DIAGNOSTYKA, 2023, Vol. 24, No. 3

e-ISSN 2449-5220
DOI: 10.29354/diag/168655

TRAIN DETECTION METHODS AS THE FOUNDATION OF POSITIONING SYSTEMS OF RAILROAD TRAFFIC CONTROL

Michał STEUER [1], Martin KRZYKAWSKI [1], Dawid SIMIŃSKI [1], Wongelawit CHEMA [1], Rafał BURDZIK [2,*]

[1] Silesian University of Technology, Doctoral School, Akademicka 2a, 44-100 Gliwice, Poland
[2] Silesian University of Technology, Faculty of Transport and Aviation Engineering, Krasińskiego 8, 40-019 Katowice email:
[*] Corresponding author, e-mail: rafal.burdzik@polsl.pl

Abstract

Detection of the current location of rail vehicles in the railway infrastructure network determines the safety, efficiency and reliability of rail transport. In addition, it indirectly affects the safety at rail-road crossings, i.e. also the BRD (Road Safety). In terms of efficiency and reliability of transport systems, the ability to detect a moving vehicle can improve the effective capacity of railway lines. As in the case of technical diagnostics, effective recognition of the current state of the transport network determines the efficiency of the transport system. The development of railways, with particular emphasis on high-speed railways, makes it necessary to modernize and improve railway traffic control devices and systems. A special area of development, ensuring the safe and effective use of rail transport, is the detection and location of rail vehicles moving on the railway infrastructure. The ability to determine the precise location of a rail vehicle is a key element in the reliable operation of rail transport. Therefore, in the field of devices and systems for the detection and location of rail vehicles, many studies and analyzes are carried out to develop existing or create new solutions dedicated to positioning rail vehicles.

Keywords: rail transport, detection, location, positioning, rail traffic control

List of symbols/acronyms
GNSS – Global Navigation Satellite System;
GSM-R – GSM for Rail;
ERTMS – European Rail Traffic Management System;
ETCS – European Train Control System.

1. INTRODUCTION

General methods and principles of technical diagnostics strongly refer to the full identification of the symptom-condition relationship [1]. A proper description of these relationships enables the creation of diagnostic models that can also be used for prediction [2]. As a result, there are opportunities to create dedicated devices and diagnostic systems [3]. This approach can be transferred to other applications. The article shows what are the possibilities of detecting a moving rail vehicle, what systems are currently used and how it determines the proper functioning and safety of the rail transport system. One of the most important functions in rail traffic control devices and systems is the detection and location of rail vehicles. The above causes that from the beginning of the railway's operation, efforts were made to develop devices dedicated to these functions in order to obtain the most accurate detection and positioning of rolling stock in the area of railway infrastructure.

The initial approach to the location of rolling stock consisted in determining the presence (occupancy) of a given route or station track by a rail vehicle. In the further development of vehicle detection and location, efforts were made to determine the direction of movement and to determine the deceleration of a given section by the entire fleet, e.g. by counting the axles of a vehicle entering and leaving a given area.

Despite the obvious benefits of using devices that meet the above requirements. These functions, the development of railways forces further development of rail vehicle detection and location systems, entering new areas, so far not used in railway traffic control devices.

2. CURRENTLY USED DEVICES FOR DETECTION AND LOCATION OF RAIL VEHICLES

In the current approach to detecting rail vehicles by means of railway traffic control devices, devices for controlling the vacancy of tracks and turnouts are

Received 2023-06-17; Accepted 2023-07-07; Available online 2023-07-09

used. These devices continuously transmit information about the occupancy status in the area of tracks and turnouts to which they are assigned. This method of controlling the occupancy of the track infrastructure has a number of limitations that significantly affect the operational parameters of the railway line equipped with this type of device.

Currently, the development of rail vehicle detection and location technology is focused on the possibility of continuous tracking of moving rolling stock. For this purpose, research and analysis of various technologies enabling real-time tracking of rail vehicles are carried out.

