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RFID Technology in Railway Traffic Management and Signaling – Simulation Tests on an Experimental Track

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Summary

RFID technology is increasingly used in various industries. This is because it makes it possible to identify and locate moving objects and facilitates the automation of processes and their control. Digitisation of information allows its rapid processing and transfer between different levels of decision-making. Experiments carried out by the author on the test stand's experimental track have confirmed the advisability of using RFID (*Radio-Frequency Identification*) technology in rail transport, both in the area of freight management and in train traffic control. Simulations have shown that an RFID system makes it possible to detect moving rolling stock, check the continuity of a train and determine where the train ends. It locates and identifies trains, railcars and cargo, and allows automatic train traffic control by displaying appropriate signals on automatic block signalling systems. Together with a vision system, it detects dangerous shift of transported loads. The research results can be used as a basis for experimental implementation and verification of the applied solutions in real operating conditions.

Keywords: RFID technology, modelling and simulation, rolling stock location and identification, signalling

1. Introduction

RFID (*Radio-Frequency Identification*) technology is increasingly used in various areas of life, primarily in logistics and warehousing, as well as in commerce, industrial processes and security. It represents the modern standard for identifying objects using wireless communication. The components of RFID systems enable the recording, reading and transmission of data between a tag (also referred to as a transponder) and a reader over distances ranging from a few centimetres to several metres. RFID uses three basic frequency ranges: the LF standard (low frequency – from 30 to 300 kHz); HF (high frequency R from 3 to 30 MHz) and UHF (ultra-high frequency – from 300 MHz to 3 GHz). The UHF standard makes it possible to read and write data over distances of up to 15 metres (using passive technology) and as many as 30–60 metres using active technology. Passive technology means using tags without their own power supply. In contrast, active technology employs tags with an integrated power supply, which is used to activate the chip and emit radio waves. The latter tags have a much larger memory storage capacity and generate a strong signal allowing them to operate in harsh environments. Battery life is usually between 2 and 10 years, although some tag manufacturers claim an operating time of around 20 years on a single battery.

The simplest tags are used for reading data only (RO — *Read Only*). WORM (*Write Once Read Many*) tags allow data to be written once, without the option to edit or delete it afterwards. RW (*Rewritable*) tags allow data to be written, modified and read multiple times. Each RFID tag is equipped with four types of memory:

- EPC Memory – editable, used for storing the object code (typically 96 bits);
- User Memory – secondary memory (typically an additional 512 bits);
- TID Memory – contains the manufacturer's unique serial number for a given tag (not modifiable);
- Reserved Memory – contains two passwords: an access password used for confidential data and a kill password (calling this password disables the tag, rendering it inoperable).

The other basic components of an RFID system are readers and antennas. RFID antennas emit radio

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waves, receive signals from tags and transmit them to the reader. RFID readers can be integrated with antennas. In cases where the reader needs to receive data from a larger number of tags, several antennas can be connected to a single reader, effectively reducing the cost of building the system. The increasing use of RFID technology in rail transport (primarily for identifying rolling stock units) has resulted in the need to standardise the numbering of identified objects.

The international organisation GS1[2] has member organisations in 112 countries. It develops and implements global standards and solutions to improve supply chain efficiency. Further, it has developed "RFID in RAIL" – European guidelines for identifying rolling stock using GS1 Standards [1, 2]. The guidelines provide information to identify rolling stock (freight cars, passenger cars and locomotives) within the GS1 System, as well as spare parts required for maintenance, repair & overhaul (MRO). They detail how to identify rolling stock using UHF tags (ISO 18000-63) within the GS1 System[3]. Moreover, they define the data format as well as the read interfaces and rules for querying individual tags.

The technical parameters of the latest elements of RFID systems, especially UHF and rewritable (RW) tags, indicate the wide possibilities of using this technology in rail transport, both in transport management and train traffic control.

2. Use of RFID technology on the test stand in the Railway Research Institute's laboratory

2.1. Test stand

The hardware and software testing station built in the laboratory of the Railway Research Institute consists of two independent experimental tracks. The first (Fig. 1) allows a back-and-forth movement of a single bogie carrying load models.

The test stand is equipped with a suite of sensors (laser and ultrasonic rangefinders, laser barrier, scanner) designed for non-contact detection of moving objects, determination of their spatial position and shift analysis [4, 5, 6]. Data from the individual sensors is read synchronously. The measurement data processing and visualisation module allows the measurement results to be presented in graphical form during the execution of the experiment (Fig. 2).

