THE METHOD OF EVALUATION OF INITIAL AVAILABILITY IN THE TRANSPORT SYSTEM OF CITY BUSES

METODA OCENY GOTOWOŚCI POCZĄTKOWEJ W SYSTEMIE AUTOBUSOWEGO TRANSPORTU MIEJSKIEGO

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Abstract: This paper presents the method of evaluation of initial availability of means of transport to carry out the assigned transport tasks. As an example of research object illustrating the presented deliberations, an actual city bus system from a selected urban agglomeration was used. In systems of this type, the technological objects (means of transport) have to initiate carrying out of the assigned transport tasks at assigned times, according to the adopted timetable. In order to assure the possibility to fulfill the transport tasks at assigned times, the so called time buffer is implemented in order for the necessary service processes to be carried out. In order to evaluate the availability of means of transport in the operational cycle of which the so called time buffer was implemented, it is convenient to use the characteristics describing initial availability of technological objects. Initial availability determines the probability of initiating (activating) the necessary number of technological objects in order to carry out the assigned tasks over a designated time period needed for their preparation and activation. The presented deliberation is illustrated by examples of the results of evaluation of initial availability in the actual tested transport system.

Keywords: transport system, initial availability, city buses

Streszczenie: W pracy przedstawiono metodę oceny gotowości początkowej środków transportu do realizacji przydzielonych zadań transportowych. Jako przykład obiektu badań, na którym zilustrowano przedstawione rozważania, wybrano rzeczywisty system eksploatacji autobusów miejskich w wybranej aglomeracji miejskiej. W systemach tego typu obiekty techniczne (środki transportu), w wyznaczonych chwilach, zgodnie z przyjętym harmonogramem, muszą przystąpić do realizacji przydzielonych zadań przewozowych. W celu zapewnienia możliwości rozpoczęcia w wyznaczonych chwilach zadań przewozowych, stosowany jest przedział czasu, tzw. bufor czasowy, przeznaczony na realizację niezbędnych procesów uzdatniania. Do oceny gotowości środków transportu, w których cyklu eksploatacyjnym zastosowano tzw. bufor czasowy, wygodnie jest zastosować charakterystyki opisujące gotowość początkową obiektu technicznego. Gotowość początkowa określa prawdopodobieństwo przystąpienia (uaktywnienia) wymaganej liczby obiektów technicznych do realizacji przydzielonych zadań, w wyznaczonym przedziale czasu przeznaczonego na ich przygotowanie i uaktywnienie. Przedstawione rozważania zilustrowano przykładowymi wynikami oceny gotowości początkowej w badanym rzeczywistym systemie transportowym.

Słowa kluczowe: system transportowy, gotowość początkowa, autobusy miejskie

1. Introduction

The concept of availability applies to such systems which are due to react fast in emergencies, that is: the army, police, emergency service, fire brigade, and transport systems as well. In general, the technical object availability (of an element or a system) can be defined as a feature which characterizes it in terms of its capability to achieve or maintain the availability state (enabling performance of the transport task) [2, 6, 7].

The transport system consists of two main subsystems: logistics and executive. In the logistics subsystem, the processes carried out are supposed to assure task-based efficiency of the used technical objects. The task of the executive subsystem is to perform the assigned transport tasks over set routes, with a given frequency, according to a set schedule. In city bus transport systems, the system's task is executed by the executive subsystem, that consists of elementary subsystems type human being – technical object (e.g. the driver – the bus).

A proper accomplishment of the transport task is possible only if the required number of elementary subsystems is prepared to perform the assigned task in a given time. In order to assure the possibility to fulfill the transport tasks at assigned times, the so called time buffer is implemented in order for the necessary service processes to be carried out. Then, to evaluate the possibility of correct carrying out of the transport task, it is convenient to use the characteristics describing initial availability of technological objects. Initial availability determines the probability of initiating (activating) the necessary number of technological objects in order to carry out the assigned tasks over a designated time period t_g (time reserve), needed for their preparation and activation. The article presents the method of evaluation of functional availability (when $t_g = 0$) and initial availability (when $t_g > 0$) of means of transport in the executive subsystem with a threshold structure [1, 3, 4, 5, 6].

2. The availability of executive subsystem with a threshold structure

In complex systems of the use of means of transport, which include municipal bus transport systems, apart from basic technological objects designed for the carrying out of transport tasks there are also additional technological objects, the so called reserve objects. The task of a reserve object is replacing the basic object (continuing the task assigned to the basic object) in case of the carrying out of the task by the basic object becoming impossible, i.e. as a result of damage.

The object of investigation is the executive subsystem of the city bus transport system. The executive subsystem consists of two subsystems:

- working subsystem, that contains n elementary components (basic technical objects), coupled with the row structure, essential for executing the task - that are marked with $E_1 \div E_n$ symbols,
- reserve subsystem, that contains k elementary components (reserve technical objects), marked with $E_{n+1} \div E_{n+k}$ symbols.