2.1. Isolated track circuits

An isolated track circuit consists of a transmitter in the form of a power source and a receiver in the form of a track relay, which is connected to part of the track. A separate part of the track closes between the so-called insolated joints and is called an isolated section.

In an isolated track circuit, the vacancy of a section is determined by the flow of a signal current in the insolated section. When the section is run over by a rail vehicle, the circuit is shorted by the wheelsets and the track relay is de-excited, thus signaling the occupation of a given insolated section.

The use of isolated track circuits, apart from controlling the vacancy of tracks and turnouts, also allows to signal possible damage to the rails, e.g. cracks, which means that the functioning of these devices is strongly related to the condition of the track.

2.2. Jointless track circuits

Jointless track circuits are also called open track circuits. They differ from isolated circuits in that the circuit is closed only after the section is driven over by a rail vehicle, which causes the track relay to be activated and the section occupied to be signaled.

Track circuits without connectors do not allow to signal damage to the rail course, however, they are characterized by fast operation and low energy consumption compared to isolated circuits.

2.3. Counter track circuits

In countering track circuits, the function of detecting a passing rail vehicle is performed by the so-called wheel sensor. The phenomenon by means of which the presence of a circle is determined consists in detecting a change in the magnetic field by a magnet with a wound coil winding. There are two pairs of such systems in the meter housing, thus it is possible not only to determine the presence of a rail vehicle, but also to determine the direction of movement.

The use of counter track circuits is exposed to many factors that may interfere with the proper functioning of the sensor. To ensure proper operation of the sensor, it is necessary to define standardized parameters to ensure proper operation of wheel sensors within devices used around railway infrastructure [4].

Wheel sensors in railway traffic control devices are currently the most common devices for monitoring the occupancy of tracks and turnouts.

3. AREAS OF RESEARCH AND DEVELOPMENT OF RAIL VEHICLE DETECTION AND LOCATION SYSTEMS

The development of rail transport, with particular emphasis on the increase in the operational speed of the moving rolling stock and the increase in the efficiency of the flow of people and goods by optimizing the capacity of railway lines, forces systems dedicated to managing and controlling rail traffic to implement new and innovative technologies in the field of detection and location of rail vehicles. In order to meet the above, many researches and analyzes are currently being carried out in the areas of various scientific fields aimed at creating new or improving existing rolling stock detection and location technologies on the railway market. In addition, the ability to accurately locate the rail vehicle in real time is important from the level of rail traffic management. Fulfillment of the above improves the process of rail traffic management in a given area, as well as enables optimization of the entire rail transport in the area of a given country or community of countries.

3.1. Passive radar technology

Intensive development of the GSM-R system as the main communication protocol for specialized services for railways in the form of voice and data transmission has potentially contributed to the expansion of the area of application of passive radar technology on railway lines. The technology of location of rail vehicles with the use of passive radar can be a kind of potential supplement to the GSM-R radio infrastructure that allows to determine the position and speed of rail vehicles on each section of the railway network being coverage of GSM-R [5].

Passive radar does not have its own transmitter, but only uses commercial transmitters available in the area of its coverage, which are built in the so-called GSM-R system. base stations. By using a radar with a high resolution of several meters, it is possible to locate a rail vehicle in space, as well as to track the object in terms of the speed at which it moves [6]. The above features of the passive radar technology, combined with the use of the existing infrastructure of the GSM-R system, make it possible to build economical solutions for the detection and location of rail vehicles on railway lines.

3.2. Positioning using satellite navigation

The positioning method using satellite navigation is based on the measurement of the wave propagation time. For this purpose, the measurement of the signal from three satellites is used and through the so-called triangulation determines the position of the localized object. Among the most widespread global navigation systems, the American GPS (Global Positioning System), the European Galileo, the Russian GLONASS and the Chinese BeiDou [7].

