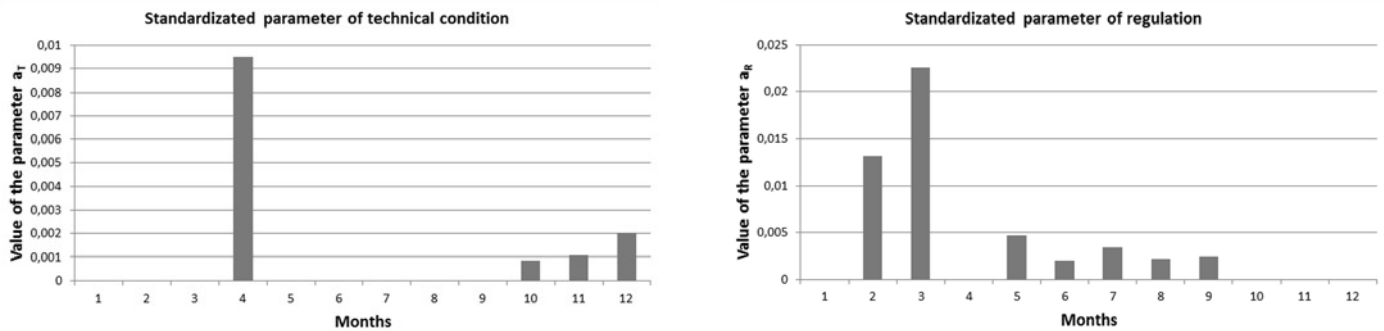


Fig. 2. Changes of normalized parameter of technical and regulation condition of bus no. 301 after eliminating negative values

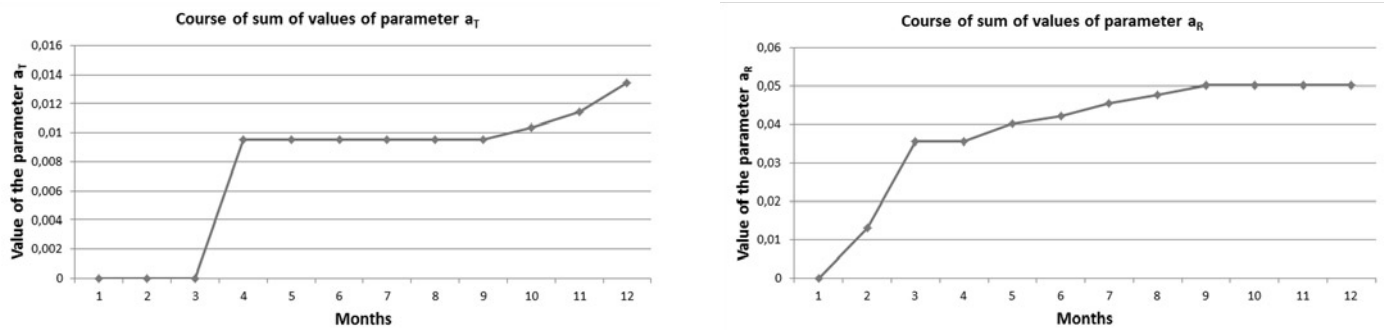


Fig. 3. Course of the sum of values of normalized parameter of technical and regulation condition of bus no. 301

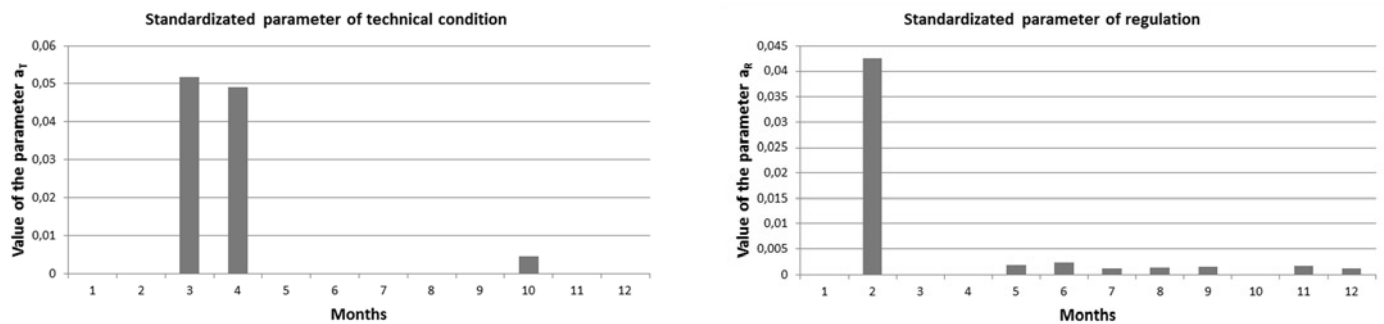


Fig. 4. Changes of normalized parameter of technical and regulation condition of bus no. 303 after eliminating negative values

