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ARTICLE

IMPROVED METHODS OF MONITORING AND MANAGING THE MOVEMENT OF URBAN PASSENGER TRANSPORT

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ABSTRACT

Research is focused on improving quality of urban passenger transport (UPT) service by assessing and eliminating the negative consequences arisen in the process of vehicles operation on routes. The improvement of the proposed methodology is based on the existing theories of road transport operation, passenger transportation, decision-making theory and the provisions of the system analysis. The selection criterion for backup vehicle based on its search and dispatching to the origin of emergency situation (ES) has been developed. At the same time, the search should be carried out both among the backup vehicles of the park, the central dispatch service (CDS), and among the vehicles operating on routes. Expert assessments of the time spent by control system in processing information and making a decision have been formed. Time estimates of movement of the backup vehicle directed from the route to the place of ES are received Methodology for estimating the efficiency of control system implementation based on assessment of the main indicators of the reliability of the urban passenger transportation system is proposed, which makes it possible to evaluate its basic reliability indicators. The reliability of the research is based on the analysis of sufficient number of sources directly related to the research topic.

KEY WORDS
control system, passenger transportation, road transport, reliability, dispatching.

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INTRODUCTION

Selection criterion for backup vehicle is the minimum expected time of arrival of backup vehicle at place of emergency with restriction: passenger capacity of the backup vehicle should not be less than required. We consider all options for searching backup vehicle - on the line, in the reserve of the park, in the reserve of central dispatch service [1].

In case of emergency situation, search and supply time of vehicle of the operational reserve T_s, it is necessary to evaluate the following components: T_{sit} - time spent on obtaining information about the situation that has arisen; T_{ass} - time spent on assessing the situation by criteria; T_r - time spent on searching and selection of alternative capabilities of the backup vehicle; T_d - delay time, which passes from the moment when dispatcher takes a decision till the selected backup vehicle starts to move to the place of ES occurrence; T_{mov} - time of the backup vehicle movement to the target [2].

METHODS

On the basis of the existing control system of urban passenger transport in the city of Orenburg, as well as taking into account review of the analysis of modern foreign and domestic control systems, assessments of possible values of variables T_{sit}, T_{ass}, T_r, T_d on a three-point scale of qualitative assessments a) "perfectly" b) "satisfactorily" C) "unsatisfactorily" were formed (adopted at the level of expert) to characterize operation of the control system during ES.

The rating "perfectly" corresponds to the best achievable indicators when using modern technologies and techniques.

If the control system in ES spends no more than one minute to report the occurrence of the ES, and for one minute to assess the situation, analyze alternative options, make a decision and report the decision to the executor, then such actions of the control system deserve the rating "perfectly".

Based on the analysis of graphs of values estimating waiting time of the backup vehicle, it is assumed that if this value does not exceed 3 minutes, then the operation of the vehicle reservation system can also be evaluated as "perfect". In the accepted designations, waiting time for the departure of the backup vehicle (delay time) is $T_d \Leftarrow 3$ [3, 4].

The satisfactory rating should correspond to the situation in which mobile communication systems are used to ensure the transmission of message to the control center while the vehicle is in the zone of final destination (FD), as well as the stationary communication facilities of linear central dispatch service, using automated control technologies. The following values of the variables are adopted for the assessment "satisfactory":

Time for communication with the center $T_{sit} \Leftarrow 5$; Time to assess the situation T_{ass}, search for alternatives $T_{ass} \Leftarrow 3$. Time for decision making and information transfer to the performer $Tr \Leftarrow 3$. Delay time. Then sum of the values of the variables [Tc + Tass + Tr] ⇐ 5 + 3 + 3 ⇐ 11. Waiting time of the backup vehicle Td ⇐ 7.

The Unsatisfactory rating corresponds to the situation in which traditional automated control technologies are used, as well as stationary communication facilities of linear central dispatch service, without using mobile communication and navigation.

The following values are adopted for «unsatisfactory" variables:

Time for communication with the center Tsit ⇐ 15; Time to assess the situation, search for alternatives Tass ⇐ 5. Time for decision making and information transfer to the performer Tr ⇐ 5.
[Tsit + Tass + Tr] ≤ 15 + 5 + 5 25.

