Discrete event-based systems of transport automated dispatching control

A I Fadeev
Siberian Federal University, 79 Svobodny avenue, Krasnoyarsk, 660041, Russia

E-mail: fai@ak1967.ru

Abstract. The paper provides a formal description of the motor transport automated dispatching control system (ADCS) as a discrete event-based system. ADCS, in conjunction with the control object, forms the “ADCS - CO” system, in which the transport process is performed. The solution of the main tasks of the dispatching control system is considered, which includes measuring the parameters of the current or executed movement, identifying violations of technological standards; calculation of compliance of the transportation program and actual traffic parameters, identification of unacceptable discrepancies. The calculation of the compliance of the transportation program with the actual traffic parameters is carried out by estimating the planned and actual traffic routes, which is performed as follows: the starting and ending points of the planned route are determined in the actual trajectory of the vehicle. The next step is to evaluate the planned and actual movement by determining the overall sequence of two ordered sets: the points of the planned and actual routes of movement. The solution of this problem is performed by the classical dynamic programming algorithm about finding the largest common subsequence of two lines.

1. Introduction
Traffic dispatching control systems play an essential role in ensuring the reliability and safety of the road transport, as well as in meeting transport demand. Dispatching systems are used for passenger public transport, freight traffic, and also for special transport: school transportations, ambulance cars, emergency services, etc. [1-6].

In case of dispatching control systems all control decisions are made by people. Automatic devices are used for collecting, processing and presenting information about tasks and management results, as well as for comparative analysis of possible solutions. Such systems are called automated control systems (ACS). To control the car fleet movement processes, Global Navigation Satellite System is used, which carries out positioning of vehicles. In other words, it determines actual traffic trajectory.

Thus, the dispatching system should record the state of traffic that allows real-time determination of the ratio of actual and planned parameters of the processes in order to identify invalid discrepancies that require corrective decisions.

2. The formal description of the road transport dispatching control system
Business processes of the dispatching system can be described by a sequence of individual discrete events. To simulate such systems, a discrete event method is currently used [7]. According to this method the system in question appears to be dynamic, asynchronous; transitions in it trigger events that occur at discrete time points.
The theory of logical control of discrete event systems was first considered in the works of P. Ramadzh and V. Wonham as a theory of supervisory control [8-9]. The systems are modelled as finite automata, which are generated by means of formal languages of discrete events.

In accordance with [10], the Automated Dispatching Control System (ADCS) together with the control object (CO) forms “ADCS-OU” system, in which the transport process is performed: a set of actions ensuring directional solution of the problem of moving goods, passengers or other transportation work.

Figure 1 shows a diagram of the motor transport dispatching control system. The control object is described by means of two subsystems: the Car Fleet and the Transport Network.

In graph theory [11], a transport network is a directed graph $G = (W, E)$ in which certain properties can be specified for an edge $(u, w) \in E$, for example, restrictions on the allowable speed of movement $v(u, w) \leq v_{max}$. Each $w \in W$ vertex has coordinates (latitude and longitude) that ensure the positioning of the vehicle on the ground through signals from the satellite navigation terminal [12].

The route of $M$ vehicle on $G$ graph is a sequence of $w_1, w_2, w_{i+1}, \ldots, w_f$ vertices, where $w_i, w_{i+1}$ pair of adjacent vertices is an edge of the graph.

![Diagram](image)

**Figure 1.** Functional diagram of the motor transport automated dispatching control system (ADCS) where: CCU is the central control unit; CU - Control Unit; GLONASS / GPS - global navigation satellite system / Global Positioning System; AWS - Automated Workstation; CarCU - Car Control Unit; TCU - Terminal Control Unit; Car - vehicle; T - transport terminal; CP - Control Unit.

The vertices of the transport network will be divided into $(T_1, \ldots, T_k)$ terminals and $(CP_1, \ldots, CP_p)$ control points. Terminals are objects in which processes of cargo points, bus terminals, etc. are carried
Control points are used to carry out auxiliary operations (for example, changing crews) or controlling the movement of a vehicle (in time and space).

