**ANALYSIS OF THE INFLUENCE OF CARRIED OUT
REPAIRS EFFICIENCY ON TRANSPORT MEANS
OPERATIONAL RELIABILITY**

**ANALIZA WPLYWU SKUTECZNOŚCI REALIZOWA-
NYCH NAPRAW NA NIEZAWODNOŚĆ DZIAŁANIA
ŚRODKÓW TRANSPORTU**

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Abstract: *The Maintenance factors and destructive processes which affect systems and elements of technical objects result in undesirable changes of values of their functional features, which causes damages. A damage to a technical object has been defined as exceeding permitted boundary values by significant features characterizing their elements. On the basis of analysis results of the author's own research concerning damages to means of transport, used in real transport systems, it has been found that these damages are the effect of different forcing factors. A certain number of damages is caused by natural wear of machine elements, whereas other damages can occur in result of ineffective repair of a previous damage. Thus, the so called recurrent (secondary) damages occur in a short period of time. On the basis of literature and maintenance and operation analysis results it was found that the most frequent cause of recurrent damage occurrence is improper quality of repairs of the analyzed means of transport. Primary damages are not dependent on each other and they appear randomly, whereas recurrent damages do depend on each other and their occurrence is conditioned by earlier occurrence of a repair, and above all, by its poor quality. In the paper, a method for evaluation the influence of carried out repairs on transport means operational reliability, has been presented. On the basis of the analysis of the moments in which damages to the means of transport and of the time interval lengths between them a simulation model representing a real stream of the damages was built, which enables to evaluate influence of the efficiency of the performed repairs of the means of transport in the real transport system*

Keywords: *transport system, mean of transport, model, damage*

Streszczenie w języku polskim na końcu artykułu

1 Introduction

The authors of the paper have made an attempt to evaluate the influence of damages occurred during transport means operation on reliable transport systems functioning.

On the basis of literature analysis and the authors' investigation results it was found that damages to transport means used in transport systems are the result of the impact of different forcing factors. These factors can be divided into:

- working factors – affecting the machine in result of execution of the working process by a machine (conditioned by the machine functioning),
- external factors – characterizing the impact of the environment on the machine (not conditioned by the machine functioning)
- antropotechnical factors – affecting the machine in result of conscious and unconscious activities of the man (eg. people's mistakes made during the process of operation and maintenance).

Due to the character of the forcing factors influence on the technical object, they can be divided into two basic classes:

- those conditioned by the machine operation (affect the machine only during its operation),
- those not conditioned by the machine operation (affect the machine also when it does not work).

A certain number of damages results from natural wear of the machine elements, whereas other damages can be caused by an ineffective repair of the previously occurred damage. In result of it, the so called repeatable damages occur over a short period of time. They are caused by inappropriate organization of repairs, poor skills of the service workers, limitations connected with pre and past repair diagnosing, etc.

On the basis of analysis of the authors' own research results, it was found that identification of the damage occurrence causes, carried out during the transport means repairs, is of great importance for transport means reliability improvement. The main causes of damages resulting from repair mistakes include:

- use of inappropriate material
- errors of regulation
- errors of the repair technology
- use of a wrong spare part
- use of inappropriate material

- use of a part with an invisible technological fault
- mounting mistakes
- post repair pollution

It results from the analysis of experimental tests, that a reduction of the number of repeatable damages is the main problem whose solution makes it possible to affect the transport means operational reliability. The main goal of the research is to evaluate the influence of transport means damages on the transport system operational reliability. The research object are damages to transport means subsystems, used within a chosen transport system. The research subject, however, is the influence of these damages on the transport system operational reliability. The following definition of the repair efficiency has been adopted on the basis of the analysed references (Woropay & Wdzięczny, 2006):

„Repair efficiency – is a goal realization degree, in which such a repair should be finished, without considering its economic aspects. The specific repair of the investigated subsystem is considered to be efficient, if it gets closer, in more positive way, to the specified goal being the assurance of the system task ability to accomplish the task within specified time interval.”

