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METHOD OF AVAILABILITY CONTROL OF THE TRANSPORT MEANS

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Abstract

The problems presented in this article deal with operation and maintenance process control in complex systems of technical object operation and maintenance. The article presents the description of the method concerning the control availability for technical objects (means of transport) on the basis of the mathematical model of the operation and maintenance process with the implementation of the decisive processes by semi-Markov. The presented method means focused on the preparing the decisive for the operation and maintenance process for technical objects (semi-Markov model) and after that specifying the best control strategy (optimal strategy) from among possible decisive variants in accordance with the approved criterion (criteria) of the activity evaluation of the system of technical objects operation and maintenance. In the presented method specifying the optimal strategy for control availability in the technical objects means a choice of a sequence of control decisions made in individual states of modelled operation and maintenance process for which the function being a criterion of evaluation reaches the extreme value. In order to choose the optimal control strategy the implementation of the genetic algorithm was chosen. Depending on one's needs, the genetic algorithm including the obtained model of operation and maintenance process may be implemented for mathematic formulation and solution of a wide array of problems connected with control of complex systems of technical object operation and maintenance. It pertains mostly to the economic analysis, safety management and controlling availability and reliability of complex systems. The opinions were presented on the example of the operation and maintenance process of the means of transport implemented in the real system of the bus municipal transport.

Keywords: *semi-Markov processes, control decisions, genetic algorithm*

1. Introduction

In the systems in which the implemented operation and maintenance process for technical objects is complex the choice of rational control decisions among from possible decisive variants is a difficult and complicated issue. The implementation of proper mathematical methods to control the operation and maintenance process makes the choice of sensible control decisions easier. In this way the proper and effective implementation of the tasks ascribed to the system is provided. In order to assure the appropriate running of decision-making process support tools are used, including all kinds of decision-making models, an important element of which is a mathematical model of technical object operation and maintenance process.

The research paper presents an example of the implementation of control semi-Markov processes to control availability of the transport means. The decisive (control) semi-Markov processes constitute a convenient mathematical tool which implementation makes the complicated process of making sensible control decisions easier in the complex operation and maintenance systems for technical objects. The paper presents genetic algorithm as an example of a tool supporting the process of determining the optimal control strategy. The genetic algorithm belongs to the group of non-determinist methods of determining the optimal solution in which particular solutions are random modifications of previous solutions and are parts of them in a significant manner. The basic assumption for using genetic algorithm in searching for an optimal solution is the fact taken from evolution theory claiming that the greatest probability of modification involves solutions with the greatest degree of adaptability defined by the fitness function (optimization task objective function) [2, 6, 8].

2. Decision-making model of availability control of the transport means

Due to the random nature of the factors influencing the running of the technical objects (transport means) operation and maintenance process introduced in a complex system, most often in the process mathematical modelling of the operation and maintenance process, stochastic processes are used. Random process includes a wide implementation of Markov and semi-Markov process for modelling the operation and maintenance process for technical objects, whereas in the case of the issues involving control of operation and maintenance processes, decision-making Markov and semi-Markov processes are used [1, 3-5, 7, 9-11].

The decisive semi-Markov process is a stochastic process $\{X(t)\colon t \geq 0\}$, the implementation of which depends on the decisions made at the beginning of the process t_0 and at the moments of changing the process $t_1, t_2, \ldots, t_n, \ldots$. At work it is assumed that the analyzed semi-Markov process possess a limited number of states $i = 1, 2, \ldots, 9$. Then:

$$D_i = \left\{ d_i^{(1)}(t_n), d_i^{(2)}(t_n), \ldots, d_i^{(k)}(t_n) \right\}, \tag{1}$$

means a set of all possible control decisions which can be implemented in i-state of the process at the moment of t_n, where $d_i^{(k)}(t_n)$ means k-control decision made in i-state of the process, at the moment of t_n. In case of implementation of the decisive semi-Markov processes making the decision at the moment of t_n, k-controlling decision in i-state of the process means a choice of i-verse of the core of the matrix from the following set:

$$\left\{ Q_{ij}^{(k)}(t) : t \geq 0,\ d_i^{(k)}(t_n) \in D_i,\ i, j \in S \right\}, \tag{2}$$

where:

