Article citation info:
GRĄDZKI R, LINDSTEDT P. Method of assessment of technical object aptitude in environment of exploitation and service conditions. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2015; 17 (1): 54–63.

Rafał GRĄDZKI
Paweł LINDSTEDT

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 (eksperckich 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 aT i parametr stanu działania aR, 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 optymanie 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 o 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 if 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].

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

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_{M1}	average fuel consumption without heating [l/100km]	15	1	16	31	46	61
D_{M2}	average fuel consumption with heating [l/100km]	15	1	16	31	46	61
D_{M3}	fogging value in engine blow [1/m]	10	1	11	21	31	41
D_{M4}	fogging value during engine operation [1/m]	10	1	11	21	31	41
D_{M5}	noise peak value [dB]	5	1	6	11	16	21
D_{M6}	noise average value [dB]	5	1	6	11	16	21

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

Signal	Diagnostic signal name	Ep	0-2	2-5	>5
D_{E1}	clatters	8	1	9	17
D_{E2}	unattended stalls (on neutral gear)	4	1	5	9
D_{E3}	stalls (during operation)	12	1	13	25

Signal	Diagnostic signal name	Ep	< 500 k	500 k – 1 mln	>1 mln
D_{E4}	bus mileage	4	1	5	9

Signal	Environment signal name	Ep	< 5 years	5-12 years	>12 years
U_{K1}	job experience [years]	3	1	4	7

Signal	Environment signal name	Ep	< 140 h	140-180 h	>180 h
U_{K2}	number of hours of work in a month [h]	6	1	7	13

Signal	Environment signal name	Ep	<10	10-15	>15
U_{K3}	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_{D1}	number of stops	4	1	5	9

Signal	Environment signal name	Ep	<10 km	10-15 km	> 15km
U_{D2}	route length	2	1	3	5

Signal	Environment signal name	Ep	good surface	mediocre surface	poor surface
U_{D3}	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_{P1}	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_{P2}	wind speed	1	1	2	3

Signal	Environment signal name	Ep	<994,66 hPa	996,66–1020 hPa	>1020 hPa
U_{P3}	atmospheric pressure	2	1	3	5

Signal	Environment signal name	Ep	no rainfall	no significant rainfall	small rainfall	rainfall	small snowfall	snowfall
U_{P3}	rainfall	3	1	4	7	10	13	16

Table 5. Compilation of diagnostic signals in physical form

Diagnostic signals																
Month	D_{M1}	D_{M2}	D_{M3}	D_{M4}	D_{M5}	D_{M6}	D_{M7}	D_{M8}	D_{M9}	D_{M10}	D_{M11}	D_{M12}	D_{E1}	D_{E2}	D_{E3}	D_{E4}
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_{K1}	U_{K2}	U_{K3}	U_{D1}	U_{D2}	U_{D3}	U_{P1}	U_{P2}	U_{P3}	U_{P4}
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_{M1P}	D_{M2P}	D_{M3P}	D_{M4P}	D_{M5P}	D_{M6P}	D_{M9P}	D_{M12P}	D_{E1P}	D_{E2P}	D_{E3P}	D_{E4P}
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_{K1P}	U_{K2P}	U_{K3P}	U_{D1P}	U_{D2P}	U_{D3P}	U_{P1P}	U_{P2P}	U_{P3P}	U_{P4P}
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 form 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 is 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):

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

$$a_T = \frac{\Delta D_K}{\frac{\Delta \Theta}{resurs}(D_K + \hat{a}_T U)} \tag{3}$$

(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).

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

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

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 θ	D_K	U	Δθ	$ΔD_K$	ΔU	D_K*U	ΣD_K*U	U^2	ΣU^2	D_K^2	ΣD_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