2 Investigation object

All the considerations deal with the transport systems performing transportation of passengers and cargo over water, land and air routes. The main operation aim of such systems is realization of transport service within a specific environment, within specific quantity and within specific time by means of technical objects being operated and maintained within the system range. Therefore, evaluation and assuring their required operation quality, both in terms of safety, efficiency, reliability, readiness with simultaneous giving consideration to the economical aspect, forms an essential factor in the process of operating and maintaining them. The investigated transport systems belong to the group of the sociotechnical systems of <H–M–E> (human – machine – environment) type, in which evaluation of their operation quality is performed depending on the changes of the feature values describing the action of the operators, technical objects controlled by them and the influence of the environment.

3 Investigation methodology

The investigations were performed within an urban transport system. The operation and maintenance investigations concern the damages to the

subsystems of the means of transport and the moment in which they occur. These investigations were performed using a passive experiment method in real operation and maintenance conditions. A set consisting of 28 means of transport used in real operation and maintenance conditions was randomly selected for the investigation purposes. The investigation results cover five-year long vehicle operation and maintenance period.

4 The analysis damage methodology

When analysing statistically the moments the damages to the means of transport occur, a difference between the theoretical distribution and empiric one of the time interval values occurring between these moments (Fig.1) was observed. The significant difference between the theoretical distribution and the empiric one occurring at the beginning of the interval $(0, t_p)$, from the moment p declines to zero. However inside the interval (t_p, ∞) the theoretical function is consistent with the empiric distribution. This discrepancy results from the secondary damages caused by improper quality of the repairs of the damaged elements that occurs in the interval $(0, t_p)$. The investigations prove that the moments of the secondary damages are included inside the interval from 0 to 7 days.

Fig.1. Changes of the value of the exponential function and the real function at the time t

The analysis of the empiric data (the length of the time intervals between the damages) indicates that it is reasonable to describe the probability distribution of the correct work times with the reliability function $R(x)$ formulated as follows (Bendat & Piersol, 1976):

$$R(x) = pe^{-\lambda x} + (1 - p)R_w(t) \quad (1)$$

It is a combination of the exponential distribution $pe^{-\lambda x}$ (with unknown value of the parameters $(p\lambda)$ and the reliability function $R_w(t)$). The estimation of the distribution parameters $(p\lambda)$ with the reliability function described with the dependence (1) is a complex problem.

Assuming that for unknown distribution (times of correct work) focused on the limited time interval $(0, t_p)$ it is possible to estimate the values of the parameters p and λ , then for high values of t it may be assumed that: $R(t) \approx p \cdot \exp(-\lambda t)$. In that case using the methods of the linear regression (in the semi-logarithmic system) the values of the parameters p and λ may be evaluated for different random tests cut off from the bottom. For each such a approximation a regression standard fault is calculated – $S(i)$, where i stands for the index of the day from which the data are analysed. The analysis of the changes $S(i)$ depending on the value of i indicates that there is a minimum $s(i)$ for various i , most frequently for $i = 5, 6, \dots, 12$.

The changes of the real function may be described by a combination of the probability distribution with density $g(t)$ and exponential distribution.

Let $\tau_i(k)$, where $i = 0, 1, 2, \dots, \tau_0(k) = 0, k = 0, 1, 2, \dots, n$ stand for the stream (moments) of the damages of the k -th technical object.

The difference $\tau_{i+1}(k) - \tau_i(k)$ for $i = 0, 1, 2, \dots$, stands for the length of the time interval between $i+1$ -st and i -th damage of the k -th technical object.