$$Q_{ij}^{(k)}(t) = p_{ij}^{(k)} \cdot F_{ij}^{(k)}(t). \tag{3}$$

The choice of the i-verse of the core of the process specifies the probabilistic mechanism of evolution of the process in the period of time $\langle t_n, t_{n+1})$. This means that for the semi-Markov process, in case of the change of the state of the process from one into i-one (entry to the i-state of the process) at the moment t_n, the decision is made $d_i^{(k)}(t_n) \in D_i$ and according to the schedule $\left(p_{ij}^{(k)} : j \in S\right)$ j-state of the process is generated, which is entered at the moment of t_{n+1}. At the same time, in accordance with the schedule specified by the distributor $F_{ij}^{(k)}(t)$, the length of the period of time is generated $\langle t_n, t_{n+1})$ to leave the i-state of the process, when the next state is the j-

state. Then as the strategy we understand the δ sequence, where the words are the vectors, comprising of the decision $d_i^{(k)}(t_n)$ made in the following moments of the t_n changes of the state of the process $X(t)$:

$$\delta = \left\{ \left[d_1^{(k)}(t_n), d_2^{(k)}(t_n), \ldots, d_9^{(k)}(t_n) \right]: \quad n = 0,1,2,\ldots \right\}. \tag{4}$$

The choice of the proper control strategy δ named the optimal strategy δ^* refers to the situation when the function being the criterion of the choice of the optima strategy takes an extreme value (minimal or maximal). In case of implementing decisive semi-Markov processes to control availability of the technical objects (means of transport) the criteria function can be the function describing availability of individual technical object G^{OT}. The choice of the optimal strategy δ^* is made on the basis of the following criterion:

$$G^{OT}\left(\delta^*\right) = \max_{\delta}\left[G^{OT}(\delta)\right]. \tag{5}$$

In order to implement the decisive semi-Markov processes to control availability of the means of transport, operated in the analysed system of the bus municipal transport the mathematical model of the operation and maintenance process was prepared [7]. The mathematical model of the operation and maintenance process for the means of transport was extended on the basis of the incidental model of the operation and maintenance process with the use of the theory of the semi-Markov's systems. The mathematical model for the operation and maintenance process constitutes the basis for evaluation availability of the implemented means of transport.

Due to the identification of the analysed operation and maintenance process of transport means, crucial states of the process as well as possible transfers between the defined states were designated. Based on this, a graph was created, depicting the changes of operation and maintenance process states, shown in Fig. 1.

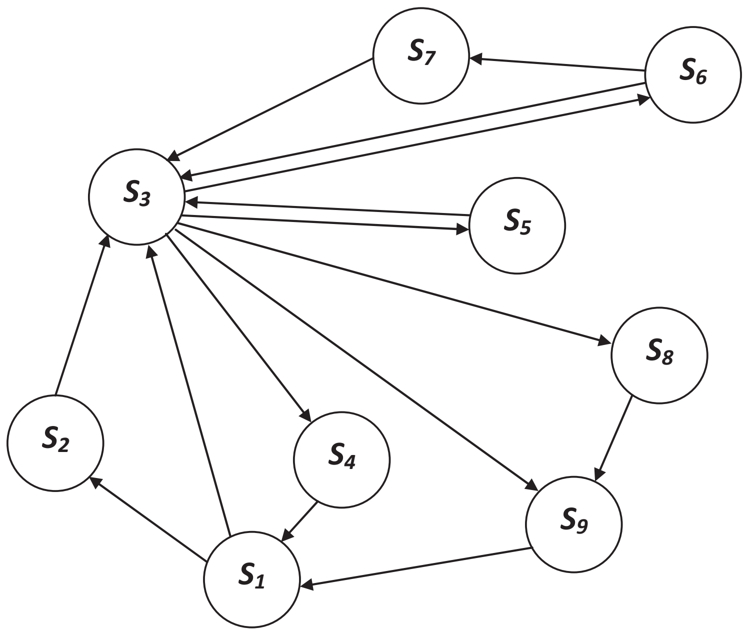

Fig. 1. Directed graph representing the transport means operation process: S_1 – refuelling, S_2 – awaiting the carrying out of the task at the bus depot parking space, S_3 – carrying out of the transport task, S_4 – awaiting the carrying out of the task between transport peak hours, S_5 – repair by technical support unit without losing a ride, S_6 – repair by the emergency service with losing a ride, S_7 – awaiting the start of task realization after technical support repair, S_8 – repair in the serviceability assurance subsystem, S_9 – maintenance check on the operation day

