AUTOMATIC CONTROL OF METRO TRAINS

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ABSTRACT

The experience of development of domestic automatic traffic control systems for metro trains is analyzed, taking into account high intensity and low redundancy of the line capacity necessary to compensate for disturbances. A brief overview of development of an automated control system is given; the dynamics of changes in the systems of automatic train operation is shown. The analysis of the transformation of algorithms for centralized control of metro trains, the features of time-travel controllers, the requirements for construction of technical means for determining the distance traveled and the speed regime are given.

Keywords: metro, automatic traffic control system, dynamics of development, safety, automatic train operation, time-travel controllers, algorithms.

Background. *Automatic traffic control systems of metro trains (ACS MTT) contain subsystems of dispatching control, automatic train operation and traffic safety.*

The system of automatic train operation is designed for high-quality performance under the control of a traffic safety system. The qualitative fulfillment of the assigned volume of transportation is transformed into the requirements for exact execution of the specified train schedule with compensated disturbances, for automatic rebuilding of the traffic schedule and its execution with uncompensated disturbances [1].

The traffic safety subsystems function either together with the systems of automatic train operation, or independently with the «manual» control of the train. From the point of view of automation of traffic control, safety systems impose restrictions on control. Their commands enjoy the highest priority.

Objective. *The objective of the author is to consider the issues of effictiveness of automatic control of metro trains traffic using retrospective analysis.*

Methods. *The author uses general scientific methods, comparative analysis, evaluation approach, engineering analysis, scientific description.*

Results.

Centralization and autonomy

The effectiveness of automatic train control offers:

– increase in the use of capacity and increase in carrying capacity due to more accurate implementation of the traffic schedule;

– improvement of traffic safety by reducing the likelihood of dangerous train approach;

– reduction of energy consumption for train traction due to the choice of energy-optimal train control modes and optimal distribution of the travel time along the line for the time of movement over the hauls, which is optimal by the criterion of minimum energy consumption.

According to the level of centralization of the automatic traffic control system of metro trains, they are divided into centralized and autonomous. Centralized ACS MTT receive information about arrival and departure times of all trains for all stations and generate control commands for each train. These commands are implemented by train devices of automatic operation. Autonomous ACS MTT in accordance with the set schedule control only one train. Compensation of disturbances is realized by the automatic control system of each train regardless of location of other trains on the line and is determined by control algorithms, availability of the control resource and restrictions imposed by the traffic safety system.

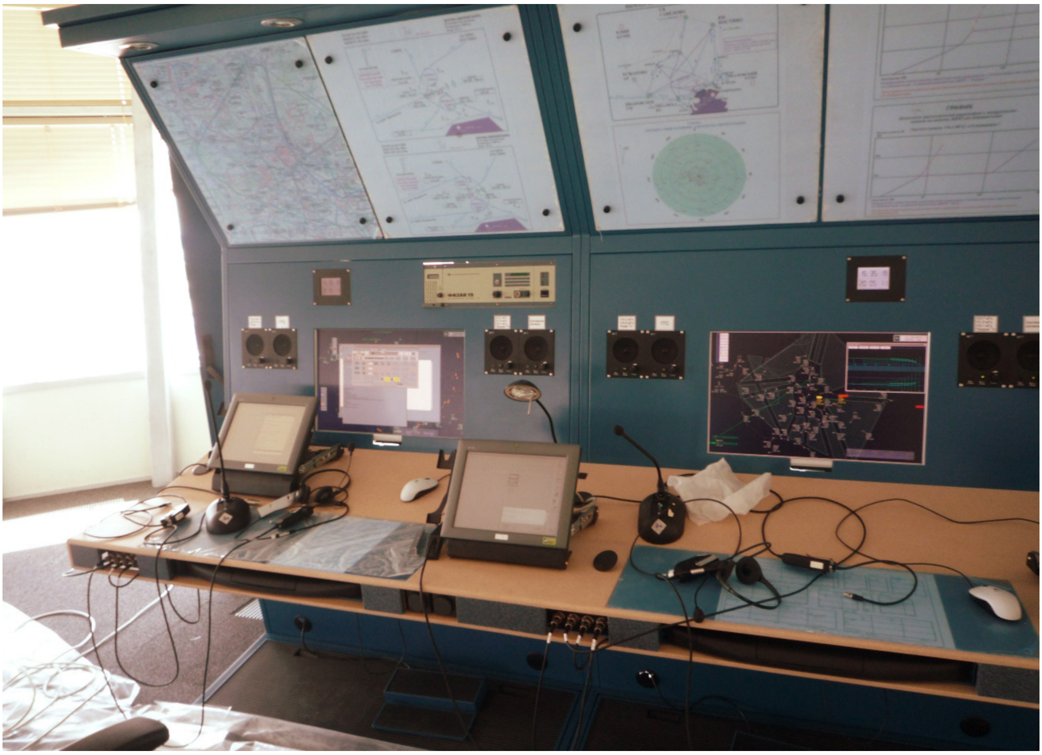
Centralized systems have great capabilities, since the availability of information on the position of all trains on the line allows for more flexible and effective compensation of various disturbances. Once intensive traffic prevails followed by small overdrive resources, high utilization of throughput, centralization adds the necessary properties to the system to ensure the required quality of control.