However, despite the wide availability of various navigation systems, the current approach to the use of satellite navigation in railway traffic control applications has been treated with some reserve. The reason for the above is primarily a different nature of the use of satellite navigation compared to air transport, where the propagation of the satellite signal is not exposed or to a limited extent exposed to signal loss resulting from various engineering structures located along the railway line, terrain or interference resulting from the accompanying infrastructure [8].

Another aspect of limiting the development of rail traffic control systems based on GNSS is that the currently used systems have a strictly defined architecture, which depends on applicable regulations, guidelines and standards as well as accepted standards resulting from traffic management in the current form. The solution to the above turned out to be the implementation of the European ETCS train control system, whose specificity of operation and system architecture show the possibility of using satellite navigation to locate rail vehicles. The analysis of ETCS integration with GNSS systems is the area of many studies aimed at confirming the fulfillment of safety and efficiency conditions in rail transport [9].

3.3. Magnetoresistive sensors

Among the modern solutions for the detection of rail vehicles, one should distinguish technologies magnetic field detection by magnetoresistive sensors.

The conducted research proved the possibility of using the sensors in question in the infrastructure dedicated to high-speed railways. As it has been proven, this technology allows not only vehicle detection, but also measurement of speed, length and number of moving rolling stock.

Train detection by magnetoresistive sensors consists in measuring changes in the electromagnetic field caused by a passing train in the place where the sensor is installed.

An important feature characterizing the sensors in question is the independence of the train detection function from the condition of the track infrastructure. The above excludes such limitations as rust or humidity, which cause difficulties or errors in the detection of rail vehicles [10].

3.4. Accelerometer

The above points of this chapter present technologies enabling the location of a rail vehicle along with tracking its location. However, not all areas of rail transport require precise train positioning. An example of such a place can be any area on a railway line where, for example, maintenance works are carried out by a team of employees.

For the example above, it is not required to know the exact location of the rail vehicles. In order to ensure safe work, it is necessary to inform that a rail vehicle is approaching the area where employees are located. One of the possible solutions is the installation of an accelerometer in the track where some activities are carried out, e.g. maintenance.

The accelerometer, combined with a dedicated analog-digital converter with the required resolution, processes the signal from the accelerometer and informs about the approach of the rail vehicle. The above solution makes it possible to detect the passage of a train at a distance of about 1 km from the installation site of the device [11].

3.5. Train detection system based on image analysis

The widespread use of cameras in every field opens up many new possibilities for their use. An example may be systems dedicated to measuring traffic volume along with detecting traffic jams and determining the length of these jams. The presented functionality in traffic engineering applications is highly desirable, but obtaining such data from image analysis is a highly complex process due to many factors affecting the correct interpretation of the image from the camera by the system analizy [12].

In rail transport, the use of cameras is also widespread and used, for example, to determine the end of a train or to record events at rail-road crossings. Another area of potential use of cameras on railway lines may be image analysis for the purpose of detecting and locating rail vehicles. The most common detection issues in the literature concern the detection of objects on the track on which the train is moving. However, using image analysis in conjunction with a set of data on railway line parameters such as characteristic points, objects and other recognizable elements implemented in the system, it is possible to recreate the train trajectory and the position of the detected object in the metric dimension [13], and thus the location of the rail vehicle. This solution is not a direct method of locating the vehicle, but only a supplement to the assumed functions of the presented solution.

3.6. Acoustic train detection system

Undesirable noise is an inherent characteristic of any form of transport. Striving to reduce noise is one of the key projects implemented by enterprises and research units dealing with broadly understood transport, including rail transport.

However, despite the fact that there is a desire to reduce the noise generated by a passing train, it is possible to use noise to detect an approaching train. This function is performed by acoustic train detection systems. These systems analyze the frequency components of audio signals picked up by a lineside microphone. Then, based on frequency component models, the system analyzes the recorded noise and assesses the probability of a train passing in a given area covered by the acoustic system [14].

