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Accounting of Transportation Work in Automated Dispatching Control Systems

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Abstract

The article analyzes information provision for modern automated systems of dispatch control of transportation processes. It gives a formalized formulation of the task of comparing the planned and the completed transportation work. It describes the method for determining an indicator of the quality of the scheduled and completed trips as well as a modified "greedy" algorithm for solving the problem. It develops a simulation model and conducts a simulation of the transportation process to evaluate the efficiency of algorithm for the accounting of transportation work.

Keywords: transportation work, algorithm, dispatching control system, simulation modeling, information provision, automated accounting, quality of transport services.

INTRODUCTION

An active use of satellite navigation in the systems of management of the freight and passenger traffic is explained by the possibility of organizing a continuous monitoring of mobile units. Against this background, it is necessary to automate many technological processes at a qualitatively new level. One of the areas of such automation in complex systems is the assessment of the state of transportation process at any time on the basis of information about the planned transportation work as well as the data on the location of vehicles. Such an assessment would be important on the early stages of implementation of the automated control system for the transportation work in order to identify deviations from the planned indicators on the early stages of their occurrence. The existing systems are characterized by:

- the registration of the executed works is made subjectively, basically by the interested persons;
- the control over the executed works is selective and also has a subjective character;
- operational management of transport vehicles in abnormal situations (down-time, road accidents, etc.) is complicated and executed with big delays;
- the results of the work for the past day are formed only on the next day.

ANALYSIS OF INFORMATION PROVISION FOR THE MODERN AUTOMATED DISPATCH CONTROL SYSTEMS OF TRANSPORTATION PROCESSES

The modern automated dispatch control systems of transportation processes provide different levels of automation of control both for municipalities and for the management of transport enterprises [1]. The monitoring does not imply an immediate reaction of the system to the occurrence of certain events. Therefore, all the information generated by the monitoring system is recorded in the "system log" and can be accessed by the user on demand at any time [2]. In contrast to monitoring, the control systems involve the input of planned information, which is used as the initial data for monitoring [3].

The control can be of the following types:

1) Control of the predetermined traffic routes.

2) Control of the occurrence of certain events.

3) Control of traffic parameters (speed, etc.).

4) Control of the cargo parameters.

Unlike monitoring, control implies an immediate reaction of the system to the onset of certain events. Therefore, the control systems always have a set parameters, upon the achievement (exceeding) of which a signal is generated in the control system. All information generated by the control system is also recorded in the "system log" and can be accessed by the user on demand at any time. The automated dispatch control systems of transportation processes involve a mandatory implementation of all management functions: planning, control, regulation. From the point of view of operational dispatch control, the main work place is an automated workstation of the dispatcher [4-8]. An automated workstation of the dispatcher provides [6]:

- formation and readout (continuous or on demand) of textual and graphic information on the monitor about the operation of the vehicle in real time mode (on the route, scheduled and actual trips, passing of checkpoints, regularity of trips, traffic intervals);
- presentation on the monitor in special working windows of deviations in the operation of vehicles from the plan (non-departure, deviation from regularity, departure from the route, etc.);
- presentation on the monitor of the exact location of vehicles on the videogram (scheme) of the route;
- voice communication between dispatchers and drivers;
- presentation on the monitor of special messages from the vehicle (signals "SOS", communication requests from drivers, etc.);
- realization of management actions to adjust the operation of the controlled vehicles;
- logging of the most important events in the work of automated dispatch control systems;
- analysis of the work of automated dispatch control systems.

Therefore: automated dispatch control systems are necessary for operational planning, instrumental accounting of transportation work, control and management of transportation processes, automated readout of data about the operation of transport on the route, provision of operational information about the state of transportation [9]. In general, the technology of dispatcher control of transport management on the basis of transportation telematics systems can be presented on the following scheme (Figure 1).

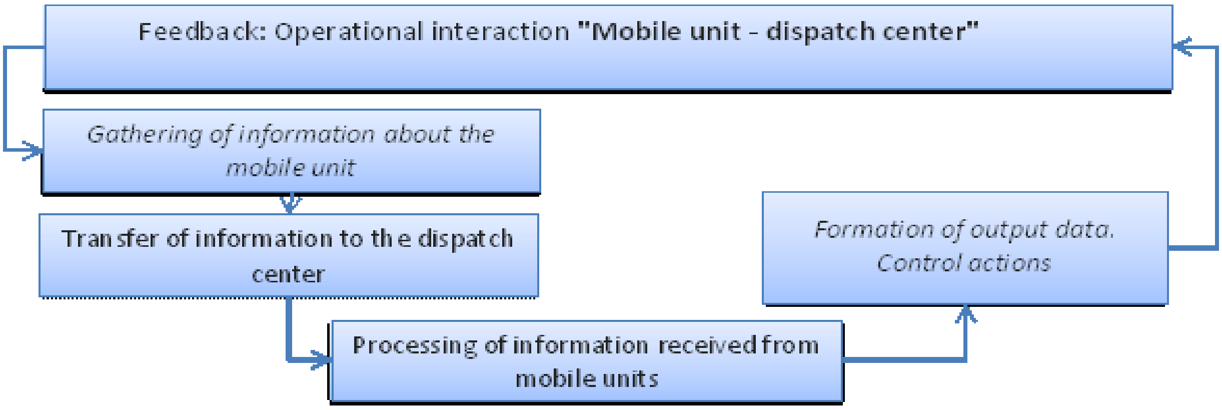


Figure 1: Enlarged scheme of the technology of automated dispatching control of transport.

We will consider each of the elements shown in the figure.

1. Collection of information about the mobile unit. Depending on the goals and tasks assigned to the automated dispatch control systems by a certain mode of transport, there is a list of vehicle parameters that need to be taken into account for the generation of output data, control actions, etc. Basically, the information received from the vehicle can be divided into two blocks:
   - information about the location of the mobile unit (time coordinates, time checkpoints, etc.),
   - information that characterizes the work of the mobile unit (in addition, such factors as fuel consumption, condition of the main mechanical components) can be taken into account.

In both cases, mobile units must be equipped with special equipment that collects information coming from both the sensors installed on the vehicle and from navigation devices [10, 11].

2. The transfer of information to the dispatcher center. It is important to note the importance of the transfer of operational and reliable information from mobile units to the control center during the realization of the function of managing vehicles in the real time mode to improve the efficiency of control over the transportation process.
3. The processing of information received from mobile units. Information from mobile units received by the control center via various data channels is processed by using specialized software.

4. The formation of output data, control actions (feedback). The main functional block of the software of automated dispatch control systems [2, 3, 5, 12-14], which is a part of the software of the dispatcher center, is a subsystem "Automated recording, control and analysis of the routed traffic", interacting with subsystems "Operational Transportation Planning", "Formation of data about the traffic" and a subsystem of administration without the data of the dispatching system.

