REQUIRED AVAILABILITY OF THE SERVICEABILITY ASSURANCE SYSTEM

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Abstract
In complex operation systems, the processes of rendering technical objects roadworthy are carried out at specifically designed technical infrastructure posts. The possibility of carrying out the assigned service and repair tasks depends on the availability and the number of such posts. The article presents the method of defining the operational availability of technical infrastructure posts required for appropriate functioning of assigned service and repair task. Then typical calculation results are presented in charts prepared on the basis of data obtained from tests at existing transport means operation system.

Key words: *technical infrastructure posts; operational availability; posts productivity.*

INTRODUCTION
In systems of means of transport operation in order to achieve appropriate completion of assigned transportation tasks it is necessary to maintain a required number of means of transport in the state of availability for carrying out of transportation task (roadworthy and stocked). In general, the processes of rendering vehicles roadworthy are connected to supplying them with fuel and operational materials, carrying out services and repairs, condition diagnostics. In the analyzed system of transport means operation, the processes are carried out in serviceability assurance subsystem SAS. The subsystem of the type may function properly only when appropriate availability of service and repair posts is granted. The problem of control of the processes carried out at serviceability assurance subsystems from the point of view of evaluation criteria such as reliability and availability is discussed in numerous scientific publications (*Knopik & Migawa, 2017; Landowski, Perczyński, Kolber & Muślewski, 2016; Chen & Trivedi, 2002*). It reflects issues connected to selection of optimal strategy (policy) of servicing and repair as well as evaluation of the operation of serviceability assurance subsystems (service and repair posts). Papers (*Kosten, 1973; Piasecki, 1996*) discuss issues connected with modeling and organization of technical objects service systems. The authors of paper (*Woropay, Żurek & Migawa, 2003*) suggested that the methods of shaping the availability of technical backup area posts, whereas papers (*Szubartowski, 2012; Woropay, Migawa & Bojar, 2010*) discuss the methods of the evaluation of the effectiveness and productivity of processes carried out at service and repair posts. Among the many methods supporting the evaluation and control process, the semi-Markov decisive processes have been implemented (*Chen & Trivedi, 2005*), non-deterministic methods of defining optimal solutions (genetic algorithms, evolutionary algorithms, Monte Carlo method) (*Migawa, Knopik & Wawrzyniak, 2016; Marseguerra & Zio, 2000*), as well as methods and models of mass service theory (*Vaurio, 1997*). The objective of this paper is to work out a method of determining serviceability assurance subsystem post availability at such a level that would ensure appropriate carrying out of service and repair tasks assigned for to be carried out at such posts.

MATERIALS AND METHODS
Presented below are formulas defining availability of individual post of a serviceability assurance subsystem. If

$$V_{ij}(t) = P(X_{ij}<t),\ i=1,2,...,p,\ j=1,2,\dots,q_i \qquad (1)$$

is the distribution function of serviceability time X_{ij}, $i=1,2,...,p$, $j=1,2,\dots,q_i$ of a single post s_{ij}, $i=1,2,...,p$, $j=1,2,\dots,q_i$ at serviceability assurance subsystem, while

$$W_{ij}(t) = P(Y_{ij}<t),\ i=1,2,...,p,\ j=1,2,\dots,q_i \qquad (2)$$

is the distribution function of renovation time Y_{ij}, $i=1,2,...,p$, $j=1,2,\dots,q_i$ of a single post s_{ij}, $i=1,2,...,p$, $j=1,2,\dots,q_i$ at serviceability assurance subsystem, then the availability $A_{ij}(t)$ of a single post s_{ij} determined at point t as probability that at point t the post s_{ij} is serviced and provided for, is defined by the formula

$$A_{ij}(t) = R_{ij}(t) + \int_0^t R_{ij}(t-x)\ dH_{ij}(x) \tag{3}$$

as well as

availability $A_{O_{ij}}(t,\tau)$ of a single post s_{ij} of serviceability subsystem, determined over time interval $<t,t+\tau)$ as probability that over time interval $<t,t+\tau)$ the post s_{ij} is available and provided for, is defined by the formula

$$A_{O_{ij}}(t,\tau) = R_{ij}(t+\tau) + \int_0^t R_{ij}(t+\tau-x)\ dH_{ij}(x) \tag{4}$$

where:

$R_{ij}(t)$ – is the function of reliability of a single post s_{ij} of the serviceability assurance subsystem,
$H_{ij}(t)$ – is the function of renovation of a single post s_{ij} of the serviceability assurance subsystem.
In the case, in which $t\to\infty$, the functions defined by formulas (3) and (4) have limit values called limit availability coefficients:

$$A_{ij} = \lim_{t\to\infty} A_{ij}(t) = \frac{E(X_{ij})}{E(X_{ij}) + E(Y_{ij})} \tag{5}$$

$$A_{O_{ij}}(\tau) = \lim_{t\to\infty} A_{O_{ij}}(t,\tau) = \frac{1}{E(X_{ij}) + E(Y_{ij})} \cdot \int_\tau^\infty R_{ij}(x)\ dx \tag{6}$$

where:

$E(X_{ij})$ – is the expected value of the time of serviceability of a single post s_{ij} of the serviceability assurance subsystem,
$E(Y_{ij})$ – is the expected value of the time of renovation of a single post s_{ij} of the serviceability assurance subsystem.

Availability of serviceability assurance subsystem depends on the structure which couples individual posts as well as groups of such posts. Presented below are formulas defining availability of individual post group s_i, $i=1,2,...,p$ of a serviceability assurance subsystem in the case of the posts of the analyzed system are coupled via a threshold structure.
Availability of group s_i, $i=1,2,...,p$ consisting of $j=1,2,...,q_i$ homogenous posts of serviceability assurance subsystem coupled by threshold structure „k_i with q_i”:

– determined at moment t defined by formula

$$A_i(t) = \sum_{c=k_i}^{q_i} \binom{q_i}{c} \cdot \left[\overline{A_{ij}(t)}\right]^c \cdot \left[1 - \overline{A_{ij}(t)}\right]^{q_i-c} \tag{7}$$

– determined over time interval $<t,t+\tau)$ defined by formula

$$A_{O_i}(t,\tau) = \sum_{c=k_i}^{q_i} \binom{q_i}{c} \cdot \left[\overline{A_{O_{ij}}(t,\tau)}\right]^c \cdot \left[1 - \overline{A_{O_{ij}}(t,\tau)}\right]^{q_i-c} \tag{8}$$

When $t\to\infty$, functions described by formulas (7) as well as (8) reach the following border values:

$$A_i = \sum_{c=k_i}^{q_i} \binom{q_i}{c} \cdot \left[\frac{E\left(\overline{X_{ij}}\right)}{E\left(\overline{X_{ij}}\right) + E\left(\overline{Y_{ij}}\right)}\right]^c \cdot \left[\frac{E\left(\overline{Y_{ij}}\right)}{E\left(\overline{X_{ij}}\right) + E\left(\overline{Y_{ij}}\right)}\right]^{q_i-c} \tag{9}$$

$$A_{O_i}(\tau) = \sum_{c=k_i}^{q_i} \binom{q_i}{c} \cdot \left[\frac{1}{\left[E\left(\overline{X_{ij}}\right) + E\left(\overline{Y_{ij}}\right)\right]} \cdot \int_\tau^\infty \overline{R_{ij}(x)}\ dx\right]^c \cdot \left[1 - \frac{1}{\left[E\left(\overline{X_{ij}}\right) + E\left(\overline{Y_{ij}}\right)\right]} \cdot \int_\tau^\infty \overline{R_{ij}(x)}\ dx\right]^{q_i-c} \tag{10}$$