$Y_i(n)$ denotes superposition n – of the damage streams.

$$\text{Let } X_i(n) = Y_i(n) - Y_{i-1}(n),$$

where: $i = 0, 1, 2, \dots, Y_0 = 0$

It is assumed that the distribution of the random variable $X_i(n)$ does not depend on i . According to the theorem of Grigelionis it is known that with $n \rightarrow \infty$ the random variable $X(n)$ has exponential distribution. It is assumed that the probability density of the random variable T is formulated as follows:

$$f(t) = \alpha \cdot g(t) + (1 - \alpha)e^{-\lambda t} \quad \text{for } f(t) \geq 0 \quad (2)$$

It is a combination of the probability distribution with the density $g(t)$ and the exponential distribution with the density given with the formula (3):

$$g_1(t) = \lambda \cdot e^{-\lambda t} \quad (3)$$

The estimation of the parameter α and λ of the density (3) is based on the assumption that the density $g(t)$ takes the values above zero, and that they are relatively low and included within the range from $\langle t_p, \infty \rangle$. The analysis of the results of the operation and maintenance investigations regarding the

moments the damages occur prove that the set of the damages may be divided into subsets of the **primary** and **secondary** damages.

It results from the fact that the consecutive moments of the damages to the same subsystems are gathered sequentially after a single damage occurred.

The figure 2 shows an exemplary damage stream of a chosen subsystem of a mean of transport.

Fig.2 Time intervals between the primary and secondary damages

t_i – the moments the primary damages occur,

t_{ij} – the moments the secondary damages occur,

T_i – the time intervals between the moments the primary damages occur,

T_{ij} – the time intervals between the moments the secondary damages occur.

As it is shown in the figure 2, the first of the damages which occurred at the moments t_i , cause the sequences of the subsequent damages to the same subsystem within short time intervals. These damages are called **primary**. Whereas the next of them, with the finite number of repetitions, occurring at the moments t_{ij} , are called **secondary**. Based on the analysis of the investigation results it has been found that the reason for the secondary damages is, in general, improper quality of the repairs of the primary damages to the subsystem elements.

The primary damages are independent on one another and they occur randomly (they are not connected with one another by the cause and effect links). The secondary damages are dependent, because their occurrence depends on prior occurrence of the primary damage and the effect of its improper repair or improper repair of the next secondary damage.

Reduction of the probability of the occurrence of a secondary damage may be an initial point for reducing the damage intensity. It may be achieved by eliminating the damages occurring due to unreasonable realization of the repair process (Muślewski & Wdzięczny, 2008).

5 Damage classification

The classification of the damages to the means of transport was done for their respective subsystems. That was why the object under investigations was decomposed to its subsystems.

So called significant subsystems, that means such systems whose damage effects occurred within the time interval under investigation affect the operation reliability of the means of transport to the highest extent were selected in order to analyse the damage stream.

In order to classify the damages as primary and secondary ones the following criteria were adopted:

- a) essential criterion – the average distance in kilometres travelled between the consecutive damages of the j -the subsystem depending on:

L_u – summarised number of the damages of the mean of transport under investigation,

P_c – total distance travelled by the mean of transport during the investigation time [km],

L_{srj} – average distance travelled between two consecutive damages of the investigated j -th subsystem [km], described with the following dependence (4):

$$L_{srj} = \frac{P_c}{L_{uj}}, \quad j = 1, 2, \dots, k \quad (4)$$

s_j' – standard deviation [km], described with the dependence (5):

$$s_j' = \pm \sqrt{\frac{\sum_{i=1}^n (L_{ij} - L_{srj})^2}{n-1}}; \quad i = 1, 2, \dots, n, j = 1, 2, \dots, k \quad (5)$$

where:

L_{ij} – the distance travelled between the consecutive repairs [km] of the j -the subsystem,

n – number of the measurements that is the number of runs between the consecutive repairs of the j -th subsystem.

s_j – standard deviation including the t-Student's index depending on the number of the measurements n and the confidence coefficient $1-\alpha$, has been described with the dependence (6):

$$s_j = f_{1-\alpha} s_j', \quad j = 1, 2, \dots, k \quad (6)$$

The closer the confidence coefficient is to 1, the more extensive coefficient range is achieved. The confidence coefficient adopted in the paper is $1-\alpha = 0.95$. It is the most frequent value of this coefficient used in the statistical research. Along with the increase of its value the standard deviation s goes up _{j} . Previous damage to the j -the subsystem was a primary one L_{upj} on condition that the following dependence was fulfilled (7):

$$L_{upj} = L_{ij} \geq L_{srij} - s_j, j=1,2,...,k \quad (7)$$

Previous damage to the j -the subsystem was secondary L_{uwj} on condition that the following dependence was fulfilled (8):

$$L_{uwj} = L_{ij} < L_{srij} - s_j, j=1,2,...,k \quad (8)$$

where:

$L_{srij} - s_j$ – the value describing the threshold between the primary and secondary damages [km].

b) auxiliary criterion – critical time $s_{t_{kr}}$ determined on the basis of the average time of correct operation between the consecutive damages to the subsystem.

Basing on the analysis of the operation and maintenance investigation results it was assumed that the time intervals of the correct operation between the consecutive damages to subsystem may be expressed by means of an exponential distribution (Zajac, 1988). While the condition of the critical time t_{kr} was set on the basis of the dependences described below (9, 10, 11).

$$F(t_{kr}) = 1 - e^{-at_{kr}} \quad (9)$$

$$F(t_{kr}) = 1 - \alpha \quad (10)$$

$$f(t_{kr}) = ae^{-at_{kr}} \quad (11)$$

After comparing the equations (9) and (11) the following dependence was achieved (12):

$$1 - e^{-at_{kr}} = 1 - \alpha \quad (12)$$

$$\alpha = e^{-at_{kr}} \quad (13)$$

By logarithming both sides of the equation the dependence (14) was achieved:

$$-\ln \alpha = at_{kr} \quad (14)$$

After transforming the dependences (9÷12) the critical area of the exponential distribution was obtained, which is expressed with the dependence (15).

$$t_{kr} = -\frac{1}{\hat{a}} \ln \alpha \quad \hat{a} = \frac{1}{t} \quad (15)$$

In order to determine the value of the efficiency factor of the performed repairs the following relationships and dependences were adopted.

$N(t)$ – summarized number of the repairs of the technical object under investigation up to the moment t , is described with the relationship (16):

$$N(t) = \sum_j N_j(t), j = 1, 2, \dots, m \quad (16)$$

$N_j(t)$ – number of the repairs of the j -th subsystem up to the moment t , was described with the relationship:

$$N_j(t) = N_j^S(t) + N_j^N(t), j = 1, 2, \dots, m \quad (17)$$

where:

$N_j^S(t)$ – number of effective repairs of the j -th subsystem up to the moment t

$N_j^N(t)$ – number of ineffective repairs of the j -th subsystem up to the moment t

The values $N_j^S(t)$ and $N_j^N(t)$ were determined on the basis of the following relationship:

$L_{srj}(t)$ – average transmission, travelled distance or transmission between the repairs of the j -th subsystem, described with the dependence (18)

$$L_{srj}(t) = \frac{L_{1j}(t) + L_{2j}(t) + \dots + L_{nj}(t)}{N_j(t)} = \frac{1}{N_j(t)} \sum_{i=1}^n L_{ij}(t) \quad (18)$$

for $i = 1, 2, \dots, n, j = 1, 2, \dots, m$

where:

$L_{ij}(t)$ – the travelled distance or transmission between the consecutive repairs of the j -th subsystem up to the moment t ,

$N_j(t)$ – number of the repairs of the j -th subsystem up to the moment t (Sobolewski, 1998).

6 Process model of the moments in which the damages occur

Because of impossibility to carry out long-term operation and maintenance investigations as well as due to difficulties to implement changes to the repair process of the means of transport system a simulation model of the moments in which the damages occur was built to facilitate generation of the streams of the damages to the means of transport. The analysis and evaluation of the results obtained at the simulation stage will enable to evaluate the efficiency of the repairs being realized in a real transport system.

By analysing the moments in which the damages to the means of transport occur and the values of the time intervals between them, the real process parameter values were estimated.

This was the basis for creating a simulation model representing a real stream of the damages, which, when being examined, enables to evaluate the efficiency of the repairs realized within a service process.