In the subsystem "Automated accounting, control and analysis of the routed traffic" the following functions are realized [13]:

a) Accounting and control of mobile units on the route network, including the following tasks: registration of vehicles departing from the park:

- automated reporting of all violations;
- input of corrective information on the actual data about the launching of mobile units in the real time mode;
- formation and issuance of operational references about the status of the launching process;

b) Accounting and control of the opening of the traffic, the beginning of functioning of vehicles on the route, including the following tasks:

- registration of the actual time of traffic launching, the beginning of operation of the vehicles;
- formation in automated mode of messages about all violations during the launching of the traffic, violations during the departure for the first trip.

c) Accounting and control of the movement of mobile units on the route, including the following tasks:

- determining the location of the vehicle;
- registration of the passing of control points by the vehicle, the recording of trips;
- determination of deviations of the mobile unit from the route and from the traffic schedule;
- registration of stoppage, down-time, returns, etc.;
- formation in the automated mode of messages and the release of operative information about all violations on the route;
- reception and processing of messages from drivers, including requests for communications, distress signals;
- display of the location and movement of vehicles on the route network with the help of electronic maps or charts;
- display on the monitor (in special windows) of information about the gross violations of traffic (absenteeism, departure from the trajectory of the route, stoppage, etc.);

d) Accounting and control of the time of completion of transportation work on the route, including the following tasks:

- automatic registration of the time of completion of transportation work on the route by each vehicle;
- formation in the automated mode of messages about the untimely completion of transportation work.
- The technology of accounting, control and operational regulation of cargo transportation processes used in practical activity has the following drawbacks [3, 6, 14]:
- the accounting of the executed works is carried out subjectively, basically by the interested persons. There is no objective accounting of the downtime during the loading and unloading operations, car mileage and fuel consumption;;
- the control over the executed work is selective and also has a subjective character;
- operational management of vehicles in case of abnormal situations (down-time, stoppage, traffic accidents, etc.) is difficult and is performed with a long delay;
- the results of the work for the previous day are formed only on the next day. There is no evaluation of the work executed at the current moment.

The transportation process is characterized by several types of organization [3]: in the form of microsystems, especially small systems, small systems with shuttle motion, small systems with circular motion, small systems with the deliveries and collection of cargo, medium systems, and large systems. Of particular interest are transportation processes of the last four types (small systems with circular motion, small systems with the delivery and collection of cargo, medium systems, as well as large systems). In other words, we specify the object of our research: the transport process, in which the total number of the loading and unloading of objects is more than two.

The experience of several years of practical exploitation of automated dispatch control systems in large cities of Russia and abroad made it possible to draw a conclusion about the need to develop new technological regimes for automated control, analysis, regulation of the transportation process that would correspond to the changed characteristics of the object of control – the process of road transportation with the use of modern satellite navigation.

The main direction of improving the basic technological processes of control, analysis and regulation of transportation should be an area associated with improvement in the quality of information provision of transport and telematics systems in cities and regions [6, 14]. The notion of "improvement in the quality of information support" is primarily associated with the provision of technological processes for the dispatcher management of mobile units, particularly with the use of indicators of the state of the transportation process on the routes due to the capabilities of satellite navigation.

This conclusion was made on the basis of the review and analysis of scientific works, domestic and foreign analytical materials, personal experience of the author in the practical work on the creation and implementation of the automated dispatch control systems [9, 15-17].

The main areas of improvement of technological processes can be:

- the use (within the relevant mathematical apparatus) of the information component of each navigation message received from the monitored vehicle to assess its current location;
- evaluation and recalculation (after receiving navigation messages) not only of the location but also of the technological characteristics of the movement of vehicles along the route and the use of this information for the current assessment of the condition and quality of the general transportation process;
- the use of information of the current assessment of quality of the transportation process to make an informed and timely decision (in advance, adequate to the current situation) about the need of regulatory actions;
- the use of information about the executed work to assess the quality of transportation based on the planned transport work.

Realization of this approach is possible on the basis of development and use of a special mathematical apparatus capable of assessing the quality of the freight road transport by comparing the indicators of planned targets with those obtained from the telematics equipment of the company's vehicles. This mathematical apparatus should use every navigation message entering the control system from the controlled vehicles to form both the current assessment of the quality of the transportation process and the executed work for a random time interval.

MISSION STATEMENT FOR COMPARING THE PLANNED AND THE COMPLETED TRANSPORTATION WORK

To determine the degree of correspondence of the executed work to the planned one we consider a number of criteria. We assign the following criteria to such criteria [19-21]:

- The degree of similarity of each planned and actual trip on the basis of concurrence of control points of trips;
- Absolute degree in the deviation of time of each planned trip from each executed trip;
- The sequence of passing of control points for the planned and the completed trips.

Expert assessments point to the fact that the first of the presented criteria is the main one among the multitude of criteria. It was also expertly determined that the presented criteria are sufficient for the person making the decision (decision maker).

To solve the problem of determining the degree of correspondence of the actual and the planned work, possible alternatives should be determined $X = \{x_p\}$ $(p = 1,2,\dots,N_x$, which represent the objects, the quality and efficiency of which are estimated by the vector indicator:

$$w(x_p) = (w_1(x_p), w_2(x_p), \dots, w_n(x_p)) \tag{1}$$

where $w_1(x_p), w_2(x_p), \dots, w_n(x_p)$ are objective functions;

$y_k(x_p) = w_k(x_p)$ – estimation of the object x_p according to the k -criterion;

$k \in J_k = \{1,2,\dots,k,\dots,N\}$ – index set of the numbers of criteria characterizing the quality and efficiency of objects (alternatives).

Let us assume that object x_g is preferable (better) than object x_h (we denote it as $x_g \succ x_h$) according to the w_k criterion if the strict inequation $w_k(x_g) > w_k(x_h)$ is observed for the direct measurement scale and $w_k(x_g) < w_k(x_h)$ reverse measurement scale. In this case, we set the task of multicriteria ranking (ordering) of objects evaluated by a set of indicators $w_k(x), k = \overline{1,N}$, namely: to find such an ordering of objects:

$$x_{i1} \succcurlyeq x_{i2} \succcurlyeq \cdots \succcurlyeq x_{is},$$

satisfying the condition:

$$w(x_{i1}) \succcurlyeq w(x_{i2}) \succcurlyeq \cdots \succcurlyeq w(x_{is}) \tag{2}$$

where $w(x_{i_s}) = (w_1(x_{i_s}), w_2(x_{i_s}), \dots, w_n(x_{i_s}))$ - vector estimation of object x_{i_s}.

For the task of multicriterion optimization it is necessary to choose one alternative (solution) $\dot{x}$ from the set of admissible alternatives X_β, providing an extreme value to the vector criterion $w(x)$:

$$w(\dot{x}) = \underset{x \in X_\beta}{\operatorname{extr}} (w_1(x), w_2(x), \dots, w_n(x)) \tag{3}$$

To simplify the model, we present the problem of multicriteria optimization as the problem of one-criterion optimization.

In this case, the most obvious method, by which this problem can be solved, is a lexicographic method for criteria ordering [22]. This is true, because is very difficult to obtain a generalized target criterion according to the selected criteria.

