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AN ATTEMPT OF A PRELIMINARY ASSESSMENT OF THE SERVICEABILITY ASSURANCE PROCESS ON THE BASIS OF STATISTICAL ANALYSIS OF A CHAIN OF DAMAGES

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Abstract

The investigation object in this paper is a real system of an urban transport bus operation and maintenance in a large urban agglomeration. The investigated system belongs to the class of operational systems with a goal oriented behaviour. The paper presents the results of the investigations concerning damages to the buses of an urban transport system. Based on the analysis of the statistical data regarding the damages to the elementary bus subsystems some feature has been found, and namely that certain sequences of the damage chain occur with excessive frequency. The damage chain is considered to be a random sequence whose elements are the codes of the successively damaged bus subsystems. The analysis of the damage chain may be one of the elements to evaluate the maintenance subsystem within complex operation and maintenance systems of technical objects.

Keywords*: chain of damages, transition probability matrix, operation and maintenance process*

1. Introduction

The essentiial source of information allowing to obtain objective results of quantitative analysis of bus damages are statistical data during the operation and maintenance investigation performed.

In scope of the operation and maintenance investigation performed a matrix of probabilities of "transitions between damages" of the selected bus subsystems was set. The term of "transition between damages" may be illustrated by the following sequence of the bus operation and maintenance events and processes: a damage to the subsystem denoted with the code U_i, $i \in N$ - renewal - usage – a damage to the subsystem denoted with the code U_j, $j \in N$. If at the moment t, $t \in R$ the subsystem denoted with the code U_i was damaged, and at the moment $(t + \tau)$, $t, \tau \in R$ the subsystem U_j was damaged and at the same time at the time interval $(t, t + \tau)$ there was no damage to the bus, then such a sequence of events is called "transition between damages" – transition from a damage to the subsystem U_i to a damage to the subsystem U_j [12].

On the basis of the analysis of the statistical data concerning damages to the elementary bus subsystems a certain property (regularity) was found, and namely that some sequences of a chain of damages (two-element sequences were analysed) occur much more frequently than others. This regularity occurs particularly distinctly for the damages of the same type (of a subsystem). It was found that a probability of occurrence of so called "repeated damage" to a bus subsystem (e.g. *a* *damage to the steering system* - renewal – usage - *damage to the steering system*) is much more frequent (sometimes by two times) than statistical frequency of its damages.

The analysis of a chain of damages may be the ground to assess efficiency of the maintenance subsystem staff.

2. Investigation object

The investigation object in this paper is a real system of an urban transport bus operation and maintenance in a large urban agglomeration. The investigated system belongs to the class of operational systems with a goal oriented behaviour. Controlling the processes being performed in that system enables to achieve the planned goals. It is a complex system operating within a specific environment. For the needs of this work the system complexity is understood as a feature of a system consisting of many subsystems, which in turn may be considered as complex systems. Assurance of serviceability state for the means of transport being used is executed by the maintenance subsystem.

Four subsets of vehicles belonging to a set of vehicles being used in the investigation object were investigated. A vehicle subset is determined by the vehicle make and type. The individual subsets represent respectively the following vehicle types: Ikarus 280.70 (subset 1 P1), Jelcz 181 MB (P2), Volvo B10 LA (P3), Volvo B10 MA (P4). The vehicles were selected in such a way to have vehicles with similar usable potential in the individual subsets. It was assumed that from the point of view of the analysed feature for the investigation purposes the vehicles belonging to the specific subset constitute a set of homogenous objects. The investigation period covered two years. Each group of the vehicles consisted of 15 buses. All the investigated busses performed transport tasks on daily basis for the full period of two years. The investigations of the selected buses being operated and maintained in the investigation object were performed by means of a passive experiment. Observation of the process was performed under normal bus usage conditions, it means during passenger transportation according to the timetable of the buses selected for the investigations.

A bus as a complex technical object consisting of the elements forming distinguishable systems, assemblies and subassemblies, according to the rigors of the system method were treated as a technical system and were divided into subsystems.

Eleven main bus systems were distinguished at the first division level.

The following bus systems were distinguished:

UK - steering system
UZ - suspension system
UE - electric installation
UW - body
UN - drive system
UJ - wheels and steering system
UO - feed system
UC - cooling system
UP - pneumatic system
US - engine
UH - braking system

In order to simplify description, the following denotations were used hereafter: The UK system is denoted with the code U_1, while the remaining systems respectively with U_i, i=2,3...11.