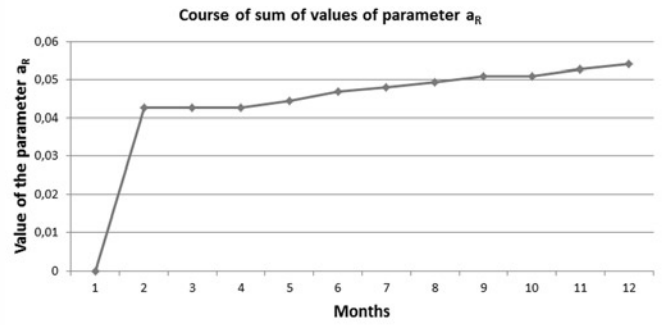
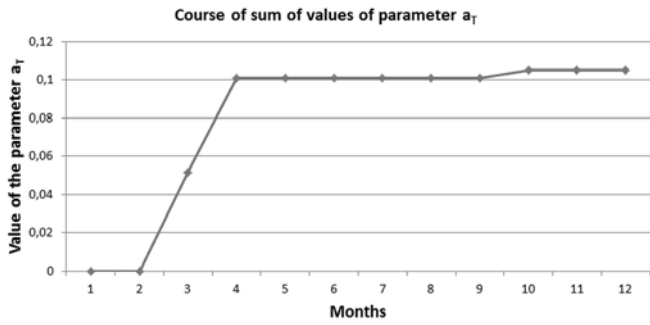


Fig. 5. Course of the sum of values of normalized parameter of technical and regulation condition of bus no. 303

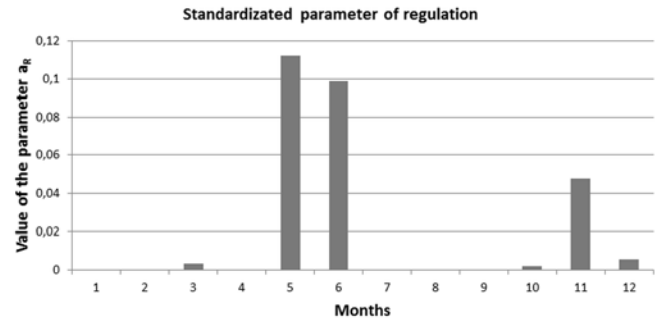
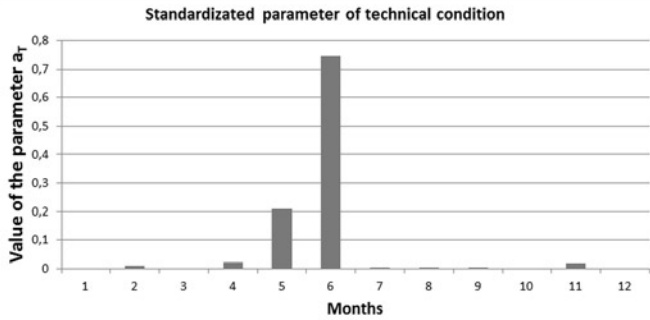


Fig. 6. Changes of normalized parameter of technical and regulation condition of bus no. 304 after eliminating negative values

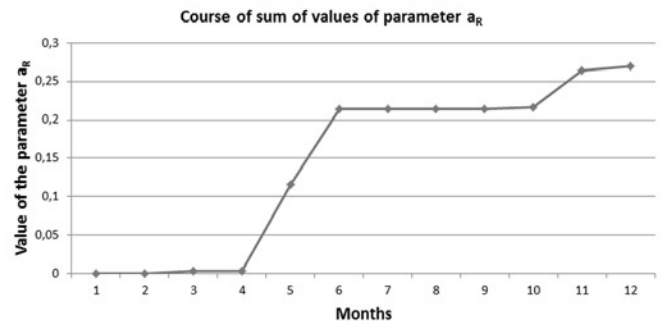
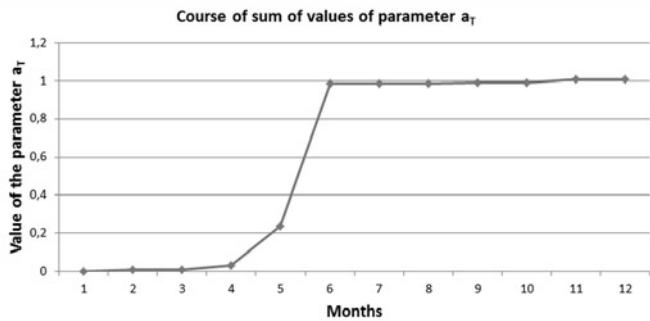


