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SELECTED ASPECTS OF THE SELECTION OF DATA SENT TO THE VEHICLE IN AUTOMATIC RAIL VEHICLE DRIVING SYSTEMS

Summary. Intensive pursuit in the introduction of automatic train driving systems, both with and without the driver in the cabin, can be observed around the world. Implementation of such a system allows for an increase in both the safety level of traffic and capacity of railway lines and consequently, an increase in the running frequency of these trains, which is extremely important in large urban agglomerations. One type of automatic train system is the CBTC class, in which a wireless network is used for data transmission. An important issue in the systems of this class is the problem of transferring information from the track to the train about the possibility and method of driving. This article describes the possible ways of sending information from the track to the train. The system of information transmission from track to trains (*SPITP*) was defined and discussed.

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The general characteristics of the CBTC class systems were presented. In Poland, a scientific project which aimed at developing the CBTC class system was recently undertaken. It is called rmCBTC and is being prepared as part of a project carried out by the Rail-Mil Computers Sp. z o. o. from Warsaw and the Faculty of Transport of the Warsaw University of Technology, co-financed by the National Center for Research and Development from the European Union Funds. This article presents the assumptions of the designed system and discusses the scope of data that is necessary in the subsystem of information transfer from the track to the train with the rmCBTC system.

Keywords: rmCBTC, ATP, ATO, ATS, transmission, railway transport

1. INTRODUCTION

Population increase in cities and urban agglomerations places a high demand on its public transport, including rail (subway, urban, suburban and regional railways). Control systems and signalling systems must evolve and adapt to meet the demand and necessary capacity increase. As a result, operators focus on maximising the capacity of railway and metro lines.

The introduction of automatic driving systems is associated with increasing safety [3] of railway traffic in both urban and regional transport. These systems exclude the train driver's participation, thus, eliminating human errors. In addition, it also allows the increase flow and capacity of the railway line. Greater traffic flow results in less energy and electricity consumption.

Currently, worldwide in 19 countries and 42 cities, similar systems of automatic control of subway trains are operated. The total length of the lines on which these vehicles move is currently around 1000 km and includes 63 metro lines. Fig. 1 shows a map with selected cities in which automated train driving systems are active.

Fig. 1. Cities with automated metro lines as of 2013 [9]

The introduction of the automatic metro train control system is associated with a significant amount of design, concept and system assumptions which take into account legal regulations that are defined by IEEE standards (Standards for the Communication-Based Train Control system), on the basis of generality and recommendations. The final element of a conceptual work is the process of certification and implementation of such solutions. In the initial phase, it requires interference in the construction of selected metro trains. Similar solutions for automatic driving are used in the European Train Control System (ETCS) level 3. It should be noted that the solution being studied is under development and has not yet been implemented in any country.

2. CHARACTERISTICS OF INFORMATION TRANSMISSION IN A TRAIN-TRACK RELATION

An important issue that arises when making decisions about the implementation of an automatic train driving system is the challenge of passing commands to the train. This transfer can be implemented in many ways [2]:

– point method (the train upon hovering over the device transmitting the information, receives the information and then initiates the appropriate train driving procedures , it should be noted that the transmitted information is constant and unchanged over time).
– section method (in the track on a given section, the train detection devices are installed (where the individual sections are not connected) and a continuous sectional transmission is carried out from track to train).
– continuous method (in the track sections along its entire length, train detection devices are installed (where the individual sections are connected) and a continuous sectional transmission is carried out from track to train).

Therefore, an important issue when implementing the automatic train system is the transmission of information from the track to the train on how to drive the train. Thanks to the use of such a system of information transmission, the level of traffic safety is increased, and a significant increase in the capacity of the analysed railway line is achieved. This is realised by transferring information about the track to the train [2]:

– status of signalling devices, which allows the driver to implement the proceeding scenario in advance (both in terms of shortening and lengthening the driving times, which has a direct impact on the capacity of the railway line).
– driver status (checking if the driver has not fainted or is vigilant enough).
– the maximum permitted speed on a given section and the possible activation of devices to limit the speed if exceeded.
– the possibility to start driving after a standstill at the platform and self-actuation of drive devices.
– necessity to stop the vehicle at the designated place (for example, at the platform).
– confirmation of precise stopping of the train at the designated place and releasing the door lock.
– the exact location of the train.
– other matters.