A centralized system of automatic train operation contains two interrelated functional levels of control. The upper level determines the discrepancy between the scheduled and executed traffic schedules and, with compensated disturbances, selects the control methods (time of stops and the optimum travel time for each train of the line). In the case of uncompensated disturbances, the upper level calculates a new traffic schedule and carries out control in accordance with this schedule. The lower layer realizes the control prescribed by the upper level. The role of the lower level is played mechanically by train devices of automatic operation. In accordance with this method of constructing of autonomous system, its development and implementation have two stages. At the first stage, the train devices of automatic train operation are processed in the autonomous mode, at the second stage algorithmic, software and hardware of the upper level and joint functioning of both levels are developed.

The International Union of Public Transport considers five levels of traffic control automation (from G0AO to G0A4) [2]. A review of the development of the systems of automatic train operation is given in [3], where, in turn, it was noted that the most complete list of subways equipped with ACS MTT is contained in [4].

High Targeting of Braking

The first autonomous system of automatic train operation was developed by the Scientific Research Institute UVM of Penza and tested on Moscow metro in 1961. The train devices were made on the basis of a control computer built on ferrite-transistor modules. Immediately thereafter, the creation of centralized systems began. In the late sixties of the last century, Lenmetro program-modeling system (PMACS MTT) was developed and implemented on Nevsko-Vasilievskaya and Petrogradskaya lines in St. Petersburg (it was the responsibility of Leningrad Metro and Giprotranssignalsvyaz Institute), followed by the system of automatic train operation of Moscow Metro (SAMM) on Kaluzhsko-Rizhskaya line (the developers were Russian University of Transport, then Moscow Institute of Transport Engineers (MIIT) and Moscow metro). The systems used hardware on



discrete semiconductor elements – transistors and diodes.

The braking program in PMACS MTT was implemented using a loop of wires located on a track. The control of the travel time on the haul was carried out by the time of selection of additional movement in the traction mode relative to the reference point. The choice of the travel time for the haul was calculated in this case by comparing the planned and executed traffic schedules (the graphical control algorithm).

The centralized system of automatic train operation SAMM, built on a transistor-diode system of elements of the Spectrum series, had a three-level structure (central control post, station and train devices). The position of a train in this system was found by inductive sensors located on a track. When sensors were passed, stationary device received impulses, the sum of which determined the coordinates of the train. The turn-off time of the traction motor was calculated by the station device, the turn-off command for the purpose of executing the specified travel time over the haul was transmitted to the train also through inductive sensors located in the traction deactivation zone. Centralized control was implemented by comparing planned and executed train intervals (interval control algorithm) [1].

