SIMULATION MODEL OF THE MEANS OF TRANSPORT MAINTENANCE PROCESS

Bogdan Landowski

University of Technology and Life Sciences
Machine Maintenance Department
Prof. S. Kaliskiego Street 7, 85-791 Bydgoszcz, Poland
tel.: +48 52 3408495, fax: +48 52 3408495
e-mail: lbogdan@utp.edu.pl

Abstract

The real operation and maintenance processes of technical objects are characterised by so called secondary action, it means that the values of the features describing the process states and the analysed operation and maintenance states of technical objects as well as the after-effect of those states depend not only on their present state, but very often on the state or sequence of the previous states, too. In spite of the fact that the mathematical models of the real processes are intrinsically a significant simplification of the actual state, it however seems that omission of a secondary action in a certain class of operation and maintenance processes is an excessive simplification and the results obtained from investigations of models of that type may be affected by a significant error. The paper presents a model of operation and maintenance process of means of transport characterised by a secondary action as well as an example of computer simulation of performance of a stochastic process describing the features of the operation and maintenance process under analysis. The elaborated model of operation and maintenance process of technical objects takes into account the specificity of the systems of the urban bus transport. The computer simulation of the maintenance process enables, among other things, to estimate the values of the chosen indicators characterising the investigated process. On the basis of the analysis of the statistical data, obtained from the operation and maintenance investigations, the values of the essential input parameters of the model were estimated. The considerations presented in the paper include an assumption that it is possible to distinguish n disjoint subsets of homogenous objects, from the point of view of the investigation purpose, in the set of the technical objects being operated and maintained in the system under analysis. The investigation object is a system of operation and maintenance of means of transport.

Keywords: *modelling, operation and maintenance process, transport system, urban public transport, computer simulation*

1. Introduction

It has been assumed that each of the operated and maintained technical objects, at the specific moment in time t, $t > 0$, may be in only one of the distinguished states, forming a finite set of the operation and maintenance states of an object. The model of the object maintenance process is the random process X(t) with a finite set of states S. If $X(t) = i$, then the analysed technical object is in the state i, $i \in S$ at the moment t. Performance of the process is a sequence of consecutive distinguished states. The order of the state sequences, duration of the particular states and frequencies of their occurrence depend mostly on the individual features of the particular technical objects, features of the processes those object subject to and on the features and structure of the subsystems working together when performing the maintenance process [4, 5].

2. Investigation object

The paper analyses a real maintenance system of buses in an urban transport system in a selected urban agglomeration. The essential purpose of the operation of the analysed system is performance of the effective (in terms of technical and economic criteria) and safe passenger transports by the operated and maintained means of transport in the determined quantitative and territorial scope.

Among the controlled maintenance processes performed in the investigation object the most important processes, from the point of view of efficiency and purpose of the work of the urban transport system, are the using, serviceability assurance and diagnostic processes.

Using a bus is a process in which the buses, including its operator, perform the transport tasks assigned to them. The transport tasks are determined by a plan of the transport routes (bus lines) and obligatory timetables for the particular routes. The using process is the only maintenance process, performance of which is related to the direct achievement of revenues by the system.

The scope of the performed (at the stands for the current repairs) repair of a bus is decisive for directing the bus to a diagnostic stand in order to perform post-repair diagnostics. The post-repair diagnostics are particularly performed after repairing the following systems and assemblies of a bus [1, 4]:
- Steering system,
- Braking system,
- Engine,
- Truss,
- Front axle suspension.

If the inspection result is negative, the bus is directed again to the current repairs stand.

The following dependencies have been ascertained in the process of identification of the maintenance system of buses in an urban transport system and the bus maintenance process being performed in it, as well as on the basis of the analysis of the maintenance study results:
- Distribution of the random variable describing duration of the renewal state on the type of the damaged bus subsystem,
- Distribution of the random variable describing duration of the diagnostics state on the type of the damaged bus subsystem,
- Repair cost on the type of the damaged bus subsystem,
- Diagnostics costs on the type of the damaged bus subsystem,
- Type of the damaged bus subsystem on the type of the previously damaged subsystem,
- Sequence of the next maintenance states on the type of the damaged bus subsystem.