Fig. 1. Straight experimental track with a moving test plane [photo by J. Moczarski]

A specialised computer application, based on the Matlab programming environment, was developed to process and analyse the measurement data. The application is used to create digital models of objects observed by sensors and their subsequent detection and identification on the experimental track. It features neural network design, implementation, visualisation and simulation functions (using Python and the Keras library). Each digital object model is a hybrid of CNN (convolutional), LSTM (*Long-Short Term Memory*) and MLP (*Multi-layer Perceptron*) networks.

The data required to create object models are collected during repeated experiments. In each experiment, both the parameters of the objects' motion and the parameters of the measurement system are changed. Thus, the application is "learning" (being trained). This results in the creation of digital models of the observed objects. Similarly, models are created for the sequence of objects moving through the area observed by the sensors.

Differentiation and identification of objects (or their sequences) takes place by comparing the observation results with a set of patterns – previously created digital models – stored in the database.

In the modified version of the application, the efficiency of distinguishing objects with similar shapes has been increased by introducing object typologisation [7, 8]. Its essence is the use of attributes that determine the similarity of the observed object to basic geometric solids in different spatial orientations (Fig. 3). The application user can set an object as similar to one of the typical solids, both at the model cre-

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[2] GS1 — an international organisation based in Brussels (Belgium) and Princeton (USA), which manages the GS1 system globally.

[3] For detailed information on tagging, see GS1 EPC Tag Data Standard [3].

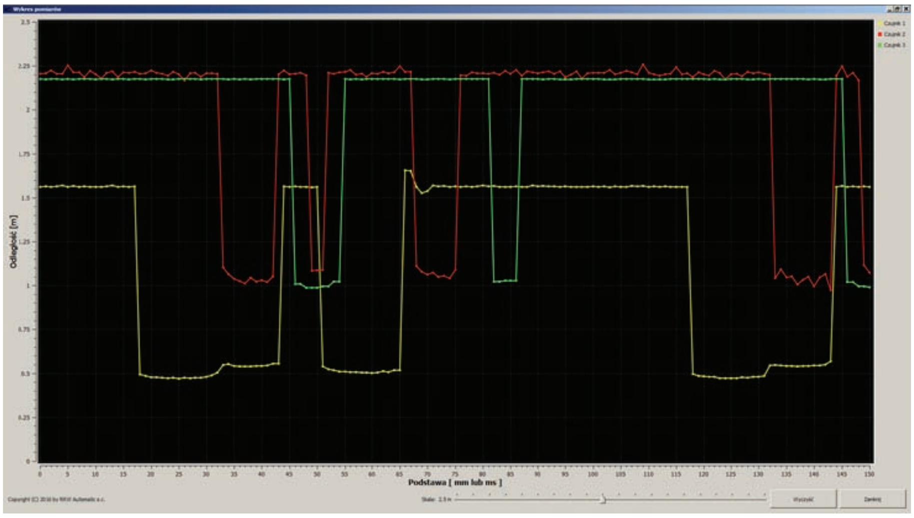


Fig. 2. Measurement results visualised during experiments on the test stand's screen monitor [photo by J. Moczarski]

ation stage and at the subsequent identification stage. Typologisation significantly reduces the time needed to create the model and increases the efficiency and effectiveness of identification.

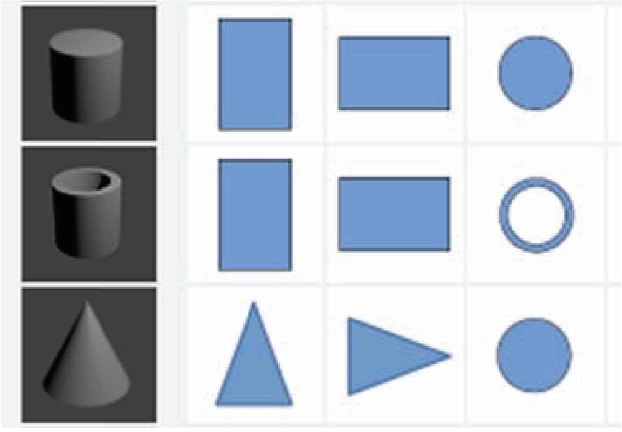


Fig. 3. Examples of several typical geometric solids and their spatial orientations [elaborated by J. Moczarski]

Model creation and training in the described measurement system require multiple observations of different objects. This identification method is effective when applied to objects with repetitive shapes (e.g. railcars and their components and subassemblies, as well as typical loads).