On the basis of the relevant references and the results of our own investigations the generalized Gamma distribution (Firkowicz, 1970) has been adopted to generate, in the simulation program, the streams of the damages to the means of transport subsystems. By means of the adopted parameter values (b – scale parameter and, p – shape parameter, ν - shape parameter) of this distribution, the time intervals between the moments in which the primary damages occur were simulated in the program. In case of adopting the values of the parameter $\nu=1$, the time intervals were generated according to the Gamma distribution. However, for the parameters with the values $p=1$ and $\nu=1$ the time intervals were generated according to the exponential distribution.

The random variable X has gamma distribution, if its density is expressed by the following formula (19):

$$f(x) = \frac{1}{bp\Gamma(p)} \cdot x^{p-1} e^{-\frac{x}{b}} \quad x > 0, \quad p, b > 0, \quad (19)$$

where: $\Gamma(p)$ is a gamma function expressed with the formula (20):

$$\Gamma(p) = \int_0^{\infty} x^{p-1} e^{-x} dx \quad (20)$$

If $p = 1$, then we have an exponential distribution as a particular case. In case when the parameter p is an integer number, then the gamma distribution is the Erlang's distribution. The Parameter p is the form (shape) parameter, while the parameter b is the scale parameter.

The average value EX is expressed with the following relation (21):

$$EX = pb \quad (21)$$

and the variation with the formula (22):

$$D^2 X = pb^2. \quad (22)$$

The equations (21, 22) may form the basis for creating estimators $\hat{p}$ and $\hat{b}$ of the parameters p and b . It results from these equations that:

$$\hat{b} = \frac{s^2}{\bar{x}}, \quad \hat{p} = \frac{\bar{x}}{\hat{b}} = \frac{\left(\frac{\bar{x}}{s}\right)^2}{s^2} \quad (23)$$

If we define a new variable:

$$T = x^{\frac{1}{v}}, v > 0 \quad (24)$$

then the random variable T has generalized gamma distribution with the probability density expressed with the relation (25) as follows:

$$f(t) = \frac{v}{b^p \Gamma(p)} \cdot t^{pv-1} e^{-\frac{t^v}{b}} \quad (25)$$

The density of the generalized gamma distribution is stated in this paper in the following form:

$$f(t) = \frac{v}{-b\Gamma(p)} \left(\frac{t}{b}\right)^{pv-1} \exp\left\{-\left(\frac{t}{b}\right)^v\right\}, t > 0. \quad (26)$$

The average value of this distribution is expressed with the formula (27):

$$ET = b \frac{\Gamma\left(p + \frac{1}{v}\right)}{\Gamma(p)}, \quad (27)$$

and the variation with the formula (28):

$$D^2T = b^2 \left(\frac{\Gamma\left(p + \frac{2}{v}\right)}{\Gamma(p)} - \frac{\Gamma^2\left(p + \frac{1}{v}\right)}{\Gamma^2(p)} \right) \quad (28)$$

The estimation of this distribution parameter has been stated herein (Firkowicz, 1970). The random numbers coming from the generalized **Gamma** distribution (three parameters: b , p , v) are obtained as random numbers coming from the gamma distribution with the parameters b and p , which were raised to the $\frac{1}{v}$ power.

The random numbers out of the Gamma distribution (b , p) were obtained by means of the GAMMAINV function built in the EXCEL 2000 program (it is

a realization of the generator of the random numbers out of the Gamma distribution (b, p) by inverting the distribution function of this distribution).

$$r(b, p, v) = \left(\text{Gamma}(b, p) \right)^{\left(\frac{1}{v} \right)} \quad (29)$$

The number of the secondary damages occurring in the sequence of the events after the primary damage (figure 2) was generated according to the Poisson's distribution with specified value of the parameter λ (expected value). The random numbers coming from the **Poisson's** distribution are obtained by means of the following algorithm:

- $q = e^{-\lambda}$ is calculated for the determined λ
- $x=0$, $S=q$ and $p=q$
- a random number r is generated out of the uniform distribution over the range $[0, 1)$,
- as long as $r > S$ the following parameters are calculated: $x=x+1$, $p=p*\lambda/x$, $S=S+p$.

