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Modern Systems of Train Traffic Interval Control on World Railways

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ABSTRACT

The review study is devoted to the analysis of the modern systems aimed at enhancing or replacing existing systems of rail automatics and refers to ERTMS (European Union), CTCS (PRC), ATACS (Japan), PTC (Unites States) and ABTS-MSH (Russian Federation).

The review study discusses the main approaches and principles applied during the research and development of train traffic interval control systems, modern trends in their developments on public railways in Russia and other countries with the account for the scale of their adoption, offers tentative identification of problems that have arisen at the stages of implementation and operation and evaluation of the outlook for their further improvements.

While each system merits detailed study, the prevailed approach focused on comparative system analysis and revealing differences and common tendencies regarding their further evolution.

Keywords: railways, interval control systems, train traffic safety, implementation experience, modern traffic control systems.

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INTRODUCTION

The history of development of means of interval regulation in railway transport is directly related to development of railways. At the early stages, when train movement was regulated solely with the help of timetables and telegraph instructions, the transportation process was inevitably followed by train crashes and collisions, which was due to both the insufficient speed of telegram transmission and the human factor.

The first technical means to control the occupancy of blocks by trains was invented in 1849, it was the token system, then replaced by the electric token system, which prevented the block from being occupied by more than one train. At the beginning of the 20^{th} century, it was first replaced by semi-automatic blocking, which is a further development of the electric token system, and then by automatic blocking, subsequently supplemented by an automatic locomotive signalling system. With further development, the automatic blocking system, combined with locomotive signalling, has become the most common interval control system on the railways of the world. However, at present, the auto-blocking system that has become traditional faces ever-increasing requirements which it can no longer satisfy.

Currently, there is a significant increase in the role of systems intended for interval regulation of train traffic as a means of increasing the transit and carrying capacity of railway sections. Modern interval control systems offer a comprehensive solution to the issues of increasing the capacity of railways, improving safety and efficiency of transportation. In the process of developing interval control systems, considerable experience had been accumulated, which caused formation of different approaches to solving problems regarding improvement of traffic safety and transit capacity of sections.

The *objective* of the study is an analysis of modern systems aimed at supplementing or replacing existing railway automatics systems. The framework of this article supposes an analytical review of modern systems of train traffic interval control used on public railways, principles of their operation, and an analysis of the problems encountered during implementation stages.

RESULTS

ERTMS and CTCS–Single Railway Management Systems

The ERTMS system (European rail traffic management system) is currently the single system used on the European public railway network. ERTMS includes the European Train Control System (ETCS) as well as the Mobile Radio System for Railways (GSM-R).

CTCS (Chinese train control system) is currently the main interval control system used on Chinese railways.

Both systems can be considered together because of their technical and functional similarity and according to the prerequisites that caused creation of these systems [1].

Both systems were created as a solution to the problem of creating a single railway space in the context of the use of many different systems of interval control on the railways of the member countries of the European space and of China, respectively. From a technical point of view, both systems are multi-level ones: each level of the system corresponds to a certain type of equipment that is used at the implementation sites.