Complexity of the existing structure coupling the individual post groups depends primarily on the equipment of posts, worker qualification as well as the type of tasks to be carried out at individual post groups. The general instance is connected to the situation involving individual serviceability assurance subsystem groups, due to specialist equipment as well as worker qualifications may not replace each other and are supposed to carry out tasks of various type and range. Thus, the post groups of serviceability assurance subsystem s_i, i=1,2,...,p are coupled by threshold structure. Then, availability of serviceability assurance subsystem is determined as product of the availability of its individual groups:

– at moment t

$$A(t)=\prod_{i=1}^{p} A_i\,(t) \tag{11}$$

– over time interval τ

$$A_O(t,\tau)=\prod_{i=1}^{p} A_{O_i}(t,\tau) \tag{12}$$

Availability of the SAS serviceability assurance subsystem is understood as capability to carry out the assigned service and repair task. Each task assigned to SAS is determined by the length of the time interval τ devoted to the completion of the task, the size of the task (how many technical objects should be rendered roadworthy and/or stocked) as well as the scope of the task (what should be done). The measure of operational availability of SAS posts in carrying out of the assigned task is the product of the probabilities of two events taking place:

– the event of SAS posts being available at any point (roadworthy and stocked) to undertake the assigned task and will remain in this condition for the time interval τ of the task duration; this probability is expressed through the operational availability value of analyzed subsystem $A_O(\tau)$,
– the event of the task assigned at the posts of the subsystem in question will be carried out, i.e. in the time interval τ the number of objects rendered technically roadworthy will be higher than k; this probability is expressed through the value of the productivity index $Z^{(k)}(\tau)$ of SAS posts – the way of defining the productivity index is presented in paper (*Woropay, Migawa & Bojar, 2010*).

Taking the above discussion into consideration, the operational availability of the serviceability assurance subsystem in carrying out the assigned service and repair task in the time interval τ, is defined as follows

$$A_{OZ}^{(k)}(\tau)=A_O(\tau)\cdot Z^{(k)}(\tau) \tag{13}$$

where:

$A_O(\tau)$ – operational availability of the posts of serviceability assurance subsystem defined as the probability of this subsystem being available at any point t and remaining in this condition over a required time interval τ,

$Z^{(k)}(\tau)$ – probability of the number of technical objects rendered roadworthy at serviceability assurance subsystem posts in the time interval τ being bigger than k.

Required operational availability of the serviceability assurance subsystem for carrying out of service and repair task (rendering k number of technical objects roadworthy in the time interval of τ length), determined as product of required availability $A_{O_{req}}^{(k)}(\tau)$ as well as the required value of productivity index $Z_{req}^{(k)}(\tau)$ for analyzed posts in the time interval of τ length is realized in the formula

$$A_{OZ_{req}}^{(k)}(\tau)=A_{O_{req}}^{(k)}(\tau)\cdot Z_{req}^{(k)}(\tau) \tag{14}$$

Service and repair task assigned to the serviceability assurance subsystem is determined by the required number k of technical objects which should be rendered roadworthy and/or stocked in the given time interval of τ length, at posts for this subsystem. Whereas the required availability $A_{O_{req}}^{(k)}(\tau)$ of serviceability assurance subsystem determined for number k of technical objects rendered roadworthy in the time interval of τ length is described as follows

$$A_{O_{req}}^{(k)}(\tau)=\frac{T_{req}^{(k)}(\tau)}{T_{req}^{(k)}(\tau)+U_{req}^{(k)}(\tau)} \tag{15}$$

where:

$T_{req}^{(k)}(\tau)$ – required availability time for SAS posts for given k and τ,

$U_{req}^{(k)}(\tau)$ – required unavailability time for SAS posts for given k and τ.

