# EVALUATION OF OPERATIONAL AVAILABILITY OF MUNICIPAL TRANSPORT SYSTEM

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*Abstract*

*The primary subject of research is the procedure leading to safe, efficient, reliable and timely completion of transport tasks. The tasks, assigned to the transport system, are carried out by an operative subsystem, comprised of elementary subsystems of the man – technical object (operator-vehicle) type. The timely and safe completion of the tasks is influenced by the level of availability and reliability of elementary subsystems. Those in control of the process of the use of means of transport (vehicles) should undertake control decisions in such a way that would correctly evaluate the efficiency of process completion. In the area of public transport, technical availability of buses constitutes an important criterion of the evaluation of transport system. As a result, the transport company should provide continuous surveillance of the process of vehicle use in order to achieve running availability of the whole system. The requirements expected from devices and machines used head towards servicing via preventive method taking into account the technical condition of the system. Such an approach is a transformation towards technical system servicing process management. Correct completion of transport tasks is possible when the required traffic safety is met, taking into consideration the technical condition of the means of transport. The municipal transport systems should ensure the quality of the services provided to meet the expectations of the users. In the set of characteristics of the researched transport system, the following ones stand out: regularity, availability, reliability, course frequency, travel comfort, timeliness, speed, service complexity, competitive cost of transport service, and safety.*

*Keywords: transport, road transport, simulation, combustion engines, air pollution, environmental protection*

## 1. Object and subject of research

The object of research is a complex, existing system of means of transport operation, which constitutes the deliberate product of man with a specific, set of implementations, and, especially, one if its subsystems – Executive Subsystem – directly carrying out the transport task. Universally available regular citizen transport is performed on the basis of the contract under which services are provided in the area of public transport as well as confirmation of transport notification.

Transport is carried out via means of transport adapted for citizen transport, which comply with the requirements due to the type of transport. List of vehicles is presented in Tab. 1.

*Tab. 1. List of vehicles in the analysed transport system as per December 31ˢᵗ, 2016*

| No. | Vehicle type | Vehicle no. | Year manufactured | Mileage [km] |
|-----|--------------|-------------|-------------------|--------------|
| 1. | Setra S 215 UL | 18105 | 1995 | 570,359 |
| 2. | Setra S 215 UL | 32173 | 1996 | 146,126 |
| 3. | Setra S 315 GT-HD | 58184 | 2001 | 745,357 |
| 4. | Setra S 415 GT-HD | 39119 | 2007 | 811,809 |
| 5. | Setra S 412 UL | 09322 | 2008 | 690,388 |
| 6. | Setra S 415 UL | 42380 | 2008 | 627,401 |
| 7. | Setra S 415UL | 39121 | 2009 | 548,540 |
| 8. | Setra S 415 UL | 66355 | 2009 | 495,998 |
| 9. | Setra S 415GT | 38002 | 2011 | 419,484 |
| 10. | Setra S 415 GT-HD | 51988 | 2013 | 315,499 |
| 11. | Setra S 415 GT-HD | 60233 | 2014 | 193,198 |
| 12. | Setra S 516 MD | 70399 | 2015 | 72,711 |
| 13. | Setra S 516 MD | 78200 | 2016 | 3,838 |

Buses used at the researched company carry out tasks at regular routes of up 50 kilometres. Transport tasks are carried out on the basis of a work schedule for individual lines according to an established timetable. The number of transport tasks depends on the time of the day and on the season. The buses performing the tasks on regular routes of up to 50 km are characterized by variability of the intensity of rides depending on the so-called *rush hours* taking place between the hours of 5 a.m. and 8 a.m. as well as between 1 p.m. and 4 p.m. The intensity of rides connected with tourist trips increases during summer holidays and winter break.