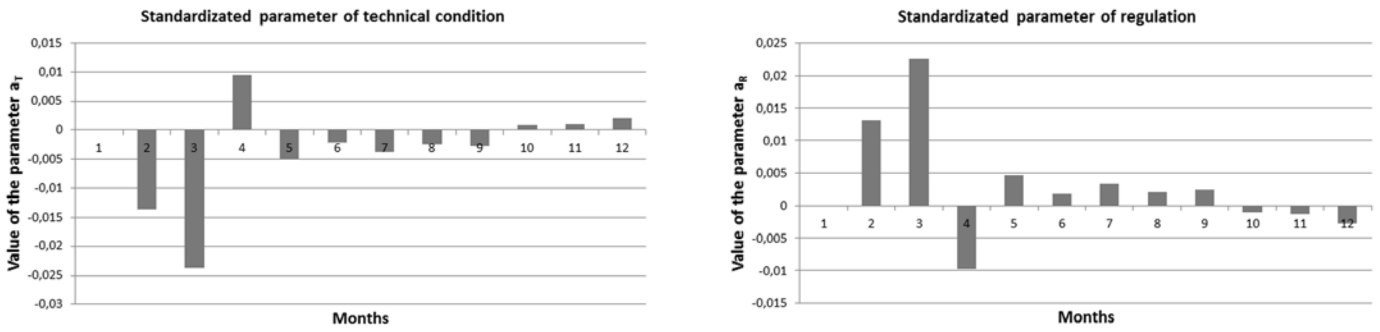

Fig. 1. Changes of normalized parameter of technical and regulation condition of bus no. 301

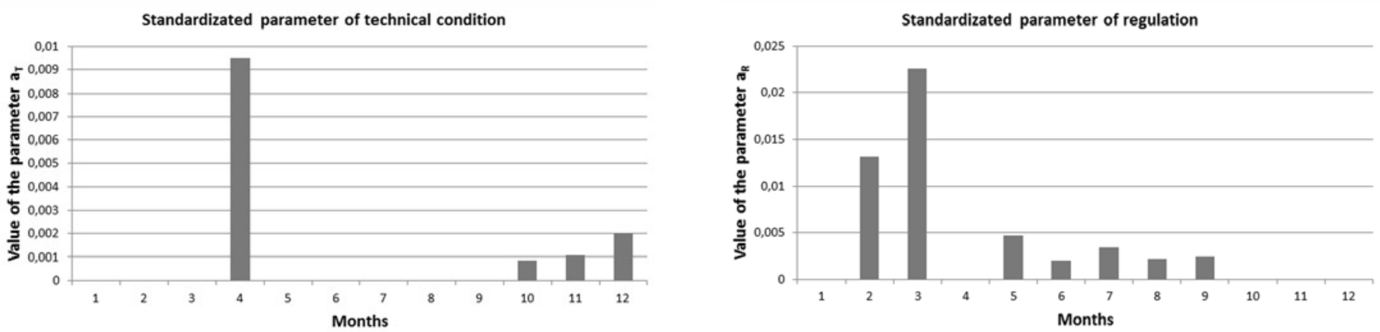

Fig. 2. Changes of normalized parameter of technical and regulation condition of bus no. 301 after eliminating negative values

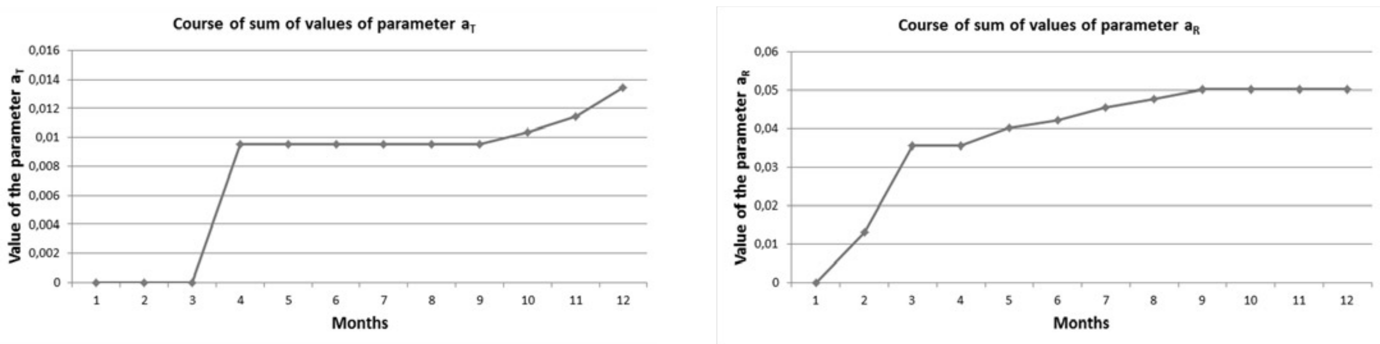

Fig. 3. Course of the sum of values of normalized parameter of technical and regulation condition of bus no. 301