The delay time for the backup vehicle departure Td ⇐ 15 (a small number of vehicles on the routes, lack of reserves in the park at the time of the emergence). The resulting values of assessments are presented in [Table 1] [5, 6].

Let us proceed to estimation of variable $V_A = V_A$ (t, d) - average speed of vehicle depending on the time of day t and day of week d. This dependence of the vehicle speed in a modern city is determined by the characteristics of the transportation flow, which are dependent on the time of day t and day of the week d.

Table 1: Adopted estimates of the characteristics of the control system and the reservation system

The adopted rating	Characteristic of the control system "time Consumption in the control system" : the sum of the values of variables [T_{sit} + T_{ass} + T_r], evaluating the quality of the communication system and the control system, min.	Characteristics of the reservation system " time Spent waiting for a free backup vehicle» The value of the variable T_d, evaluating the redundancy system vehicle, min.
«perfectly»	1+1+1 ⇐ 3	⇐ 3
«satisfactorily»	5+3+3 ⇐ 11	⇐ 7
«unsatisfactorily»	15 + 3 + 3 ⇐ 21	⇐ 15

In accordance with [7], the transportation flow is divided into six groups according to vehicle speed characteristic: 1) free; 2) stable; 3) almost stable 4) close to unstable; 5) unstable; 6) constrained.

Performance characteristics of urban streets, depending on the characteristics of the traffic flow [Table 2].

Thus, having determined characteristics of the transportation flow for each route of backup vehicle, depending on the time of day t and weekday d, on the basis of the relation (1), the required estimate of the traveled distance was obtained by substituting instead of V_A its value from [Table 2].

$$S_s = \frac{1}{2D_1D_2} \quad (1),$$

где S_s – the area of search, D_n – the diagonal of a square search.

Table 2: The operational performance of urban streets

Characteristics of traffic flow		The speed of movement of the vehicle on a city street, km/h
A	Free	≥48
B	Stable	≥40
C	Almost stable	≥32
D	Close to the unstable	≥24
E	Unstable	≈24
F	Constrained	<24

Combining the results of the control system and traffic situation analysis, we will obtain generalized characteristics of the control system at liquidation of ES consequences under various conditions [Table 3].

When considering the vehicle location, the following assumptions are made: 1) all vehicles are equipped with either satellite or local navigation; 2) The location of the vehicle must be determined by the navigational data received by the system. In this case, method of determining the vehicle location depends on what type of navigation equipment is installed on the vehicle's board.

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Table 3: Generalized description of the capabilities of the control system and the backup system of the vehicle at liquidation of consequences of ES

Evaluation of the characteristics of the control system and the reservation system of the vehicle	Characteristics of the control system "time Spent in the control system", min.	Characteristics of the reservation system "time Spent waiting for a free standby vehicle", min.	Characteristics of traffic flow	The speed of movement of the vehicle on a city street, km/h
«perfectly»	⇐ 3	⇐ 3	Free	≥48
			Stable	≥40
			Almost stable	≥32
			Close to the unstable	≥24
			Unstable	≈24
			Constrained	<24
«satisfactorily»	⇐ 11	⇐ 7	Free	≥48
			Stable	≥40
			Almost stable	≥32
			Close to the unstable	≥24
			Unstable	≈24
			Constrained	<24
«unsatisfactorily»	⇐ 21	⇐ 15	Free	≥48
			Stable	≥40
			Almost stable	≥32
			Close to the unstable	≥24
			Unstable	≈24
			Constrained	<24

Calculation should be carried out stepwise in the following sequence.

1) Calculation of probability of vehicle arrival at each FD for each route in the standby vehicle search area at time I (one minute), depending on the period of the day.
2) Calculation of waiting time of vehicle at each FD in the standby vehicle search area with a probability of at least 0.95.
The ratio (2) is taken as the basis for calculating the delay time for the arrival of reserve vehicles at the place of ES occurrence.

$$P(T_{d=t}) = \sum_{i=1}^{m} PA_i(t) - \sum_{i=1}^{m}\sum_{j=1}^{m}\left(PA_i(t)PA_j(t)\right) + \sum_{i=1}^{m}\sum_{j=1}^{m}\sum_{k=1}^{m}\left(PA_i(t)PA_j(t)PA_k(t)\right) + \ldots$$
$$\ldots + (-1)^{m+1}\left(PA_1(t)PA_2(t)\ldots PA_m(t)\right) \quad (2)$$

where $P(T_{d=t})$ - probability of arrival of the vehicle at least on one of m routes to the FD in Td minutes; - probability of arrival of vehicle at the i-th FD in t minutes.