The type of the damaged bus subsystem has a significant influence on the course of the maintenance process. Moreover, the applied methods of proceeding and sequences of actions aimed at restoring serviceability of technical object as well as the measures to perform them depend on the type of the damaged subsystem of that object.

3. Maintenance process model

The model of the process of changes of the maintenance states of technical objects is the stochastic process $\{X_t, t \in T\}$, $t \geq 0$ with finite set (space) of states $S = \{1, 2, 3, \ldots, n\}$.

In order to define the analysed stochastic process $\{X_t, t \in T\}$ it is needed to determine: the initial distribution of the process $\{X_t, t \in T\}$, conditional probabilities of changes in a single step of the process states $\{X_t, t \in T\}$ and the random variables representing durations of the process states $\{X_t, t \in T\}$.

Moreover, staying in the specific states may be related to achieving revenues or bearing costs by the system.

$[p = p_1, p_2, \ldots, p_n]$, $\sum_{i \in S} p_i = 1$, $p_i \geq 0$ for $i \in S$ was used to denote the initial distribution of the process $\{X_t, t \in T\}$.

Probability of changing the state in a single process step $\{X_t, t \in T\}$ from the state i, $i \in S$ to the state j, $j \in S$ is denoted as p_{ij}, $\sum_{j \in S} p_{ij} = 1$, $p_{ij} \geq 0$, $i, j \in S$.

Probability of changing the state in a single process step $\{X_t, t \in T\}$ from the state i, $i \in S$ to the state j, j∈S, provided that the condition a, a∈A is met is denoted as p_{ij}^{a}, $\sum_{j\in S} p_{ij}^{a} = 1$, $p_{ij}^{a} \geq 0$, for i, j ∈ A and a∈A.

The sequence of the process states $\{X_t, t\in T\}$ is a non-homogeneous Markov chain.

The stochastic process described that way is a special event of a non-stationary Markov decision process.

Moreover, it has been assumed that the model of changes of the maintenance states of the set n of homogenous, from the point of view of the purpose of the bus investigations, are independent processes $\{X_t, t\in T\}$. The random vector $\mathbf{X}(t) = [X_1(t), X_2(t), \ldots, X_n(t)]$ describes the process of changes of the maintenance states of the bus set [2, 3].

A computer program has been developed that facilitates simulation of execution of the stochastic process described that way. When executing the simulation, values of the selected sets of indicators enabling to analyse the modelled process of changes of states of the objects are determined.

The Fig. 1 shows a block diagram of the simulation program.

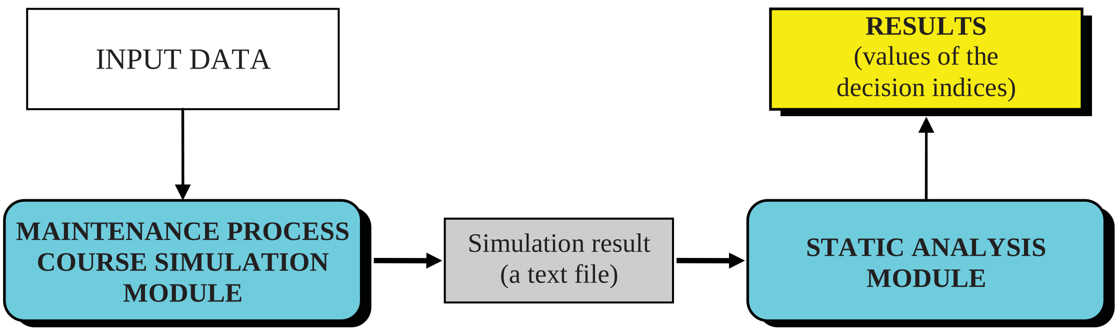

Fig. 1. Block diagram of the simulation program

Because this model describes the process with so called secondary action (probability of changing the current state to the next state depends not only on the current state, but also on the future event – called the condition a, a∈A, e.g. type of the damaged subsystem of a technical object) this model has been called the process model with "memory" features. For instance this feature of the process may be interpreted as follows: if the current maintenance state of a bus is the post-repair diagnostics state, then the probability that the next state of the bus is the state of using depends on the type of the subsystem of this bus that was repaired recently.