The company has at its disposal a Class 2 depot or a depot with servicing station of limited operating range (Fig. 1). The depot comprises auxiliary facilities and garages, parking sites and areas, devices and tools connected directly to service and repair. Basic tasks of the depot include storage and reinforcement of the facilities with operating resources (fuels, lubricants, other media, etc.). These facilities comply with requirements and regulations in the field of service technology, work safety and environmental protection. It provides its workers with safe and least inconvenient work while protecting the very objects from threats such as fires, harmful environmental effects as well as the effects of the facilities on the environment. Technological task of the technical support infrastructure is preparation of the used vehicles for work. The cycle consists of the following activities [3]:

– motor vehicle service, i.e. checking their condition as well as maintaining cleanliness, regulation, lubrication,
– running repair of vehicles, i.e. all damage repair, removal of worn-out elements and replacement with new ones,
– supplying vehicles with operating materials such as fuel, oils, lubricants, water, fluids,
– protection of vehicles from atmospheric effects, i.e. proper storage on parking spaces or in garages,
– keeping operating documentation required to carry out transport and road traffic.

The task of the technical emergency unit is the treatment of the means of transport en route, in the shortest possible time interval after which further carrying out of the transport task is possible. When the repair en route by technical emergency units is impossible to carry out, the damaged means of transport is directed to traffic maintenance subsystem posts; either drives there by itself or is moved by a towing vehicle.
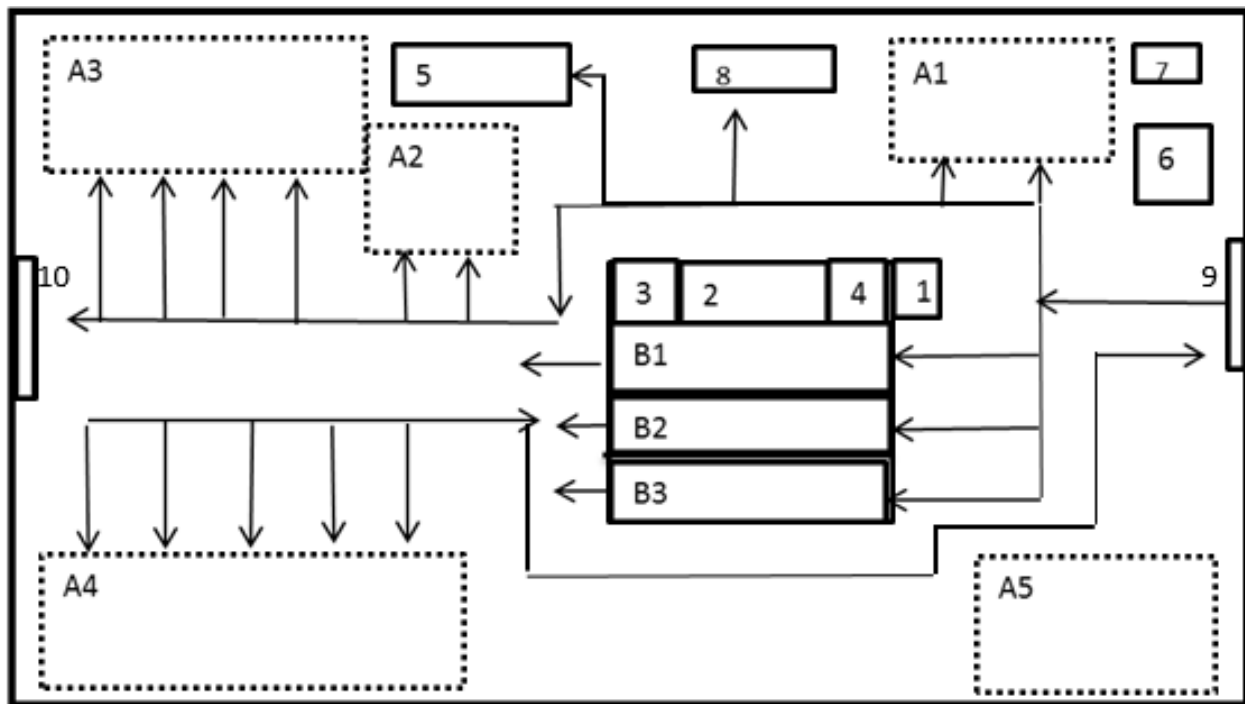
*Fig. 1. Diagram of the tested company. A1, A2, A3, A4, A5 – vehicle parking posts, B1, B2, B3 – diagnostic-repair posts, 1 – double piston compressor unit, 2 – ground floor: staff rooms, 1st floor: administrative offices, 3 – ground floor: spare parts warehouse, 1st floor: dispatcher, 4 – ground floor: boiler room, 1st floor: office, 5 – car-wash, 6 – reception desk, 7 – bicycle storage room, 8 – mobile gas station, 9 – main entrance, 10 – emergency entrance*