In some cases, active functional blocks that interconnect an automated control system (ACS) with a control object are considered as intermediate control devices (ICD) separated from the control automaton [10]. In our case, it is advisable to provide functional control units of transport terminals (T₁ CU, ..., Tₙ CU) and vehicles (Car₁ CU, ..., Carₘ CU) as intermediate control devices.

Some transport terminals do not have functional control blocks (for example, T₂ in figure 1). Such objects are used to describe stopping points at which no dispatching control is carried out for some reasons (technical, technological or organizational).

The functional control units of vehicles (Car₁ CU, ..., Carₘ CU) are divided into two types: CU: equipped with a satellite navigation system, and CU without this system. In most cases, the vehicles have satellite navigation systems, however, sometimes information from these systems may not be available for one reason or another. In figure 1 there is no satellite navigation system on the Car₂ vehicle. In this case, there is no data transmission channel from the vehicle to the dispatching control system (figure 1).

The Automated Dispatching Control System consists of two subsystems: Control Automata and automated workstations (control panels [10], Automated Workstation - AWS). Control Automata subsystem performs the automatic execution of certain operations or procedures for managing control objects, i.e. carries out the collection and processing of information from managed objects, the formation of data for workstations and active vehicle units (Car CU). Automated workstations are connected to the supervisory control system via control units (CU₁, ..., CUᵢ).

Automated workstations (AWS) fall into two categories: active and passive. Passive workstations are not controlled. In figure 1 AWS₃ is marked as a passive workstation. Passive workstations are used to provide traffic information without control, for example, for authorized organizations, regulatory bodies, etc. The management functions of active workstations may vary according to the authority of the staff for whom the stations are intended.

The transport technological process implemented by the control object is a sequence of operations of the transport process. The technological process is set by the Program of Transportations and Technological Standards. The Program of Transportations establishes the parameters of operations for the execution of transport routes. The route is set by means of a sequential list of terminals and control points. The operations performed at each terminal or control point, the time of their beginning and end are determined by the schedule. The Technological Standards establish the permissible parameters of processes, for example, high-speed modes of movement, modes of work and rest of drivers, etc.

In accordance with the above formal description of the dispatching control system we will define its tasks as follows:

- measurement of the parameters of the current or executed movement, detection of violations of Technological Standards in real time;
- calculation of the compliance of the Program of Transportations and the actual parameters of the movement, the identification of invalid discrepancies in real time.

The discrete-event method [13 - 15] involves the description of the system functioning as a chronological sequence of events. The event occurs at a certain point in time and causes a change in the state of the system.

The state space of a discrete-event system is a set \( S_1, ..., S_n \), switching between which occurs in accordance with the onset of some events \( e_1, ..., e_m \).

Thus, in the dispatching system we define the list of controlled events \( E \), which are described by the following relation:

\[
E(A, I^E, T, I, I^1, L^a).
\]
where: $A$ - vehicle identifier; $E$ - event identifier; $T$ - time of the event; $I$ - identifier of the route network point (terminal or checkpoint); $L', L''$ - vehicle coordinates (latitude and longitude).

The event information sources are the functional units of the transport terminals (T, CU) and motor vehicles (Car CU), as well as the central control unit (CCU).

The functional blocks of transport terminals send information about events that determine the beginning or end of the processes with vehicles: arrival at the terminal, start of service (embarkation-disembarkation of passengers, loading, unloading, etc.), completion of the maintenance process, departure from the terminal, etc.

As it was mentioned above, some terminals do not have functional control blocks. Information about the processes at these terminals is formed by the data coming from the functional blocks of vehicles.

Functional blocks of vehicles initiate certain events, for example, pressing a panic button by the driver or going outside the limits of a parameter controlled by a functional block of a vehicle, for example, a signal from a cargo security system. In addition, after a certain time interval, on the basis of global satellite positioning signals, the functional units of vehicles form packages of navigation tracks describing the location of the car fleet.

The following states of the controlled object are defined for the dispatching control system:

- going beyond the permissible limits of another controlled parameter, for example, exceeding the permissible speed of movement (a subset $S' \in S$);
- vehicle stops ($S'' \in S$);
- location of the vehicle in the area of the control point of the transport network ($S' \in S$);
- finding the vehicle in motion, under maintenance (loading, unloading, embarking-disembarking passengers, etc.).

