Method for initial assessment of unit costs of public city transport means operation

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Abstract. The study deals with the problems connected with modeling and simulation of technical objects operation processes carried out within a certain class of complex technical systems. The analyzed system is a city bus transport system. The study presents a method for assessment of unit costs involved in a technical object’s being in selected operational states. One of the subsets of data to be used for modeling the process of a technical object operational state changes, includes data concerning the costs borne by the system when the object is in the analyzed operational states. In order to determine this data, it is often necessary to modify the system of costs registration used in a given operation system. Since it is a very expensive and log process, a method of initial assessment of indispensable data has been proposed, on the basis of a costs registration method and simulation of the operation process. The study also includes basic assumptions of the operation process model, being an important element of the developed method. The assumptions of the operation model have been formulated on the basis of identification of a real operation system of city bus transport system and experimental tests carried out in system.

1 Identification

The technical objects analysed in the study are buses used in a public city transport system. The complexity of its operation is caused by both a big number of its subsystems and elements situated at different levels performing different functions as well as dynamically changing processes and task the technical objects have to accomplish in the system they are used. Some processes are carried out in a predetermined and planned way, whereas others are of random character.

The analysed technical system operates buses of different types and makes. Services are provided on a several traffic routes. One of the most important decision issues is the choice of transport means to be used for particular transport routes. In work [1], an example is given of a method used for the choice of technical objects to provide transport services, on the basis of a homogenous Markov process as the operation process model, whereas in work [2], economic aspects connected with a purchase of a transport means to be used in a public transport system, are discussed.

The primary goal of a public bus transport system operation is to provide passengers with safe transport services within an assigned quantitative and territorial scope. However, due to limited financial means, to be provided to achieve the goal, economic efficiency of

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the offered transport services needs to be constantly increased, thus reducing the outlays on public transport functioning.

In order to determine the values of selected decision variables to be used for rational control of the operation process carried out in a given system, an operation model and a software for the process simulation, have been developed [3, 4]. One of the subsets of data necessary to conduct simulation experiments, is the one which contains the values of unit costs borne by the system while a bus (of a given type and form the identified category of objects [3]) is in the distinguished operational states. For the purpose of accurate determination of this data, it is necessary to modify the system of costs registration used in this system. Since it is an expensive and time consuming process, a simple method for initial assessment of necessary data, developed on the basis of the costs registration method used in the analyzed system, has been proposed.

It needs to be emphasized that the obtained in such a way data, enables only rough estimation of the above mentioned costs and cannot replace necessary modifications of the costs registration system. The results of an experimental simulation are based on input data obtained in this manner, however, they do not enable its qualitative analysis.

2 Model of the operation process

The model of the operation process has been developed on the basis of an analysis of the operational states space and events from the operation of vehicles used in the public bus transport system.

The model of the operation process has been described in terms of its states and possible transitions between these states. The states of the process are characterized by distributions of times of being in particular states and profits (losses) connected with technical objects' being in the identified states [3].

Random process X(t) with finite state space S and a set of parameters R+ (subset of real numbers >= 0) is a natural mathematical model of the operation process of many categories of technical objects [5, 6]. Homogeneous stochastic processes, including Markov and semi Markov processes, and decision Markov and semi Markov processes, are commonly used for modelling of operational state changes. [3, 4, 6-11].

Sets of source data, necessary to formulate the model assumptions and its initial verification, were obtained from experimental tests performed in a real research object by the method of passive experiment. Due to a limited volume of this study, only the major assumptions of the proposed model have been presented.

Let $S_1, S_2, ..., S_k$ ($k \in N$) denote the analysed, significant operational states, which technical objects can go through.

Each of the operated technical objects can, in a given time t, $t \in R_+$, be only in one of the identified states. Being in a particular state generates incomes and/or costs connected with the system operation.

The operation process consists of a sequence of particular states. The order of their occurrence, time of being in particular states and frequency of their occurrence depend on individual features of particular technical objects, characteristics of the processes they undergo and the structure of subsystems cooperating during cooperation.

In result of a city bus transport system identification and the process of its functioning, on the basis of its states significance criteria, (criterion of profit), the following bus operational states have been distinguished [3]:

S_1 – state in which a technical object is functioning (while providing transport services),
S_2 – state in which a technical object is waiting for a technical emergency service,
S_3 – state in which a technical object is being repaired and the repair is performed within the transport system environment,

S_4 – state in which a technical object is waiting for a repair to be performed within the transport system environment,
S_5 – state in which an object‘s being repaired within the transport system environment,
S_6 – state in which a technical object is waiting to be diagnosed,
S_7 – state in which a technical object’s being diagnosed,
S_8 – state in which a technical object’s daily servicing,
S_9 – state in which a technical object waiting to undertake the transport task,
S_{10} – state in which a technical object stands idle due to inoperability of the environment,
S_{11} – state in which a technical object stands idle because of organizational reasons.