At the traffic maintenance subsystem the activities carried out are the following: supplying vehicles with fuel, diagnostic check-up of vehicle condition, preventive measures, servicing activities on day of use, periodic technical service as well as damaged vehicle renewal. The object of tests are relations taking place between technical object states utilized at executive subsystem and the level of their operational availability as well as the influence of the level on the level of availability of the transport system as a whole [5].

As a rule, literature delineates the following two states of machine reliability:
– roadworthiness state,
– road-unworthiness state.

On the other hand, the operational tests prove that among these states one may delineate an infinite set of limited roadworthiness states.

*As limited roadworthiness, state of the system one should understand such state at which the acceptable value was exceeded by any feature of the system occurring in the description of the state of the element without causing improbability of carrying out the task by the system* [6].

During the analysis of the states as well as limits of these changes one should take into consideration both the *relevance of the subsystems as well as the extent of the values of the features of these subsystems exceeded the acceptable intervals of tolerance.*

Irrelevant system damage does not result in a significant difference of the change of system into worthiness state, while damage of critical system causes a change in the worthiness of the system into unworthiness state. As a result, operational problem lies in providing appropriate level of availability of the system in which the task is carried out. The problem is relevant, as the vehicles used in the tested system are, to a large extent, worn-out. In order to determine the relations appearing between the states of tested object, a model of the operation process was created. The model was created on the basis of the analysis of states as well as operational events connected to availability of technical objects (buses) used in the analysed existing transport system [4].

## 2. Objective of article

The objective of this article is the evaluation of operational availability of the means of road transport necessary for proper rational decision making for system control.

## 3. Model of operational availability of the tested system

The model is built based on the analysis of operational events connected to technical objects (buses) used in the analysed existing transport system. Each change of the state of an object is an **event**. The physical state of the object may be defined with vector function $x(t) = [x_1(t), ..., x_n(t)]$ at each moment $t \in [t_0, t_g]$, where $x_1(t), ..., x_n(t)$ are selected variables.

In order to calculate operational availability of the system it is necessary to determine task availability as well as potential availability. Potential availability, on the other hand, relies on the level of functional availability. On the basis of literature, he following relations was implemented.

Initial availability, therefore, reflects the probability of the technical object attempting to complete the established task at proper time $T \leq t$ and at proper spatial position. The relation looks as follows:

$$G_p(t) = P(T \leq t). \tag{1}$$

The value of the ratio of system availability was estimated using the relation:

$$K_g = \frac{E(T)}{E(T) + E(\theta)}. \tag{2}$$

The value of functional availability of transport system $K_g(t)$ was calculated on the basis of the number of technical objects roadworthy at moment $t$ and the number of objects owned according to registration status using the following relation:

$$K_g(t) = \frac{N_{0-n(t)}}{N_0} = \frac{N(t)}{N_0}, \tag{3}$$

where:
$N_0$  – overall number of technical objects in the transport system,
$N(t)$ – number of technical objects in transport system roadworthy before moment $t$,
$n(t)$ – number of technical objects at transport system road-unworthy before moment $t$.

The article presents possibility of determining task availability $G_z(\tau)$ of the technical object using the reliability function $R(t)$, understood as probability of carrying out the task in a determined time interval $\tau$ as well as established levels of force factors effect:

$$G_z(\tau) \approx R(t). \tag{4}$$

Potential availability $G_{pot}(t, t_g)$, on the other hand, is the product of functional availability $K_g(t)$ as well as initial availability $G_p(t_g)$, represented in the relation:

$$G_{pot}(t, t_g) = K_g(t) \cdot G_p(t_g). \tag{5}$$

To add, operational availability of the technical object $G_o(t, t_0, \tau)$ defined as the product of potential availability $G_{pot}(t, t_g)$ as well as task availability $G_z(\tau)$:

$$G_o(t, t_0, \tau) = G_{pot}(t, t_g) \cdot G_z(\tau). \tag{6}$$

## 4. Operational tests

Operational tests were performed via passive experiment method at existing bus transport

system. The tests covered 47 buses used in the analysed system. The tests cover a time interval from January 1$^{st}$, 2016 to December 31$^{st}$, 2016.