The acoustic train detection system, like magnetoresistive sensor technology, is not dependent on the condition of the track infrastructure. However, this system is strongly dependent on the environmental conditions related to the ambient noise in which it is to operate, which necessitates the development of many acoustic models and training the system for precise detection of the approaching rail vehicle.

4. ERTMS / ECTS DEVICES

Railway traffic control devices, depending on the types of signaling, are very diverse. In many cases, infrastructure managers are outdated. As a consequence, obsolete rail traffic control devices affect the capacity and safety of rail transport. This fact forced the introduction of a unified ERTMS/ECTS rail traffic control system.

The European Train Control System (ECTS) is to provide cab signaling and control of the driver's work to increase the level of safety. The ECTS system uses digital data transmission, which depends on the level of Eurobalise, Euro-loops, GSM-R radio communication and STM modules that enable downloading data on national solutions. This allows information such as maximum train speeds to be transmitted. This solution can illustrate the situation on the railway line, on the control panel in the traction vehicle, and not only on the semaphores along the railway line, as is currently the case on most railway lines in Poland [15].

The European rail traffic control system ERTMS / ECTS is a European solution with an international range for long-distance trains that most often cross-national borders. This solution is also part of the description of technical specifications on railway interoperability for telematic applications in rail transport TAF / TAP TSI. The operation of the ERTMS / ETCS system includes the following elements:

- ATC Automatic train control features;
- Traffic management features.

ERTMS assumes standardization of the process and consists of:

- European Train Control System ECTS;
- GSM / GSM - R, radio transmission system;
- Traffic, train and signaling management system;
- Standardization of European railway regulations for the needs of the ERTMS/ECTS system.

The introduction of the described system is aimed at ensuring the interoperability of high-speed lines throughout Europe, as well as standardization of rail traffic control systems, lowering operating costs, increasing the capacity of individual railway lines by reducing the system switching time and work on a moving block. A very important element is to increase the global safety of rail vehicles in rail transport. The figure below shows the Human-Machine Interface in terms of the ERTMS system [16].

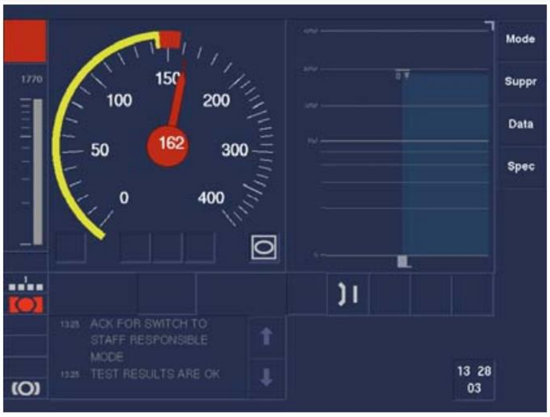


Fig. 1. Human-machine interface for the ERTMS system [16]

Within the framework of European directives and technical specifications on railway interoperability, TSI, as well as functional requirements of the FRS, the functions of the ECTS system have been defined. [16] ECTMS can operate in 3 levels. Level 1 has the least continuous update than level 2, because the higher level already has a continuous update of the railway traffic. In the highest level 3, the train monitors its position continuously using, among other things, the "moving block" technology. In level 1, the train clear signal is updated discreetly when the traction vehicle passes the Eurobalise. Therefore, the level 1 system requires signals to detect the occupancy of a track section on a particular railway line. The on-board computer of the EVC locomotive constantly monitors the situation and, based on the collected data, calculates the braking curve and the maximum speed of the train. Fig. 2 [17].

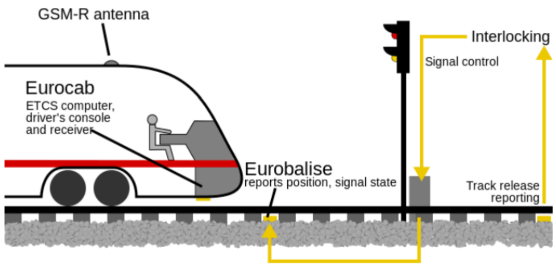


Fig. 2. Visualisation of ERTMS/ECTS Level 1 performance [17]

The ERTMS / ECTS level 2 system uses the RBC radio block signal using the GSM-R network. In addition, it is required to be able to detect the occupancy of a railway line section using axle counters, and balises are used to transmit messages such as speed limits, train location 3 [17].