3. Comparison of planned and actual traffic routes

The planned route is described by the relation $R(K, I, T^b, T^e)$ with the following attributes: $K$ - the number of the route point; $I$ - checkpoint identifier; $T^b$ - time of arrival at the control point; $T^e$ - departure time from the control point. The actual motion path on the transport network is formed in accordance with [19].

Thus, the planned route $R_j$ must be aligned with the actual route $S_j$. This task is divided into two phases:

- In the actual trajectory of the vehicle, the starting and ending points corresponding to the planned route are determined.
- Evaluation of planned and actual movement by comparing control points and parameters for performing operations (arrival, start - end of service, etc.).

The first stage of the problem is solved as follows. We consider that the reference point and the planned start time of the route are defined in the transportation program. It is required to establish the starting and ending points of the planned route in the actual path of the vehicle. To do this, we determine in the actual trajectory the control point of the beginning of the planned route. For the end of the planned route we will consider the control point of the beginning of the next planned route or, if the next planned route does not exist (for example, the current route has not yet completed), the last control point of the actual vehicle path is taken as the end of the planned route considered.

The determination of the control point of the beginning of the planned route will be carried out using the method of assessing the belonging of the variant to the population [22].
Figure 2 shows the sequence of control points of the actual trajectory of the car fleet, planned routes and graphs of the distribution of the probability of deviations of planned and actual departures. Thus, the assessment of compliance $\Lambda_{ij}$ with the $i$-planned and $j$-th actual control points is defined as:

$$
\Lambda_{ij} = \begin{cases} 
\frac{1}{\sqrt{2\pi} \sigma} \exp\left(-\frac{1}{2\sigma^2}(t_j^f - t_i^{pl} - \mu)^2\right), & \text{если } Id_j^f = Id_i^{pl}, \\
0, & \text{если } Id_j^f \neq Id_i^{pl}
\end{cases}
$$

(2)

where: $\mu$ - mathematical expectation of the deviation of the actual time from the planned; $\sigma$ - standard deviation; $t_j^f$ - departure time from $j$-th point of the actual trajectory of the car fleet; $t_i^{pl}$ - departure time from the first control point of the $i$-th planned route.

$Id_j^f, Id_i^{pl}$ are identifiers of the control point of the actual motion path and the first point of the planned route, respectively.

To simplify calculations by analogy with the least squares method, the assessment of compliance with the planned control point of the beginning of the route to the point of the actual trajectory can be defined as:

$$
\Lambda_{ij} = \begin{cases} 
(t_j^f - t_i^{pl} - \mu)^2, & \text{если } Id_j^f = Id_i^{pl}, \\
0, & \text{если } Id_j^f \neq Id_i^{pl}
\end{cases}
$$

(3)

At the second stage, a common sequence of two ordered sets is formed: points of the planned and actual routes of movement. The solution of the problem is carried out according to the classical dynamic programming algorithm about finding the largest common subsequence of two strings [20, 21].

![Figure 2](image)

**Figure 2.** Illustration of planned routes and the actual trajectory of the vehicle: 1 - graphs of the density of the probability distribution of the deviations of the time of scheduled departures from the actual; 2 - graphs of the squares of the deviation of the time of scheduled departures from the actual; $Id_1, Id_2$ - identifiers of control points of the beginning of the first and second planned routes, respectively; $Id_3$ - identifiers of control points of the actual trajectory of movement.

**4. Conclusion**

The paper provides a formal description of the system of dispatching control of road transport. The automated dispatching control system (ADCS) of motor transport in conjunction with the control object (CO) forms the “ADCS-CO” system in which the transport process is performed: a set of actions that
provide directional solution to the problem of moving goods, passengers or other transport work. The control object consists of two subsystems: the car fleet and transport network. The proposed formal structure of the automated dispatching control system was tested in the dispatching control subsystem of “BusTrafficManagement” bus traffic information system. Experience in practical implementation allows us to conclude that the proposed approach ensures good performance of the dispatching control system.