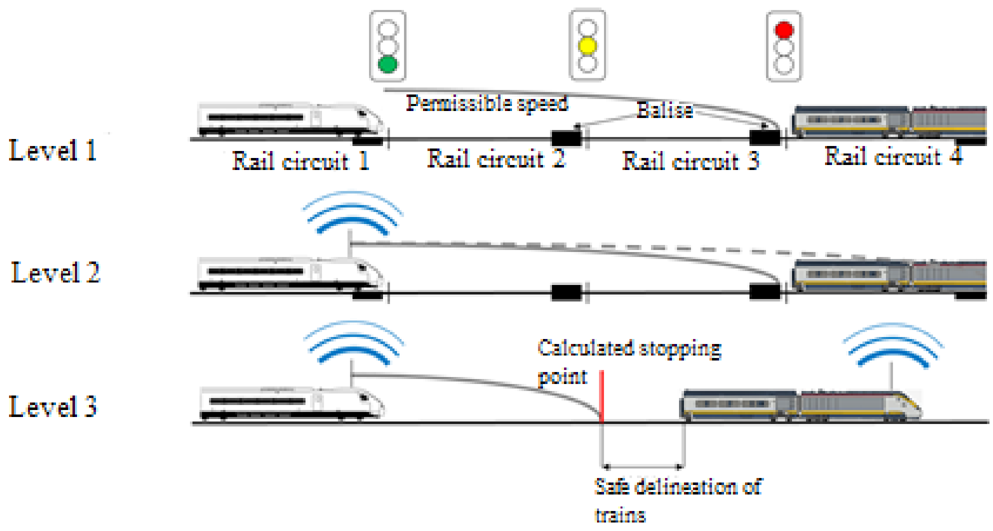
The principle of operation of both systems is based on the widespread use of balises (called Eurobalise in the EU) which are radio beacons located on the track and exchanging data with the locomotive, tracking its location. At the initial technical stages of development of the systems (ETCS Level 1, CTCS Level 1), they played greatest role in the transfer of information. Balises are divided into active and passive ones. Active balises, when a train passes over their location, transmit information to the train about the indication of the colour light signal ahead, the permissible speed, the target speed, the current restraints, and the coordinate. When a train passes through a passive balise, only information about the coordinate and speed limits is transmitted to the train. Further (ETCS Level 2), the main role in transmission of information to the train is played by the digital radio channel of the GSM-R standard, while the balises play an auxiliary role. The CTCS system at the higher levels (CTCS Level 2, CTCS Level 3) is also supplemented by a multivalued automatic locomotive signalling (ALS) system, which provides extended reception of information about the number of free block sections [2, 3].

Table 1

List of ERTMS equipment and functions at various levels [1, 2]

Level	Permissible movement speed	Signalling type	Control of train position and train integrity	Speed control
ETCS Level 1	Up to 160 km/h	Colour light signal + ALS	Rail circuits + axle counters	Eurobalises + ETCS locomotive devices
ETCS Level 2	Up to 250 km/h	ALS through digital radio channel	Rail circuits + axle counters	Digital radio channel + eurobalises + ETCS locomotive devices
ETCS Level 3 (movable block sections)	Over 250 km/h	ALS through digital radio channel	Digital radio channel + train on-board devices	Digital radio channel + ETCS locomotive devices

The delineation of trains in the ETCS system at different levels is shown in Pic. 1.



Pic. 1. Delineation of trains in the ETCS system at different levels.

There are three levels in the ETCS system. The list of functions and equipment is shown in Table 1.

In contrast to ETCS, the CTCS system has five levels of technical equipment: from zero to four. The list of equipment and functions is shown in Table 2.

Train control at different levels of the CTCS system is shown in Pic. 2.

The advantages of the systems include a wide possibility for system upgrading for the purpose of its further use in conditions of increasing traffic volumes, mutual compatibility of different levels provided that the specification versions coincide, as well as high reliability and efficiency.

However, operation of the systems also revealed a few problems, some of which were not sufficiently analysed during implementation. They are most noticeable in a detailed examination of the ERTMS system, the first of the two.

During implementation of the system on the railways of the EU member countries, the biggest problem was associated with the need to adapt the system to the conditions of national railways,[3] which is a significant obstacle for several reasons [4, 5]:

– the need to retrofit locomotives circulating in the implementation areas with the ETCS onboard unit when implementing level 1, to

[1] ERTMS–Delivering flexible and reliable rail traffic [Electronic resource]: https://uic.org/IMG/pdf/eu-ertms-en.pdf. Last accessed 10.01.2023.

