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APPLICATION OF GENETIC ALGORITHM TO CONTROL THE AVAILABILITY OF TECHNICAL SYSTEMS

K. Migawa*, L. Knopik, S. Wawrzyniak*****

Abstract: *This study presents the problems connected with control of operation and technical objects maintenance systems. In particular, it discusses assessment and control of the availability of technical objects. In case of complex operation and maintenance systems, in order to control the availability it is essential to use the proper and effective methods and mathematical tools. The factors influencing the running and efficiency of the operation and maintenance process introduced in a complex system are of random nature. Most often the stochastic processes are used in mathematical modelling of the operation and in maintenance. In order to control the availability of technical systems, the following genetic algorithm was implemented on the basis of the semi-Markov model of operation and maintenance. Genetic algorithm may serve as a convenient tool to implement and facilitate the use of a complicated rational control decision making process in complex operation and maintenance systems. These include: systems operating machines, construction equipment, and means of transport. Due to its general character, the presented method may be implemented to solve a broad spectrum of optimization issues concerning the operation and maintenance systems. Among them are: controlling availability and reliability, analysis of costs and profits, and analysis of risk and safety.*

Keywords: Technical systems, Availability, Genetic algorithm.

1. Introduction

In actual complex operation and maintenance systems, the process of making control decisions should be implemented with the use of proper methods and mathematical tools. It should not be limited to the "intuitive" system based only on knowledge and experience of the decision-makers. Implementation of proper mathematical methods to control the process makes the choice of sensible decisions easier. Proper and effective implementation of the tasks ascribed to the system is thus provided.

Genetic algorithm may serve as a convenient tool. Its implementation facilitates the use of a complicated rational control decision making processes in a complex technical object operation and maintenance system (Goldberg, 2003).

2. Decisive model of availability control

The research paper presents an example of the implementation of control semi-Markov processes. They control availability in the operation and maintenance system for the means of transport. In order to implement them, a mathematical model of the operation and maintenance process was prepared on the basis of the event model of this process shown in figure 1.

* Assoc. Prof. Klaudiusz Migawa, PhD.: Faculty of Mechanical Engineering, UTP University of Science and Technology, Prof. S. Kaliskiego Street 7, 85-789 Bydgoszcz, Poland, klaudiusz.migawa@utp.edu.pl

** Assoc. Prof. Leszek Knopik, PhD.: Faculty of Management, UTP University of Science and Technology, Fordońska Street 430, 85-790 Bydgoszcz, Poland, knopikl@utp.edu.pl

*** Assist. Prof. Sylwester Wawrzyniak, PhD.: Faculty of Mechanical Engineering, UTP University of Science and Technology, Prof. S. Kaliskiego Street 7, 85-789 Bydgoszcz, Poland, sylwester.wawrzyniak@utp.edu.pl

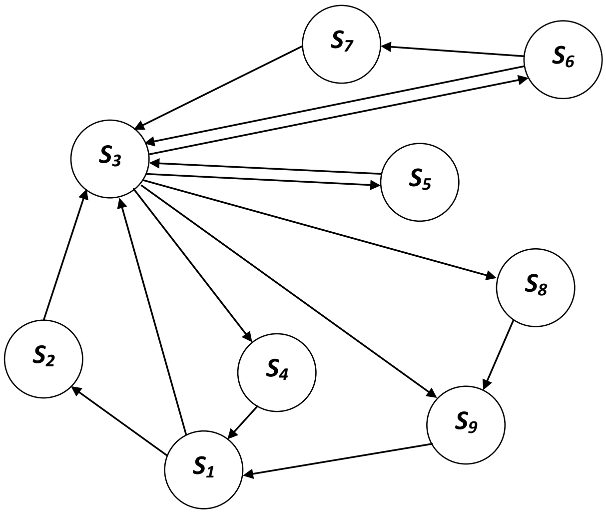

Fig. 1: Directed graph representing the transport means operation process

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

In order to assign the values of limit probabilities p_i^* of remaining in the states of semi-Markov model of operation and maintenance process, matrix $P = \left[p_{ij}\right]$ of the states change probabilities and matrix $\Theta = \left[\overline{\Theta_{ij}}\right]$ of conditional periods of duration of the states in process $X(t)$ were created. Based on matrix P and matrix Θ, average values of non-conditional duration periods of process states $\overline{\Theta_i}, i = 1,2,...,9$ were defined.

Therefore, the limit probability p_i^* for remaining in the states of semi-Markov processes can be determined. It is based on the limit statement for the semi-Markov process (Grabski, 2014; Kulkarni 1995):

$$p_i^* = \lim_{t \to \infty} p_i(t) = \frac{\pi_i \cdot \overline{\Theta_i}}{\sum_{i \in S} \pi_i \cdot \overline{\Theta_i}} \tag{1}$$

where probabilities $\pi_i, i \in S$ constitute the stationary layout of the implemented Markov's chain in the process $X(t)$.