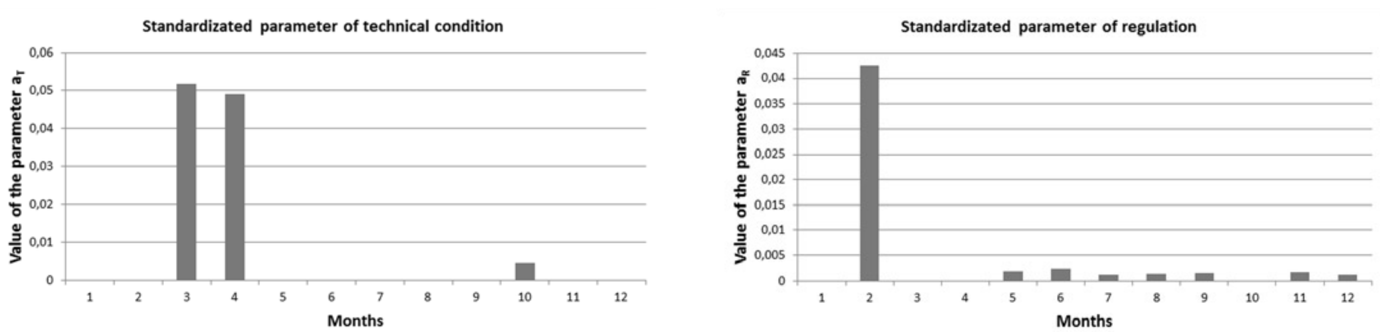

Fig. 4. Changes of normalized parameter of technical and regulation condition of bus no. 303 after eliminating negative values

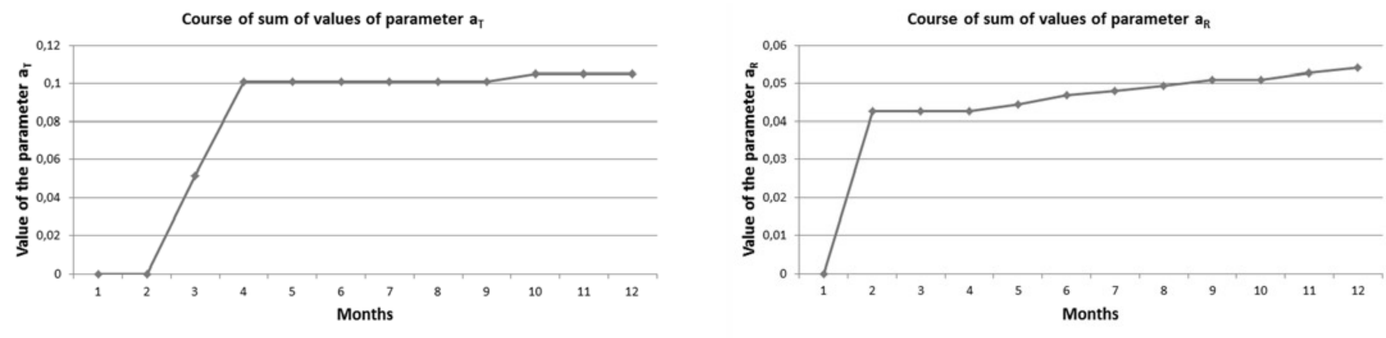

Fig. 5. Course of the sum of values of normalized parameter of technical and regulation condition of bus no. 303

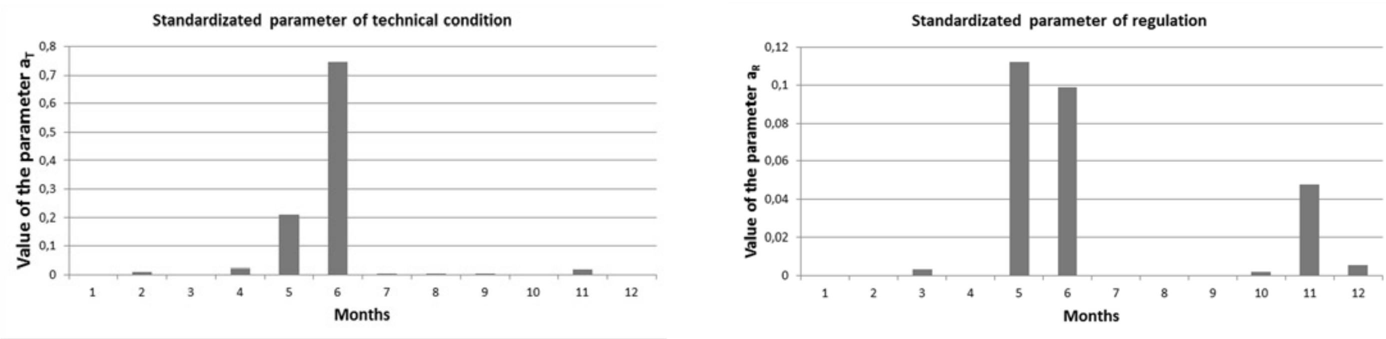

Fig. 6. Changes of normalized parameter of technical and regulation condition of bus no. 304 after eliminating negative values