Modelling accuracy and unambiguous representation of real objects depend not only on the parameters of the sensors used but also on their number and spatial configuration, as well as their position relative to the surface of the moving objects. As the conducted experiments have shown, the results of the implemented measurements are also significantly influenced by such factors as the shape of the object, the type of material from which it is made, the surface texture, the movement speed and many others.

The test stand makes it possible to assess the suitability of various sensor types in object identification while also allowing the principles of their spatial configuration to be defined and facilitating verification of the measurement methods used.

A separate and independent measurement system comprising two TriSpector 1060 laser triangulation vision systems [9] was also used to observe objects on the test stand. Using a vision system for object identification does not require training of the model by repeated observations. Once the application user has defined the values of the relevant variables and constraints, the image of the object (load, railcar) is created during a single observation.

The vision system is equipped with tools that are particularly useful in detecting changes in the spatial position of objects (e.g. damaged rolling stock components, shifted loads, etc.). Fig. 4 shows an example of detecting the shift of an observed object (cuboid), transported on the test stand measurement plane, beyond the predefined space where it should be located.

As part of the 2020–2023 expansion effort, the test stand was equipped with an additional running track, five independent bogies, localisation and position visualisation systems and a bogie control and speed control system. Unlike the straight track, the closed oval-shaped running track (Fig. 5) enables the continuous movement of the bogies and their repeated passage through the measuring zone. For a detailed description of the new track, see [10].

The measuring bogie, much like the track itself, is designed for a top speed of approximately 10 m/s. It is driven by a brushless direct-current (*BLDC*) motor and can carry objects weighing up to 1 kg on the railcar bed (a perforated plate that allows test object models to be attached). Using information from Hall

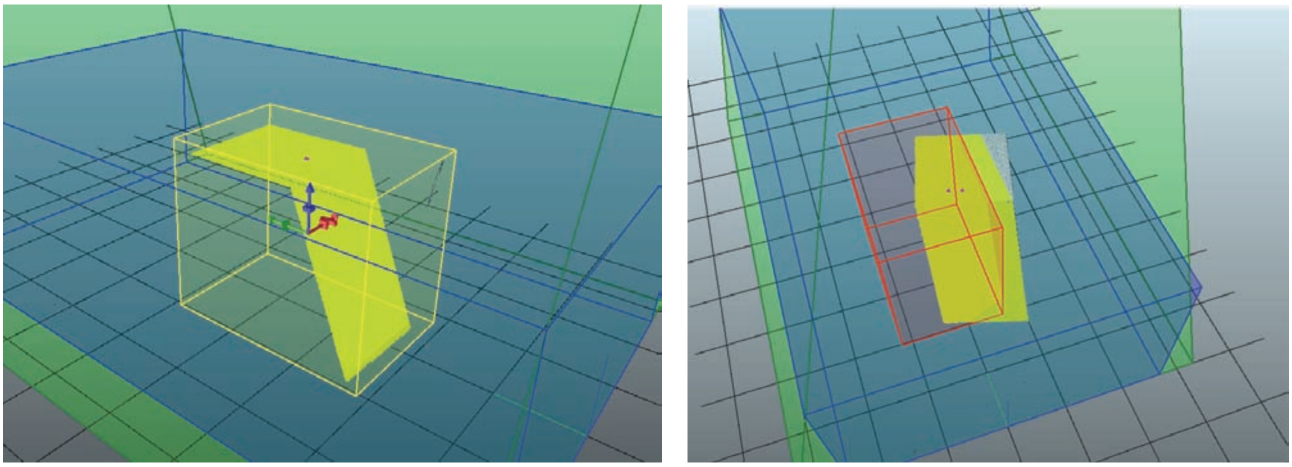


Fig. 4. Image of the surface of an object observed by the vision sensor (left) and the image of this surface shifted beyond the predefined space [elaborated by J. Moczarski]

sensors, the control system maintains the bogie speed set by the operator. In practice, due to the power of the motors used, the top speed is about 7.5 m/s. The bogies can be combined into groups using bearing-supported connectors. The new measuring track features standalone configurable 3D TriSpector 1060 laser sensors (Fig. 6).