When S becomes greater or equal to r the value of x is adopted as a number out of the Poisson's distribution with the parameter λ .

The time intervals between the secondary damages were generated out of the Erlang's distribution with the defined values of the parameters of this distribution, such as: number of the secondary damages occurred in the sequence after a primary damage and the value of the parameter λ .

The random numbers out of the Erlang's distribution with the parameters n and λ are obtained on the basis of the following formula (30):

$$r(n, \lambda) = \sum_{k=1}^n \left(-\frac{1}{\lambda} \ln(rnd) \right) \quad (30)$$

where: rnd – is a random number out of uniform (rectangular) distribution over the range $[0, 1)$.

The number of the events, in the damage stream generated by the simulation program, was determined on the basis of the statistical analysis of the real streams of the damages to the subsystems of the means of transport.

7 Chosen investigation results and verification of the model adequacy

On the basis of the analysis of a real stream of the damages to the selected means of transport subsystem, the damages were classified according to the

adopted criteria (value of the limiting distance travelled expressed in kilometers and the critical time of correct work) to the subset of the primary or secondary damages. Due to the analysis carried out, the average times of correct work between the damages were determined. The determined statistics were entered to the simulation model (table 1) and the damage streams with similar parameters of the statistics, if compared to the statistics determined on the basis of the empiric data, were generated with its help (Woropay & Wdzięczny, 2006).

Table 1. Exemplary values of the parameters adopted to simulate a stream of the damages to the electric installation subsystem

Name or parameter symbol	Value
b – scale parameter	1,073
p – shape parameter	19,985
v - shape parameter	0,902
λ - number of secondary damages	2,14
row	1,87
λ	0,3924
Number of damages	115
T ₁ - Average time of correct work between the primary damages	22,9026
T ₂ - Average time of correct work between the secondary damages	4,8295

In order to verify consistency of the real damage stream and the one generated by the simulation program, Kolmogorov-Smirnov goodness of fit test being used in case of small number of tests was applied. The goodness of fit test was used in order to check the consistency of the hypothesis saying that two tests have the same distribution. The differences between both distribution functions were considered in this test. The limiting distribution of the appropriate statistics, used to build the critical range for this test, is the same as limiting distribution of the statistics λ by Kolmogorov.

The critical value λ_α was read from the table of this distribution for the predefined significance level $\alpha=0.95$ to have $P\{\lambda \geq \lambda_\alpha\}=\alpha$. when the calculated value of the statistics λ meets the inequality $\lambda \geq \lambda_\alpha$, The hypothesis H_0 was rejected because both tests have different

distributions. However in case, when $\lambda < \lambda_\alpha$, there are no grounds to reject the hypothesis saying that the distributions of both tests are the same. The limiting value λ_α for the adopted value of the significance level α is $\lambda_\alpha = 1.358$.

Table 2 Selected results of the consistence test of one subsystem of buses

Parametr	Number of buses				
	2400	2402	2403	2404	2407
1	2	3	4	5	6
b – scale parameter	1	1	1	1	1
p – shape parameter	44	49	60	50	115
v - shape parameter	0,9543	0,981	0,917	0,832	0,927
λ - number of secondary damages	2,6	1,9	1,8	2,6	2,6
row	3	2	2	2	2,4
λ	0,487	0,28	0,248	0,248	0,105
Number of damages	1000	1000	1000	1000	1000
T ₁ - Average time of correct work between the primary damages	44,93333	49,41379	62,5	55,16667	119,1
T ₂ - Average time of correct work between the secondary damages	6,164384	7,188679	8,076923	8,05	22,95833
λ - statistica	1,299007	0,943986	0,95429	1,357213	0,958469
Test	Ok.	Ok.	Ok.	Ok.	Ok.