Assuming that for any time interval of τ length the sum of required availability and unavailability times for serviceability assurance subsystem equals the time interval of τ length, i.e. $T_{req}^{(k)}(\tau)+U_{req}^{(k)}(\tau)=\tau$, then formula (15) may be written as follows

$$A_{O_{req}}^{(k)}(\tau)=\frac{T_{req}^{(k)}(\tau)}{\tau} \tag{16}$$

Required availability time $T_{req}^{(k)}(\tau)$ for SAS posts depends on the anticipated total time of rendering k number of technical objects (transport means) roadworthy in the time interval of τ length as well as the q number of uniform posts of the analyzed subsystem and is described by the condition

$$T_{req}^{(k)}(\tau)=\frac{k\cdot \overline{U^{OT}}(\tau)}{q}\le \tau \tag{17}$$

where

$\overline{U^{OT}}(\tau)$ – mean time of technological object remaining at serviceability assurance subsystem (mean time of rendering technical objects roadworthy).

When $T_{req}^{(k)}(\tau)>\tau$, then in the time interval for the posts of the analyzed subsystem (SAS) the rendering of the required k number of technical objects roadworthy is not possible.

Evaluation of operational availability of serviceability assurance subsystem SAS for carrying out the assigned task consists of determining the value of actual availability of the subsystem (for the required time interval of τ length as well as required k number of technical objects which should be rendered roadworthy and/or stocked) and then comparing to the value of required availability the SAS should has in order for the assigned task to be carried out according to the relation

$$A_{OZ}^{(k)}(\tau)=A_O(\tau)\cdot Z^{(k)}(\tau)\ge A_{OZ_{req}}^{(k)}(\tau),\quad for\quad k=N_{U_{req}}(\tau) \tag{18}$$

where

$$Z^{(k)}(\tau)=P\left(k\ge N_{U_{req}}(\tau)\right) \tag{19}$$

means the probability of the number of technical objects rendered roadworthy at posts of SAS in the time interval of τ length is not lower than the required number $N_{U_{req}}(\tau)$ of technical objects which should be rendered roadworthy in this time interval. If the value of operational availability of the SAS posts for carrying out the assigned task is lower than required, e.g. $A_{OZ}^{(k)}(\tau)<A_{OZ_{req}}^{(k)}(\tau)$, the assigned task at SAS posts may not be carried out properly (in the time interval of τ length it is not possible to render the required number $N_{U_{req}}(\tau)$ of technical objects roadworthy).

In the case of the serviceability assurance subsystem comprise $i=1,2,\ldots,p$ of groups containing $j=1,2,\ldots,q_i$ of posts linked to a given structure, it is possible to determine the required availability of posts $A_{ij_{req}}$ at individual groups. Assuming that the i-th group comprises uniform posts, the required availability of posts $A_{ij_{req}}$ is assigned (when posts are liked by threshold structure)

$$A_{ij}=A_{ij_{req}}\Leftrightarrow A_{O_i}(\tau)=\sum_{c=k_i}^{q_i}\binom{q_i}{c}\cdot\left[A_{ij}\right]^{c}\cdot\left[1-A_{ij}\right]^{q_i-c}\ge A_{O\,i_{req}}(\tau) \tag{20}$$

RESULTS AND DISCUSSION

The sample results presented below were prepared for serviceability assurance subsystem posts in an existing system of municipal bus transport in which 182 municipal buses are in use.

