Journal of Polish CIMAC
Gdansk University of Technology
The Faculty of Ocean Engineering and Ship Technology

EVALUATION OF THE EFFECTIVENESS OF REPAIRS CARRIED OUT OF CENTRES OF THE ROAD TRANSPORT

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Abstract

The transport systems and especially the means of transport are the sources of life and health hazard and the natural environment pollution. Exploitation process influence on the elements of the technical objects and decrease the values of the important features of them. This is the mechanism of the damage process. Wear factors could be divided into two groups. One of them are the factors results from the bed operation of the object operators and the second group consists of the factors results from the environment interaction. The damages are the events which are very important from the reliability point of view because are the reason of the partly or full disability. In the paper the damage is defined as the exceeding the acceptable thresholds of the technical object important features.

Keywords: transport, system, damage,

1. Introduction

Based on the analysed references in question as well as on the results of our own research it has been found that the damages to the means of transport, being utilised within the transport systems, are a result of interaction of various forcing factors. These factors may be divided into:

- working factors – affecting a machine due to realization of the working process by the machine (depend on the machine performance),
- external factors – describing influence of the environment on the machine (do not depend on the machine performance),
- antropotechnic factors – affecting the machine due to conscious or un conscious men's actions (e.g. men's faults made during the process of utilisation and maintenance).

Because of the nature of the forcing factors affecting a technical object, they may be divided into the fundamental classes:

- which depend on the machine performance (they affect the machine only when the working process is being performed by the machine),
- which do not depend on the machine performance (they affect the machine also when the machine does work).

Some number of the damages result from the natural wear of the machine elements, while some other damages may be caused by ineffective repair of the damage occurred previously. Subsequently so called secondary damages appear within a short time interval. They result from incorrect organization of the repairs, poor training level of the repair team workers, constraints related to the before and after repair diagnostic activities, etc.

In the framework of the operation and maintenance investigations carried out within a real system of operation and maintenance of the means of transport, the time intervals occurring between the consecutive damages to the elements of the means of transport and the moments they appear were analysed.

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).

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:

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

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: $R(t) \approx p*exp(-\lambda t)$. 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 $i = 5, 6, 7,..., 12$.

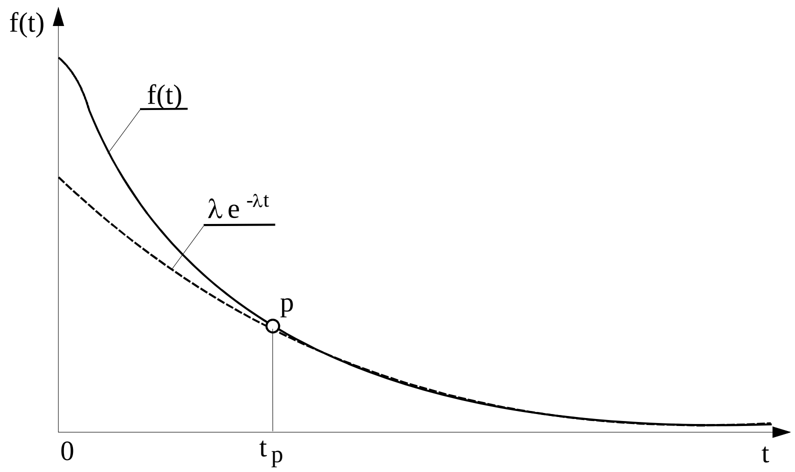

Fig. 1. Changes of the value of the exponential function and the real function at the time t [1,4]

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

The difference $\tau_{i+1}(k)$ - $\tau_i(k)$ for $i = 0, 1, 2, \ldots$, 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. Let $X_i(n) = Y_i(n) - Y_{i-1}(n)$, where $i = 0, 1, 2, \ldots, Y_0 = 0$

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 $n \to \infty$ the random variable $X(n)$ has exponential distribution.

It is assumed that the probability density of the random variable T is formulated as follows:

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

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):

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

The estimation of the parameter α and λ of the density (2) 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.

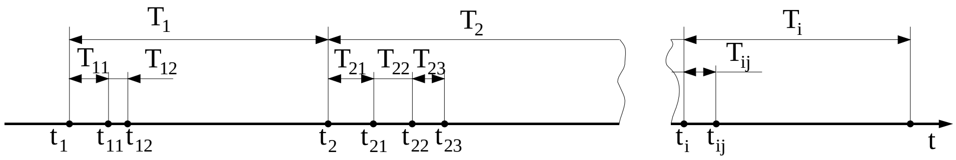

Fig. 2. Time intervals between the primary and secondary damages t_i – the moments the primary damages occur,
t_{ij} – the moments the secondary damages occur,
T_i – the time intervals between the moments the primary damages occur,
T_{ij} – the time intervals between the moments the secondary damages 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.Reduction of the conditional 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.

As it is shown in the figure 2 the faulty repairs represent one of the most important reasons for the occurred damages to the vehicle subsystems. Comparison of the significant reasons for the damages to the means of transport are shown in the figure 3.