Ranking them according to the degree of importance we get:

$$w_{j1} \succ w_{j2} \succ w_{j3} \quad (4)$$

where:

w_{j1} - The degree of similarity of each planned and actual trip on the basis of concurrence of control points;

w_{j2} - Absolute degree in the deviation of time of each planned trip from each executed trip;

w_{j3} - The sequence of passing of control points for the planned and the completed trips.

Optimization means the choice according to the first most important criterion:

$$w_{j1}(\dot{x}) = \underset{x \in X_\beta}{\text{extr}}(w_{j1}(x)) \quad (5)$$

If the same values are found for the first criterion, then during the second phase the choice is among the remaining alternatives:

$$w_{j2}(\dot{x}) = \underset{x \in X_\beta^{(1)}}{\text{extr}}(w_{j2}(x)) \quad (6)$$

where $X_\beta^{(1)} = \left\{x \in \dot{} X_\beta | w_{j1}(\dot{x}) = \underset{x \in X_\beta}{\text{extr}}(w_{j1}(x))\right\}$

In general, these operations are performed until at some point there is one alternative left:

$$w_{j3}(\dot{x}) = \underset{x \in X_\beta^{(2)}}{\text{extr}}(w_{j3}(x)) \quad (7)$$

$$\text{where } X_\beta^{(2)} = \left\{x \in \dot{} X_\beta | w_{j_2}(\dot{x}) = \underset{x \in X_\beta^{(2)}}{\text{extr}}(w_{j_2}(x))\right\} \quad (8)$$

Generally, we obtain the inclusion:

$$\dot{x} \in X_\beta^{(2)} \subseteq X_\beta^{(1)} \subseteq X_\beta \quad (9)$$

We will present quantitative estimates in the form of a matrix. We vertically arrange elements $p_i \in P$, and horizontally $f_j \in F$ (Table 1). We denote as k_{ij} the estimate of p_i and f_j by one of the criteria.

Since the characteristics of vehicles are taken into account when planning the trips, then any scheduled trip can be executed by one single actual trip. Therefore, the optimal solution is defined as $\max(\sum_{i,j} k_{ij})$, if the summand is vj , then i -string and j-column are excluded from further analysis. The problem of finding extremum can be solved by many methods (for example, by heuristic methods or methods of dynamic programming).

In this regard, the calculated coefficients form an oriented acyclic graph. The set of vertices of this graph can be divided into two disjoint subsets F and P, so that: $\forall f \in F: f \notin P$.

Table 1. Matrix of weight coefficients

		Actual trips F			
		f1	***f2***	**…**	***fn***
Planned trips P	***p1***	*k11*	*k12*	…	*k1n*
	p2	*k21*	*k22*	…	*k2n*
	…	…	…	…	…
	pm	*km1*	*km2*	…	*kmn*

Therefore, the graph is ***bipartit***e. A combination of a simple graph is its subset of edges, neither two of which have a common end. Since there is a comparison of all elements of subsets among themselves, the graph is also ***complete***. As each edge has a certain value k_{ij}, the graph is also ***weighted***.

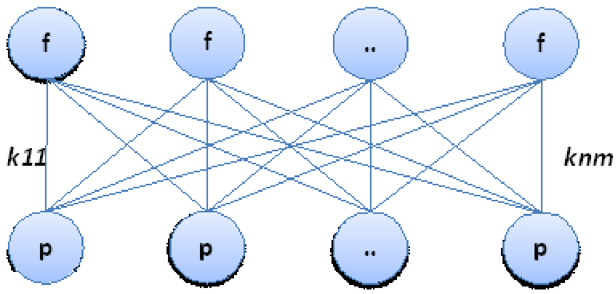


Figure 2: The graph of connectedness of sets F and P.

Thus, we have obtained a connected undirected graph

$$G = (V, E), V = F \cup P, F \cap P = \emptyset \quad (10)$$

with $N(V)=n+m=|V|$ — a set of vertices (nodes), $E=l$ — a set of arcs (oriented edges) consisting of Θ components of connectedness

$G_t = (V_t, E_t), t = 1,2, ..., \Theta$

and Θ articulation,

$|V_t| = r_t, |E_t| = l_t,$

$$\sum_{t=1}^{\Theta} l_t = l, \sum_{t=1}^{\Theta} r_t = r - \Theta + 1 \quad (11)$$

The matching of graph $G = (V, E)$ is a subgraph $G_x = (V_x, E_x)$ generated on the set of pairwise non-adjacent edges $E_x \subsetneq E$, $V_x \subsetneq V$. The matching x_0 is said to be maximal [23] if the number of edges in it is the biggest among all matchings of graph G. The matching problem consists in finding the maximum matching x_0 of graph G (maximum cardinality matching).

Obviously, it is not always that $n = m$, but the graph can be augmented to make it perfect. In this case, the number of edges is defined as $\left(\frac{r}{2}\right)^2$. The weight coefficients considered above represent the function c_{ij}, determined on the set of edges $(f_i, p_i) \in E$.

The task is to determine such a permutation

$$\sigma = (i_1, i_2, \dots, i_n), \tag{12}$$

on which the maximum of the function is reached:

$$f(C) = \sum_{j=1}^{n} C_{ji_j} = C_{1i_1} + C_{2i_2} + \dots + C_{ni_n} \tag{13}$$

The currently existing numerous algorithms for finding a maximum matching provide acceptable results in solving the problems of small and medium complexity.

We introduce r^2 of variables k'_{ij}, each of which can assume values from the set $\{0,1\}$. An arbitrary permutation σ (12) is supplied with a set of unit values of the variables $k'_{ji_j}(j = 1,2, \dots, n)$.

Then the original problem is formulated as follows:

$$(C) = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} k'_{ij} \rightarrow extr,\ \sum_{j=1}^{n} k'_{ij} = 1 \forall i \text{ и } \sum_{i=1}^{n} k'_{ij} = 1 \forall j, k'_{ij} \in \{0,1\} \tag{14}$$