The plan of tests consisted of the following stages:
- obtaining data connected with kilometre mileages of buses carrying out transport tasks in the analysed time interval,
- obtaining data establishing the map of subsystem damage in the tested technical objects, i.e. the information on the number and location of damage, obtaining data connected to the causes of damage,
- obtaining data connected to the time of diagnosis, waiting for the repair as well as the productivity of diagnostic post.

Data for the analysis were generated on the basis of company's documents made available by the company tested, including:
- system report on the fuel consumption and mileage in km,
- reading of digital tachograph and analogue record sheet, diagnose and repair records, driver-working schedule.
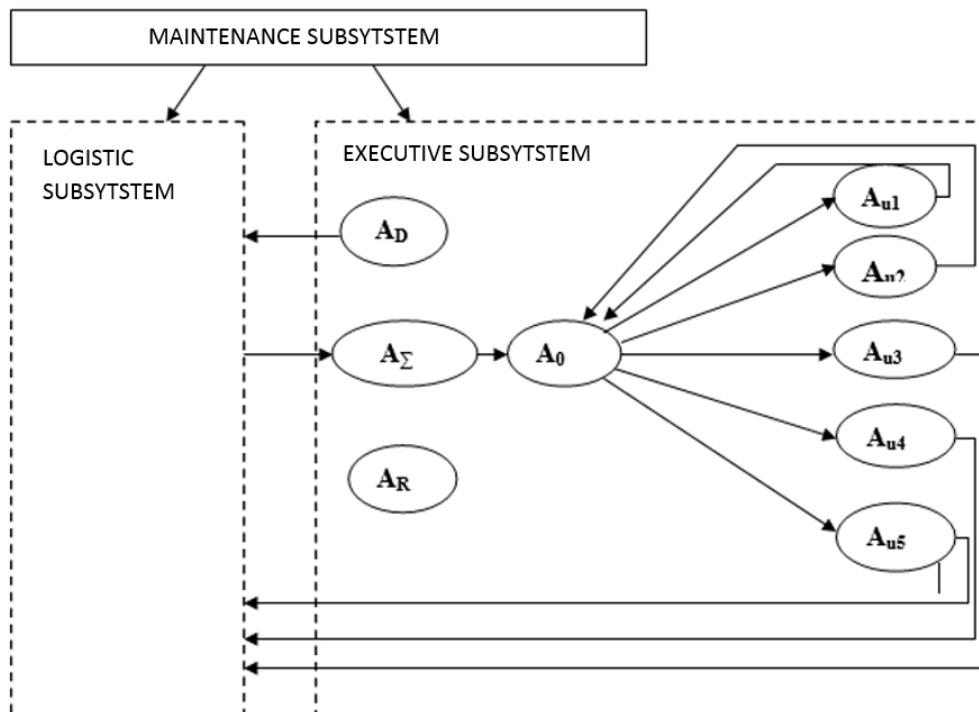


*Fig. 2. Graphic projection of the process of bus use in the analysed system*

$A_0$ – number of roadworthy buses beginning the carrying out of transport task,
$A_D$ – number of damaged buses at the parking area,
$A_R$ – number of buses included in the reserve,
$A_{u1}$ – number of damaged buses en route without loss of rides carried out, repaired by PT (technical emergency unit),
$A_{u2}$ – number of buses damaged en route with loss of rides carried out repaired by PT (technical emergency service),
$A_{u3}$ – number of buses damaged en route which emergency service failed to repair, after which they departed for a selected service station SO by themselves,
$A_{u4}$ – number of buses damaged en route where PT technological emergency service did not intervene, as a result of which they departed to the service station SO by themselves,
$A_{u5}$ – number of buses damaged en route which emergency service failed to repair, and after which they were towed by the emergency service PT to the service station SO.