The analysis of the operation and maintenance investigation results prove that reduction of the number of the secondary damages is an essential problem, the solution of which makes it possible to have an influence on the operation reliability level of the means of transport.

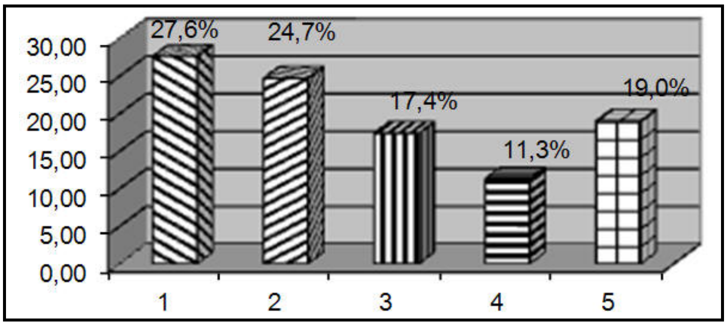

Fig. 3. Occurrence frequency of the reasons for the damages to the elements of the means of transport
1-faulty repairs, 2-faulty utilisation, 3-influence of the environment, 4-damages to the co-working elements, 5-others.

2. Purpose of the paper

The purpose of this paper is to evaluate the influence of the means of transport on the operation reliability level of a transport system.

3. Object of the investigations

The objects of the investigations are damages to the subsystems of the means of transport being operated and maintained within a chosen transport system. Whereas the subject of the investigation is the influence of these damages on the operation reliability level of the transport system.

A detailed example of a transport system is one of the road transport systems – an urban transport, covering the bus transport system. Despite a series of advantages such as: punctuality, frequency, regularity, reliability, accessibility, directness, comfort, movement speed, transport fare, safety, no need to use a traction or railway subgrades, being characteristic for an urban bus transport system when compared it to the trolley-bus or tramway transport system, it is also characterised by some disadvantages, and namely: it is a source of various road dangers to the health and life of the people, technical objects and the natural environment.

The investigations performed within a bus urban transport system referred to the damages to the subsystems of the means of transport and to the moments they occurred. They were carried out by a passive experiment method under real operation and maintenance conditions. A random set consisting of 28 means of transport utilised in the real operation and maintenance conditions was selected for the investigation purposes. The results of the investigations cover five-year long period of the operation and maintenance of the means of transport.

4. Damage classification methodology

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. Symbols denoting the subsystems of the mean of transport were determined at the decomposition stage, as presented in the Table 1.

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.

Table 1. Set of the subsystems of the decomposed mean of transport

Subsystem Code	Subsystem Name

SI	**- Engine**
PN	**- Drive transmission**
UJ	- Wheels and steering system
IE	**- Electric system**
HA	**- Braking system**
NA	**- Bodywork**
UK	- Steering system
SP	- Compressed air feed system
ZA	- Suspension system
IN	- Others

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 – stands for the summarized number of the damages to the bus under investigation,
   L_{u1} – stands for the number of the damages to the electric system IE,
   L_{u2} – stands for the number of the damages to the bodywork NA,
   L_{u3} – stands for the number of the damages to the drive transmission system PN,
   L_{u4} – stands for the number of the damages to the engine SI,
   L_{u5} – stands for the number of the damages to the braking system HA,
   P_c – stands for the total distance travelled by the bus during the investigation time [*km*],
   $L_{śrj}$ – average distance travelled between two consecutive damages of the investigated *j-th* subsystem [km], described with the following dependence (4):

$$L_{śrj} = \frac{P_c}{L_{uj}} \quad , \quad j = 1,2,3,4,5, \tag{4}$$

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

$$s_j' = \pm\sqrt{\frac{\sum_{i=1}^{n}\left(L_{ij} - L_{śrj}\right)^2}{n-1}} \, , \tag{5}$$

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 $1\text{-}\alpha$, has been described with the dependence (6):

$$s_j = f_{1-\alpha}\, s_j', \; j = 1,2,3,4,5 \tag{6}$$

The closer the confidence coefficient is to *1*, the more extensive coefficient range is achieved. The confidence coefficient adopted in the paper is $1\text{-}\alpha = 0.95$. 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):

$$L_{upj} = L_{ij} \geq L_{śrj} - s_j, \; j=1,2,3,4,5 \tag{7}$$

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

$$L_{uwj} = L_{ij} < L_{śrj} - s_j, \; j=1,2,3,4,5 \tag{8}$$

where:

$L_{śrj}$ - 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 a bus subsystem may be expressed by means of an exponential distribution. While the condition of the critical time t_{kr} (9) [1,2,3,4].

$$t_{kr} = -\frac{1}{\hat{a}} \ln \alpha \tag{9}$$

where:

α - significance level,

$\hat{a} = \frac{1}{\bar{t}}$ - parameter estimator with the moment method,

$\bar{t}$ - average value of the time interval of the correct operation between the damages to the subsystem.