The tasks of the ADCS are defined as follows:

- measurement of parameters of the current or executed movement, identification of violations of Technological Standards;
- calculation of compliance of the Program of Transportations and the actual parameters of the movement;
- identification of unacceptable discrepancies.

The calculation of the compliance of the transportation program with the actual traffic parameters is carried out by evaluating the planned and actual traffic routes. In order to do it:

- the starting and ending points of the planned route are determined in the actual trajectory of the vehicle;
- evaluation of the planned and actual movement is carried out by determining the overall sequence of two ordered sets: the points of the planned and actual routes of movement. The solution of this problem is performed by the classical dynamic programming algorithm about finding the largest common subsequence of two strings.

References

[1] Efimenko D B 2012 Methodological foundations of building navigation systems for dispatching control of the transportation process in road transport: using the example of urban passenger transport (Moscow)

[2] Pol’gun M B, Vorobyeva A V and Ostroukh A B 2011 Analysis of models of operational dispatching control of urban passenger transport Yuong Scientist 4(3) 9-13

[3] Ozhereleyev M Yu 2008 Improving the quality of information support of transport and telematic systems in cities and regions (on the example of the dispatching control of passenger transport) (Moscow: MADI (STU))

[4] Bogumil V N, Efimenko D B and Sidikov F A 2012 Organization of automatic control of the traffic regularity of urban passenger transport vehicles Vestnik of Moscow Automobile and Road Construction State Technical University (MADI) 3(30) 63-9

[5] Yagudaev G G, Vasyugova S A, Ismailov A R, Berner L I and Mel'nikova T E 2017 Accounting of Transportation Work in Automated Dispatching Control Systems International Journal of Applied Engineering Research 12(14) 4502-17

[6] Ostroukh A V, Surkova N E, Polgun M B and Vorobieva A V 2015 Automated supervisory control system of urban passenger transport ARPN Journal of Engineering and Applied Sciences 10(10) 4334-40

[7] Khadeev A S 2013 Modeling and control of technological objects with discrete behavior using the theory of supervisory control (Moscow)

[8] Ramadge P and Wonham W 1987 Supervisory control of a class of discrete event processes Siam J. Control and Optimization 25(1) 206–30

[9] Ramadge P J and Wonham W M 1987 On the supremal controllable sublanguage of a given language SIAM Journal of Control and Optimization 25(3) 637-59

[10] Lazarev V G and Piyl E N Synthesis of control automata (Moscow: Energyatom publishing)

[11] Distel P 2002 Graph theory (Novosibirsk: Institute of Mathematics Publishing)

[12] Fadeev A I 2019 IOP Conf. Ser.: Mater. Sci. Eng. 537 022043
[13] Babkin E A 2006 On the synthesis of event models of discrete systems *Scientific notes: electronic scientific journal of Kursk State University* 1

[14] Ben-Naoum L, Boel R, Bongaerts L, De Schutter B, Peng Y, Valckenaers P, Vandewalle J and Wertz V 1995 Methodologies for discrete event dynamic systems: A survey *Journal A* 36(4) 3–14

[15] Cassandras C G and Lafortune S 1999 *Introduction to Discrete Event Systems* (USA: Kluwer Academic Publishers)

[16] Edvards M *et al.* 2012 Conceptual model for event processing systems Available from https://www.ibm.com/developerworks/ru/library/ws-eventprocessing

[17] Cassandras C G and Lafortune S 2008 *Introduction to Discrete Event Systems* (Springer)

[18] Babkin E A 2010 *Information systems: Theory and Practice* (Kursk: Kursk state university) pp 46–51

[19] Ambartsumyan A A 2008 *Technical and software tools for control, monitoring and measurement systems* (Moscow: IPU RAS) pp 268-88

[20] Panin A G 2010 About one search algorithm of the greatest common subsequence of two strings *Vector of TSU science* 4(14) 19-22

[21] Bellman R 1960 *Dynamic programming* (Moscow: Foreign Literature Publishing)

[22] Johnson N and Lion F 1980 *Statistics and Experiment Planning in Engineering and Science: Experiment Planning Methods* (Moscow: Mir)