*Tab. 2. List of typical operational values per 24 hrs in a given month*

| No. | Date | $A_\Sigma$ | $A_D$ | $A_0$ | $A_R$ | $A_{u1}$ | $A_{u2}$ | $A_{u3}$ | $A_{u4}$ | $A_{u5}$ | $G_p$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 2016-07-01 | 44 | 2 | 41 | 1 | 2 | 1 | 0 | 0 | 0 | 0.893 |
| 2. | 2016-07-02 | 42 | 5 | 37 | 0 | 3 | 1 | 1 | 0 | 1 | 0.787 |
| 3. | 2016-07-03 | 42 | 3 | 37 | 2 | 3 | 2 | 1 | 0 | 0 | 0.829 |
| 4. | 2016-07-04 | 43 | 4 | 39 | 0 | 4 | 0 | 0 | 0 | 0 | 0.829 |
| 5. | 2016-07-05 | 42 | 3 | 37 | 2 | 3 | 2 | 1 | 0 | 0 | 0.829 |
| . | . | . | . | . | . | . | . | . | . | . | . |
| 27. | 2016-07-27 | 42 | 4 | 38 | 0 | 2 | 3 | 2 | 0 | 1 | 0.808 |
| 28. | 2016-07-28 | 44 | 3 | 41 | 0 | 2 | 2 | 3 | 1 | 0 | 0.872 |
| 29. | 2016-07-29 | 43 | 3 | 39 | 1 | 2 | 0 | 0 | 1 | 0 | 0.851 |
| 30. | 2016-07-30 | 43 | 3 | 39 | 1 | 1 | 2 | 0 | 0 | 0 | 0.851 |
| 31. | 2016-07-31 | 44 | 1 | 41 | 2 | 1 | 3 | 0 | 0 | 0 | 0.914 |
| | Mean: | 43 | 4 | 38 | 1 | 2 | 1 | 1 | 0 | 0 | 0.829 |

On the basis of the test results in the analysed system it was assumed that the operator's availability equals one. The results of the tests performed have been presented in Fig. 3 as well as Fig 4.
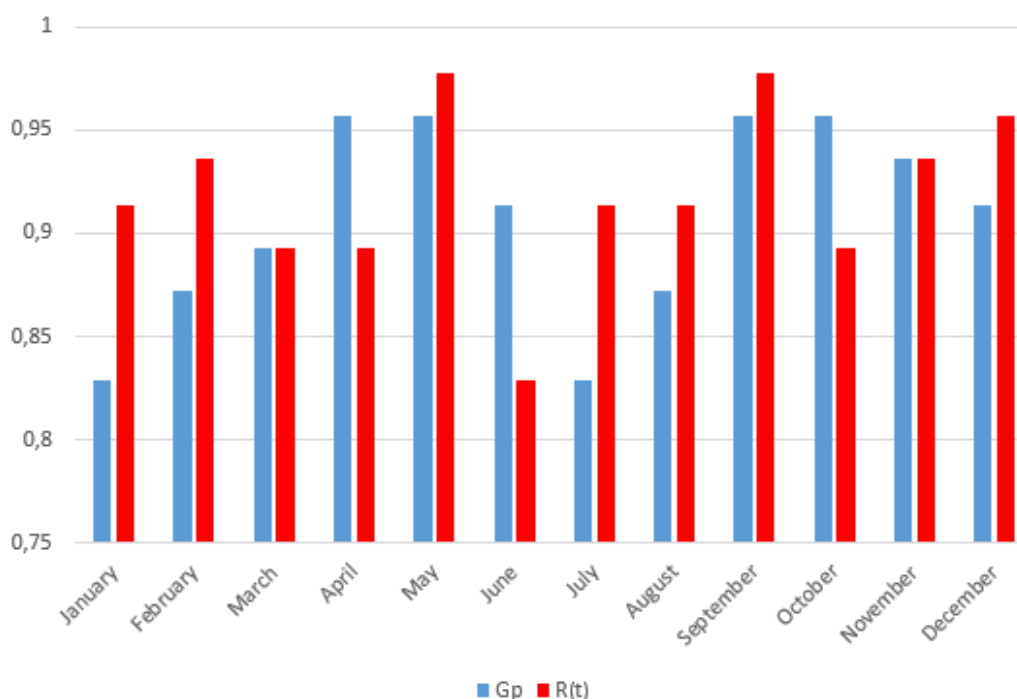