Necessary calculations of the probabilistic characteristics of the routes were carried out by the example of the municipal state-own enterprise "Orenburg Passenger Transportation" of the city of Orenburg. The calculation of the probabilities for all routes is based on the ratios (3, 4).

$$t_{\mathrm{int}_i} = \frac{t_{ret_i}}{n_i(t)} \quad (3)$$

where t_{int_i} - estimated time of the movement interval, min.; t_{ret_i} - turnaround time, min..

$$P\left(A_1(t) \cup A_2(t) \cup \ldots \cup A_m(t)\right) = P\left(A_1(t)\right) + P\left(A_2(t)\right) + \ldots + P\left(A_m(t)\right) - P\left(A_1(t)A_2(t)\right) - \ldots$$
$$\ldots - P\left(A_{n-1}(t)A_n(t)\right) + P\left(A_1(t)A_2(t)A_3(t)\right) + \ldots + (-1)^{m+1} P\left(A_1(t)A_2(t)\ldots A_m(t)\right) \quad (4)$$

Event with probability of 0.95 and higher will be considered practically reliable. Thus, the estimated time of arrival of at least one vehicle at FD is equal to the estimated arrival time with a probability of 0.95 or more. On the basis of ratio (2), the following parameters are accepted as the initial calculation parameters.
- average traffic interval of vehicle on routes (in minutes). To simplify calculations and obtain a universal analytic dependence, we will assume that traffic interval is the same on all the considered routes. We will accept in our calculations range of traffic interval variation from 5 to 40 minutes.

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m - number of FDs, at which the arrival of vehicle is expected. We will accept in our calculations change of this parameter from 1 to 20, which most closely corresponds to a possible variety of practical situations.

t - current waiting time of arrival of at least one vehicle (in minutes), for which the probability of arrival is estimated. It is a cycle variable and can take values from 1 minute to the accepted in calculations traffic interval in minutes.

We will consider arrival of the vehicle at FD as a reliable event for the period of time that equals traffic interval. Traffic interval is the highest variable.

The calculation is performed alternately for each specified traffic interval from 5 to 40 minutes in increments of 1 minute. That is, the limit value of the variable is 40 minutes.

Thus, the "amount of FD" is a variable of the first nested cycle. Based on practical experience, we assume in calculations the limiting value of this variable - 20.

The initial number of FD is one. The probability of arrival for 1 minute, for two minutes, etc. is calculated.
Estimated waiting time for the arrival of vehicle is a variable of the second nested cycle. The maximum waiting time is 40 minutes. Calculation of the second nested cycle ends when the number of waiting minutes is determined, for which the probability of arrival of at least one vehicle equals or exceeds 0.95.

Then the number of FDs in calculation increases by 1. If the limit quantity of 20 is not exceeded, then the calculation for the second nested cycle is repeated.

RESULTS AND DISCUSSION

Assessment of the main reliability indicators of UPT system shall be carried out according to the scheme applicable to production technological systems according to GOST 27.503-81 "Dependability/Reliability in technics. Key indicators " [8], GOST 27.204-83 " Industrial product dependability. Technical requirements for methods of reliability evaluation on productivity parameters " [9] and in accordance with GOST 27.301-95 "Dependability in technics. Dependability prediction. Basic principles" [10].

When assessing vehicle reliability on productivity parameters, in accordance with GOST 27.204-83, four levels of consideration of the vehicle are distinguished: technological operation vehicle; technological process vehicle; production department vehicle (workshop, site, etc.); enterprise vehicle.

We will choose and interpret levels as follows: level of technological operation vehicle – level of transportation system in a single trip; level of technological process vehicle – level of the passenger transportation system on a single route; level of the enterprise vehicle – level of the transportation system by one enterprise.

When choosing reliability indicators, one of the most important concepts of reliability theory is a failure. In accordance with GOST 27.002-83 [11] failure is interpreted as inability of the system to perform one of its main functions.