In case when the distribution consistency was found a damage stream in which the primary and secondary damages existed was simulated according to the previously adopted values of the parameters, as stated in the table 1. Afterwards, the repair efficiency coefficient was determined according to the relation (16).

The value of the repair efficiency index of the j -th subsystem is described with the relation (Jaźwiński, Smalko & Żurek, 2005):

$$WS_j = \frac{N_j(t) - N_j^N(t)}{N_j(t)} = \frac{N_j^S(t)}{N_j(t)}, j = 1, 2, \dots, m \quad (31)$$

The next step was to simulate, by means of the program, improvement of the efficiency of the repairs being realized by reducing the value of the parameter λ by 25% each time, as it is presented in the table 2.

Table 2. Values of the model parameters adopted to simulate the streams of a selected subsystem for different number of secondary damages L_{uw}

Name or parameter symbol	Value 100% L_{uw}	Value 75% L_{uw}	Value 50% L_{uw}	Value 25% L_{uw}
b	1,073	1,073	1,073	1,073
p	19,985	19,985	19,985	19,985
v	0,902	0,902	0,902	0,902
λ	2,12	1,16	0,463	0
n	1,91	1,46	1,07	0,48
λ	0,3924	0,3924	0,3924	0,3924
N	1000	1000	1000	1000
T_1	22,9026	22,9026	22,9026	22,9026
T_2	4,8295	4,8295	4,8295	4,8295

In order to evaluate operation efficiency and reliability, the values of the selected reliability and efficiency factors were determined based on the references in question.

Currently, works on creating universal efficiency indexes are being carried out. Maintenance and operation investigations involve defining value changes of these indexes, especially, determining the level of financial losses born by the transport company which have been caused by inappropriate operation and maintenance. Times of resultant repairs and being unfit for use have been analyzed, as well as costs of repairs, spare parts, maintenance and operation.

8 Summary

On the basis of the analysis of results of carried out investigations, it can be said that the simulation model makes it possible to generate a stream of damages with statistical values approximate to the real damage stream

which reflects its adequacy. The presented in the paper model of damage occurrence times, meets the set requirements and can be used for generation of damage streams of transport means subsystems, also in other real transport systems. Use of the presented model enables performance of simulation research, depending on different variants of transport means repair efficiency improvement which in turn makes it possible to take proper actions aiming at rational control of the process of repairs carried out in investigated real objects.

9 References

- [1] Bendat S. J., Piersol A. G. 1976. *Metody analizy i pomiaru sygnałów losowych*. Warszawa: PWN.
- [2] Firkowicz Sz. 1970 *Statystyczne badanie wyrobów*. Warszawa: WNT.
- [3] Jaźwiński J., Smalko Z. & Żurek J. 2005 *Związki między nieuszkodzalnością i skutecznością systemów transportowych*, XXIII Zimowa Szkoła Niezawodności. Szczyrk.
- [4] Juran, J.M. & Gryna, F.M. 1974. *Jakość – projektowanie – analiza*. Warszawa: WNT.
- [5] Muślewski Ł., Wdzięczny A. 2008. *Damage rate as a reliability characteristics having significant influence on the operational quality of the technical objects being operated and maintained in the transport systems*. Warsaw: Journal of KONES Powertrain and Transport, vol. 15 No. 4.
- [6] Muślewski Ł. & Woropay M. 2005. *Theoretical grounds to evaluate of the transport system operation*. IMAM 2005, Maritime Transportation and Exploitation of Ocean and Costal Resources – Guedes Soares, Garbatov & Fonseca. Taylor & Francis Group: London.
- [7] Muślewski Ł., Woropay M., Hoppe G. 2008. *The operation quality assessment as an initial part of reliability improvement and low cost automation of the system*. Safety, Reliability and Risk Analysis: Theory, Methods and Applications – Martorell S., Guedes Soares C., Barnett J., vol.3. Taylor & Francis Group: London.