Stochastic process $\{X(t), t \geq 0\}$ with a finite set of S states is a mathematical model of the process of technical objects operation. If $X(t) = S_i$ ($i = 1, 2, ..., k$), then the considered technical object, in time t, is in state S_i. For the purpose of this study, a semi Markov process has been assumed to be $X(t)$ process.

Using semi-Markov processes for mathematical modelling, the following major assumptions have been accepted:
- semi-Markov process reflects the modelled real operation process well enough from the point of view of the research purpose,
- the modelled operation process has a finite number of states,
- random variables denoting duration times of the operation process have finite and positive mean values and variances,
- the distinguished states of the operation process are positively returning states,
- random process $X(t)$, being a mathematical model of the operation process, is of homogenous character.

Analysed process $X(t)$ (homogenous semi-Markov process) is fully defined when the following data is known [6]: initial distribution of process $\mathbf{P_0}$, matrix $\mathbf{P}$ of probabilities of transitions between the process states (probability of transitions of the inserted Markov chain) and distribution of random variables T_{ij} (T_{ij} - random variable denoting the time when the object is in state S_i under the condition that the next state is state S_j).

A computer program for a numerical simulation of the operation process simulation has been developed for the proposed model. The problems connected with simulation of operational state changes is presented, among others, in works [3, 4, 8-10, 12-13]. Data necessary for simulation of the stochastic process which is mathematical model of the operation process, has been assessed on the basis of initial experimental tests.

3 The research method

Values of synthetic indexes of costs involved in the system operation in respect to the accepted structure, in monthly periods, have been determined on the basis of the existing costs registration system.

The measure of transport tasks accomplishment degree by buses of a given type is the distance they have covered while providing their daily transport services. The so called ‘vehicle kilometres’ are used for financial settlements and economic analyses. One ‘vehicle kilometre” corresponds to the distance of 1 km. covered by the vehicle of a given type.

The idea of the method involves simulation of the analysed operation process and determination of selected characteristics of the analysed process and next estimation of incomes and unit costs connected with technical objects’ being in a given state, on the basis of economic data obtained from the analysed company and simulation results.

The operation process simulation of a single technical object, according to the accepted assumptions, involves numerical simulation of the analysed stochastic process, being a mathematical model of the process of a technical object operational state changes. Algorithms enabling numerical simulation of the stochastic process have been developed. Data necessary for determination of the analysed stochastic process is the data necessary for simulation. Indexes enabling analysis of the modelled state change process are determined during the simulation.

After determination of time interval, for which, appropriate components of the unit costs vector **N**, unit incomes **P**, need to be determined, on the basis of the existing costs registration system, particular components of costs (KSMZK). The next step involves carrying out a simulation of the operation process. Particular components of vectors **N** and **P** are determined on the basis of particular components and simulation results costs, according to the below dependency.

Applied denotations:

a) resultant data:

$\mathbf{P}=[p_i]$ – unit income vector,

$\mathbf{N}=[n_i]$ – unit costs vector,

p_i – income generated by a random bus for a time unit (given type and category), when it is in the i-th operational state,

n_i – cost per time unit, borne by the system, when a random bus (of a given time and a given category) of the system is in the i-th operational state,

$i = 1, 2, ..., k$ – index of the operational state,

k – number of identified operational states (for the analysed system $k = 11$).

b) data from the costs registration system:

T – time of experiments, days

La – real number of buses (of a given type) used in a given system,

KSMZK = {*MPA*, *MPO*, *P*, *PZU*, *OG*, *KPC*, *KRB*, *KW*, *KO*, *WK*, *CWK*} – data obtained from the costs registration system for a given type of buses in period of investigation *T*,

MPA – costs of fuel,

MPO – costs of the remaining materials,

P – costs of drivers' salaries with derivatives,

PZU – costs of insurance,

OG – costs of tires,

KPC – costs of daily services,

KRB – costs of current repairs,

KW – department costs,

KO – general costs,

WK – number of the so called 'vehicle kilometres',

CWK – income gained by the system for one 'vehicle kilometres'.

c) data necessary for simulation of the operation process (data for the analysed type and category of buses obtained from the experimental tests):