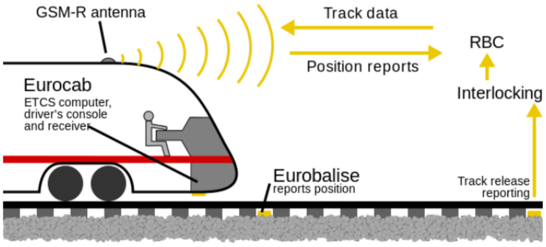


Fig. 3. Visualisation of ERTMS/ECTS Level 2 performance [17]

The last level of the ETMS/ECTS system is level 3. It also has continuous control of the traction vehicle. An important difference at this level is the lack of fixed blocks, which are monitored by axle counters or track circuits. In this way, a running train creates its own block. This solution allows to increase the capacity of a given section of the railway line equipped with the ERTMS/ECTS system. In this case, the position of the train is reset by the Eurobalises and the odometer in the traction vehicle, and this information is sent to the central control Fig. 4 [17].

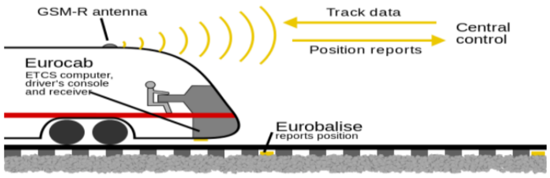


Fig. 4. Visualisation of ERTMS/ECTS Level 3 performance [17]

Differences between the functionality of ERTMS/ECTS systems at levels 1, 2, 3 are presented in table 1.

Table 1. Differences between levels of ERTMS/ECTS systems [17]

	LEVEL 1	LEVEL 2	LEVEL 3
Minimum block length	Short	Short	No blocks
Communication	Discrete	Continuous	Continuous
Signal visibility	Usually needed	Not needed	No signals
Train detection in track	Needed	Needed	Limited
Train integrity	Not needed	Not needed	Crucial
Position known	Block section	Block section	Exact position
Gap in communication	NO	Possible	Possible

5. IMPACT OF ERTMS / ECTS DEVICES ON THE CAPACITY OF RAILWAY LINES

The implementation of the ERTMS/ECTS system in accordance with the TSI guidelines not only affects safety, but also improves the throughput of railway lines, depending on the level used. The higher the level of ERTMS/ECTS used, the higher the capacity of the railway line section. Higher levels of ERTMS/ECTS lead to higher capacity and this is well explored in the UIC charters. These relationships can be seen in Fig. 5 [18].

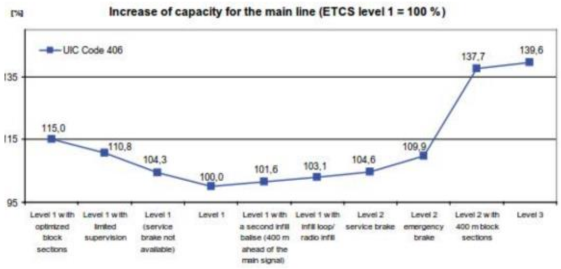


Fig. 5. Impact of different ETCS levels online throughput according to UIC [18]

As it can be seen, different use of the ERTMS/ECTS level can achieve a different impact of these parameters on the capacity of the infrastructure. Communication has the greatest differences in system levels and their impact on throughput. The higher the level of the ERTMS/ECTS system used, the better the communication between the traction vehicle (train) and the signaling system on the railway line. Differences in communication between system levels can be seen in Table 2 [18].