- [8] Saaty T.L. 1980. *The Analytic Hierarchy Process, Planning, Priority Setting and Resource Allocation*. Mc Graw-Hill: New York
- [9] Smalko Z., Woropay M., Muślewski Ł., Ślęzak M. & Jankowski A. 2004. *The concept of the evaluation model design In the case of the transport system operation quality*. ACSIM vol.II. New Delhi: Allied Publishers Pvt. Limited.
- [10] Sobolewski K. 1998. *O pojęciu skuteczności i pojęciach związanych*. Koszalin: Wydawnictwo Uczelniane Politechniki Koszalińskiej.
- [11] Villemeur A. 1992. *Reliability, Availability, Maintainability and Safety Assessment*. New York: Wiley.
- [12] Woropay M., Muślewski Ł. 2005. *Jakość w ujęciu systemowym*. Radom: ITeE.
- [13] Woropay M., Wdzięczny A. 2006. Analysis and evaluation of risk in a transport system. Warszawa – Nałęczów: Journal Of KONES. European Science Society of Powertrain and Transport Publication, vol. 13 no. 2.
- [14] Woropay M., Wdzięczny A. 2006. *Analysis and evaluation of the influence of the bus braking subsystem damages on origination of damagers in a sociotechnical system*. Kraków: Journal of KONBiN. the 4th International Conference on Safety and Reliability KONBiN, vol.1.
- [15] Woropay M., Wdzięczny A., Muślewski Ł. & Piętak A. 2007. *The analysis and the assessment of the means of transport repair efficiency influence on their reliability level*. Maritime Industry, Ocean Engineering and Coastal Resources. Volume 2, Carlos Guedes Soares , Peter N. Koley (eds), London, Leiden, New York, Philadelphia, Singapore: Taylor & Francis Group.
- [16] Wymore, A.W. 1967. *A Mathematical Theory of Systems Engineering – the Elements*. New York: Wiley.
- [17] Zajac K. 1988. *Zarys metod statystycznych*. Warszawa: PWE.

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Streszczenie: Czynniki eksploatacyjne i procesy destrukcyjne wpływające na układy i elementy obiektów technicznych powodują niekorzystne zmiany wartości ich cech funkcjonalnych, powodujących uszkodzenia. Uszkodzenie obiektu technicznego zdefiniowano w pracy jako przekroczenie dopuszczalnych wartości granicznych przez istotne cechy opisujące jego elementy. Na podstawie analizy wyników badań własnych dotyczących uszkodzenia środków transportu, użytkowanych w systemach transportowych stwierdzono, że są one wynikiem oddziaływania różnorodnych czynników wymuszających. Pewna liczba uszkodzeń wynika z naturalnego zużywania się elementów maszyn, natomiast inne uszkodzenia mogą być spowodowane nieskuteczną naprawą poprzednio powstałego uszkodzenia. Na wskutek tego powstają tzw. uszkodzenia powtarzalne (wtórne), w krótkim przedziale czasu. Na podstawie analizy literaturowych oraz wyników badań eksploatacyjnych stwierdzono, że przyczyną powstawania uszkodzeń powtarzalnych jest przede wszystkim niewłaściwa jakość napraw rozpatrywanych środków transportu. Uszkodzenia pierwotne są niezależne od siebie i występują w sposób losowy, natomiast uszkodzenia powtarzalne są zależne, a ich wystąpienie jest uwarunkowane wcześniejszym wystąpieniem uszkodzenia pierwotnego i w głównej mierze skutkiem niewłaściwej jego naprawy. W niniejszym opracowaniu przedstawiono metodę oceny wpływu skuteczności realizowanych napraw na niezawodność działania środków transportu. Na podstawie analizy chwil wystąpienia uszkodzeń środków transportu oraz długości przedziałów czasowych zawartych między nimi, zbudowano model symulacyjny odwzorowujący rzeczywisty strumień uszkodzeń, którego badanie umożliwia ocenę wpływu skuteczności napraw realizowanych w rzeczywistym systemie transportowym.

Słowa kluczowe: system transportowy, środek transportu, model, uszkodzenie