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

$N(t)$ – summarized number of the repairs of the mean of transport under investigation up to the moment *t*, described with the dependence (10):

$$N(t) = \sum_j N_j(t), \quad j = 1,2,...,m \tag{10}$$

$N_j(t)$ – number of the repairs of the *j*-the subsystem up to the moment *t*, described with the dependence (11):

$$N_j(t) = N_j^S(t) + N_j^N(t), \quad j = 1,2,...,m \tag{11}$$

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 dependence:

$L_{śrj}(t)$ – average travelled distance between the repairs of the *j*-the subsystem, described with the dependence (12):

$$L_{śrj}(t) = \frac{L_{1j}(t) + L_{2j}(t) + ... + L_{nj}(t)}{N_j(t)} = \frac{1}{N_j(t)} \sum_{i=1}^{n} L_{ij}(t) \tag{12}$$

for i = 1,2,...,n, j = 1,2,...,m

where:

$L_{ij}(t)$ – the travelled distance 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*.

The value of the *efficiency factor* of the performed repairs of the *j*-th subsystem of the investigation object is described with the dependence (13):

$$WS_j = \frac{N_j(t) - N_j^N(t)}{N_j(t)} = \frac{N_j^S(t)}{N_j(t)}, \quad j = 1,2,...,m \tag{13}$$

The value of this factor may be expressed as follows:

$$WS_j = \frac{N_j^{\,S}}{N_j} * 100[\%], \qquad j = 1,2,3,4,5 \tag{14}$$

Based on the analysis of the values of the travelled distance and the time intervals between the damages to the subsystems of a mean of transport, a criterion to classify the damages as primary and secondary ones was adopted according to the dependence (7), (8) and (9). Having classified the damages, the essential statistical parameters such as: numbers of the primary damages (L_{up}), numbers of the secondary damages (L_{uw}), etc. were determined.

6. Investigation results

Table 2 presents selected investigation results regarding the number of the repairs of the selected bus subsystems, which are characterised by the highest numbers of the damages occurred when performing the operation and maintenance investigations.

Table 2. Comparison of the number of repairs of the selected bus subsystems under investigation

Number of bus	Subsystem code	Number of repairs	Number of effective repairs	Number of ineffective repairs	Repair efficiency factor expressed in %
Ikarus IK260					
1	IE	147	48	99	32,65
	PN	126	45	81	35,71
	NA	86	26	60	30,23
	SI	66	20	46	30,30
	HA	55	20	35	36,36
2	IE	186	66	120	35,48
	PN	141	42	99	29,79
	NA	99	31	68	31,31
	SI	62	28	34	**45,16**
	HA	76	24	52	31,58
3	IE	108	29	79	26,85
	PN	84	26	58	30,95
	NA	78	22	56	28,21
	SI	49	19	30	38,78
	HA	115	44	71	38,26
4	IE	53	16	37	30,19
	PN	29	12	17	**41,38**
	NA	61	25	36	**40,98**
	SI	43	14	29	32,56
	HA	64	22	42	34,38
5	IE	61	23	38	37,70
	PN	81	26	55	32,10
	NA	38	12	26	31,58
	SI	45	13	32	28,89
	HA	56	17	39	30,36
6	IE	230	70	160	30,43
	PN	237	90	147	**37,97**
	NA	158	50	108	31,65
	SI	86	26	60	30,23
	HA	189	65	124	34,39
7	IE	99	36	63	36,36
	PN	51	20	31	39,22
	NA	64	20	44	31,25
	SI	38	13	25	34,21
	HA	42	14	28	33,33

7. Analysis of the investigation result and conclusions

As it results from the data stated in the table 4 the maximal percentage of the secondary damages in the total number of the damages is equal to *74%*. Such a high percentage causes significant reduction of the operation reliability of the means of transport resulting from impossibility to perform the tasks. It makes the decision maker of the transport system use so called substitutive buses in order to follow the scheduled runs, what in turn is related to extra expenditures to accomplish the tasks.

The results of the operation and maintenance investigation prove that the realization of the actions aimed at reduction of the number of the secondary damages is reasonable and that they are to be considered as the essential actions to increase the operation reliability level of a transport system.

From the analysed source information it results that the secondary damages to the bus subsystem elements are to be eliminated inside the service and repair process. It may be accomplished by:

-correct diagnostic activities performed before and after repairs,
-using correct spare parts,
-using adequate repair measures,
-observing scheduled times to carry out surveys and replacements,
-correct assembly and disassembly,
-introducing technical control over the repairs performed,
-increasing the employee’s qualifications,
-appropriate employee’s motivation,
-providing the repair stands with the technological and repairing tools,

After completing the investigations in a repair department it was found that it was necessary to introduce identification of the person repairing the damaged subsystem. Having introduced these changes, a significant reduction of the number of the secondary damages was noticed.

It is reasonable to carry out further operation and maintenance investigations regarding the identification of the reasons for the secondary damages and the evaluation of their significance in terms of the possibility to undertake reasonable actions aimed at increasing the operation reliability of a transport system.

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