THE METHOD FOR DETERMINING AN INDICATOR OF THE QUALITY OF THE PLANNED AND COMPLETED TRIPS

Suppose that after the previous step there are some alternatives regarding the value of $\sigma_{\Delta t}$. For $X_\beta^{(1)}$ we calculate a new matrix of weight coefficients. As values of the coefficients we choose the *permutation coefficient* v_{ij}. We will assume that in the scheduled trip, as in the completed trip, the same control point cannot be present more than once, because this contradicts the principles of optimal planning. Let us assume that among the alternatives there are correspondences p_i and f_j – trips. We will consider a subset of control point as an intersection of these two trips:

$$CP_{ij} = CP_{P_i} \cap CP_{F_j}, CP_{ij} \neq \emptyset \tag{15}$$

Let us assume that ρ_{ij} is a number of elements of the set CP_{ij} and $x_{\rho_{ij}}$ is a serial number of the control point in the trip. Then, considering the sequence of identical control points in the sets $CP_{ij} \cap CP_{P_i}$ and $CP_{ij} \cap CP_{F_j}$, we can calculate the absolute difference of ordinal numbers ρ_ij-KP in both sets. In this case, the permutation factor will be:

$$V_{ij} = \sum_{y=1}^{\rho} v_{ij_{\rho_{ij}}} \tag{16}$$

It is easy to prove that the minimum value that can be obtained from (16) is zero. This value is obtained by the permutation coefficient when the sequence in CP_{P_i} and CP_{F_j} fully coincides. The maximum value of the permutation coefficient is obtained in the case of complete discrepancy of the above-mentioned sets. Such a discrepancy is obtained if the control point with the number 1 in CP_{P_i} corresponds to the control point with the number ρ_{ij}, in CP_{F_j}; the control point with the number 2 in CP_{P_i} corresponds to the control point with the number $\rho_{ij} - 1$, and so on. In this case, the extreme value V_{ij} is equal to:

$$V_{ij\,max} = \begin{cases} \rho_{ij}^{\ 2} - 2 * \sum_{k=0}^{\frac{n}{2}-1} (1 + 2k), if \rho_{ij} - even \\ \rho_{ij}^{\ 2} - \rho_{ij} - 2 * \sum_{k=0}^{\frac{n-1}{2}-1} (1 + 2k), if\ \rho_{ij} - uneven \end{cases} \tag{17}$$

Since V_{ij} is directly proportional to the disruption of the sequence of control points, it is necessary to minimize v_{ij} and, as a consequence, to decipher (7):

$$w_{j3}(\dot{x}) = \min_{x \in X_\beta^{(2)}} (w_{j3}(x)) \tag{18}$$

This approach to the calculation of permutation coefficient is not flawless, however, with certain assumptions it can correspond to the set tasks. As a result, we obtain an estimate according to the third criterion. If, step (7) is completed, we obtain alternative solutions and choose any of them. As an example, to illustrate the above-mentioned methods for determining quality indicators, we will consider a trivial case of comparing two planned trips and one completed trip (Fig. 3).

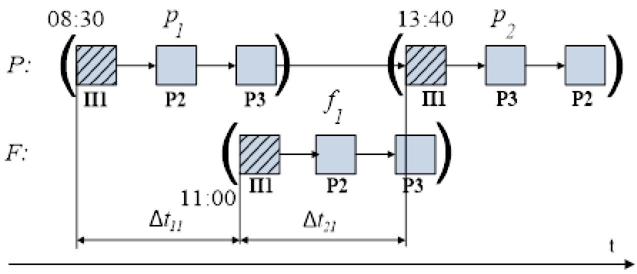


Figure 3: Examples of execution of scheduled trips.

The figure shows two scheduled trips and one completed trip. We calculate the optimal correspondence between the scheduled and the completed trips based on the assessment of the quality indicators (16). In this case, theoretically, there are two available options for linkage: the only actual trip is placed in accordance with the first scheduled trip or the second scheduled trip. "Theoretically" this means that it is necessary to check whether these trips can be compared. This can be understood by finding the optimal solution (5).

Step 1.

A set of control points of loading for the completed trip A_{F1}={П1}, a set of control points of loading for scheduled trips: $B_{P1} = B_{P2}$={П1}=A_{F1}. The sets for the control points of unloading will be similar, therefore (with g=1.5)

$$k_{11} = k_{21} = 1.5 * 1 + 1 = 2.5$$

The matrix of weight coefficients will consist of one column and two strings. Coefficients are elements that are equal to:

	f1
p1	2.5
p2	2.5

Thus, after the first step some alternatives were obtained. We continue to optimize.

Step 2.

The value $\sigma_{\Delta t}$ = 1 hour. We calculate absolute deviations:

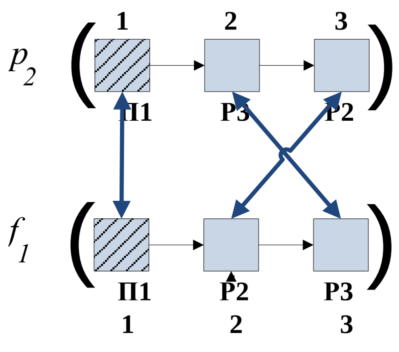
$$\Delta t_{11} = |08{:}30 - 11{:}00| = 02{:}30\ hours$$

$$\Delta t_{21} = |13{:}40 - 11{:}00| = 02{:}40\ hours$$

We calculate the value $|\Delta t_{11} - \Delta t_{21}|$: $|02{:}30 - 02{:}40|$=00:10 hours < $\sigma_{\Delta t}$ hence we assume $\Delta t_{11} = \Delta t_{21}$. We have obtained alternatives again. We continue to optimize.

Step 3.

Since the sequence of control points in p_1 fully coincides with the sequence f_1, $V_{11} = 0$. The sequence of violation for p_2 and f_1 is shown in the following figure:



П1 in (16) = 0, P3: |2-3|=1, P2: |3-2|=1. Therefore $V_{21} = 2$. In connection with the fact that $V_{11} < V_{21}$, as a correspondence p_1 we choose f_1. In this case, we would say that for the trip p_2 no completed trip was found. Currently, navigational dispatch systems in transport use a number of methods and algorithms to compare the planned and the executed work. Despite the limited possibilities during the execution of complex trips, these methods have become widely used in the systems of analysis of transportation work. We will describe one of these methods, which is based on the full coincidence of control points of the trips (*the method of full coincidence*) (Figure 4).

This method is one of the easiest to implement and which consists in the sequential search of fully accounted trips among the completed ones. In this case, $p_i \in P, i = \overline{1,n}$ corresponds to $f_j \in F, j = \overline{1,m}$ only if $CP_{p_i} \setminus CP_{f_j} = 0$, after which p_i and f_j are removed from the subsequent search.

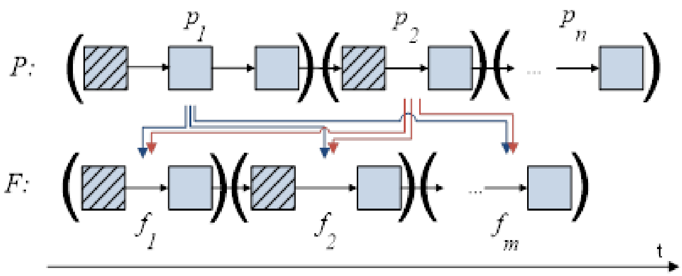


Figure 4: The method of full coincidence.