Due to the high speeds of the bogies, the test stand operators are behind a safety screen during the experiments. The bogies can be stopped by clicking the STOP button in the main application window on the control unit screen or, in an emergency, by switching off the power to the control unit or pressing the E-Stop button on the test stand. The bogies are automatically brought to an emergency stop when a collision between them is detected, communication with the control unit is interrupted or the battery voltage drops below an acceptable value.

Fig. 5. A bogie with a load on the experimental track [photo by J. Moczarski]

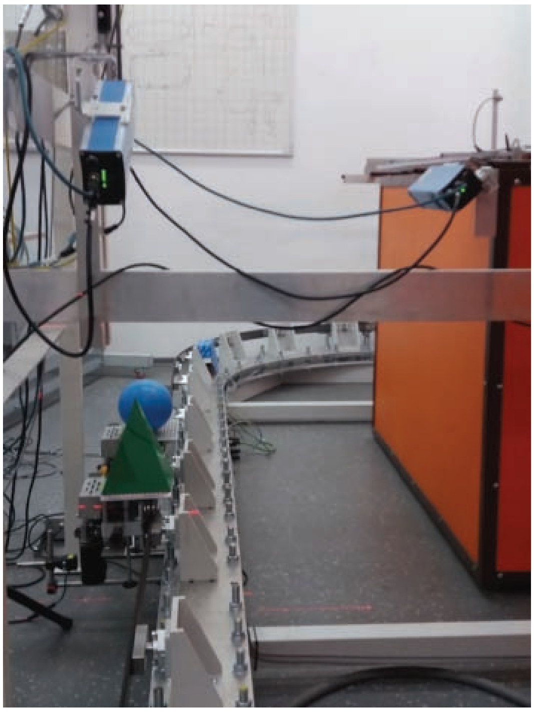


Fig. 6. Object models placed on two connected bogies, observed by two 3D TriSpector laser cameras [photo by J. Moczarski]

2.2. System for locating the bogies on the experimental track

RFID technology was used to locate and identify individual bogies (railcars) and sets of bogies (trains) on the experimental track. RW-type passive tags (Fig. 7) were used, allowing the necessary information to be written and read repeatedly. Each bogie was equipped with two tags.

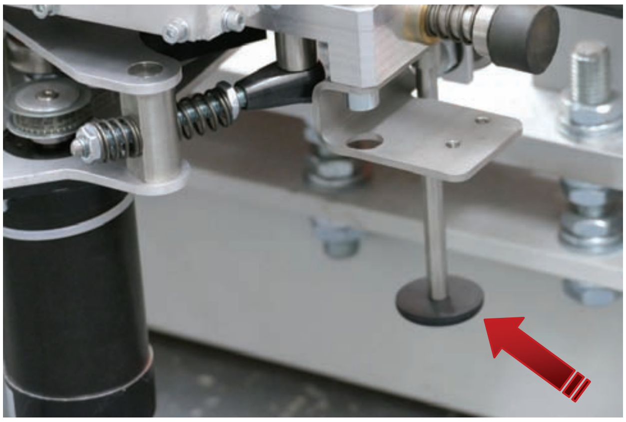


Fig. 7. Passive RW tag installed on a bogie [photo by J. Moczarski]

The experimental track was divided into four block sections. At the beginning of each section, an RFID antenna and a light signal are installed, which displays an appropriate signal (green or red) depending on the occupation of the next section (Fig. 8).


Fig. 8. Light signal (red light) and RFID antenna (right) [photo by J. Moczarski]

The RFID heads communicate via the DTE10x interface with the central unit that processes the recorded data. The following data describing individual bogies (railcars) and their sets (trains) on the track can be entered into the application: the identification number or name of each bogie and the train identification number or name of each bogie set. Further, the following information is entered to identify the beginning and the end of the train: for the first bogie in the set – the P indicator of the front of the train; for the last bogie in the set – the K indicator of the end of the train.

The movement of the bogies on the test stand can be controlled in several ways. One of the available options is *colision-free driving*, whereby bogie movement happens based on occupation control of individual sections using an RFID system. At the same time, light signals set up at the beginning of each section indicate whether the section is free (green light) or occupied (red light). The vehicles are automatically stopped before entering the occupied section (Fig. 9) and continue as soon as it is empty (Fig. 10).