Table 2. Differences in communication between ERTMS/ECTS levels [18]

	LEVEL 1	LEVEL 2	LEVEL 3
Communication between train and infrastructure	Line Electronic Units and Eurobalises	Eurobalises and RBC	Eurobalises and RBC
Role of Eurobalise	Position and signal state	Position	Position
Location of train	Track detection equipment	Mainly track detection equipment	Position infromation from train
Movement Authority Radio	From Eurobalise Voice	From RBC Voice and data	From RBC Voice and data

Differences in communication and increased positional accuracy, plus the common integrity of ERTMS/ECTS Level 3, makes it possible to move around the block, which shortens train intervals. The situation of different travel times for different speeds and different levels of the ERTMS/ECTS system is shown in Fig. 6 [18].

Depending on the speed, there are different travel times for different levels of the ERTMS/ECTS system. Hence, at level 1, optimal travel times occur when the braking distance is equal to the blocks in the braking distance of the train. When lag times are not taken into account, system delays are not taken into account for levels 1 and 2. If we want to talk about the optimal speed of the train, we can talk about it when the minimum travel time is the shortest [18].

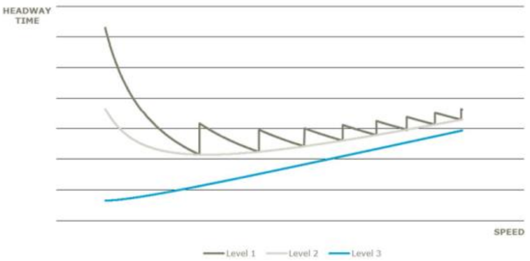


Fig. 6. Travel times for different speeds and ERTMS levels [18]

6. CONCLUSIONS

In the era of developing rail transport, the issue of safety is important. The development of train detection and detection equipment is very important [19]. This allows not only to achieve a high safety index. The extension of the European infrastructure with modern location and detection systems also allows for increasing the throughput of railway lines. This will allow you to achieve a faster speed, and consequently shorten the delivery time to the customer [20]. This is a very important aspect, in particular when it comes to the competitiveness and attractiveness of rail transport in relation to road transport.

The article presents the dynamic development in the area of rail vehicle detection systems and their positioning in the transport network. Selected issues, including throughput, are also presented, which are strongly determined by the possibilities of train detection. It should also be emphasized that there are many targeted studies. Some previous studies of selected authors focused on innovative methods of vehicle detection and positioning in the railway network [21, 22].

Author contributions: *research concept and design, M.S., R.B.; Collection and/or assembly of data, M.S., M.K., S.D.; Data analysis and interpretation, M.S., S.D., W.C.; Writing the article, M.S., M.K.; Critical revision of the article, W.C., R.B.; Final approval of the article, R.B.*

Declaration of competing interest: *The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.*