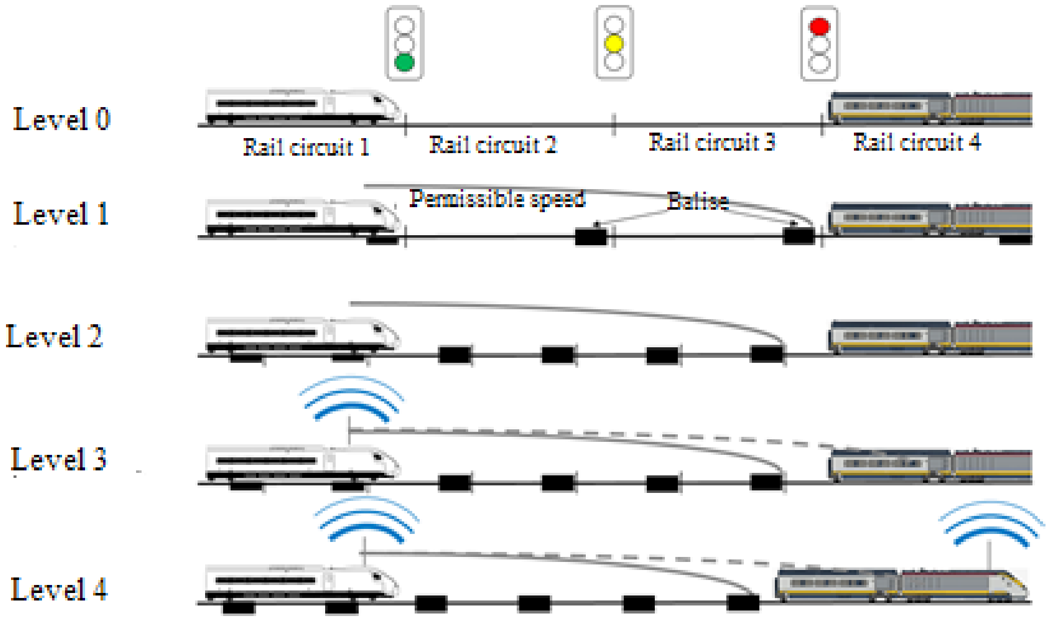
[2] ERTMS. European Commission website. Transport and Mobility. [Electronic resource]: https://transport.ec.europa.eu/transport-modes/rail/ertms_en#:~: text=ERTMS%2C%20which%20stands%20for%20 %E2 %80 %98European, the%20Single%20European%20Railway%20Area. Last accessed 10.01.2023.

[3] Challenges and Prospects for ETCS Deployment in Europe [in Russian]. Zheleznie dorogi mira, 2021. [Electronic resource]: https://zdmira.com/articles/trudnosti-i-perspektivy-razvertyvaniya-etcs-v-evrope. Last accessed: 10.01.2023)

Table 2

List of CTCS equipment and functions at various levels (data retrieved from [2])

Level	Permissible movement speed	Signalling type	Control of train position and train integrity	Speed control
CTCS Level 0	Up to 120 km/h	Colour light signal + ALS	Rail circuits	ALS onboard equipment
CTCS Level 1	Up to 160 km/h	ALS	Rail circuits	Travel balises + ALS onboard equipment
CTCS Level 2	Up to 250 km/h	Multivalued ALS	Rail circuits	Track balises + multivalued ALS onboard equipment
CTCS Level 3	Over 250 km/h	Multivalued ALS, digital radio channel	Rail circuits	Track balises + multivalued ALS onboard equipment
CTCS Level 4 (movable block sections)	Over 250 km/h	Multivalued ALS, digital radio channel	Rail circuits	Digital radio channel + track balises + multivalued ALS onboard equipment



Pic. 2. Delineation of trains in the CTCS system at different levels.

further modify them when moving to the level 2 of the system, as well as to update the software in case new versions of the ETCS system specification appear. An additional obstacle is also the need to achieve the compatibility of the locomotive equipment with the installed ETCS unit, which, for example, was the reason for changing the timing of the transition of the system to level 2 on the Danish railways (from 2023 to 2030)[4];

– incompatibility of different versions of the systems specification;

– long period of certification and admission to operation, the need to confirm compatibility of systems while performing international traffic.

The high cost of implementing the system [6] has led to the fact that since 2011, the Swiss railways[5] and a number of sections of the German railways have been implementing the version of ETCS level 1 «Limited supervision», which implies the maximum use of the existing railway automatics system with limited

[4] ERTMS: Its Rise and (Occasional) Stall // Critical software. [Electronic resource]: https://criticalsoftware.com/en/news/rise-and-stall-of-ertms. Last accessed 10.01.2023.