The system of transmission of information from the track to the train (*SPITP*) can be presented as follows:

$$\boldsymbol{SPITP} = \langle \boldsymbol{EPITP}, \boldsymbol{RPITP} \rangle \tag{1}$$

where:

EPITP – a set of elements related to the transmission of data from the track to the train, whereby:

$$\boldsymbol{EPITP} = \boldsymbol{ETPITP} \cup \boldsymbol{EPPITP} \tag{2}$$

ETPITP – a set of track elements related to the transmission of data from the track to the train ($ETPITP = \{etpitp\colon\ etpitp \in \mathbb{N}\}$).

EPPITP – a set of train elements related to the transmission of data from the track to the train ($EPPITP = \{eppitp\colon\ eppitp \in \mathbb{N}\}$).

RPITP – a set of relations connecting elements of the system with each other, as well as elements within the system's environment, which can be defined as follows:

$$\boldsymbol{RPITP} \subset \boldsymbol{EPITP} \times \boldsymbol{EPITP} \tag{3}$$

Thus, the relation combines elements from the set (*EPITP*) and is formulated in the form of a Cartesian product. The relation that exist in the track to train information system (*SPITP*) may be formulated as follows:

- $RPITP_1$ – a relation connecting two track system elements:

$$\boldsymbol{RPITP}_1 \subset \boldsymbol{ETPITP} \times \boldsymbol{ETPITP} \tag{4}$$

$$\boldsymbol{RPITP}_1 = \{(etpitp, etpitp)\} \tag{5}$$

- $RPITP_2$ – the relation connecting two elements - the track system and the on-board element of the system:

$$\boldsymbol{RPITP}_2 \subset \boldsymbol{ETPITP} \times \boldsymbol{EPPITP} \tag{6}$$

$$\boldsymbol{RPITP}_2 = \{(etpitp, eppitp)\} \tag{7}$$

- $RPITP_3$ – the relation connecting the on-board element of the system and the track element of the system:

$$\boldsymbol{RPITP}_3 \subset \boldsymbol{EPPITP} \times \boldsymbol{ETPITP} \tag{8}$$

$$\boldsymbol{RPITP}_3 = \{(eppitp, etpitp)\} \tag{9}$$

- $RPITP_4$ – the relation connecting two on-board elements of the system:

$$\boldsymbol{RPITP}_4 \subset \boldsymbol{EPPITP} \times \boldsymbol{EPPITP} \tag{10}$$

$$\boldsymbol{RPITP}_4 = \{(eppitp, eppitp)\} \tag{11}$$

The set of track elements related to the transmission of data from the track to the train (*ETPITP*) contains the following elements [2]:

- *etpitp* = 1 – device track.
- *etpitp* = 2 – device reading the information from the track device.
- *etpitp* = 3 – device coding the information from the track device.
- *etpitp* = 4 – transmitter of information from track device.
- *etpitp* = 5 – transmission system.

The set of train elements related to transmission of data from the track to the vehicle (*EPPITP*) contains the following elements [2]:

- *eppitp* = 1 – transmission system.
- *eppitp* = 2 – receiver of information from the track device.
- *eppitp* = 3 – device coding the information from the track device.
- *eppitp* = 4 – cabin devices displaying information from the track device.

- *eppitp* = 5 – speedometer reading the value of vehicle speed from the wheel.
- *eppitp* = 6 – devices controlling the driver's work.
- *eppitp* = 7 – braking system.
- *eppitp* = 8 – starting system.
- *eppitp* = 9 – driver.

Many types of data can be transmitted using the elements of the track-to-train (*SPITP*) communication system. Examples include [7], [14], [16], [17]

- data on the location of the train (beginning and end of the train).
- speed data for a given section of the railway line.
- data concerning the direction of a given train.
- information intended for the conductor and the driver (regarding the state of the door in the train and on the platform (closed/open/damaged), the correct stopping position in the platform).
- data on the status of track-side devices transmitting data from the track to the train.
- data on the status of stationary devices of the automatic train driving system.
- data regarding the previous vehicle - its location and its state.
- information whether the train is in an area equipped with automatic train driving system devices or not.
- data regarding transmission delays.
- data on the course performed by the train (for example, riding on a track terminated with a stopper).
- data regarding the indications of trackside signallers.
- data regarding orders relating to train running (setting up an additional stop at the station, introduction of an additional speed limit).
- details on the continuity of the train.
- data on entry into the track work area.
- data on the occurrence of rail rupture.
- data on the status of track crossings.
- data on driver's driving style for energy consumption.

In addition, the track to vehicle information transfer system (*SPITP*) can be integrated with the passenger information system, both vehicle and platform system [8], [122]. Using the *SPITP* system, it is possible to deliver and display relevant messages at any given moment, which are directed to passengers. The *SPITP* system can also be integrated with systems such as:

- electric traction [4], [188].
- tunnel and station ventilation.
- security.
- communication.