A significant drawback of this method is a reduction in the probability of detecting correspondence of the planned and completed trips with an increase in the number of partially completed trips, and especially with the changed order of trips. According to the observations, it was found that a changing sequence of trips can in some cases reach 50-55% of the total number of scheduled trips. At present, there are many algorithms for working with graphs [60, 64], in particular, with complete bipartite graphs. The main feature of the search for optimal matching is the time complexity of algorithms. Thus, in the algorithm of the full brute-force search of the matrix *n*n* time complexity has the order of *O(n!)*. In practical applications the brute-force search method can be used, because *n* rarely exceeds 5-6 trips per shift. At the same time, with incorrect formation of orders without drivers (the cycle is 24 hours), this value can increase two times. There are heuristic algorithms (for example, modifications of the traveling salesman algorithms), parallel algorithms. The assessment of permutation with the attainment of maximum of the function can also be obtained with the help of linear programming methods. It is possible to solve the problem by using *the simplex method*. Another method for assessing the matching with the maximum sum of edges is *the "greedy" algorithm*. An example of a modified "greedy" algorithm for solving the problem:

1. **Cycle 1** to i **from** 1 **to** n

2. **Cycle 2** to j **from** 1 **to** m

The search of the maximum k for all values remaining in the j-string ->Kj

Finding the max value among the elements of the column j+Kj

If several max are found, **then**

Analysis of criterion number 2 for trips with the same max

If there are alternatives, continue with criterion number 3

If there are alternatives, select an element of the column with the lowest j

End If

Mark the string and the column of the selected element as excluded from further analysis

2. **End Cycle 2**

1. **End Cycle 1**

SIMULATION MODELING OF THE TRANSPORTATION PROCESS FOR ASSESSING THE EFFICIENCY OF ALGORITHM FOR THE ACCOUNTING OF TRANSPORTATION WORK

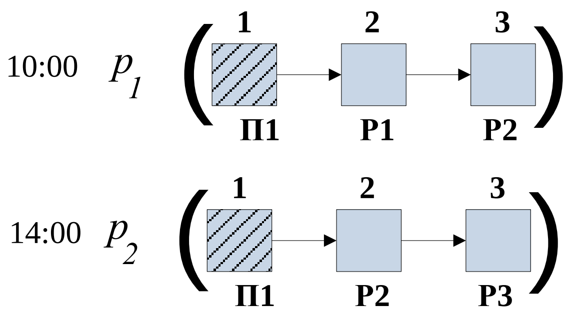
The model reflects the state of the transport process by one vehicle. The input data are the results of the algorithm for generating scheduled trips as well as the simulation parameters presented in Table 2.

Table 2. Parameters of the initial state and algorithms for the search of extremum

Parameter	**Designation**	**Groups**
Number of scheduled trips	n	2-4, 5-6, >6
Number of control points in the scheduled trip	$r(p_i), i \in [1; n]$	2, 3-4, 5-6, >6
Number of loading points	pC	>=1,<=10
Number of unloading points	rC	>=1,<=10
Number of days	day	1,2
Coefficient of importance of loading to unloading	g	>0,<=3
Time interval of the beginning of trips in the method of successive concessions for criterion w_{j2}	Δtu	30,60,90 minutes

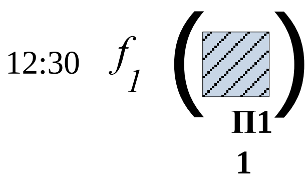
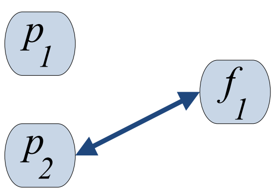
Features of the discrete-event model

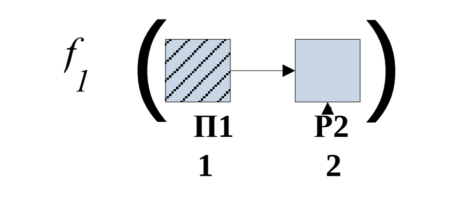
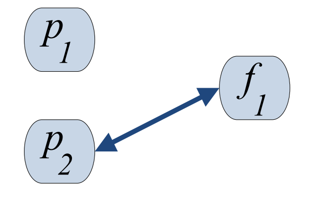
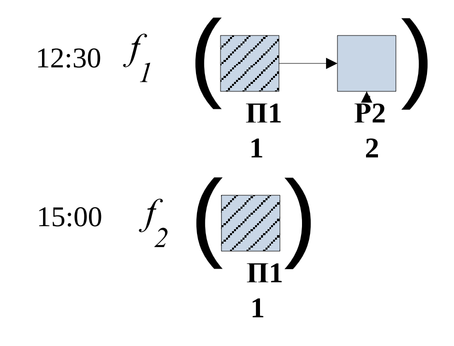
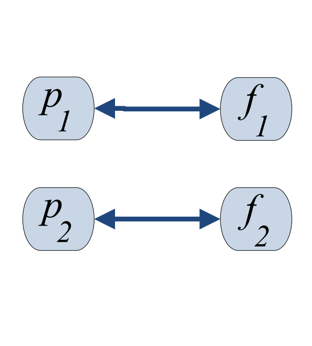
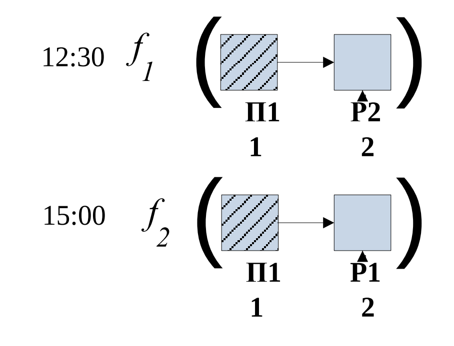
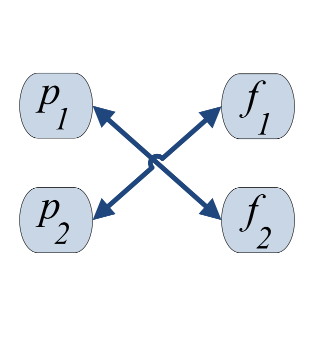
Let us consider the transportation process when the same inclusion can be repeated several times. We will call this a "jump" situation. Let us assume that for the transportation system two scheduled trips are determined:



We will consider discrete events of control points (Table 3).

Table 3. Analysis of the "jumps"

	Control points to be counted	**Scheme of trip**	**Graph of connectivity**	**Comparison**
1.	First loading			p_2 <=> f_1

2.	P2 to be counted in f_1			p_2 <=> f_1
3.	Start of the second trip			p_1 <=> f_1 p_2 <=> f_2
4.	P1 to be counted in f_2			p_1 <=> f_2 p_2 <=> f_1

In different moments of time different actual trips are compared. f_1 is compared with the scheduled trip more than once. In the discrete-event model it is necessary to take into account the possibility of "jumps" and also to assess the probability of their appearance in different versions of the transportation process.

The modeling complex of the proposed model is described by a finite automaton, since the result of the simulation should not only be the analysis of the static solution for the inclusion through sequential determination, but also the analysis of the dynamics of transportation process. The described automaton is given five parameters:

$$M = (Q, q_0, PF, \vartheta, \sigma) \qquad (19)$$

where Q is a finite set of the states of the automaton (finite alternatives),

q_0- initial state of the automaton (a set of scheduled trips)

PF- a set of admissible states of the automaton (local alternatives)

ϑ- input alphabet (control point, time of entry into the control point zone, control point number, etc.)