Fig. 7. Course of the sum of values of normalized parameter of technical and regulation condition of bus no. 304

Table 10. Procedure of calculating technical and regulation condition parameters

|               | bus no. 301 | bus no. 303 | bus no. 304 |
|---------------|-------------|-------------|-------------|
| $a_T$ average | 0,0027      | 0,0263      | 0,1120      |
| $a_T$ sum     | 0,0134      | 0,1053      | 1,0081      |
| $a_R$ average | 0,0063      | 0,0060      | 0,0385      |
| $a_R$ sum     | 0,0501      | 0,0541      | 0,2698      |

Using data from Tab. 7 and 8 and equations 1–6, increases of technical condition described by parameter  $a_T$  and operating (regulation) condition described by parameter  $a_R$  were calculated.

Algorithm of calculating  $a_T$  (based on equation 4) and  $a_R$  (based on equation 6) are presented in Tab. 9

Subsequently,  $\Sigma a_T$  expressing degree of object wear as well as  $\Sigma a_R$  expressing degree of proper operation ability loss are determined.

Results of course of changes of normalized parameters  $a_R$  and  $a_T$  for bus no. 301 are presented on Fig. 1 and 2, for bus no. 303 and Fig. 4 and for bus no. 304 on Fig. 6. Courses of sums of these parameters are presented on Fig. 3, 5 and 7 respectively. Charts do not contain first month, as  $a_R$  and  $a_T$  parameters are impossible to determine (initial value of  $D_K$  and  $U$  signals is unknown).

The buses have mileage of – bus no. 1 – 241 392 km, bus no. 2 – 239 829 km, bus no. 3 – 244 003 km. Expert may therefore assume that the buses are already run in. Hence, no possibility exist to improve technical condition of analyzed buses (in case where bus would be in running in process, negative values of  $a_T$  and  $a_R$  should also be considered). Therefore assumption is made that  $a_T$  and  $a_R$  parameters may not be negative (Fig. 1). Hence the negative values are considered 0. The above chart assumes the following form (Fig. 2).

Basing on data from Tab. 10, expert obtains complex information on operating ( $a_R$ ) and technical ( $a_T$ ) condition of the object. Sum of  $a_T$  is information on object wear and sum of  $a_R$  is information on change of regulation susceptibility. Therefore assumption can be made that best technical condition (i.e. the least worn) is that of bus no. 301. The



greatest potential of operating (regulation) condition is also that of bus no. 301. The above conclusion was verified by 20 experts (Tab. 3).

Such approach allows for simple qualification of objects to further exploitation or to service.

## 5. Summary

Exploitation research activity is conducted in the process of object exploitation in order to determine its current and future operating and technical condition. In advanced and complex technical objects, multiple research methods are applied simultaneously, each based on data in different form (determined signals, probabilistic, heuristic). [4, 5, 8, 9, 12, 13, 16, 18, 21, 25, 26, 29]

Assumption of innovatory method of using diagnostic data (presented in form of points) was presented in the article. For each change of signal (depending on its value and moment of occurrence) proper amount of points set by the experts is assigned. In previous diagnostic method, points are summed and, subsequently, range to which the

object belong is determined as well as its condition and extent of its exploitation [22].

This method is versatile and may be applied to any technical object (bus, helicopter, aircraft). The method requires itemization of signals connected to analyzed object and signals connected to its environment and, subsequently, expressing these signals in form of points using proper weights. This activity is performed by expert or team of experts. Subsequently, signals in form of points are used to determine technical and operating condition parameters (equation 4, 6) [3, 6, 7, 12, 13, 14, 15, 19] from coupled interaction equations [1, 2, 3, 6, 12, 13]. This allows for constant control of technical and operating condition of the object during its exploitation. The described method might prove very useful, as global exploitation condition is unequivocally presented using  $a_R$  and  $a_T$  parameters and thus allows to predict how the object should be exploited and when should it be serviced (repaired, overhauled).

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