In order to describe the "memory" feature of the process being modelled, the following designations were applied:

$Y(t), t \geq 0$ - random process with a finite set of states S,

$S = \{S_1, S_2,\ldots, S_a, S_{a+1},\ldots, S_w\}$ - set of the process states Y(t), $a,w \in N$, $a < w$,

w - number of the distinguished process states Y(t),

A, U - distinguished subsets of the process states Y(t), $A \subset S$, $U \subset S$, that meet the following conditions:

$A \cap U = \varnothing$,

$A \cup U = S$,

$A = \{S_1, S_2,\ldots, S_a\}$,

$U = \{S_{a+1},\ldots, S_w\}$,

a - amount of the distinguished subset A of the process states,

u = w – a - amount of the distinguished subset U of the process states,

t_i - random variables representing the moments at which the process state change occurs Y(t), i = 1, 2, ..., n,

$\Pi = \{t_1, t_2, \ldots, t_n\}$ - set of the moments t_i, such ones that: $0 = t_0 < t_1 < t_2 < \ldots < t_n$, n - number of the step in which the process state change occurs, $n \in N$,

τ_m - random variables representing the moments at which the process state change Y(t) from the state $S_i \in S$ (i = 1, 2, ..., w) to the state $S_j \in U$ (j = a+1, a+2, ..., w-1, w), m = 1, 2, ..., k occurs,

$\psi = \{\tau_1, \tau_2, ..., \tau_k\}$, $\psi \subset \Pi$ - set of the moments τ_m, such ones that: $0 = \tau_0 < \tau_1 < \tau_2 < \ldots < \tau_k$, $k \le n$.

The "memory" feature of the process being modelled may be described as follows [1, 4]: if the state of the process at the moment t_n is known, the state reached at the moment t_{n+1} depends on the state in which the process was at the moment τ_k, $\tau_k \le t_n$ (last state $S_i \in U$ – denoted in the relation (1) with the symbol S_v, v = a + 1, a +2, ..., w – which means that in the time interval $(\tau_k, t_n\rangle$ the process state Y(t) was not changed to the state $S_i \in U$), however it does not depend stochastically on the preceding states $S_i \in A$ and the durations of the preceding states $S_i \in S$ of the process which may be described as follows:

$$P\{Y(t_{n+1}) = S_j / Y(t_n) = S_i, Y(t_{n-1}) = S_{i(n-1)}, ..., Y(t_1) = S_{i(1)}, Y(t_0) = S_{i(0)}\} =$$
$$= P\{Y(t_{n+1}) = S_j / Y(t_n) = S_i, Y(\tau_k) = S_v\}. \quad (1)$$

4. Computational example

In order to illustrate the considerations and show possibilities of applying the elaborated tool to simulate process of changes of the maintenance states of objects, a simplified computational example has been performed.

The following maintenance states of an object are considered:

- State of using (state 1),
- State of waiting for performance of tasks (state 2),
- State of repairing (state 3),
- State of post-repair diagnostics (state 4).

Moreover, in order to take into account influence of the dependence of duration of the states and costs borne by the system, when the object is in the state of repairing and in the diagnostics state on the type of the damaged bus system, four (to simplify the example) vehicle systems have been additionally distinguished, e.g.: steering system U_k, engine system U_s (including the power supply system), braking system U_h, other systems U_p.

The probabilities of occurrence of the analysed conditions have been estimated on the basis of identification of the investigation object and preliminary results of the study.