The homogenous semi-Markovian process $X(t)$ is unequivocally defined when initial distribution and its kernel are given. The initial distribution takes up the following form:

$$p_i(0) = \begin{cases} 1 & when \quad i = 3, \\ 0 & when \quad i \neq 3, \end{cases} \tag{6}$$

where:

$$p_i(0) = P\{X(0) = i\}, \quad i = 1,2,...,9, \tag{7}$$

whereas the kernel of process $Q(t)$ takes up the form:

$$Q(t) = \begin{bmatrix} 0 & Q_{12}(t) & Q_{13}(t) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Q_{23}(t) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & Q_{34}(t) & Q_{35}(t) & Q_{36}(t) & 0 & Q_{38}(t) & Q_{39}(t) \\ Q_{41}(t) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Q_{53}(t) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & Q_{63}(t) & 0 & 0 & 0 & Q_{67}(t) & 0 & 0 \\ 0 & 0 & Q_{73}(t) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & Q_{89}(t) \\ Q_{91}(t) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}, \tag{8}$$

where:

$$Q_{ij}(t) = p_{ij} \cdot F_{ij}(t), \tag{9}$$

p_{ij} – means that the conditional probability of transfer from state S_i to state S_j,
$F_{ij}(t)$ – is a distribution function of random variable Θ_{ij} signifying period of duration of state S_i, under the condition that the next state will be state S_j.

In order to assign the values of limit probabilities p_i^* of staying in the states of semi-Markov model of operation and maintenance process, the following were created: matrix $P = [p_{ij}]$ of the states change probabilities and matrix $\Theta = [\overline{\Theta}_{ij}]$ of conditional periods of duration of the states in process $X(t)$. Based on the matrix P and on the matrix Θ, average values of non-conditional duration periods of process states were defined, according to the dependence:

$$\overline{\Theta}_i = \sum_{i=1}^{9} p_{ij} \cdot \overline{\Theta}_{ij}, \quad i, j = 1,2,...,9. \tag{10}$$

Therefore, the boundary probability p_i^* for staining in the states of the semi-Markov processes can be determined on the basis of the boundary statement for the semi-Markov process [3, 5], in accordance with the following pattern:

$$p_i^* = \lim_{t \to \infty} p_i(t) = \frac{\pi_i \cdot E(\Theta_i)}{\sum_{i \in S} \pi_i \cdot E(\Theta_i)}, \tag{11}$$

where probabilities $\pi_i, i \in S$ constitute the stationary layout of the implemented Markov's chain in the process which fulfils the system of linear equations:

$$\sum_{i \in S} \pi_i \cdot p_{ij} = \pi_j, \quad j \in S, \quad \sum_{i \in S} \pi_i = 1. \tag{12}$$

Availability of a single technical object defined on the basis of the semi-Markovian model of operation and maintenance process is determined as the sum of limit probabilities p_i^* of remaining at states belonging to the availability states set:

$$G^{OT} = \sum_i p_i^*, \quad dla \quad S_i \in S_G. \tag{13}$$

3. Determining the optimal strategy of availability control of the transport means

In case of complex models of the operation and maintenance process of the technical objects, in order to determine the optimal control strategy it is essential to use the proper and effective methods and mathematical tools. At work, as the tool for choosing the optimal strategy δ^* of controlling the availability of the means of transport, on the basis of the semi-Markov model of operation and maintenance process the following genetic algorithm was implemented [2, 6, 8]. For the description of the operation of genetic algorithm presented in the article, terminology generally used in technical literature was used, while, at the same time reflecting names and terms connected with optimal strategy for technological object operation process:

- gene (decision) – individual element of the chromosome,
- chromosome (strategy) – an object representing crucial variables in the process of looking for optimal solution (eg. optimal strategy),
- population – chromosome set (strategy set),
- fitness function – objective function or a function connected with objective function in the process of looking for optimal solution (optimal strategy), it makes a numerical evaluation of the adaptability of individual elements (strategies) possible.