[5] Raymond, G. Siemens' Rollout of ETCS L1 Limited Supervision on SBB. IRSE News, 2014, pp. 13–14. [Electronic resource]: https://webinfo.uk/webdocssl/irse-kbase/ref-viewer.aspx?type=&RefNo=1981059986&GroupMembers=_&document=IRSE%20News%20199 %20(Apr%20 2014).PDF. Last accessed 10.01.2023.

functionality for controlling the permissible speed and transmission of information to the train.

Another problem of the system is the problem of implementing the third level of system equipment (ETCS Level 3), which implies a complete renouncement to track equipment with organisation of traffic control exclusively via a digital radio channel. The issues of monitoring the integrity of the track and rolling stock at the implementation sites have not yet been resolved, that is why, now, traffic safety is not fully guaranteed. As for feasibility, the most controversial is complete abandonment of the track equipment, which does not allow implementation of the level 3 before actual payback of the track equipment of earlier versions of the system.[6] For these reasons, there has been no single section equipped with a ETCS Level 3 system yet.

The CTCS system at the final level of development does not provide for the renouncement to the track equipment. But till recently, as is the case with ETCS Level 3, there have been no CTCS Level 4 application areas [7]. However, the disadvantages of the CTCS system are similar to those of ERTMS, which is expressed in the high cost of implementation and the need to adapt the existing infrastructure and locomotive fleet to effective operation of the system.

Currently, both systems, ERTMS and CTCS, are being actively implemented on the railways of Europe and China, respectively. Currently, about 110 thousand kilometres[7] of the core railway network, as well as urban railway lines, are equipped with the ERTMS system of all levels [8]. The system is operated on the railways of the Western and Eastern Europe, of the countries of the Scandinavian Peninsula, Australia, Asia, and Latin America. The CTCS system has been most actively operated on high-speed highways in China [9]. About 40 thousand kilometres of the Chinese railway network have been equipped with CTCS levels 2 and 3 [10], lower levels of the system are widely used in areas with intensive and predominantly cargo traffic.

ATACS: Japanese Approach to the Implementation of ETCS Level 3

ATACS (Advanced Train Administration and Communications System) is a Japanese version of the interval control system based on the use of digital radio communications. The renouncement to track equipment is justified by the desire both to reduce the cost of installation and maintenance of the system, and to increase reliability of the system due to the frequent cases of damage to track circuits during earthquakes. The system is positioned as a promising replacement for the automatic blocking system both on public lines and on sections of circulation of high-speed Shinkansen trains.

The principle of operation of the system consists in the continuous transmission by trains of information about their positioning and speed over the radio channel. The coordinates and parameters of train movement are determined using onboard track and speed sensors, as well as track transponders. Track transponders are the only equipment that is installed on the track and serve to correct the train coordinate measured by onboard sensors. To avoid accumulation of measurement errors, transponders are installed at intervals of 1 km.

Further, information about the parameters of train movement is transmitted from the onboard equipment to the station control device using digital radio communication. The station control device contains a database on a section of the railway track, which is divided into segments with known coordinates of the beginning and end. Based on the information from the onboard devices, the control of the vacancy of track sections is carried out, and then instructions about the occupied track sections are transmitted to the onboard devices of the trains.

Due to the presence of data on the occupancy of the ahead track section, which are continuously transmitted to the train via a radio channel, locomotive safety devices monitor the distance to the tail of the train in front with adjustment of the maximum allowable speed when approaching and performing a targeted or emergency stopping of the train if necessary [11, 12]. The delineation of trains in the ATACS system is shown in Pic. 3.