Availability of an individual technical object is defined on the basis of the semi-Markovian model of operation and maintenance process. It is determined as the sum of limit probabilities p_i^* of remaining in the states belonging to the set of availability states $S_i \in S_G$:

$$G^{OT} = \sum_i p_i^* = \frac{p_{12} \cdot (p_{34} + p_{38} + p_{39}) \cdot \overline{\Theta_2} + \overline{\Theta_3} + p_{34} \cdot \overline{\Theta_4} + p_{35} \cdot \overline{\Theta_5} + p_{36} \cdot p_{67} \cdot \overline{\Theta_7}}{\left[(p_{34} + p_{38} + p_{39}) \cdot \left(\overline{\Theta_1} + p_{12} \cdot \overline{\Theta_2}\right)\right] + \overline{\Theta_3} + p_{34} \cdot \overline{\Theta_4} + p_{35} \cdot \overline{\Theta_5} + \left[p_{36} \cdot \left(\overline{\Theta_6} + p_{67} \cdot \overline{\Theta_7}\right)\right] + p_{38} \cdot \overline{\Theta_8} + (p_{38} + p_{39}) \cdot \overline{\Theta_9}} \tag{2}$$

The decisive semi-Markov process is a stochastic process $\{X(t): t \geq 0\}$. Its implementation 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, …, 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 (Cao, 2003; Kashantov, 2010; Puterman, 1994):

$$\left\{Q_{ij}^{(k)}(t) : t \geq 0,\ d_i^{(k)}(t_n) \in D_i,\ i, j \in S\right\} \tag{3}$$

where:

$$Q_{ij}^{(k)}(t) = p_{ij}^{(k)} \cdot F_{ij}^{(k)}(t) \tag{4}$$

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 $d_i^{(k)}(t_n) \in D_i$ is made. According to the schedule $\left(p_{ij}^{(k)} : j \in S\right)$, j-state of the process is generated. It 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 $\langle t_n, t_{n+1})$. It leaves 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. They comprise of the decision $d_i^{(k)}(t_n)$ made in the following moments of the t_n changes of the state of the process $X(t)$:

$$\delta = \left\{ \left[d_1^{(k)}(t_n), d_2^{(k)}(t_n), \ldots, d_9^{(k)}(t_n) \right] : \quad n = 0,1,2,\ldots \right\} \tag{5}$$

The choice of the proper control strategy δ is called the optimal strategy δ^*. It refers to the situation when the function being the criterion of the choice of the optimal strategy (e.g. availability of individual technical object) takes an extreme value. The choice of the optimal strategy δ^* is made on the basis of the following criterion:

$$G^{OT}\left(\delta^*\right) = \max_{\delta} \left[G^{OT}(\delta) \right] \tag{6}$$

The genetic algorithm is a convenient tool for choosing the optimal strategy δ^* of process control operation of technical objects. It is bases on developed semi-Markov model of the process. General scheme of choice of the optimal strategy using genetic algorithm is presented in Figure 2 (Vose, 1998).

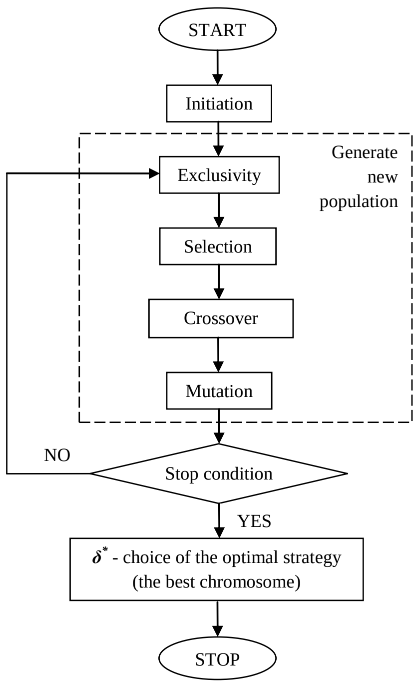

Fig. 2: General scheme of the genetic algorithm of choice of the optimal strategy δ^*

When using the genetic algorithm to determine the optimal strategy process control operation of technical objects, the following assumptions should be adopted:

–in each state one of the two ways of proceeding can be used (called the decision),

–if decisions are labelled 0 and 1, the set of stationary and deterministic strategies will be the set of function $\delta : S \rightarrow D$, where S is the set of states of the process, $S = \{1, 2, \ldots, m\}$ and D – is the set of decisions made in the state of the process, $D = \{0,1\}$;

This determines the possible control decisions in the state of the analyzed model of the process of operation of technical objects. It also estimates the value of the items of the kernel process $Q(t)$ of the matrix P probabilities of transitions and the matrix Θ durations of the states of the process. For the analyzed model of transport means operation process, the values of genetic algorithm input parameters and possible decisions made in decision-making process states were determined (table 1).

Tab. 1: The control decisions in the states of the analyzed operation process

Process state	Decision „0" - $d_i^{(0)}$	Decision „1" - $d_i^{(1)}$
S_1	non decision-making process state	
S_2	non decision-making process state	
S_3	The route marked code L ('easy' conditions of delivery task)	The route marked code D ('difficult' conditions of delivery task)
S_4	non decision-making process state	
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_7	Non decision-making process state	
S_8	Treatment in positions PZZ type N (normal)	Treatment in positions PZZ type I (extensive)
S_9	Operate in positions OC type N (normal)	Operate in positions OC type I (extensive)

Next, calculations were made with the help of developed computer software. Genetic algorithm was implemented. As a result of the calculations performed, the optimal control strategy was determined in the tested system for the adopted criterion (6). Calculation results were presented in table 2.

Tab. 2: Availability function value, determined on the basis of genetic algorithm

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

3. Conclusions

Due to its general character, the presented method can be implemented for solving a broad spectrum of optimization issues. They concern the operation and maintenance systems for the technical objects. Among them are the following: controlling availability and reliability, analysis of costs and profits, analysis of risk and safety etc.. In each case there is a necessity to form the definition of the criterion properly. It is also required to specify possible control decisions made in the states of the tested operation and maintenance process of the technical objects.

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