In 1979–1980 integrated systems for automatic traffic control of trains on Moscow, Leningrad, Kharkov and Tashkent metro systems were introduced. The distinctive features of these systems focused on a control computer complex in the central office and functional integration of the systems of automatic train operation with traffic safety systems (ARS). The term «complex» reflected precisely this unification. The developers of integrated systems, in addition to the metros themselves, comprised MIIT, VNIIZhT, Giprotranssignalsvyaz.

The development of microprocessor equipment, increasing reliability and economy of computing systems made it urgent to develop a new generation of automatic train control systems. By 1985, at MIIT ACS MTT was created, in which microprocessor-based computer facilities were widely represented. The latter allowed to use more complex and effective control algorithms, increase reliability and «survivability» of the system due to reasonable redundancy, remove wiring trains, inductive sensors. Jointly with NPO Almaz, a special train device was developed [5]. In 1990, the operational tests of on-board devices of trains with passengers were carried out in autonomous mode of automatic train operation in Kharkov metro. The error in fulfillment of the specified travel times over the haul in the entire range did not exceed ±2,5 s, the error in stopping the train at the station was 30 cm. At the same time, the intensity of the impact braking was of the order of 0,75–0,8 m/s² [6].

The collapse of the USSR deprived participants of opportunity to continue this work. At the same time, its results were used in the joint project of MIIT and the Research Institute of Precision Mechanics (St. Petersburg). The variant of the on-board device of automatic train operation was introduced within the framework of the system «Movement» in metro systems of St. Petersburg and Kazan. In 1990s MIIT began similar work with the Scientific Research Institute of Instrument Engineering (NIIP) n. a. V. V. Tikhomirov.

A new stage of development

NIIP n. a. V. V. Tikhomirov created and implemented an automated system of control, diagnostics and traffic safety of the new generation «Vityaz» [7]. Its logical continuation was the use of on-board microprocessor train devices in the modes of automatic train operation, operating at the first stage in an autonomous mode. Train devices realize automatic train start-up, selection of pre-fixed traction control modes, impact braking of the train at the platform, independent braking of the train respecting speed limits, automated door control.

The principle of construction and algorithms for functioning of a train automatic operation device use the experience gained in the design of ACS MTT. Information on the path travelled by a train, its speed is obtained by the on-board device from the pulse-frequency wheel set rotation sensor. To compensate for the measurement error at fixed points of the track, RFID radio sensors are installed that do not require power connection. The energy for functioning of RFID is obtained from the high-frequency signal generated by the train when passing near sensor. In turn, RFID generates a signal that sends a message to the train about its coordinates, the number of the haul. The digit capacity of a message allows transfer of additional information on the characteristics of the haul.

The response signal generated by the sensor has a bell-shaped direction pattern. From the point of view of the need to transmit a large amount of information at high speeds, this is a positive feature. At the same time, the «fuzziness» of fixing the correcting point adversely affects the increase in the accuracy of measuring the distance traveled by the train. The additional location of the RFID sensors on the station at lower train speeds makes it possible to reduce the effect of «fuzziness». As shown by the tests carried out in Moscow metro, today the required stopping accuracy can be achieved [8, 9].

Nevertheless, the necessary accuracy of the target stop is obtained at a high price – a decrease in intensity of braking, which leads to an increase in the braking time. For a given travel time over the haul, an increase in the braking time leads to a significant overconsumption of energy per traction. Studies carried out at MIIT showed that an increase in the braking time by only 1 second at a fixed travel time on the haul raises the power consumption by approximately 1 %. This figure practically does not change either with the use of a recuperative brake, or without it. The requirement to maximize the intensity of braking to ensure a minimum of energy consumption for a given travel time over the haul is proved in [1, 10].