When reserve objects are used, the structure which links the technological objects is a threshold structure of the “ n of N ” type, where:

- $N = n + k$ – the number of all technological objects used in the system,
- n – the number of basic technological objects,
- k – the number of reserve technological objects.

The executive subsystem with a threshold structure is schematically shown on the figure 1.

Fig. 1. The diagram of the executive subsystem with a threshold structure

A feature of threshold structure systems is the possibility of appropriate realization of an assigned task even when a given number of technological objects used in the system are not available for the carrying out of the task (nonoperational and/or unsupplied objects). The acceptable number of unavailable technological objects in the system may not be higher than k .

The availability of the utilization subsystem with threshold structure including N technological objects, for which the required minimum number of objects available for the realization of the assigned transport task is equal to n , is described by the following relationship:

$$G(t) = \sum_{j=n}^{n+k} \binom{n+k}{j} [p_i(t)]^j [q_i(t)]^{n+k-j}, \quad (1)$$

where:

$p_i(t)$ – availability of a single technological object (means of transport),

$q_i(t)$ – unavailability of a single technological object (means of transport).

Let's suppose, the executive subsystem operates in successive maintenance 24 hour cycles $c = 1, 2, \dots$. In every single cycle we can distinguish four periods of operation and maintenance process:

- f_1 – the first phase (the technical object is awaiting, just to join the action), from t_0 moment to t_1 moment,
- f_2 – the second phase (the technical object is becoming active), from t_1 moment to t_2 moment,
- f_3 – the third phase (the technical object is on duty and can execute system's task), from t_2 moment to t_3 moment,
- f_4 – the fourth phase (service or repair) from t_3 moment to t_0 moment, in the logistic system.

The functional availability of executive subsystem

The functional availability - probability, that the executive subsystem can be available to get the brand new task at the t_l moment (i.e. at the end of the phase f_1 and with a time reserve $t_g = 0$).

Every single element (technical object) of the executive subsystem after repair or service, while awaiting to join the duty action can be damaged on the parking ground, because of both poor weather conditions and poor conditions of the parking ground.

Let the variable $e_i^{(1)}(t)$, $i = 1, 2, \dots, n + k$, $t \in < t_0, t_1$, mean the condition of the E_i element at the t moment, while the phase f_1 takes place:

$$e_i^{(1)}(t) = \begin{cases} 1, & \text{if } E_i \text{ element is available at the } t \text{ moment of the phase } f_1, \\ 0, & \text{if } E_i \text{ element is unavailable at the } t \text{ moment of the phase } f_1. \end{cases}$$

Then the (2) equation circumscribes the probability of the fact that the E_i element is available at the t moment, during the phase f_1 , since t_0 moment to t_l moment:

$$p_i^{(1)}(t) = P(e_i^{(1)}(t) = 1), \quad i = 1, 2, \dots, n + k, \quad t \in < t_0, t_1). \quad (2)$$

Let's suppose, that values of those probabilities at the t_l moment (i.e. at the end of the phase f_1) are constant, and circumscribed with the (3) equation:

$$p_i^{(1)}(t_l) = p_i^{(1)}, \quad 0 \leq p_i^{(1)} \leq 1, \quad i = 1, 2, \dots, n + k. \quad (3)$$

Because, according to the assumption, system's elements can be damaged independently, the functional availability, calculated for the executive subsystem during the phase f_1 can be described with the following (4) equation:

$$G^{(1)}(t) = \sum_{j=n}^{n+k} \binom{n+k}{j} [p_i^{(1)}(t)]^j [q_i^{(1)}(t)]^{n+k-j}, \quad t \in < t_0, t_1), \quad (4)$$

where:

$q_i^{(1)}(t)$ - probability of fact, that the E_i element can be unavailable at the t moment, during the phase f_1 ; the probability is described with the (5) equation:

$$q_i^{(1)}(t) = 1 - p_i^{(1)}(t) = P(e_i^{(1)}(t) = 0), \quad i = 1, 2, \dots, n + k, \quad t \in < t_0, t_1). \quad (5)$$

The functional availability of executive subsystem at the t_l moment (i.e. at the end of the f_1 phase) can be circumscribed with the following (6) equation:

$$G^{(1)} = G^{(1)}(t_l) = \sum_{j=n}^{n+k} \binom{n+k}{j} [p_i^{(1)}]^j [q_i^{(1)}]^{n+k-j}, \quad (6)$$

where:

$q_i^{(1)}$ - probability of fact, that the E_i element is unavailability at the t_1 moment, at the end of the phase f_1 ; the probability is described with the (7) equation:

$$q_i^{(1)} = 1 - p_i^{(1)} = P(e_i^{(1)}(t_1) = 0). \quad (7)$$

The initial availability of executive subsystem

The initial availability - probability, that the executive subsystem can be available to get the brand new task at the t_2 moment (i.e. at the end of the phase f_2 and with a time reserve $t_g > 0$).