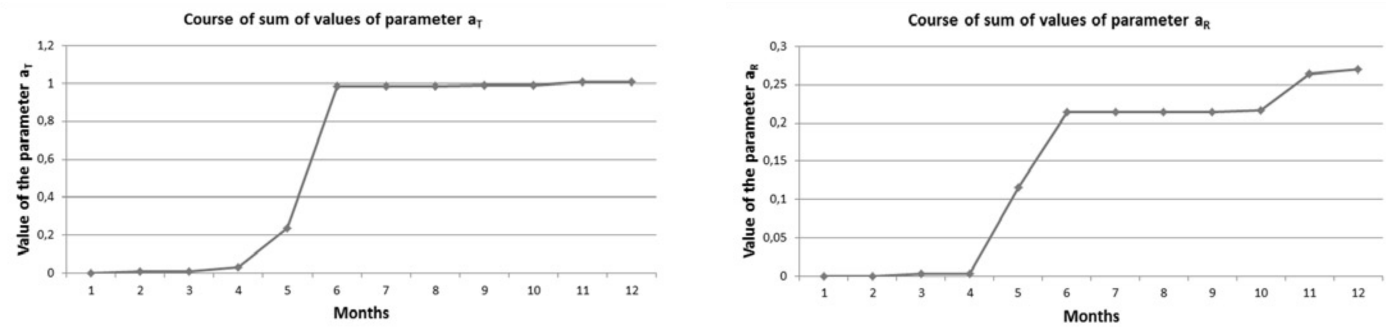

Fig. 7. Course of the sum of values of normalized parameter of technical and regulation condition of bus no. 304

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, Σa_T expressing degree of object wear as well as Σa_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).

The article was created during realization of young PhDs scholarship, granted from project "Podniesienie potencjału uczelni wyższych jako czynnik rozwoju gospodarki opartej na wiedzy" implemented by Białystok Technical University as a part of Operational Programme Human Capital 2007-2013, financed by European Social Fund and National Budget.