In the author's opinion, the integrated use of RFID and infrared track correctors (DCT) [1, 11], consisting of a transceiver installed on a train and passive corner reflectors attached to the tunnel wall, is promising. A transmitter operating in the infrared range generates a signal – an IR beam directed toward the side wall of the tunnel. When a passive multi-element optical corner reflector (cataphot) passes, a beam is reflected, which hits the receiver, where the passage of the correcting point is fixed. In addition, when two DCT are located at a fixed distance, for example 100 m, the on-board device, summing the number of pulses coming from the pulse-frequency sensor, automatically determines the radius of the wheel each time, which eliminates the error in measuring the track and speed caused by the change in wheel radius in operating time [1]. The advantage of DCT is also the accuracy of determining the coordinate of the correcting point.

There is a positive experience of using this sensor when testing ACS MTT in Kharkov Metro and the long-term operation of DCT in the system of automatic train operation of St. Petersburg metro. Complex use of RFID and DCT allows realizing the advantages of both sensors: ability to transfer a large amount of information from the track and the accuracy of fixing the correcting point. At the same time, it is possible to increase the functional reliability of the measurement section and train speed.

Taking into account the extreme importance of measuring the distance traveled and the speed of the train, the development of Doppler meters is becoming topical. Minimizing the error in track measurement and speed has a significant impact on modern traffic safety systems based on the radio channel. The throughput in this case is uniquely related to the accuracy of the track and speed measurements. Analysis of the possibility of implementing traffic safety systems based on the radio channel was considered in [12].

In train devices developed by NIIP n. a. V. V. Tikhomirov communication is provided via a radio channel with stationary systems. The adopted principles for construction of an on-board automatic train operation device and the automated control system, technical diagnostics and traffic safety of metro cars of a new generation (Vityaz system) [7] that are integrated with it make it possible to realize new opportunities that go beyond automation of traffic control. Through the radio channel, diagnostic and static information about a train can be transferred to the control center, which helps to significantly improve the efficiency of the metro operation. The carried out tests of onboard devices of automatic train operation in Moscow metro have yielded positive results [8, 9].

To date, Russian University of Transport (MIIT) has developed a lot of top-level algorithms – algorithms for centralized traffic control of all train of the line, e.g. graphic-interval algorithms of motion control with compensated disturbances are developed [14, 15]. With small discrepancies between the planned and executed traffic schedules, the required time of stops and run of the trains of the line are calculated in accordance with the graphics algorithm. The transition to control according to the intervals of motion is carried out when the line resource is insufficient to compensate for disturbances. After the interval is equalized, the transition to the graphical control algorithm is carried out.

A separate place is occupied by control algorithms during large traffic failures and algorithms that implement control after eliminating the causes of the failure. Simulation modeling of these algorithms on the models of lines of Moscow Metro for various types of failures and comparison of the results of automatic control with the history of control by dispatchers taken from the archive showed the possibility of their use in automated mode under the control of dispatchers [16–19].

Conclusion. The developed algorithms of centralized traffic control use artificial intelligence methods for decision making under uncertainty conditions. An example of this is finding an allowed interval for sending $(n + 1)$ trains for the known calculated travel times of the n-th and $(n + 1)$-th trains. A permissible interval of passing motion, at which the following train that runs without any speed limit imposed by safety system, depends linearly on the duration of stop of the n-th train at the n-th coming station. At the time of calculating the permissible departure interval, only the planned duration of stop is known, there is no information on the deviation of the parking time from the planned one due to the presence of disturbances. In this case, it is necessary to predict unknown deviations based on the automatic self-learning system.

The application of methods of artificial intelligence makes it possible to use the name «intelligent centralized system for automatic traffic control of metro trains». The term «intelligent» is associated not so much with creation of a complex integrated system, but rather with the use of artificial intelligence methods in control algorithms.

The existing experience in development and operation of automatic control systems, the results of research, design and testing work, with proper organization of implementation, promise to master the modern train control system, improve the quality of the assigned volume of automatic traffic and traffic safety in the country's metro.

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