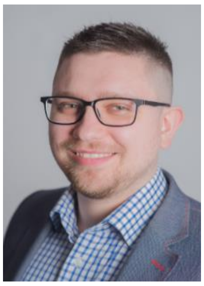
REFERENCE

1. Natke HG, Cempel C. Model-aided diagnosis of mechanical systems: Fundamentals, detection, localization, assessment. Springer Science & Business Media; 2012. https://doi.org/10.1007/978-3-642-60413-3.
2. Dąbrowski Z, Zawisza M. Diagnostics of mechanical defects not recognized by the OBD system in self-ignition engines. Silniki Spalinowe; 2011;50(3).
3. Li X, Su K, He Q, Wang X, Xie Z. Research on fault diagnosis of highway Bi-LSTM based on attention mechanism. Eksploatacja i Niezawodność – Maintenance and Reliability. 2023;25(2). https://doi.org/10.17531/ein/162937
4. Yudhistira Y, Yoppy Y, Trivida E, Wahyu Wijanarko TA, Nugroho HW, Mandaris D. Electromagnetic interference measurement for axle counters light rapid transit railway in Indonesia. Int J Electr Comput Eng (IJECE); 2022;12(5):4632-4639. https://doi.org/10.11591/ijece.v12i5.pp4632-4639.
5. Chetty K, Che, Q, Woodbridge K. Train monitoring using GSM-R based passive radar. IEEE Radar Conference; Philadelphia, PA; USA; 2016:1-4. https://doi.org/10.1109/RADAR.2016.7485069.
6. Kulpa K, Malanowski M, Misiurewicz J, Samczynski, P. Passive radar for strategic object protection. IEEE International Conference on Microwaves, Communications, Antennas and Electronic Systems (COMCAS 2011); Tel Aviv; Israel; 2011:1-4. https://doi.org/10.1109/COMCAS.2011.6105922.
7. Marais J, Beugin J, Berbineau M. A survey of GNSS-based research and developments for the European railway signaling. IEEE Transactions on Intelligent Transportation Systems, 2017;18(1):2602-2618. https://doi.org/10.1109/TITS.2017.2658179.
8. Jonáš, M. GNSS integrity for railway transportation. Transactions On Transport Sciences, 2011;4(4):183-192.
9. Himrane O, Beugin J, Ghazel M. Toward formal safety and performance evaluation of GNSS-based railway localisation function. IFAC Pap; 2021; 54(2); 159-66. https://doi.org/10.1016/j.ifacol.2021.06.049.
10. Zhang S, Lee WK, Pong PT. Train detection by magnetic field sensing. Sensors and Materials; 2013; 25(6):423–436.
11. Angrisani L, Grillo D, Schiano L, Moriello R. Automatic detection of train arrival through an accelerometer. Instrumentation & Measurement Technology Conference Proceedings; Austin, 2010: 898-902, https://doi.org/10.1109/IMTC.2010.5488089.
12. Zanin M, Messelodi S, Modena C. An efficient vehicle queue detection system based on image processing. 12th International Conference on Image Analysis and Processing; Proceedings. Mantova, Italy; 2003;232-237.
13. Fioretti F, Ruffaldi E, Avizzano C. A single camera inspection system to detect and localize obstacles on railways based on manifold Kalman filtering. IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA); Turin; Italy; 2018:768-775. https://doi.org/10.1109/ETFA.2018.8502651.
14. Ishida S, Fukuda A, Tagashira S. Initial evaluation of acoustic train detection system. In: Proc. ITS Asia–Pacific Forum Fukuoka; 2018:1-12.
15. https://utk.gov.pl/pl/interoperacyjnosc/ertms/etcs/17422,ETCS.html; 13.04.2023 17:38.
16. Barger P, Schön W, Bouali M. A study of railway ERTMS safety with colored perti nets. The European Safety and Reliability Conference (ESREL'09). 2009:1303-1309.
17. Landex A, Jensen LW, Jokiranta A, Mustro M. ERTMS/ETCS level 2 capacity benefits on the city lines of the Helsinki Region. Finnish Transport Infrastructure Agency; FTIA publications 2019;43.
18. Landex A, Jensen LW. Infrastructure capacity in the ERTMS signaling system. In RailNorrköping 2019; 8th International Conference on Railway Operations

Modelling and Analysis (ICROMA), Norrköping. 2019;069:607-622.