σ- next-state function of automaton (a discrete random event of control points to be counted).

We will describe the general form of a finite automaton:

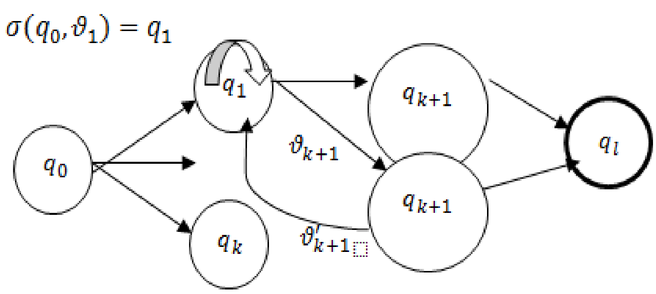


Figure 5: Diagram of the states of the finite automaton in the modeling complex.

The network reflects the main possible states of the finite automaton reflecting the transitions from one state to another. The presented automaton is non-deterministic, because there is a possibility of transition from state q, into more than one state (including into any of the previous ones). The possible variants of the input parameters defining the form σ are divided into the ranges presented in Table 4 When choosing a range, the values are set randomly, which made it possible for us to evaluate algorithms with bigger number of possible states.

Table 4. Basic input parameters for the transition function

Parameter	**Designation**	**Groups**
The ratio of production and idle runs	*procPr*	1-25%, 26-50%
The number of points of different types	*procCPCountType*	Randomly, one loading point, one unloading point, two loading points
The number of executed trips	*procF*	0-50%, 51-99%, 100%
Percentage of the visited control points in the completed trips	*procCP*	50-80%, 81-99%, 100%
Trips can be executed with violation of the sequence		Yes/No
Control points in the trip can be accounted in the changed order		Yes/No

The parameters and ranges are chosen based on the analysis of typical transportation processes occurring when transporting goods of industrial enterprises in the ways described above. We consider a simulation model for analyzing the state $q_i, i > 0$ (Figure 6).

On the basis of input parameters we form input data arrays for analyzing the state q_i (Table 5). The block responsible for the generation of trips forms the above-mentioned attributes: the list of control points, times of the beginning of events, trips. The list of control points (route) is formed based on the parameters *procCPCountType, procCP, procPr*.

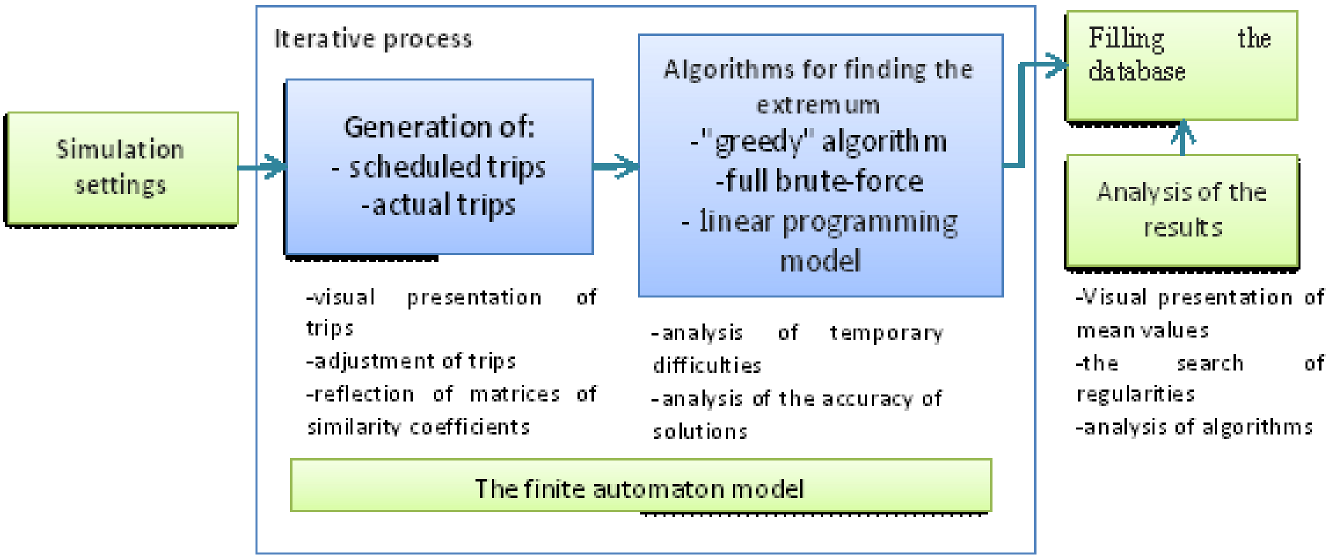


Figure 6: The structure of the simulation model for assessing the state q.

Table 5. Sampling of the generated input parameters

The number of scheduled trips, n	The number of actual trips, m	The number of different control points in the scheduled trips	The number of different control points in the actual trips	Total deviation in the time of the trips' beginning, min
4	5	11	12	1160
5	3	13	8	1045
2	5	7	12	930
5	4	13	10	1160
4	4	11	10	1068
6	3	15	8	1114
3	4	9	10	976
5	3	13	8	1045
4	4	11	10	1068
5	4	13	10	1160
6	6	15	14	1528
3	4	9	10	976
4	3	11	8	976
3	2	9	6	838
3	6	9	14	1114
4	4	11	10	1068
4	6	11	14	1252
4	3	11	8	976
2	2	7	6	792
3	6	9	14	1114
4	6	11	14	1252
5	2	13	6	930
5	2	13	6	930
6	4	15	10	1252
3	5	9	12	1045
4	4	11	10	1068
4	4	11	10	1068
5	5	13	12	1275
4	5	11	12	1160
2	4	7	10	884
3	5	9	12	1045
4	2	11	6	884
6	3	15	8	1114
5	3	13	8	1045
5	4	13	10	1160
6	6	15	14	1528

Based on the generation of input data with the change of the key parameters, we obtained multiple samples corresponding to the possible states of the transportation process. On the basis of multiple generated datasets, we analyze the necessity and sufficiency of a system of criteria:

- Using K_β
- Using K_β, V_β
- Using K_β, V_β, T_β

As an estimate we use the number of alternatives formed during the phase of using the listed criteria in accordance with the scheme (Figure 7).