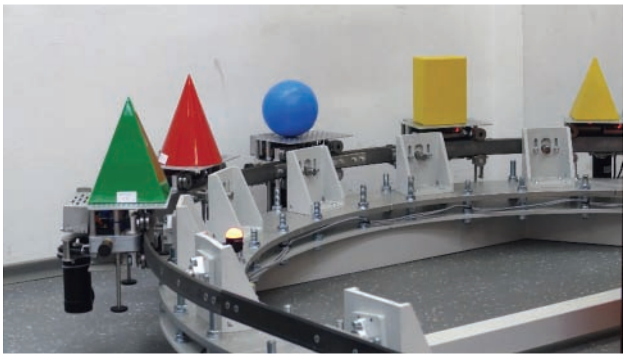


Fig. 9. Train (set of bogies) waiting before entering an occupied section (red light) [photo by J. Moczarski]


Fig. 10. The next section is empty – a signal to proceed is given (green light) [photo by J. Moczarski]

Due to the number of block sections, a maximum of 3 trains can be on the track. The test stand features 10 RW tags and 4 antennas. The design and principle of operation of the bogie speed control and regulation system, as well as the Motor Control App computer application running in the central control unit, which enables the modelling and visualisation of traffic situations on the experimental track, are described in [10].

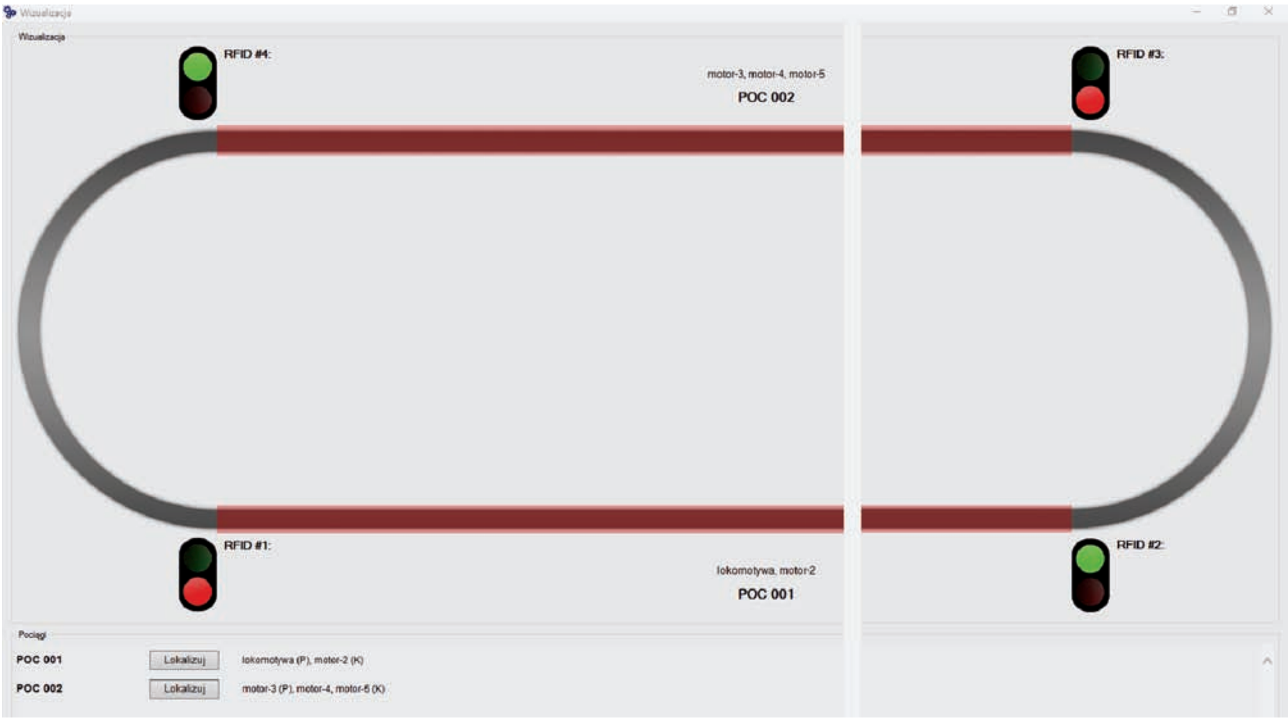
3. Modelling and simulation of train movement using RFID technology – test results

Before the experiment, individual trains are defined in the system. The railcars and trains are assigned numbers and names. During the initial run past any antenna, the relevant information is automatically stored in the tags of the individual bogies (railcars). The P or K indicators (indicating the start or end of the train, respectively) are stored in the tags of the first and last train bogie. The individual bogies, combined into sets, are aggregated in the control system by assignment to the selected train. The control system treats such a set as a single regulated object. All bogies in a set are given the same operating parameters (signal allowing entry to an empty block section, halting before a "stop" signal light, movement speed on straight track sections, speed limits on curves, measuring zone travel speed, etc.).