3. Chain of damages

A chain of damages is understood as a random sequence, the elements of which are the codes of consecutively damaged subsystems of a technical object TO. However, if at the moment t, $t \in R$ there was the m-th damage to the TO, and the damaged subsystem is a system (an element) denoted with the code U_i, $i \in N$ and at the moment $(t + \tau)$, $t, \tau \in R$ there was a damage to the subsystem U_j, $j \in N$ and at the same time in the time interval $(t, t + \tau)$ there was not damage to the TO, then such a sequence of events is called a one step transition between damages – transition from a damage to the subsystem U_i to a damage to the subsystem U_j. From the above statement it results that at the moment $(t + \tau)$ a damage to the subsystem U_j is (m+1)-th damage to the TO.

By using the following denotations:

U_i	-	code of the damaged elementary subsystem of the TO, $i = 1, 2, ..., k$,
k	-	number of the elementary subsystems distinguished,
$p_i = P(U_i)$	-	probability of occurrence of such an event that if there was a damage to a bus, then the damaged subsystem of the TO is the subsystem denoted with the code U_i,
$p_{ij} = P(U_j/U_i)$	-	probability that the damaged subsystem of the TO is the subsystem denoted with the code U_j provided that the formerly damaged subsystem was the subsystem U_i, $i,j = 1, 2, ..., k$,
$m = 1, ..., n$	-	consecutive number of the damage, $n \in N$,

it is possible to built a random process (chain) $X(m) = U_j$, where $m = 1, 2, ..., n$, $j = 1, 2, ..., k$, with a finite set of states $U = \{U_1, U_2, ...,U_k\}$.

Probability of transition of the chain X(m) from the state U_i to the state U_j in the n-th step is presented by the following relation:

$$p_{ij}^{(n)} = P(X_n = U_j / X_{n-1} = U_i). \quad (1)$$

It was assumed that the transition probabilities $p_{ij}^{(n)}$ do not depend on the number of the step n (the index (n) is omitted in the record hereafter).

The following relation was adopted as an estimator of the transition probability p_{ij}:

$$\hat{p}_{ij} = n_{ij}/n_i \;, \; i,j = 1, 2, ..., k, \quad (2)$$

where:

n_{ij} - number of such m, $1 \le m \le n$, that $X_m = U_i$, $X_{m+1} = U_j$ (number of the process transitions from the state U_i to the state U_j,

$n_i = \sum_{j=1}^{k} n_{ij}$.

All the chain transition probabilities X(m) may be formulated together in the form of the matrix P as follows:

$$P = [p_{ij}] = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1k} \\ p_{21} & p_{22} & \cdots & p_{2k} \\ \cdots & \cdots & \cdots & \cdots \\ p_{k1} & p_{k2} & \cdots & p_{kk} \end{bmatrix} \; i,j = 1, 2, ...,k. \quad (3)$$

The probabilities occurring in the individual lines of the matrix P meet the following condition:

$$\sum_j p_{ij}=1, \ p_{ij} \geq 0 . \quad (4)$$

4. Selected investigation results

On the basis of the investigation results the elements of the matrix P (3) were assessed by applying the relation (2) for the chain of damages with the number of the states k =11. The matrix P of probabilities of state changes of the chain of damages is called the matrix of transitions between damages.

Because the analysed properties of the determined matrices for the particular subsets of the investigated vehicles are similar and in order to present more clearly the investigation results, the further part of the document presents the investigation results for a set of all the investigated vehicles.

The assessed values of the elements of the matrix $P = [p_{ij}]$ of transitions between damages are is presented by the following relation:

$$P=[p_{ij}]=\begin{bmatrix} 0{,}28 & 0{,}02 & 0{,}24 & 0{,}14 & 0{,}02 & 0{,}03 & 0{,}02 & 0{,}07 & 0{,}14 & 0{,}05 & 0{,}05 \\ 0{,}02 & 0{,}25 & 0{,}25 & 0{,}14 & 0{,}01 & 0{,}04 & 0{,}04 & 0{,}08 & 0{,}17 & 0{,}03 & 0{,}03 \\ 0{,}02 & 0{,}03 & 0{,}43 & 0{,}22 & 0{,}02 & 0{,}03 & 0{,}03 & 0{,}08 & 0{,}10 & 0{,}05 & 0{,}05 \\ 0{,}02 & 0{,}03 & 0{,}34 & 0{,}32 & 0{,}01 & 0{,}04 & 0{,}03 & 0{,}08 & 0{,}09 & 0{,}05 & 0{,}05 \\ 0{,}02 & 0{,}03 & 0{,}28 & 0{,}17 & 0{,}25 & 0{,}01 & 0{,}03 & 0{,}05 & 0{,}07 & 0{,}10 & 0{,}04 \\ 0{,}02 & 0{,}03 & 0{,}35 & 0{,}20 & 0{,}02 & 0{,}12 & 0{,}04 & 0{,}07 & 0{,}10 & 0{,}05 & 0{,}06 \\ 0{,}04 & 0{,}02 & 0{,}21 & 0{,}17 & 0{,}02 & 0{,}05 & 0{,}25 & 0{,}08 & 0{,}10 & 0{,}07 & 0{,}04 \\ 0{,}02 & 0{,}02 & 0{,}31 & 0{,}17 & 0{,}02 & 0{,}03 & 0{,}03 & 0{,}25 & 0{,}10 & 0{,}07 & 0{,}04 \\ 0{,}02 & 0{,}05 & 0{,}25 & 0{,}16 & 0{,}02 & 0{,}04 & 0{,}03 & 0{,}08 & 0{,}31 & 0{,}04 & 0{,}06 \\ 0{,}02 & 0{,}01 & 0{,}25 & 0{,}16 & 0{,}01 & 0{,}03 & 0{,}03 & 0{,}11 & 0{,}07 & 0{,}33 & 0{,}04 \\ 0{,}01 & 0{,}03 & 0{,}27 & 0{,}19 & 0{,}01 & 0{,}03 & 0{,}02 & 0{,}06 & 0{,}11 & 0{,}05 & 0{,}27 \end{bmatrix}, \quad (5)$$

where:
$i,j = 1, 2, ...,11$.

On the basis of the analysis of the obtained results a significant difference between values of probabilities of transitions between damages p_{ij} and the values of unconditional probabilities p_i of occurrence of the damages to the distinguished systems was found. It refers to all the subsets of the investigated buses. The largest differences occur for the elements of the matrix P lying on its main diagonal. The values of those elements of matrix (p_{ii}) are distinctly higher than the values of the unconditional probabilities p_i and than the values of other elements of the specific matrix column ($p_{ii} > p_{ij}$, for $i \neq j$). The P matrix elements lying on the main diagonal represent assessments of probability of "reoccurrence" of a damage to the same bus system.

Tab. 1. Quotient of the conditional p_{ii} and unconditional p_i probability

i	p_{ii}/p_i
1	15,39
2	8,03
3	1,27
4	1,47

5	17,14
6	3,56
7	8,69
8	2,70
9	2,57
10	5,06
11	4,63

In scope of performance of the investigations a simulation of a chain of damages was carried out. The moments of damages to the subsystems of the TO were simulated. It was assumed that the damages to the subsystems of the TO are independent, and the times between the damages to the distinguished subsystems are exponential. Different values of the distribution parameters between damages to the particular subsystems were assumed. The resultant chain of damages was obtained by ranking the codes of damages according the moment of the damage occurrence. The matrix of probabilities of transitions between the states of the generated chain of damages was set. The determined values of the quotients p_{ii}/p_i oscillated around 1. Only with a small number of the state changes (with a smaller number of the state entries than 200) that quotient deviated by more than 5% from the value of 1.

The observed regularity, such that a damage to the subsystem U_i has influence on a repeated damage to that system is called the reoccurrence of damages [2], [12].

The quotient of the conditional p_{ii} and unconditional p_i probability, that is $MP_i = p_{ii}/p_i$ was adopted as a measure of reoccurrence of damages.

The values of the quotients p_{ii}/p_i determined for the analysed bus systems are gathered in the Table 1.

5. Summary

It seems that the analysis of a chain of damages may be one of the elements to assess a maintenance subsystem in complex operation and maintenance systems of technical objects. The damage reoccurrence index, determined on the basis of a chain of damages, being a quotient of the conditional p_{ii} and unconditional p_i probability of a damage to an object may constitute a premise to take actions aimed at increasing the efficiency of the repairs performed in a maintenance subsystem.

It should be mentioned that on the basis of the value of the reoccurrence index MP_i the assessments concerning the maintenance subsystem should be formulated carefully. The determined values of that index may be burdened with a significant error in case of a small number of transitions between damages and for small values of probabilities p_i.

On the basis of the analysis of the performance of the investigation object it may be stated that the possible reasons for the damage reoccurrence phenomenon are: limited scope of performing post-repair diagnosis, no reliable diagnostic information on the actual bus state, no reliable diagnostic information concerning the past states of a bus.

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