During the phase f_2 , the element of executive subsystem (technical object) is stimulated to action (executing the task) by the service team. Every single element is checked and stimulated to action. However, it is possible that some elements can't be included in action, because they have been damaged during the stopover on the parking ground, while awaiting to join the duty.

Let the variable $e_i^{(2)}(t)$, $i = 1, 2, \dots, n + k$, $t \in \langle t_1, t_2 \rangle$, mean the condition of the E_i element at the t moment, while the phase f_2 takes place:

$$e_i^{(2)}(t) = \begin{cases} 1, & \text{if } E_i \text{ element is available at the } t \text{ moment of the phase } f_2, \\ 0, & \text{if } E_i \text{ element is unavailable at the } t \text{ moment of the phase } f_2. \end{cases}$$

Then the (8) equation circumscribes the probability of the fact that the E_i element has been correctly stimulated to action at the t moment during the phase f_2 , since t_1 moment to t_2 moment. At the same moment the E_i element is available to start executing the task:

$$p_i^{(2)}(t) = P(e_i^{(2)}(t) = 1), \quad i = 1, 2, \dots, n + k, \quad t \in \langle t_1, t_2 \rangle. \quad (8)$$

Let's suppose, that values of those probabilities at the t_2 moment (i.e. at the end of the phase f_2) are constant, and circumscribed with the (9) equation:

$$p_i^{(2)}(t_2) = p_i^{(2)}, \quad 0 \leq p_i^{(2)} \leq 1, \quad i = 1, 2, \dots, n + k. \quad (9)$$

Because, according to the assumption, system's elements can be damaged independently, the initial availability, calculated for the executive subsystem during the phase f_2 can be described with the following (10) equation:

$$G^{(2)}(t) = \sum_{j=n}^{n+k} \binom{n+k}{j} [p_i^{(2)}(t)]^j [q_i^{(2)}(t)]^{n+k-j}, \quad t \in < t_1, t_2), \quad (10)$$

where:

$q_i^{(2)}(t)$ - probability of fact, that the E_i element can be unavailable at the t moment, during the phase f_2 ; the probability is described with the (11) equation:

$$q_i^{(2)}(t) = 1 - p_i^{(2)}(t) = P(e_i^{(2)}(t) = 0), \quad i = 1, 2, \dots, n+k, \quad t \in < t_1, t_2). \quad (11)$$

The initial availability of executive subsystem at the t_2 moment (i.e. at the end of the f_2 phase) can be circumscribed with the following (12) equation:

$$G^{(2)} = G^{(2)}(t_2) = \sum_{j=n}^{n+k} \binom{n+k}{j} [p_i^{(2)}]_j [q_i^{(2)}]^{n+k-j}, \quad (12)$$

where:

$q_i^{(2)}$ - probability of fact, that the E_i element is unavailability at the t_2 moment, at the end of the phase f_2 ; the probability is described with the (13) equation:

$$q_i^{(2)} = 1 - p_i^{(2)} = P(e_i^{(2)}(t_2) = 0). \quad (13)$$

3. Test results

Presented below are selected results of the evaluation of availability of the executive subsystem in the transport system of city buses. The presented results exemplify changes in the values of the availability of the executive subsystem $G^{(f)}$ for the carrying out of the assigned transport task in the availability function $p_i^{(f)}$ of a single technological object (means of transport) while the number of all technological objects used within the system amounts to $N = 180$. The size of the transport task is defined by the required number $n = 160$ of technological objects (means of transport) necessary for appropriate carrying out of the task. The availability of the executive subsystem was determined for two cases:

- When reserve time is $t_g = 0$ – (functional availability),
- When reserve time is $t_g = 0,5$ h – (initial availability).

Data necessary to determine the characteristics defining the availability of the executive subsystem were obtained on the basis of the carried out operational tests and source documentation used in the actual tested transport system of city buses. The obtained results were presented in figure 1.

Fig. 2 Availability of the executive subsystem in availability function of a single technological object

4. Summary

The method presented in this article makes it possible to evaluate the availability of the executive subsystem in means of transport operation system in which technological objects are linked by threshold structure. This type of structure is known for using the so-called reserve objects, replacing primary objects in case of damage.

The use of reserve time $t_g > 0$ in actual transport system of city buses makes it possible to increase the initial availability of the executive subsystem for a given number of technological objects operational in the system and a given availability of a single technological object. In the tested operation system the time reserve t_g is used in order to carry out the processes of conditioning on a small scale and is connected with repairs carried out at the depot site as well as en route by specialized units of emergency service.

At further stages of the conducted research, in order to evaluate the influence of the parameters of the carried out operation process of means of transport (city buses) a mathematical model of the process will be prepared.

5. References

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