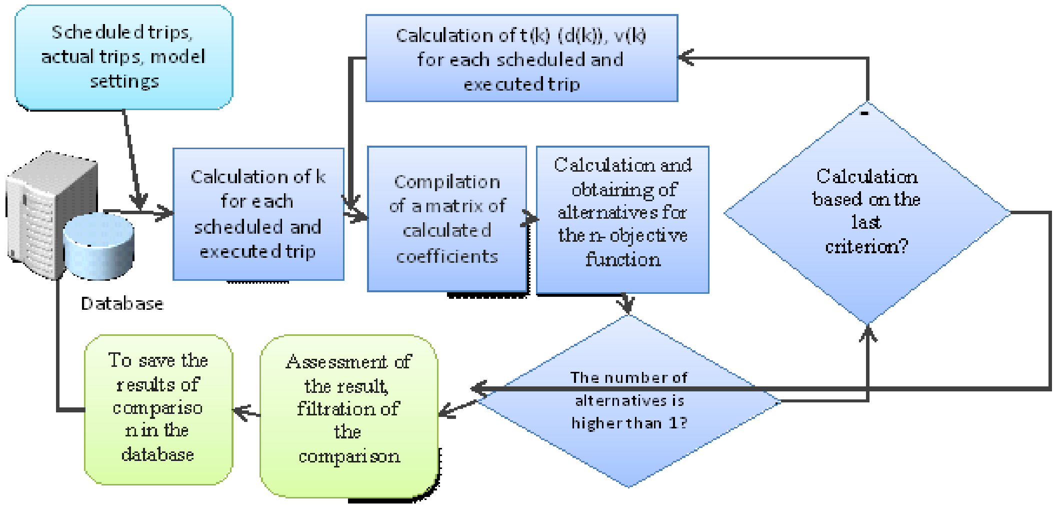


Figure 7: Structural diagram of the proposed model.

We will consider the option of determining the state of transportation process based only on K_β. Input parameters of the simulation:

Designation	*Value*
n	4
pC+ rC	5,7,9
day	1
g	1.5
procCPCountType	Randomly
procF	100%

The result of simulation is shown in Figure 8. On the graph of the average smoothed values it is clear that with other conditions being equal, the uncertainty expressed in the number of alternatives, increases if the number of different control points in trips (1000 realizations) decreases. This situation is observed in "assigning" certain points for certain mobile units. The nature of curves indicates that the degree of uncertainty increases if:

n=m (n~m), pC+ rC~n

The result of determination of K_β, V_β for analogous input parameters is presented in Figure 9. The maximum number of alternatives (value CountCP = 5: 1.217) indicates the inadequacy of the two criteria.

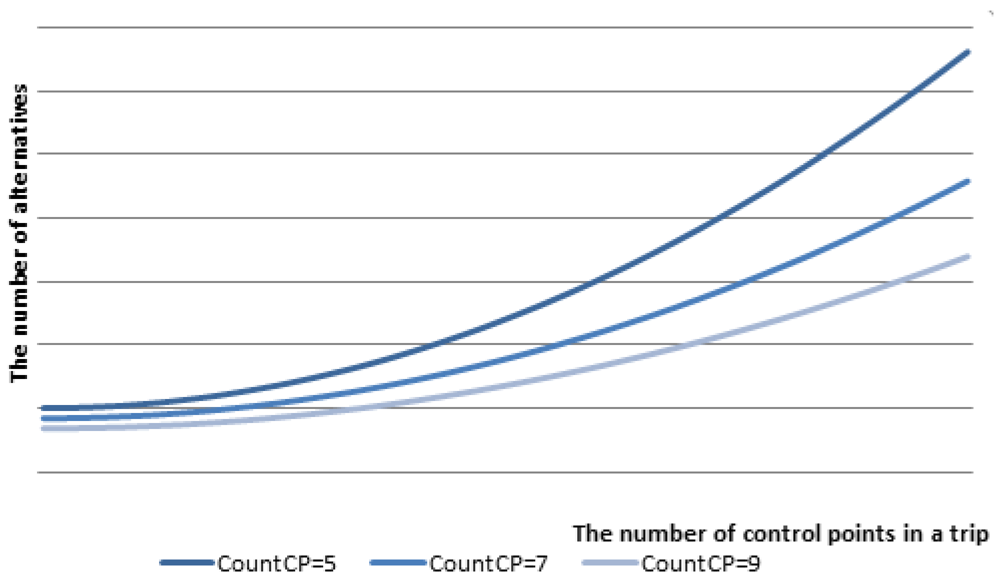


Figure 8: Dependence of the number of alternatives on the number of control points in a trip (variant K_β).

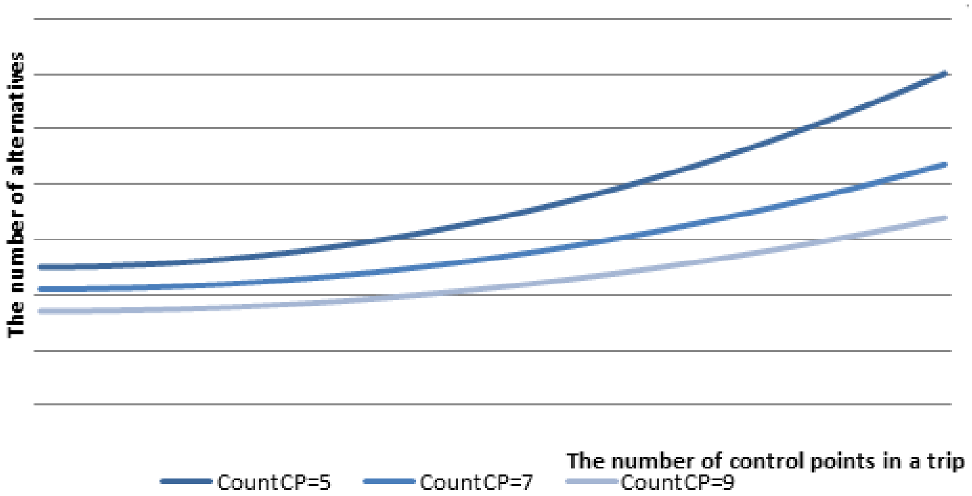


Figure 9: Dependence of the number of alternatives on the number of control points in a trip (variant K_β, V_β).

This is possible if the value of Δtu is too high, while the trips are executed without changes in the order of control points during the trip. If the order can change, the number of alternatives decreases dramatically. On graph (Figure 10) the value of the curve (CountCP=5) with the number of control points in a trip = 6 is the maximum and is 0.00193.

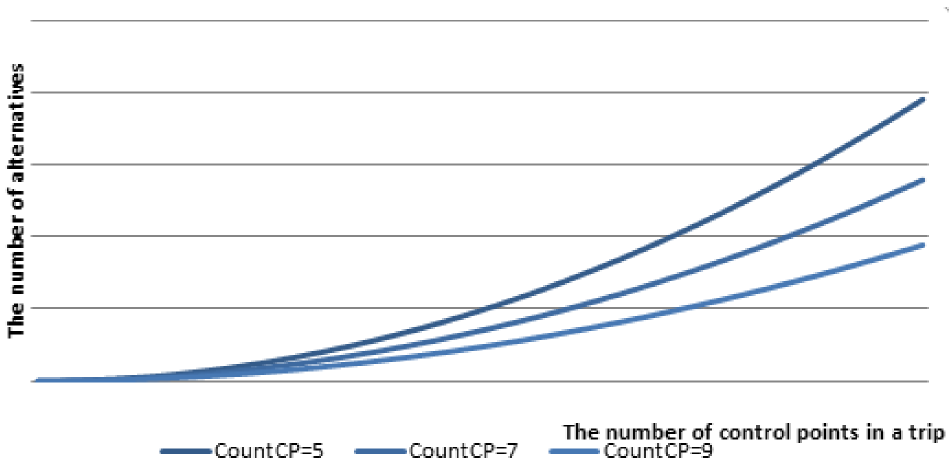


Figure 10: Dependence of the number of alternatives on the number of control points in a trip (variant K_β, V_β, T_β).