The integration allows for sending relevant data to the train using the track to train information transfer system (*SPITP*) and calling appropriate on-board equipment operations. One class of automatic train driving systems in which it is necessary to send information from the track to the train is the CBTC class systems.

3. CBTC SYSTEMS CHARACTERISTICS

CBTC is a rail signalling system that uses telecommunications between the train and trackside devices for traffic management and infrastructure control. The CBTC system is a "continuous, automatic train control system" that uses, among others: determination of the position of a high-resolution train, continuous and fast bidirectional transmission of data from the track to the train [5], [6]. The Automatic Train Driving System ATC (Automatic Train Control), can consist of three subsystems [11], [15]:

- ATP – Automatic Train Protection.
- ATO – Automatic Train Operation.
- ATS – Automatic Train Supervisory.

The ATP system automatically limits the speed of the train to the value guaranteeing safe driving, it also protects against collisions and negligence by the driver to the "stop" signal on the traffic light. In the case of a driver's erroneous actions, the ATP system shall initiate service or emergency braking causing the train to stop. The ATO system plays the role of "autopilot", realising the automatic regulation of the train speed while ensuring the scheduled time of train travel between stations. The system through its interfaces, controls the train drive as well as the braking system, adjusting the speed to the traffic situation.

The ATS system controls the operation of signalling, locates all trains and displays relevant data in the traffic control centre [11]. Fig. 2 shows CBTC onboard devices, including the ATP and ATO subsystems in the train.

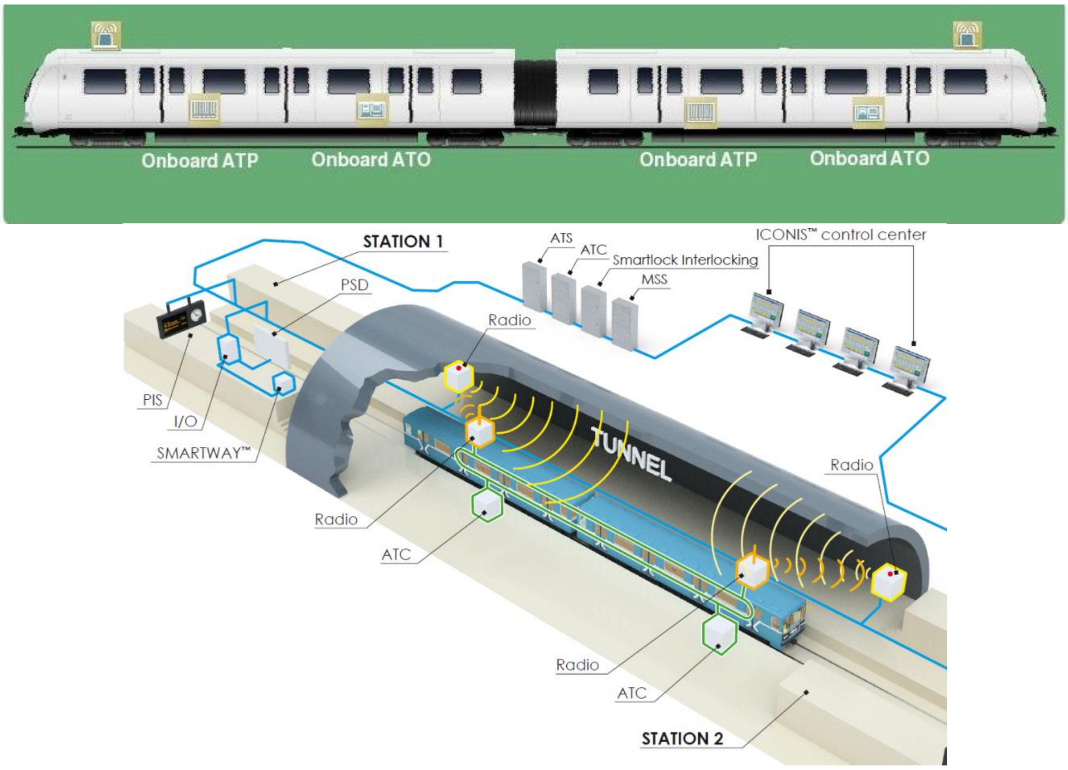

Fig. 2. CBTC on-board equipment, including the ATP and ATO subsystems in the vehicles [6]

In metro systems, automation refers to a process in which the responsibility of the train's operation management is transferred from the driver to the train control system. There are various degrees of automation (GoA - Grades of Automation) as defined in the standard [15]. For example, the 4th degree of automation refers to a system in which vehicles are wholly automatically started without onboard maintenance personnel. Figure 3 presents the division stages of automation and the connection of the automation stages with the operation of individual subsystems.