For the purposes of the example it has been assumed that the set of conditions A consists of six elements, i.e. $A=\{a_1, a_2, a_3, a_4, a_5, a_6,\}$. The conditions adopted for the purposes of the example a_m, m=1,2, …, 6, affecting the sequences of the next process states may be interpreted as follows:

a_1 - the damaged system is the steering system U_k – post-repair diagnostics are necessary,

a_2 - the damaged system is the engine system U_s (including the power supply system) – post-repair diagnostics are necessary,

a_3 - the damaged system is the braking system U_h - post-repair diagnostics are necessary,

a_4 - the damaged system is one of the remaining systems of the vehicle U_p – post-repair diagnostics are not necessary,

a_5 - due to the post-repairs diagnostics it was found that the diagnosed system is in the state of serviceability, and the performed repair was effective,

a_6 - due to the post-repairs diagnostics it was found that the diagnosed system is in the state of unserviceability, and the performed repair was ineffective.

During the simulation the following items are generated for the particular objects: maintenance states, durations of states, costs related to entering the current state and staying there, others.

The sets of the input data being necessary to perform the simulation experiments have been estimated on the basis of the results of the preliminary maintenance study performed in the investigation object.

The chosen results of the simulation are presented in the Tab. 1-4. The simulation was performed for 60 buses and the simulation time equal to 700 days.

Tab. 1. Durations of repairs and diagnostics of the distinguished bus systems

Feature	System code			
	U_k	U_s	U_h	U_p
Repair (state 2)				
Average [h]	4.53	3.13	4.22	0,82
Stand. deviation [h]	0.54	0.52	2.17	0,81
Diagnostics (state 3)				
Average	0.26	0.70	0.20	—
Stand. deviation [h]	0.09	0.70	0.10	—

Tab. 2. Numbers of entries and durations of the analysed states

Feature	State code			
	1	2	3	4
Duration				
Average [h]	18.00	5.45	1.34	0.78
Stand. deviation [h]	0.50	0.50	1.45	1.13
Number of entries of an object				
Sum	44124	36701	8749	1767

Tab. 3. Total number of the performed repairs of the particular vehicle systems

Feature	Repair (state 2)			
	System code			
	U_k	U_s	U_h	U_p
Number of entries	193	974	594	7164

Tab. 4. Number of improperly performed repairs

System code			
U_k	U_s	U_h	U_p
14	101	61	—

5. Summary

The real operation and maintenance processes of technical objects are characterised by so called secondary action, it means that the values of the features describing the process states and the analysed operation and maintenance states of technical objects as well as the after-effect of those states depend not only on their present state, but very often on the state or sequence of the previous states, too. In spite of the fact that the mathematical models of the real processes are intrinsically a significant simplification of the actual state, it however seems that omission of a secondary action in a certain class of operation and maintenance processes is an excessive simplification and the results obtained from investigations of models of that type may be affected by a significant error.

Application of mathematical models to analyse processes with a secondary action is a complex, and frequently an impossible issue. It seems that development of the simulation models and analysis of the results of the simulation experiments, after verification of the model, may constitute a useful tool supporting the decision makers of the complex operation and maintenance systems.

The elaborated model of operation and maintenance process of technical objects takes into account the specificity of the systems of the urban bus transport. The computer simulation of the maintenance process enables, among other things, to estimate the values of the chosen indicators characterising the investigated process.

References

[1] Landowski, B., *Method of determination values of the chosen decision variables to control rationally the operation and maintenance process in the transport system*, Doctoral thesis, Academy of Technology and Agriculture, Bydgoszcz 1999.

[2] Landowski, B., Woropay, M., Neubauer, A., *Controlling reliability in the transport systems*, Library of Maintenance Problems, Maintenance Technology Institute, Bydgoszcz-Radom 2004.

[3] Woropay, M., Grabski, F., Landowski, B., *Semi-Markov model of the vehicle maintenance processes in an urban transport system*, Scientific Publishers of the Polish Scientific Association of Automotive Engineering, Archives of Automotive Engineering, Vol. 7, No, 3, 2004.

[4] Woropay, M., Knopik, L., Landowski, B., *Modelling maintenance processes in a transport system*, Library of Maintenance Problems, Publishers and Printing Department of the Institute of Technology and Maintenance, Bydgoszcz-Radom 2001.

[5] Woropay, M., Knopik, L., Landowski, B., *Analysis of the results of investigations of a machine maintenance model*, Literature of the 9th Scientific Conference Problems in construction and exploitation of metallurgical and ceramic machines, Cracow 1998.