The main advantages of the system are reliability and relative cheapness due to the almost complete absence of track equipment. However, now, the widespread use of the system is constrained by the fact that the issues of

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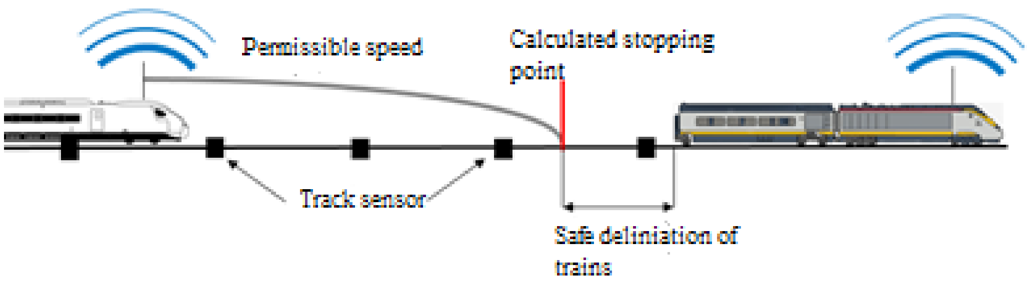
[6] Kessel, C. ERTMS–A reality check. RailEngineer. 2015. [Electronic resource]: https://www.railengineer.co.uk/ertms-a-reality-check/. Last accessed 10.01.2023.

[7] ERTMS Website. [Electronic resource]: https://www.ertms.net/. Last accessed 10.01.2023.



Pic. 3. Delineation of trains in the ATACS system [performed by the authors].

monitoring the integrity and position of cargo trains have not been fully resolved. For the above reasons, although ATACS is positioned as a system for mixed traffic sections, it is used exclusively on passenger train lines.[8] Currently, the system implementation sites are the Senseki and Saikyō lines, the total length of which is 87 km.

PTC: Positive Control Principle

On the US railway network, the use of railway automation has been historically considered as justified only in areas with heavy train traffic, high cargo density, and in case of organising movement of high-speed passenger trains (Amtrak) on them. On a significant part of the railway network, the so-called «dark territory», which is about 40 % of the length of the network, interval control systems are not used at all. The organisation of train traffic is carried out with the help of registered dispatcher orders (the so-called system of timetable and train orders). However, since 2008 [13], in accordance with the order of the US Federal Railroad Administration, all cargo-intense sections, sections with heavy traffic, on which transportation of dangerous goods (class 1 lines) or passenger traffic (Amtrak corridors) is organised, must be equipped with automatic blocking systems based on the PTC (Positive train control) standard [14].

In accordance with this standard, the locomotive must continuously transmit permissive (positive) information about the permissible speed of movement, considering the current speed limits. Auto-blocking systems based on the PTC standard are positioned as a means of preventing unauthorised entering an occupied block, controlling the permissible movement speed, and performing an emergency stop of the train in case of violation of the permissible train movement modes.

Currently, the US railway network uses four PTC systems: I-ETMS, E-ATC, ITCS, ACSES. I-ETMS, E-ATC systems are automatic blocking systems supplemented by an automatic locomotive signalling system. The difference is that in the E-ATC system, the transmission of information about the readings of colour light signals is carried out via the rail circuit, while in the I-ETMS system, extended data transmission through the radio channel is carried out not only about the readings of colour light signals, but also about the permissible speed and current speed limits. The ACSES system is a locomotive signalling system used as an independent instrument of signalling and communication through a radio channel without installing colour light signals at the block section.[9] The ITCS system is an auto-blocking system with virtual block sections: the block is divided into virtual segments loaded into the memory of locomotive devices, the position of trains is controlled using navigation systems, and the permission to occupy the ahead lying virtual block section is an enabling command transmitted over a radio channel. Thus, the ITCS system is essentially a virtual autoblocking, with the transmission of enabling commands to virtual colour light signals via digital radio channel [15].

The list and main functions of the systems are shown in Table 3. The principle of delineation in systems is shown in Pic. 4.