Grade of Automation	Type of train operation	Setting train in motion	Stopping train	Door closure	Operation in Event of Disruption
GoA 1	ATP with driver	Driver	Driver	Driver	Driver
GoA 2	ATP, ATO with driver	Automatic	Automatic	Driver	Driver
GoA 3	Driverless	Automatic	Automatic	Train attendant	Train attendant
GoA 4	UTO	Automatic	Automatic	Automatic	Automatic

Fig. 3. Grades of automation and linking of the grades of automation of individual subsystems [9]

4. ASSUMPTIONS OF THE rmCBTC SYSTEM FOR DATA TRANSMISSION

As previously mentioned, when implementing the automatic train driving system, it is very important to provide information from the track to the train about the possibility and manner of driving. This issue is one of the topics considered in the project implemented by Rail-Mil Computers Sp. z o. o. from Warsaw and the Faculty of Transport of the Warsaw University of Technology. The aim of the project is to develop an automatic CBTC train driving system, using a unique combination of a two-way wireless data transmission and components of the interoperable ETCS rail system, increasing the level of efficiency and safety of the agglomerate rail transport. The project is implemented as a part of the Smart Growth Operational Programme and is co-financed by the National Center for Research and Development. Work on the project began in 2017 and will be finished by 2020.

The most important components that will be involved in the transmission of data from the track to the train are rmMAC (central movement authority computer) and rmATO (automatic train operation). Communication between the permit and vehicle will be carried out using a fibre-optic communication system and secure communication via WiFi and radio access points. It should be emphasised that the permit for driving depends on a number of data provided by the WT UZm dependency devices (via the WT GSS interface) that support the control of occupancy of track sections, switches and signalling devices both at the stations and lines.

Permission to drive in automatic mode will be the basis for the rmATO system, whose basic functions are [1]:

- switching the engines on and off.
- switching the brakes on and off.
- regulation of the driving force.
- braking force regulation.

Therefore, it would be required to enter the necessary data for proper operation into the rmATO system. It should be noted that in addition to the basic data, additional data on the occurrence of an emergency situation (unforeseen situation of detecting an object in the danger zone) will be sent to the system.

In order for the central rmMAC driving computer to permit driving for a given train, the data from the trackside equipment has to be sent to that computer [16]:

- information on the status of a given track sections occupancy.
- information on the location of the rail crossovers.
- information on the signaller's indication.
- information about the travel railroad.
- information about a fixed direction of travel.
- information on the existence of objects in the danger zone.

The second component of the rmCBTC system, which receives data from the trackside devices, is the train automatic driving system, rmATO. This system will receive the following set of input data [**Błąd! Nie można odnaleźć źródła odwołania.**6]:

- information on the status of a given track section's occupancy.
- information on the signaller's indication.
- information on the maximum permitted speed on a given track section's of the railway network.
- information on the location of platforms.
- information about the need to stop at a specific station.
- information about temporary voltage decay in the traction network.
- information about the loss of transmission between the track and the train.

5. SUMMARY

Intense efforts to implement automated train driving systems can be observed all over the world. Some countries decide to introduce the system in a variant where the driver is present on board the train. Other countries choose the variant where the driver is absent. Therefore, it is necessary to ensure the highest level of traffic safety, especially when it is carried out without the presence of a driver. The introduction of automatic train driving systems has one more important advantage; it enables increase of the capacity of the railway lines, and thus, increase the running frequency, which is extremely important in large urban agglomerations.

One of the classes of automatic train driving systems is the CBTC class. The most important element of the CBTC class system is data transmission using the wireless WiFi network. In Poland, work has been undertaken to develop such a system. It is called the rmCBTC and is being prepared as part of a project carried out by Rail-Mil Computers Sp. z o. o. from Warsaw and the Faculty of Transport of the Warsaw University of Technology, co-financed by the National Center for Research and Development from the European Union Funds. Ultimately, the prototype of the system will be set-up in the Warsaw Metro on the Alstom Metropolis 98B vehicle.

As previously mentioned, an important issue of the CBTC class systems is the transfer of information from track to train. The article presents elements constituting the track to train information transfer system (*SPITP*) and discusses the data ranges that are necessary in the subsystem of information transfer from the track to the vehicle of the rmCBTC system. The range of the data leads to the conclusion that due to the implementation of the rmCBTC system, traffic will be conducted in a safe manner and an increase in the capacity of the Warsaw metro line.

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