GOST 27.204-83 [Table 2] [9] regulates four main indicators of reliability of technological systems: 1) probability of failure-free operation; 2) mean time between failures; 3) gamma-percentile operating time to failure; 4) preset operating time before corrective adjustment; 5) Mean restoration time.

On the basis of this, we shall choose the following indicators of reliability: 1) probability of execution of volume of transportation; 2) probability of trouble-free operation on routes with the announced schedule.
Assessment of reliability of the existing UPT system is also important in assessing the various options of the management system implementation.

Taking into account specifics of the UPT transportation, we shall calculate «probability of volumes execution" of transportation only for city routes and according to transport modes (bus, trolleybus) for routes with interval traffic.

In accordance with GOST 27.204-83 (clause 1.13), calculation of reliability indicators for the current state of transportation system can be carried out by calculation methods according to experimental-statistical data in accordance with GOST 27.503-81 [12].

For the accounting calendar period, we shall select main operational/srtategic planning period for UPT - 24 hours.

In this case, the assessment of the indicator "probability of traffic volumes execution per day":

$$P_{day} = \frac{Q_{fday}}{Q_{pday}} \qquad (5)$$

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где P_{day} - "probability of execution without failure" of a single flight of UPT per day; Q_{fday} - actually performed the traffic volumes for the day; Q_{pday} - planned volume of traffic per day.

For routes with the announced schedule, including suburban routes, we shall use the second indicator: "probability of trouble-free operation on routes".

From the point of view of the passenger, non-execution of flight on route with the declared schedule for any reason is a failure of transportation. Therefore, for route with a declared schedule, "probability of carrying out without traffic on the route" is equal to probability of carrying out without failure of all scheduled flights.

Let ni be the planned number of flights on the route i. Then, taking into account the expression (5), we obtain the following estimate of the probability of execution without traffic failure on the route i with the announced schedule per day:

$$P^i_{day} = \frac{R^i_{fday}}{R^i_{pday}} \qquad (6)$$

где P^i_{day} - "the probability of execution without failure" of traffic on i-th route for the day; R^i_{fday} - the actual number of flight movements at the i-th route for the day; R^i_{pday} - the actual number of flight movements at the i-th route for the day.

These estimates (5, 6) are applicable to the existing transport system, since they use statistical information.

Reliability assessment for future possible states of the system when implementing one or another version of control system, in accordance with GOST 27.301-95 [4], can be based on forecasting methods using, in particular: a typical model of transportation system functioning under control of modernized transportation management system; structure and distribution of functions between dispatchers and means of automatic monitoring (control) of state and object management; types and characteristics of human-machine interfaces that determine parameters of working capacity and reliability of the operators; level of personnel qualification; quality of software tools used in the facility; planned technology and organization of transportation for each version of the management system implementation.

Adequacy of the chosen calculation method and constructed calculation models to the goals and objectives of the object reliability forecast should be characterized by: completeness of use in the forecast of all available information about passenger transportation system and capabilities of control system in the event of traffic failure liquidation; validity of admissions and assumptions made while constructing transportation process models and models of control system functioning; degree of correspondence of the complexity level and accuracy of the calculation models of the object reliability to the available accuracy of the initial data for calculation.

CONCLUSIONS

1 Main characteristics of Orenburg UPT as well as the topological features of city bus routes are considered.
2 A methodology for collecting and analyzing experimental data on ES and violations in UPT operation in the city of Orenburg has been developed.
3 It was established that there is a need to process the available statistical data in two areas: ES and situations that arise in case of the transportation process violation, associated with the emergence of undesirable social consequences, but not connected with threat to life and health of passengers.
4 Technique of estimation of arrival time of reserve vehicles to the place of ES occurrence of is developed.
5 The minimum expected time of arrival of backup vehicle at place of emergency can act as a selection criterion for backup vehicle.
6 The main reliability indicators of UPT system were evaluated at various levels before and after system implementation.

Adequacy of the chosen calculation method should be characterized by completeness of use in the forecast of all available information about passenger transportation system and capabilities of control system in case of traffic failure liquidation; validity of admissions and assumptions made while constructing transportation process models and models of control system functioning; degree of correspondence of the complexity level and accuracy of the calculation models of the object reliability to the available accuracy of the initial data for calculation.

CONFLICT OF INTEREST

There is no conflict of interest.

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