The visualisation screen of the test stand shows the running track (grey ellipse) graphically, divided into 4 sections (Fig. 11). Next to the track, at the borders of the block sections, the 4 light signals are depicted, with the identifiers of the installed antennas indicated next to the individual signals (e.g. RFID #1). The block section currently occupied by a train is highlighted in red. A "stop" signal is displayed on the light signal applicable to that section.

Fig. 11 and 12 present a visualisation on the monitor screen of two example traffic situations. The vehicles travel counterclockwise on the measuring track. Two trains are on the track in both cases, shown in Fig. 11 and 12. A train called POC-001 (made up of two bogies: a *locomotive* and a *motor-2*) and a train called POC-002 (made up of three bogies: *motor-3*, *motor-4* and *motor-5*).

A list is displayed next to each occupied section, showing the trolleys (small font) and trains (large font) currently on it. Fig. 13 illustrates a part of the track covering a section protected by the light signal with RFID #4 antenna, with train POC-001 consisting of bogies labelled: *locomotive* and *motor-2*.



POC 001 lokomotywa (P), motor-2 (K)
POC 002 motor-3 (P), motor-4, motor-5 (K)

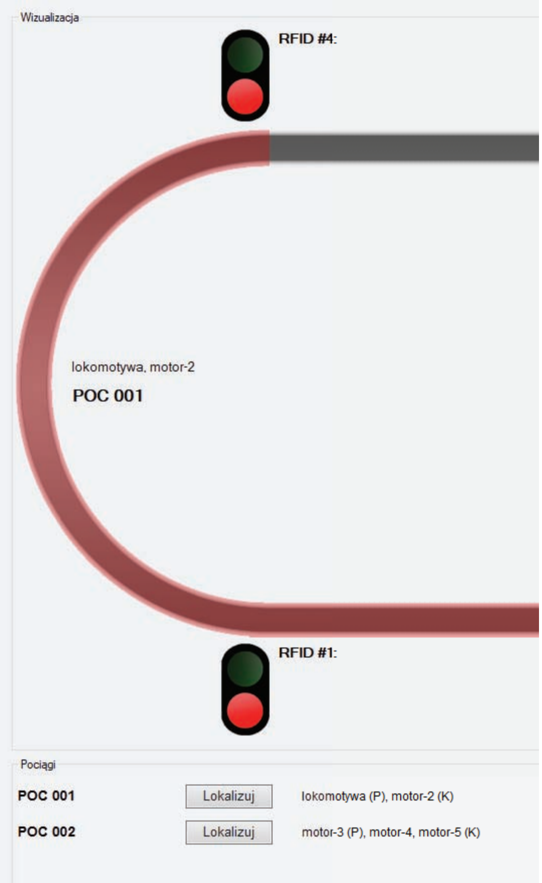
Fig. 11. Two experimental track sections, occupied by trains POC-001 and POC-002 [J. Moczarski's resources]

POC 001 Lokalizuj lokomotywa (P), motor-2 (K)
POC 002 Lokalizuj motor-3 (P), motor-4, motor-5 (K)

Fig. 12. Three experimental track sections, occupied by trains POC-001 and POC-002 [J. Moczarski's resources]

The traffic situation on the track (occupied sections, locations of railcars and trains) is shown on the screen in online mode. When a railcar/train leaves a section, the displayed vehicle numbers and names automatically disappear and appear at the next occupied section, following the moving vehicles. At the bottom of the window (Fig. 13) is a list of trains on the track. Buttons initiating the function of locating the selected train or railcar are also available. When the *Locate* button is pressed, the track section (or sections) currently occupied by the searched train flashes several times on the screen. The selected bogie/railcar can be found by clicking on its name (next to the *Locate* button). The bogies representing the start or end of a train are marked with the letters P or K, respectively. Each bogie is equipped with two tags (installed at the beginning and end of the bogie) so the location of the front tag of the first bogie (P) or the end tag of the last bogie (K) is shown on the screen.