Currently, over 200 thousand km of US and Canadian railways are equipped with I-ETMS

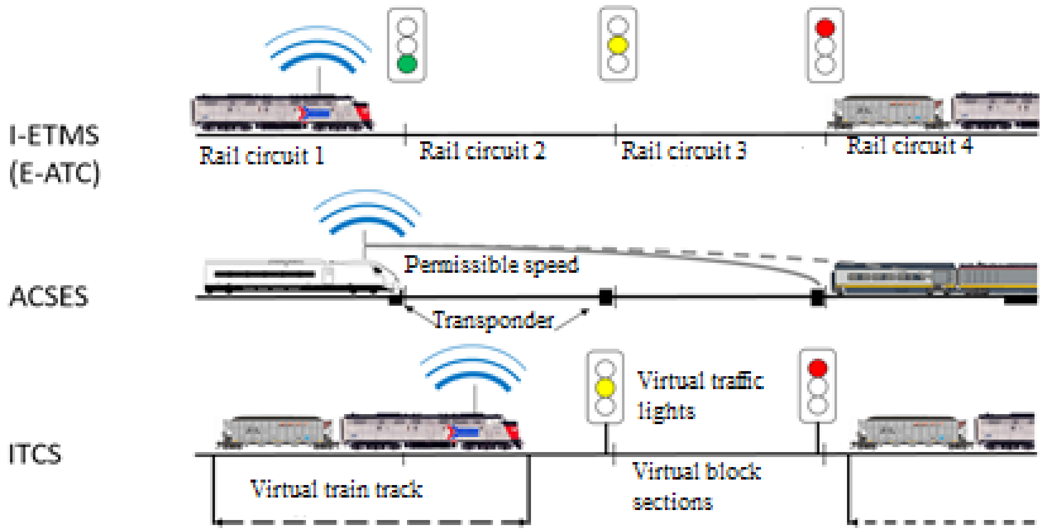
[8] Stacy, M. ATACS–The Japanese Level 3? RailEngineer,2016. [Electronic resource]: https://www.railengineer.co.uk/atacs-the-japanese-level-3/. Last accessed 12.01.2023.

[9] Overview: Positive train control (PTC). Amtrak media brief. [Electronic resource]: https://media.amtrak.com/wp-content/uploads/2018/06/PTC–Media-Brief_June-2018.pdf. Last accessed 12.01.2023.

Table 3

List of systems based on the standard PTC [performed by the authors based on [10]]

System	Signalling type	Method of transmitting information to the locomotive	Locomotive position tracking method	Conditions for using the system
I-ETMS	Colour light signal + ALS	Radio channel	GPS	Lines of class 1
E-ATC	Colour light signal + ALS	Rail circuit	-	Lines of class 2 and 3
ITCS	ALS (virtual block sections)	Radio channel	GPS	Low-intensity sections of railways
ACSES	ALS	Radio channel + rail circuit	Track transponder	Sections for organisation of high-speed passenger traffic



Pic. 4. Delineation of trains in PTC systems [compiled by the authors].

and E-ATC systems. ACSES systems are used on a section of Amtrak's Northeast Corridor (NEC) of a length of 735 km. The ITCS system is currently used in the United States on a 105 km section of the Michigan line.

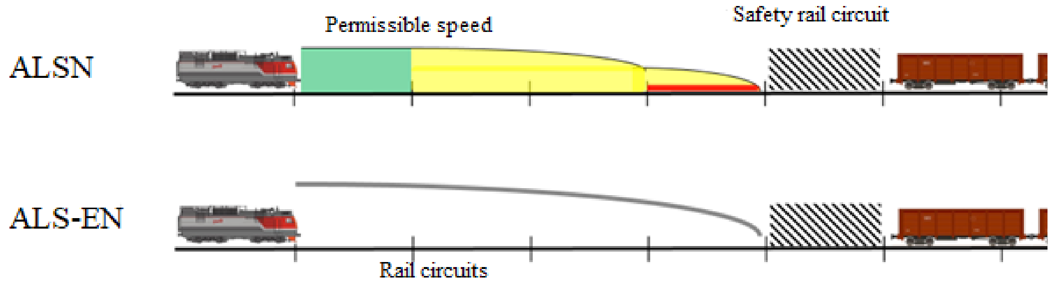
The advantages of the systems used include the relative ease of implementation and operation, since they are based on the already operated auto-blocking systems and the main costs in terms of system implementation relate to modernisation of locomotive safety devices and organisation of a data transmission network over the radio channel.[11] At the same time, the key disadvantages of systems based on the PTC standard refer to the mutual incompatibility of systems [16], the high cost of retrofitting locomotives, and the impossibility of further modernisation in terms of the transition to moving block sections, which significantly hinders development of the system.