$\mathbf{T} = [T_i]$ – vector of mean times of a bus being in the distinguished operational states,

T_i – mean time of a bus being in the i-th operational state time,

$\mathbf{D^2T}=[D^2T_i]$ – vector of standard deviation of times of being in a distinguished operational state,

D^2T_i – standard deviation of the mean time of being in the i-th operational state,

$\mathbf{R}=[R_i]$ – vector of codes of time distributions of being in the i-th operational state,

R_i – code of the type of distribution of random variable defining the time of a bus being in the i-th operational state, was accepted to be: $R_i=\{1,2,3\}$, 1 - gamma distribution, 2 – Weibul distribution, 3 – logonormal code,

$\mathbf{P}=[p_{ij}]$ – matrix of probabilities of transitions between the distinguished operational states,

p_{ij} – probability of transition from state i to state j,

La – number of buses.

d) simulation results:

Ts – total time of simulation,
ST_i – summary time of being in the *i*-th state, $i = 1, 2, ..., k$,
LW_i – summary number of entrances to the *i*-th state.
Calculations:
- income p_i while being in states from S_2 to S_{11} (it is assumed that the system generates income only when the bus is in state S_1):

$$p_i = 0 \qquad \text{for } i = 2, 3, ..., 11 \tag{1}$$

- income p_1 in state S_1:

$$p_1 = WK \cdot CWK / ST_1 \tag{2}$$

- regular costs KS_i:

$$KS_i = (KW + KO) / Ts \text{ for } i = 1, 2, ..., k, \tag{3}$$

$$KS_1 = KS_2 = KS_k = KS \tag{4}$$

- unit cost n_1 born in state S_1:

$$n_1 = KS + KZ_1 \tag{5}$$

$$KZ_1 = (MPA + MPO + P + PZU + OG) / ST_1 \tag{6}$$

- unit cost n_i born in state S_i, for $i = 2, 4, 6, 9, 10, 11$:

$$n_i = KS \tag{7}$$

- unit cost n_3 borne in state S_3:

$$n_3 = KS_3 + KZ_3 \tag{8}$$

$$KZ_3 = (x \cdot KRB) / ST_3 \tag{9}$$

where:
x – share of current connected with technical emergency unit repairs in the total costs of repairs,
- unit cost n_5 born in state S_5:

$$n_5 = KS_5 + KZ_5 \tag{10}$$

$$KZ_5 = (\mathrm{z} \cdot KRB) / ST_5 \tag{11}$$

where:
z – share of current costs connected with renovation of the technical object, performed within the operation system, in the total repair costs,
- unit cost n_7 born in state S_7:

$$n_7 = KS_7 + KZ_7 \tag{12}$$

$$KZ_7 = [(1\text{-x-z}) \cdot KRB] / ST_7 \tag{13}$$

- unit cost n_8 borne in state S_8:

$$n_8 = KS_8 + KZ_8 \tag{14}$$

$$KZ_8 = KPC / ST_8 \tag{15}$$

The presented calculation procedure does not include an event when a bus needs to be replaced by another bus due to its failure, and there is a need to use a substitute bus instead of the damaged one. If the data obtained from the research object makes it possible to estimate probability values of occurrence of a necessity to provide a substitute bus for the one which is damaged, there is a possibility of the calculation procedure modification. For instance, the following dependencies can be used for states S_2 and S_3:

$$KZ_2 = (Pw \cdot LW_2 \cdot KW) / ST_2 + Pw \cdot n_1 \tag{16}$$

$$KZ_3 = (x \cdot KRB) / ST_3 + (Pw \cdot LW_3 \cdot KW) / ST_3 + Pw \cdot n_1 \tag{17}$$

where:
Pw – probability of occurrence of an event involving the necessity to provide a substitute bus to replace a bus which has been damaged and is in state S_2 (estimated on the basis of data obtained from the analysed system),
KW – regular cost connected with providing a substitute bus.

It is possible to say, on the basis of the research object identification, that assuming that $n_{10} = KS_{10}$ is not a significant error because there are no additional costs borne by the studied system due to delays caused by inoperability of the environment.

4 Conclusions

The procedures presented in this study refers to a system of a city bus transport. However, due to assumed generality of the provided description, they can be used for analysis of the operation processes applied in other transport systems.

It needs to be emphasized, that the data on unit costs provided by the proposed method, can only be used for estimation of the above listed costs. The proposed method cannot replace necessary modifications of the costs registration system used in similar transport companies. However, according to the authors of this study, the results of simulation experiments with the use of input data obtained in this way, enable their qualitative analysis.

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