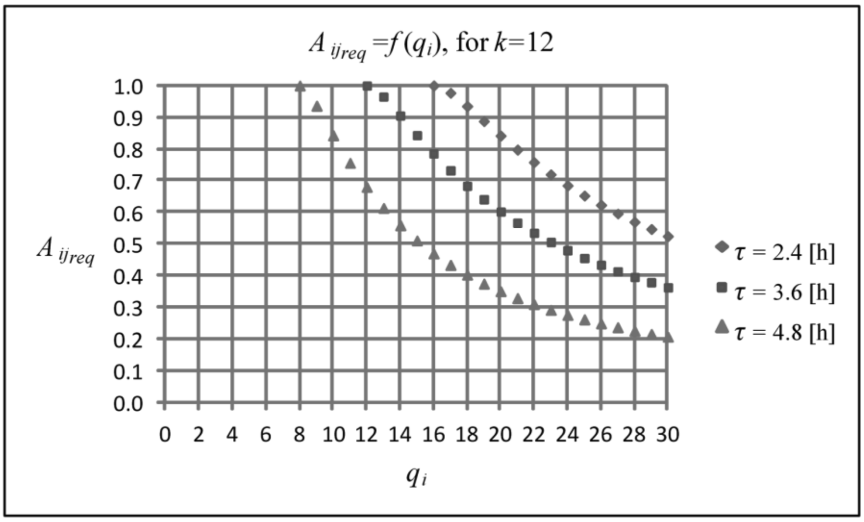

Fig. 1 Required availability of individual post $A_{ij_{req}}$ of functions of the number posts of the *i*-th group q_i, for given values of roadworthiness time period τ and the number of objects rendered roadworthy k

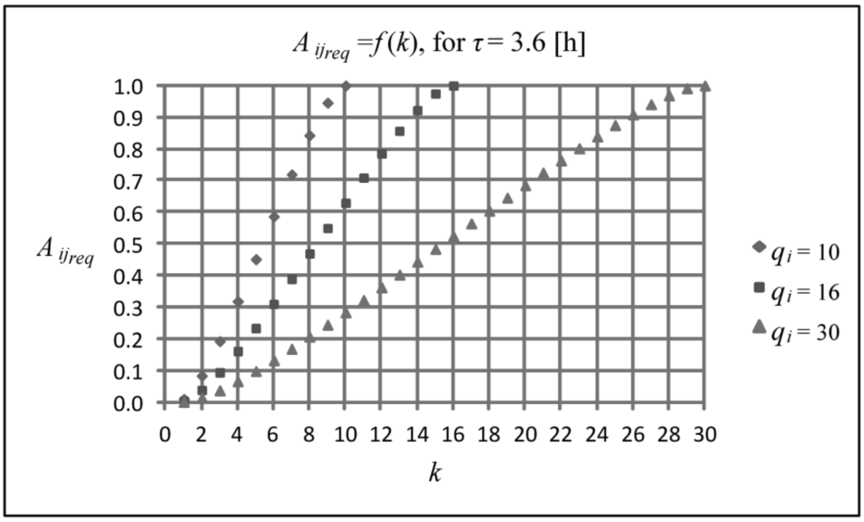

Fig. 2 Required availability of individual post $A_{ij_{req}}$ of functions of the number of objects rendered roadworthy k, for given number of q_i posts of the *i*-th group as well as roadworthiness time period τ

Fig. 1 and Fig. 2 present values of required availability $A_{ij_{req}}$ of posts at *i*-th group of serviceability assurance subsystem, determined in relation with number of posts of the *i*-th group q_i as well as the value of parameters determining the assigned service and repair task (number of objects as well as the time of rendering them roadworthy). For example, for the number of objects rendered roadworthy $k = 12$, the time of rendering $\tau = 2.4$ [h] and the number of posts $q_i = 18$, the required availability of a single post $A_{ij_{req}} = 0.935$(Fig. 1) as well as rendering period $\tau = 3.6$ [h], number of posts $q_i = 10$ and the number of objects rendered roadworthy $k = 8$, the required availability of a single post $A_{ij_{req}} = 0.853$(Fig. 2).

CONCLUSIONS

On the basis of the method presented in the paper, it is possible to select (determine) the minimum required availability of posts at *i*-th group of serviceability assurance subsystem so that the assigned service and repair tasks are carried out properly. It is completed on the basis of the selected criteria for evaluation when actual availability of *i*-th group of serviceability assurance subsystem equals at least the required availability.

The presented method may be utilized in order to evaluate operational availability of an individual post as well as a group of posts of a given type coupled with an appropriate structure or a serviceability assurance subsystem consisting of various types of posts. Providing the required availability of serviceability assurance subsystem is possible due to:

– adjusting the number and structure of service and repair posts,
– adjusting the equipment at posts in order to, when necessary, facilitate carrying out of particular tasks at posts in various groups,
– implementation of posts (devices and tools) of higher reliability, durability, and productivity.

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