According to the visualisation shown in Fig. 11, train POC-001 occupies the section protected by the light signal with RFID #1 antenna, and train POC-002 occupies that protected by the light signal with RFID #3 antenna. In the traffic situation shown in Fig. 12, train POC-001 occupies a section protected by the light signal with RFID #4 antenna. Train POC-002, on the other hand, temporarily occupies two sections: the one protected by the light signal with RFID #1 antenna (where the last railcar of this train, *motor-5*, is located) and that protected by the light signal with



POC 001 Lokalizuj lokomotywa (P), motor-2 (K)
POC 002 Lokalizuj motor-3 (P), motor-4, motor-5 (K)

Fig. 13. Location of trains and railcars on the survey track [J. Moczarski's resources]

RFID #2 antenna (containing *motor-3* and *motor-4* railcars). The section protected by the light signal with RFID #3 antenna is unoccupied ("go" signal).

During the experiments, the trains moved automatically along the experimental track, stopping before light signals indicating the occupation of the next section and continuing where the sections were unoccupied. The light signals showed "go" or "stop" signals according to the traffic situation in the protected sections.

Using the visualisation screen, the system operator (in real life, that would be the person managing train traffic on the line, control area or network) can monitor the occupation of individual sections, the current position of trains and railcars (as well as the transported loads) and control the position of the front and end of each train. Where numerous moving trains and railcars are present, the operator can locate selected rolling stock units using the *Locate* function. The necessary information is read, processed and visualised automatically, without human intervention. Train data (and possibly cargo data) are entered into the system only once, during train marshalling.

4. Applying RFID technology in railway traffic management and signalling

RFID solutions are increasingly used in various industries worldwide. Attempts to implement this technology in transport should be recognised as well.

In the United States, RFID readers have been used on motorways as part of the tolling system for many years. Vehicles equipped with tags (usually passive) are identified as they travel [11]. In China, RFID technology is used in identifying rolling stock on long-distance routes. In about 20 years, more than 600,000 railcars and locomotives have been equipped with tags. RFID readers have been installed at selected railway hubs, stations and transshipment points. The system makes it possible to track the location of rolling stock and transported cargo in real-time. Annual savings from the use of RFID are estimated to be around $38 million [11–13].

In Poland, Orlen has implemented an innovative system for locating tank cars [14]. 101 RFID gates were installed throughout Poland. Moreover, employees received 64 mobile readers to read data from the tags. Each railcar and locomotive were fitted with two RFID tags. A total of around 11,000 tags were used for this purpose. GS1 numbering was used to identify the tank cars. The system makes it possible to locate rolling stock on the railway network and in siding areas, as well as to track trains along the route. It also provides information on whether a tank car is loaded, empty or, for example, out of service.

To carry out rail transport tasks safely and efficiently, solutions are needed that enable:

- rolling stock detection,
- train continuity control,
- train end identification,
- rolling stock and cargo identification and location,
- cargo shift detection,
- providing information on the technical condition of rolling stock and infrastructure components.

Currently, various signalling devices and systems make it possible to determine whether track sections and turnouts are occupied. Different types of sensors (typically inductive) are used to check for the presence of wheelsets at specific points. Other relevant information on moving rolling stock and cargo is obtained by visual observation and analysis of transport documents.

With rising train traffic and speed, it is becoming increasingly challenging to ensure the safety and timeliness of transport and the reliability of the transport system. Due to high construction and operating costs, efficient use of rolling stock and infrastructure components is becoming a major problem. This requires the optimisation of transport processes over large areas, the automation of decision-making or the use of automated advisory systems. This approach necessitates the integration of local structures involving, among other things, the acquisition and exchange of the necessary information.

Laboratory experiments have confirmed the feasibility of using RFID technology in organising and managing rail transport and train traffic control. The bogie traffic control system on the experimental track correctly detected the presence of bogies on individual block sections, caused the appropriate signals to be displayed on the light signals ("go" or "stop"), stopped the bogies before entering an occupied section and continued their movement where the relevant section was unoccupied. It also monitored the continuity of the train (a set of connected bogies), detected the first and last bogie (identifying the beginning and end of the train), read and visualised the information stored in tags fitted on individual bogies (e.g. train number/name, railcar number) and, together with the TriSpector vision system, detected deliberately introduced shifts of loads (geometric solids transported on the beds of individual bogies).

RFID technology makes it possible to not only automatically collect the information necessary to manage the transport process but also to digitise it. It thus enables automatic information processing at various levels of decision-making.