*Fig. 3. List of values of operating indicators in the analysed time interval*

## 5. Summary

The calculations performed for 47 buses used in the tested transport systems in the selected month of 2016 presented in Tab. 2. They show that $A_\Sigma$ – annual value of the number of buses at parking area before carrying out of the transport starts amounts to 43 vehicles, including:

$A_0$ – July monthly mean number of roadworthy buses beginning the carrying out of the transport task amounts to 38 vehicles,
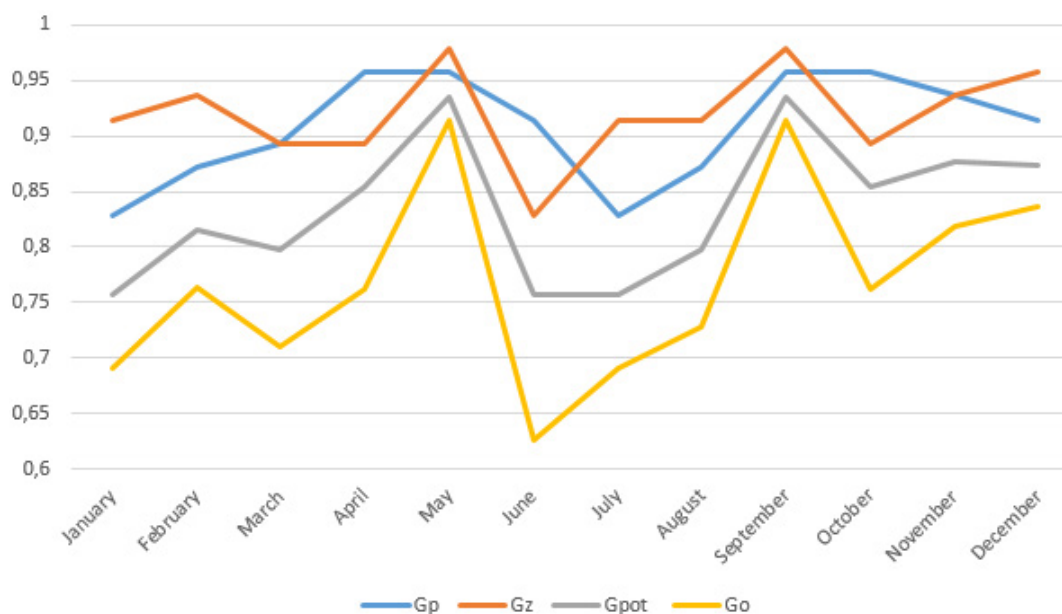
*Fig. 4. Values of availability indicators over 12 consecutive months*

$A_D$ – July monthly mean number of damaged buses at parking area amounts to 4 vehicles,
$A_R$ – July monthly mean number of buses included in reserve amounts to one vehicle.

Initial availability $G_p$ for the selected month of July 2016 amounts to 0.829. Similarly, the lowest availability indicator was observed in January. Operational tests prove that initial availability $G_p$ of the vehicles, i.e. the ability immediately to commence the carrying out of the task decreases in the months of January and July due to a high amount of damage at the parking area resulting in a shortening of time reserve. Mean value of initial availability for the whole year amounts to 0.907 and it is an acceptable level. The value of reliability function $R(t)$ for the whole system amounts to 0.920. Potential availability $G_{pot}$ for the whole system amounts to 0.834. Operational availability value for the system as a whole amounts to $G_o \approx 0.76$. According to the adopted criteria for the value of operational availability of the system, it is a borderline condition. It results from a large number of downtime caused by periodic maintenance of the oldest buses having been moved to the summer period as well as unexpected repairs of the other buses. Such condition results from a large number of damages of varying degree as well as a large number of secondary repairs, the type of operation and the use of worn-out, oldest vehicles.

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