ABTS-MSH: Autoblocking with Moving Block Sections for Public Mainlines

The automatic blocking system with implementation of the technology of the moving block section [Russian abbreviation is ABTTs-

[10] Positive Train Control (PTC) in the United States. ITC Signaling Seminar by Robert Burkhardt. [Electronic resource]: https://webinfo.uk/webdocssl/irse-kbase/ref-viewer.aspx?type=&RefNo=1559545879&GroupMembers=%7B03 %20Seminar%20or%20Tech%20Visit%7D%7B08 %20IRSE%20ITC%20paper%7D%7B12 %20Traffic%20Management%7D%7B-16 %20Train%20Prot.%20Systems%7D%7B18 %20Level%20Crossings%7D%7B2A%20Systems%20Engineering%7D_&document=2–3 %20Positive%20Train%20Control%20in%20the%20United%20States%20 %28Robert%20Burkhardt%29.PDF. Last accessed 13.01.2023.

[11] Positive Train Control in the US: A Vital, Complex and Expensive Technology. Railway News [Electronic resource]: https://railway-news.com/positive-train-control-in-the-us-a-vital-complex-and-expensive-technology/. Last accessed 13.01.2023.



Pic. 5. Delineation of trains in the ABTS-MSH system using various ALS systems [compiled by the authors].

MSh that can be adapted for ease of reading as ABTS-MSH] is currently one of the most modern interval control systems used on the Russian public railway network. The main components of the technology are track and onboard devices.

The system of automatic blocking with tonal rail circuits acts as a track equipment without insulating joints or intermediate colour light signal. The movement of trains is carried out according to the signals of automatic locomotive signalling, used as an independent instrument of signalling and communication. On sections equipped with ABTS-MSH, both the traditional ALSN (continuous automatic locomotive signalling) and the more advanced ALS-EN, a digital locomotive signalling system with extended information transmission, can be used. The onboard equipment is represented by the CLUB/BLOCK locomotive safety devices, which control the permissible speed in accordance with the received ALSN or ALS-EN codes.

The delineation of the trains following in the same direction is carried out using a group of non-coded track circuits that form a protective section behind the tail of the train [17]. During train movement, the boundaries of the protective section are shifted by one or more track circuits following the train. The movement of trains in accordance with the received ALS codes is carried out in the «towards the obstacle» mode with construction of a permissible speed curve up to the border of the protective section [18, 19]. The delineation of trains in the ABTS-MSH system is shown in Pic. 5.

Currently, about 1000 km of the network are equipped with this type of automatic blocking. The most significant implementation sites are Bolshoy Lug–Slyudyanka, Zhuravka–Millerovo and the section of Moscow Central Circle (a hybrid system using a radio channel) [20].

The advantages of this system include its versatility, the adaptability to any sections of railways and the ability to significantly reduce the inter-train interval. The disadvantages of the system include the lack of compatibility with most coded automatic blocking systems, as well as the need to update the locomotive safety devices on locomotives of older series to be able to fully enjoy the benefits of moving block technology, which causes a high cost of implementation.

CONCLUSION

Based on the results of the analysis, it can be concluded that the most significant direction of developments in building modern systems for train traffic interval control is gradual reduction in the number of track equipment, primarily colour light signals, as well as the transfer of the information transmission function to locomotive safety devices along with the function of controlling the permissible speed and vigilance of the driver. Another important direction is to increase the amount of critical information transmitted to the locomotive, which increases the need for widespread use of digital radio communications. In accordance with the established trends, the most promising technology is associated with moving block sections.

At the same time, at present, the interval control systems that remain the most common on public railways either rely on previously installed devices of railway automatics or operate in a hybrid format as a combination of track equipment with data transmission over a radio channel. Interval control systems using either moving block sections or exclusively a radio channel are currently limited in scope due to, in some cases, the high cost of implementation and the presence of unresolved technical issues, which hinder their widespread use on public railways.

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