Due to the low cost of tags, every locomotive and railcar (as well as other railway vehicles) can be fitted with them as a standard, carrying both modifiable and unmodifiable rolling stock information. Examples include the registration number, permitted speed, gauge parameters, last inspection date, train number, railcar number in the train, train beginning or end indicator, destination station, etc.

RFID antennas set up near light signals of automatic block systems (as on the test stand) will make it possible to detect the presence of rolling stock at individual block sections and to identify it and verify the data stored in the tags. The information from the RFID system will allow direct control of the signalling systems, regardless of the adopted block arrangement.

It should be noted that such a solution provides information on whether the section is occupied by rolling stock equipped with tags. Therefore, to enable the control function, each vehicle/train operating on the route must have at least two tags containing information about its beginning (P) and end (K). The information from the antennas set up by the automatic block systems will make it possible to track the position of trains, locomotives, individual railcars and transported cargo on the railway line network with accuracy down to a block section. Research carried out as part of a project by the Swedish Transport Administration has shown that RFID readers can read data from tags installed on rolling stock at > 200 km/h [15]. Further, experiments with sports cars [16] have also confirmed reliable data reading at 200 km/h.

On lines not equipped with automatic block systems, it is sufficient to set up antennas and readers close to the station entrance and exit light signals and, crucially for passenger traffic and greater localisation accuracy, at individual passenger stops and junction signal boxes. At large passenger stations, antennas can be positioned at each platform edge.

Using RFID technology for rail traffic control requires special attention to the security of the storage and transmission of tag data. Authors of publications on the application of RFID in transport highlight the importance of this issue. For example, [17] identifies existing risks and presents methods to counteract their occurrence, as well as proposing solutions to avoid hazardous situations. Further, [18] presents considerations for the security of the data transmission process between the tag and the antenna.

In high traffic volume conditions (e.g. metropolitan services), knowing the location of each train and the sequence of trains on the line is essential for efficient and safe traffic organisation. The chaotic movement of crowds of passengers carrying luggage along the platform (and often between platforms) in search of "their" train and carriage is an everyday image at major railway stations. The passenger information systems in use today may generate erroneous messages for travellers, especially in the case of unusual traffic situations (e.g. delays and changes in the order of arriving trains). Incidents of trains being diverted onto the wrong track, which have been publicised in the media, indicate that this is also a problem for staff in signal boxes and traffic control centres. The current structure and operating principles of railway passenger information systems are described in [19].

The use of RFID tags and placing the antenna at an appropriate distance in front of a station or stop will provide the interested persons with precise, real-time information about the approaching train: number (name), route, railcar sequence, expected stopping place for a railcar with an appropriate number (according to the reservation). The possibility of obtaining such information was confirmed by experiments carried out on the laboratory's experimental track.

Equipping marshalling yards, shunting yards, sidings and stabling tracks with antennas and readers will make it possible to locate individual railcars and transported loads. It will also allow the precise positioning of railcars at industrial sidings, container terminals and logistics centres, as well as loading, transshipment and unloading points [13].

In the case of passenger transport, the use of RFID tags to locate rolling stock components (e.g. railcar entrance doors) will enable the precise positioning of the train at platforms equipped with doors synchronised with the train doors, especially when using automatic trains running without a driver (e.g. metro trains).

5. Conclusion

Developments in rail transport indicate the need to implement automated or fully automatic control and management systems for transport. Decision-making effectiveness depends on continuous access to up-to-date and reliable information, particularly on moving rolling stock and transported loads. A vital factor influencing the efficiency of such systems is the digitisation of information, enabling its automatic processing and rapid transfer between different levels of management.

The presented test stand makes it possible to model and simulate the movement of trains on the part of a railway line divided into block sections. The RFID system effectively locates and identifies trains, individual railcars and transported loads. It detects the occupation of individual sections, displays appropriate signals on the signalling systems and automatically controls the movement of trains on the experimental track. The vision system also makes it possible to detect any shifts of cargo carried on the railcar beds.

Simulations carried out by the author on the test stand's experimental track have fully confirmed the feasibility and usefulness of the practical use of RFID technology in rail transport. They have demonstrated the wide spectrum of applications and the possibility of rapid acquisition and processing of various information relevant to both customers and managers of the transport process. The results of this study may be the basis for pilot or trial implementation of the applied solutions by selected passenger and freight carriers in cooperation with PKP PLK S.A., in real operating conditions.

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