References

1. Ashby R. W. Wstęp do cybernetyki. Warszawa: PWN, 1963.
2. Bukowski L. Prognozowanie niezawodności i bezpieczeństwa systemów zautomatyzowanych, Materiały XXXI Szkoły Niezawodności, Szczyrk 2003.
3. Cempel C. Teoria i inżynieria. Poznań: Wydawnictwo Naukowe Instytutu Technologii Eksploatacyjnej PIB, 2006.
4. Cempel C, Natke H G. Damage Evolution and Diagnosis in Operating Systems. Safety Evaluation Based on Identification Approaches Related to Time-Variant and Nonlinear Structures. Springer 1993: 44-61.
5. Filipczyk J. Faults of duty vehicles in the aspects of securing safety. Transport Problems 2011, Vol. 6; 1: 105-110.
6. Grądzki R, Lindstedt P. Determination of parameters of a technical and control states of the bus engine by using its discretized operation information. Journal of KONBIN 2013; Z.2: 97-108.
7. Günther H. Diagnozowanie silników wysokoprężnych. Warszawa: Wydawnictwo Komunikacji i Łączności, 2006.
8. Jardine A K S, Lin D, Banjevic D. A review on machinery diagnostics and prognostics implementing condition-based maintenance. Mechanical Systems and Signal Processing 2006, Vol 20; 7: 1483–1510.
9. Jaźwiński J, Klimaszewski S, Żurek J. Metoda prognozowania stanu obiektu w oparciu o badania kontrolne. Zagadnienia Eksploatacji Maszyn 2003, Vol. 38; 2: 33-44.
10. Jaźwiński J, Szpytko J. Zasady wyznaczania zespołu ekspertów w badaniach niezawodności i bezpieczeństwa urządzeń technicznych. XXXIV Zimowa Szkoła Niezawodności PAN „Niekonwencjonalne metody oceny trwałości i niezawodności". Szczyrk 2006: 157–167.
11. Jaźwiński J, Żurek J. Modelowanie i identyfikacja systemu „Człowiek−obiekt techniczny−otoczenie" w aspekcie jego niezawodności i gotowości. XIV Zimowa Szkoła Niezawodności PAN „Człowiek–obiekt techniczny–otoczenie. Problemy niezawodności i utrzymania ruchu". Szczyrk 1986.
12. Lindstedt P. Reliability and its relation to regulation and diagnostics in the machinery exploitation systems. Journal of KONBiN 2006, Vol. 1; 2: 317-330.
13. Lindstedt P. The Method of complex worthness assessment of an engineering object in the process of its use and service. Solid State Phenomena 2009; 144: 45-52.
14. Lindstedt P. The effect of pilot's work quality on technical condition of propeller engine bearing. Journal of Vibroenginering 2006, 8(2): 6-10.
15. Lindstedt P, Sudakowski T. The Method of Assessment of Suitability of the Bearing System Based on Parameters of Technical and Adjustment State. Solid State Phenomena Mechatronic systems and materials V 2013; 73-78.
16. Madej H, Filipczyk J. The methods of assessment of car technical condition regarding ennironmental protection. Journal of KONES 2009; 16(2): 103-108.
17. Nowakowski T. Reliability Model of Combined Transportation System. Probabilistic Safety Assessment and Management. Springer 2004: 2012-2017.
18. Sarangaa H, Knezevicb J. Reliability prediction for condition-based maintained systems. Reliability Engineering & System Safety. Elsevier 2001; 71(2): 219–224.
19. Smalko Z. Podstawy eksploatacji technicznej pojazdów. Warszawa: Oficyna Wydawnicza PW, 1998.
20. Söderström T, Stoica P. Identyfikacja systemów. Warszawa: PWN, 1997.
21. Sudakowski T. Premises of operational method of calculation of reliability of machines on the base of parametric and momentary symptoms of damage. Acta mechanica et automatica 2009; 3(4): 73-79.
22. Szawłowski S. Przegląd kontrolny ASPA w systemie obsługiwania śmigłowca pokładowego SH-2G, 8 Międzynarodowa konferencja AIRDIAG Warszawa 27-28.10.2005.

23. Szczepaniak C. Podstawy modelowania sytemu człowiek – pojazd – otoczenie. Warszawa: PWN, 1999.
24. Szpytko J, Kocerba A. Metodyka kształtowania niezawodności eksploatacyjnej środka transportu. Methodology of exploitation reliability shaping of transport device. XXXV Zimowa Szkoła Niezawodności PAN „Problemy niezawodności systemów". Szczyrk 2007:483–492.
25. Szpytko J, Kocerba A. Przyczynowo-skutkowa metodyka oceny stanu technicznego środków transportu. XXXIII Zimowa Szkoła Niezawodności PAN „Metody badań przyczyn i skutków uszkodzeń". Szczyrk 2005.
26. Tylicki H, Żółtowski B. Zmiana stanu maszyny w procesie eksploatacji. XXXIII Zimowa Szkoła Niezawodności PAN „Metody badań przyczyn i skutków uszkodzeń". Szczyrk 2005.
27. Woropay M, Muślewski Ł, Ślęzak M, Szubartowski M. Assessment of the impact of human on safety of transportation system operation. Journal of KONBiN 2013; (1)25: 97-106.
28. Zając M. Wykorzystanie badań ankietowych do oszacowania niezawodności systemu transportu intermodalnego. XXXIV Zimowa Szkoła Niezawodności PAN „Niekonwencjonalne metody oceny trwałości i niezawodności". Szczyrk 2006.
29. Żółtowski B. Metody diagnostyki technicznej w ocenie destrukcji maszyn. XXXV Zimowa Szkoła Niezawodności PAN „Problemy niezawodności systemów". Szczyrk 2007.

Rafał GRĄDZKI
Bialystok University of Technology
Faculty of Mechanical Engineering
ul. Wiejska 45C, 15-351 Bialystok, Poland

Paweł LINDSTEDT
Air Force Institute of Technology
ul. Księcia Bolesława 6A, 01–494 Warsaw, Poland

E-mails: r.gradzki@pb.edu.pl, sekretariat.naukowy@itwl.pl