The following stages of genetic algorithm operation are presented below:

Stage I – Initiation

Initiation is an initial stage of the carrying out of genetic algorithm. At this stage, establishing of the basic parameters of the algorithm and of the rules of encoding of optimization variables, determining of initial population, outlining fitness functions as well as determining the value of fitness function value for individual chromosomes (δ strategies) of initial population all take place.

Stage I.a – Determining basic parameters of genetic algorithm

The basic parameters of genetic algorithm are as follows:

- length m of the chromosome, determined by the number of genes in the chromosome,
- population size n, or the number of chromosomes in the population,
- η factor – determining the probability of selecting chromosomes on the basis of elitism,
- κ factor – determining the probability of hybridization,
- μ factor – determining the probability of mutation.

Stage I.b – Determining optimization variable encoding rules

While using genetic algorithm, from among the numerous methods of optimization variables encoding, binary encoding is the one used the most often. When using binary encoding method the establishing of the number of m chromosome genes unequivocally determines the maximum number of chromosomes in the set of acceptable solutions, which amounts to 2^m.

Stage I.c – Determining initial (starting) population

Having established basic optimization parameters as well as encoding rules, with the help of random method, the initial population with n number of elements (chromosomes).

Stage I.d – Determining the value of fitness function for initial population

A fitness function may be both an objective function and any function strictly connected with the objective function of the analyzed optimization task. Determining the value of fitness function makes it possible to numerically evaluate the adaptability of individual chromosomes in the analyzed population.

Stage II – Generating Populations In Successive Iterations

The result of carrying out of this stage is generation of elements (chromosomes) of new populations (created in successive iterations *I*) out of elements (chromosomes) of previous populations. The method of generating elements of new populations involves n–fold drawing of n chromosome pairs, the so-called parent pair, and then creating n offspring of the new population.

Stage II.a – Elitism

Elitism principle involves the choice of the best (best adapted) elements (chromosomes) from out of the elements (chromosomes) of previous population and copying them to new populations.

Stage II.b – Selection

The goal for the stage of selection is the choice of such chromosomes from out of the chromosomes of the previous population, which at the stage of hybridization will create the so called parent chromosome pairs. Chromosome selection is a random process in which the choice of parent pair should be significantly influenced by the given chromosome having desirable features (fitness function value).

Stage II.c – Hybridization

Hybridization operation involves an exchange, with the help of specific hybridization operator, of genes between chromosomes coming from individual parent pairs. As a result of carrying out of hybridization operation, offspring chromosomes are created as certain combinations of genes of appropriate parent chromosome pairs.

Stage II.d – Mutation

Mutation is the final stage of generating elements (chromosomes) of the new population and involves the change of individual genes of the offspring chromosome created previously at the hybridization stage. Using mutation makes it possible to include among the elements of the new population also these chromosomes which, by definition, are practically impossible to obtain as a result of hybridization only (out of the elements of previous population).

Stage III – Stop Condition

When the choice of optimal strategy (superior chromosome) is made on the basis of genetic algorithm, it is possible to implement two stop conditions:

– Attaining the assumed number of iterations,
– Small changes of the value of objective function (fitness function) determined for the strategy (chromosome) best adapted among the elements of the tested populations within the course of successive iterations.

Presented below is an example of assigning optimal operation process control strategy carried out in the chosen transport means operation system – the city bus transport system. In the presented example, the criterion of determining optimal strategy δ^* constitutes the value of the function describing the availability of the transport means G^{OT} (13). In order to define availability of technical objects (means of transport) based on the semi-Markovian model of operational process, the operational states of the technical object should be divided into availability states S_G and non-availability states S_{NG} of the object for the carrying out of the assigned task. In the presented model, the following technical object availability states were enummerated:

– state S_2 – awaiting the carrying out of the task at the bus depot parking space,
– state S_3 – carrying out of the transport task,
– state S_4 – awaiting the carrying out of the task between transport peak hours,
– state S_7 – awaiting the start of task realization after technical support rep air.