19. Kochan A, Folęga P, Skirkus R, Bureika G. Multigraph is: part 1. A formal description of railway infrastructure for the digital twin of the ETCS application. Transport Problems, 2023;18(2):43-52. https://doi.org/10.20858/tp.2023.18.2.04.
20. Mindur L, Mindur M. The development of high-speed rail in the Federal Republic of Germany between 2002-2020. Scientific Journal of Silesian University of Technology. Series Transport, 2022;117;151-174. https://doi.org/10.20858/sjsutst.2022.117.11.
21. Celiński I, Burdzik R, Młyńczak J, Kłaczyński M. research on the applicability of vibration signals for real-time train and track condition monitoring. Sensors, 2022;22(6);2368. http://dx.doi.org/10.3390/s22062368.
22. Burdzik R, Konieczny Ł, Nowak B, Rozmus J. Research on vibration employed for the train traffic control. Vibroengineering Procedia, 2017;14; 227–232. https://doi.org/10.21595/vp.2017.19237.
23. Michalski R. (edit.). Diagnostyka maszyn roboczych. ITE Radom, 2004.
24. Niziński S, Wierzbicki S. Zintegrowany system informatyczny sterowania pojazdów. Diagnostyka. 2004;30:47-52.
25. Merkisz J, Pielecha I, Łegowik A. The assessment of autoignition of modified jet fuels. Energies 2021:14: 633. https://doi.org/10.3390/en14030633.
26. Gągorowski A. Analysis of the combustion engine exhaust system structure in aspect of shaping acoustic energy. Combustion Engines. 2023;193(2):112-116. https://doi.org/10.19206/CE-162935.
27. Szaciłło L, Jacyna M, Szczepański E, Izdebski M. Risk assessment for rail freight transport operations. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2021;23(3):476–488. http://doi.org/10.17531/ein.2021.3.8.
28. Merkisz J, Pielecha J, Lijewski P, Merkisz-Guranowska A, Nowak M. Exhaust emissions from vehicles in real traffic conditions in the Poznan agglomeration. WIT Transactions on Ecology and the Environment 2013;174:27-38.
29. Regulski P. The material and economic assessment of the life cycle of city buses in the operational phase. Combustion Engines. 2023;192(1):50-54. https://doi.org/10.19206/CE-151942.

Michał STEUER Michal works as a designer at Egis Poland Sp. z o.o., which implements infrastructure projects around the world. He obtained a master's degree from the Department of Transportation at the Silesian University of Technology in 2009. Then, in 2017, he completed a postgraduate degree in rail traffic control systems. In 2022, he obtained a second master's degree from the Faculty of Electrical Engineering at the Silesian University of Technology. He is now a PhD student at the Doctoral School of the Silesian University of Technology. His main area of interest is railroad systems with a special focus on train positioning. He is a member of the Research Development Team on Innovation Research in Transport.
Contact: michal.steuer@polsl.pl



Martin KRZYKAWSKI is employed as an International Transport Coordinator at DB Cargo Polska S. A. He obtained his master's degree in 2020. He is a doctoral student at the Doctoral School of the Silesian University of Technology. His main interests are rail transport and digitalisation. He is a member of the Research Development Team on Innovation Research in Transport.
Contact: martin.krzykawski@polsl.pl

Dawid SIMIŃSKI is employed as a project specialist in DR-TECH Sp. z o.o. company. He received his Masters degree in Transport in 2019 at the Silesian University of Technology, Faculty of Transport and Aviation Engineering, Katowice, Poland. He is a PhD student in Doctoral School at Silesian University of Technology. His main research interests include innovative railway systems and railways and pedestrians solutions which have influence on safety. He is a member of the Research Development Team on Innovation Research in Transport.
Contact: dawid.siminski@polsl.pl

Wongelawit CHEMA is a PhD student at the Doctoral School of Silesian University of Technology starting from 2021. She received a master's degree with the Faculty of Transport and Aviation Engineering at the Silesian University of Technology in 2021. Her main area of interest is safety and risk analysis on transpiration system. She is a member of the Research Development Team on Innovation Research in Transport.
Contact: wongelawit.petros.chema@polsl.pl

Rafał BURDZIK is a professor in the Faculty of Transport and Aviation Engineering at Silesian University of Technology, Poland and visiting lecturer at many European Universities with more than twenty years of transport research experience. He is an author or co-author of books and more than 450 scientific papers, and an editorial board member for several high level scientific journals and active member of numerous scientific associations, editorial boards and committees. He manages numerous innovative and implementation research projects in partnership with industrial entities. He is a well-recognized international expert in transport, mechanical engineering, vibroacoustic, machine diagnostic, transport safety and environmental issues.
Contact: rafal.burdzik@polsl.pl