Designation	*Value*
n	5-6
pC+ rC	4
day	1
g	1.5
procCPCountType	Randomly
procF	100%
The number of realizations	1000

The total percentage of a single-valued solution for the initial situation is presented in Figure 11. The graphs reflect an average estimate for 1000 realizations. The number of alternatives after determining the minimum of the third objective function is 0,07%, which reflects the presence of an alternative in 1 out of 1,428 comparisons of the planned and the completed work.

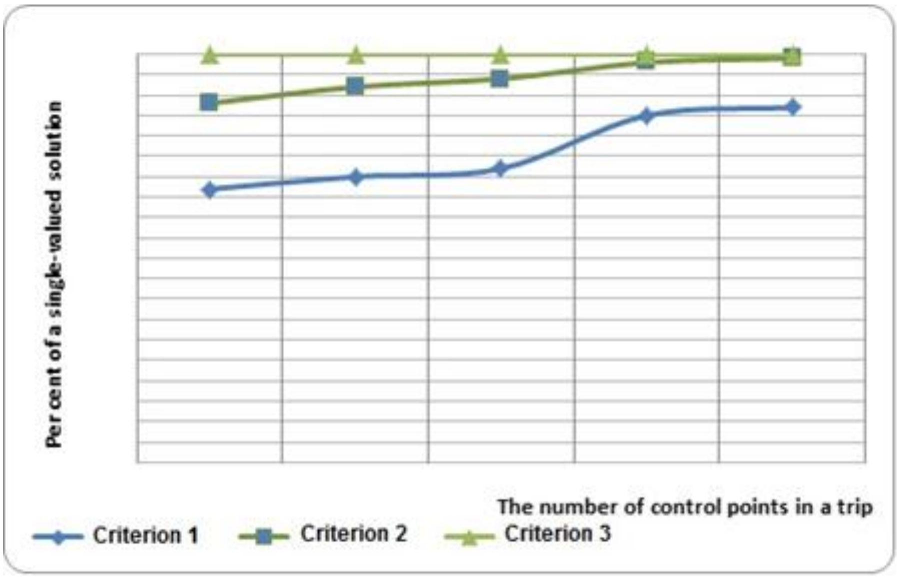


Figure 11: Percentage of a single-valued solution for the criteria depending on the number of control points in a trip (1000 realizations); Parameters: n=5-6, pC=2, procF=100%.

Analysis of algorithms for finding optimal matchings of the scheduled and actual trips

Since the task of finding a maximal (minimal) matching is a task of linear programming, one of the ways to solve it is a simplex method. The second method is exhaustive search. The third method is a modification of the "greedy" algorithm. Exhaustive search is effective, but has a disadvantage: polynomial complexity $O(n!)$. In the complete graph 8*8 the number of options is 8!=40320. The modified "greedy" algorithm is similar to Kuhn's algorithm and with an appropriate storage of data in memory has a time complexity of $O(n^3)$. We will simulate the solution for the optimal matching when the coefficient of similarity of control points in trips is used (Figure 12).

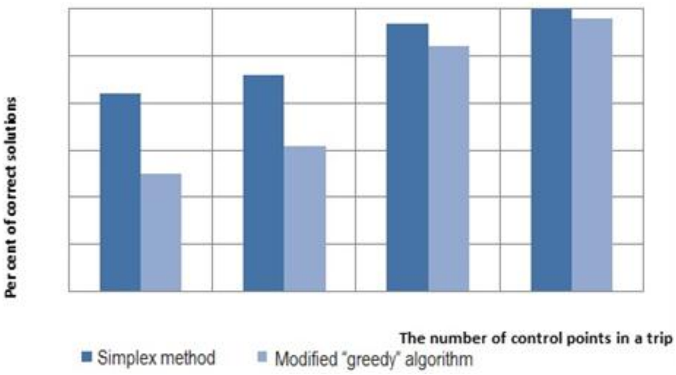


Figure 12: Analysis of algorithms for the search of maximum matching.

The method of exhaustive search is the standard. The graph shows the values for input data:

Designation	*Value*
n	6
pC+ rC	6
day	1
g	1.7
procCPCountType	Randomly
procF	100%
Number of realizations	1000

The "greedy" algorithm has a lower accuracy compared to the simplex method and exhaustive search, but its accuracy is acceptable and is within the range of average permissible error. The accuracy of solution grows with an increase of control points in a trip (at *pC+ rC=6*), which is related to the increase in different values of similarity coefficients.

Analysis of "jumps" in the finite automaton model

To model the "jumps" it is necessary to simulate the development of transportation process on the basis of a finite automaton. The modeling's input data:

Designation	*Value*
n	5
pC+ rC	5
day	1
g	1.5
procCPCountType	Randomly
Number of realizations	1000

With the number of realizations at 1000 and the number of control points = 9 at 30 mobile units of an enterprise and the fulfillment of 5 tasks with the number of control points equal to 3 (15 control points per mobile unit a day), the number of "jumps" is 1.78 (~ 2). As regards the "jumps", it is 1 "jump" a day.

CONCLUSION

We have conducted the analysis of information provision for modern automated systems of dispatch control of transportation processes, the analysis of stages in the planning of transportation work. Based on the analysis, we offer a system of criteria of similarity of the planned and actual trips based on:

A) the degree of similarity between the planned and the actual points;

B) absolute deviations in the times of beginning of the scheduled and the completed trips;

C) the sequence of control points of the planned and the completed trips

We propose a method for comparing the actual information obtained on the basis of telematics information with the planned information based on the functions of similarity of the planned and actual trips. The task of finding an optimal comparison of the planned and actual trips based on the proposed system of criteria is reduced to the problems on bipartite graphs, the typical examples of which are the problems of finding optimal matchings. It is proved that this method provides technological solutions in terms of traffic accounting and control, operational control as well as the analysis of the executed trips of mobile units. The technique of simulation is developed. The stages of modeling are determined. The drawback of the model is the presence of "jumps" - a situation when the current linkage of planned and actual trips may change to the version different from the current one. The analysis of the "jumps" indicates the necessity of fixing the linkage $p_i <=> f_j$ by the decision-making person to exclude the trips' data from the subsequent analysis.

It is expedient to continue the research by using the developed models to increase the automation of control functions in transportation operations at road transport enterprises and to develop additional services that take into account the maximum possible number of peculiarities of an enterprise. An adaptation of models for the control of transportation work is possible in the systems for cleaning municipal solid wastes as well as automated systems for the maintenance of roads.

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