Then, with the use of the MATHEMATICA software, the limit probability p_i^* of staying in states of semi-Markov process and the availability of technical objects of the transport system were determined:

$$G^{OT} = \frac{p_{12} \cdot (p_{34} + p_{38} + p_{39}) \cdot \overline{\Theta_2} + \overline{\Theta_3} + p_{34} \cdot \overline{\Theta_4} + p_{36} \cdot p_{67} \cdot \overline{\Theta_7}}{\left[(p_{34} + p_{38} + p_{39}) \cdot \left(\overline{\Theta_1} + p_{12} \cdot \overline{\Theta_2}\right)\right] + \overline{\Theta_3} + p_{34} \cdot \overline{\Theta_4} + p_{35} \cdot \overline{\Theta_5} + \left[p_{36} \cdot \left(\overline{\Theta_6} + p_{67} \cdot \overline{\Theta_7}\right)\right] + p_{38} \cdot \overline{\Theta_8} + (p_{38} + p_{39}) \cdot \overline{\Theta_9}}. \quad (14)$$

Then the optimal strategy δ^* process control operation is determined by the maximum value of the function describing the availability of means of transport, on the basis of the criterion (5). For the analyzed model of transport means operation process the values of genetic algorithm input parameters (Tab. 1), possible decisions made in decision-making process states were determined (Tab. 2) as well as, based on operational data, absolute values of process state duration periods were defined (Tab. 3).

Tab. 1. Genetic algorithm input parameter values

Length of chromosome	$m = 9$
Size of population	$n = 100$
Number of iterations	$I = 100$
Probability of chromosome selection via elitism principle	$\eta = 0.2$
Probability of hybridization occurrence	$\kappa = 1$
Probability of mutation occurrence	$\mu = 0.05$

Tab. 2. The control decisions in the states of the analyzed operation process

Process state	Decision „0" - $d_i^{(0)}$	Decision „1" - $d_i^{(1)}$
S_3	The route marked code L („light" conditions of the delivery task)	The route marked code D („difficult" conditions of the delivery task)
S_5	Treatment by a PT type B (basic range)	Treatment by a PT type E (extended range)
S_6	Treatment by a PT type B (basic range)	Treatment by a PT type E (extended range)
S_8	Treatment in positions PZZ type N (normal)	Treatment in positions PZZ type I (intensive)
S_9	Operate in positions OC type N (normal)	Operate in positions OC type I (intensive)

Tab. 3. Values of the absolute process state duration periods

Process state	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9
$\Theta_i^{(0)}$ [h]	0.096	5.659	8.852	3.450	0.070	0.545	0.442	3.744	0.122
$\Theta_i^{(1)}$ [h]	0.096	5.659	7.967	3.450	0.063	0.436	0.442	2.995	0.092

Next, calculations were made with the help of developed computer software, implemented genetic algorithm. As a result of the calculations performed the optimal operation process control strategy was determined in the tested system of transport means operation – city bus operation system (Tab. 4).

Tab. 4. Optimal transport means operation process control strategy and criterion function value, determined on the basis of genetic algorithm

Optimal strategy δ^*	$G^{OT}\left(\delta^*\right)$
[1,1,1,0,0,1,0,0,1]	0.8426

4. Conclusions

The presented method controlling availability of the technical objects (means of transport) means determination a proper strategy (a sequence of control decisions made in individual states of the model process) for which the function constituting the criterion of evaluation achieves an extreme value. In order to specify the optimal strategy controlling the availability of the technical objects the genetic algorithm was recommended.

Due to the general character the presented method canoe implemented for solving a broad spectrum of optimization issues concerning the operation and maintenance systems for the technical objects such as: controlling availability and reliability, analysis of costs and profits, analysis of risk and safety etc. In each case there is a necessity to form properly the definition of the criterion and specifying possible control decisions made in the states of the examined operation and maintenance process of the technical objects and estimating entrance date for the mathematical model of the process which consists of the values of the elements included in the matrix of the core of the process *Q(t)*, the matrixes of probabilities for changes *P* and the conditional matrixes for duration times of the states of the process Θ .

The method of determining optimal control strategy of technical object availability with the use of genetic algorithm presented in the article, constitutes one of the stages of work the goal of which is developing a complex method of technical object operation and maintenance process control with the use of decision-making models. A complex method of transport means operation and maintenance process control is supposed to make it possible to control both the processes carried out at the executive subsystem (evaluation of transport means tasks carried out) as well as at the serviceability assurance subsystem (evaluation of service and repair tasks carried out), taking into consideration both the technical and economic criteria of the functioning of this type of operation and maintenance systems.

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