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Historical Outline of Railway Control Command and Signalling Systems Development Based on Research Conducted at the Railway Research Institute

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Summary

Railway control command and signalling systems ensure the safe operation of rolling stock by utilising appropriate equipment, either automatically or with the involvement of an operator. This paper presents a historical outline of the development of railway control command and signalling equipment from its beginnings to the present day. The process of refining traffic control equipment is illustrated through the example of work conducted in Poland, particularly at the Railway Traffic Control and Telecom Department of the Railway Research Institute. Attention is drawn to the elements of traffic control equipment that have evolved due to technological developments. The paper also highlights the international cooperation of the Railway Traffic Control and Telecom Department at the Railway Research Institute, as well as its knowledge dissemination activities.

Keywords: rail transport, traffic control, development, research

Introduction

Railway control command and signalling systems (CCS) ensure safe operation of the rolling stock (including trains) utilising appropriate equipment, either automatically or with the involvement of an operator, such as a traffic controller or a train driver/auxiliary staff operating the rolling stock. Terminology of the railway signalling systems and equipment has evolved over the last 100 years. At the beginning of the 20th century, the terms railway traffic safety systems/equipment and signalling systems were commonly used – such terminology was employed by Professor A. Wasiutyński in successive editions of his renowned book "Iron roads" (pol. „Drogi żelazne") [33, 34], which summarised contemporary knowledge about railway systems, including rail operation techniques, construction of the railway lines and stations, as well as design of the railway equipment.


WYDAWNICTWA NAUKOWE

DROGI ŻELAZNE

POWSTANIE I ORGANIZACJA DRÓG ŻELAZNYCH. TABOR I TECHNIKA RUCHU KOLEJOWEGO. PROJEKTOWANIE DROGI ŻELAZNEJ. BUDOWA SPODNIA I WIERZCHNIA. POŁĄCZENIA TORÓW. STACJE. SYGNALIZACJA I URZĄDZENIA BEZPIECZEŃSTWA.

NAPISAŁ

ALEKSANDER WASIUTYŃSKI

WARSZAWA—1925

In later years, terms such as securing train operation , railway signalling, and secured train movements emerged. In the 21st century, the term "Safe Control Command" (pol. „Bezpieczna Kontrola Jazdy Pociągu" – BKJP) was introduced, referring to the railway signalling equipment installed on-board of the rolling stock and its safe operation. BKJP distinguishes: automatic warning systems AWS, automatic train protection ATP, automatic train control ATC, and automatic train operation ATO. Those terms are commonly used in English expressions across all railway administrations of the UIC (*International Union of Railways*) and the EU (European Union). The exception is BKJP, a term developed at the Railway Research Institute and primarily used on Polish railways.

In the interwar period, work on railway control command and signalling systems primarily focused on developing unified Polish railway regulations concerning the construction, operation, maintenance, and management of traffic, as well as standardising procedures in the event of railway failures and accidents. This also included the standardisation and development of technical equipment used to ensure

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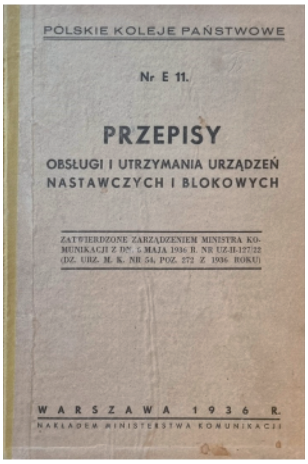
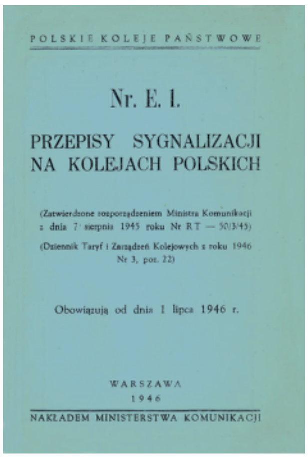
safe railway traffic. This was necessary because the regulations and equipment on Polish railways, which were established in territories previously belonging to three different partitions, differed significantly, posing a considerable challenge to ensuring safe railway traffic. The outcome of these efforts was the development of appropriate regulations applicable across the entire railway network. As an example from the field of railway control command and signalling systems, one can cite the E11 [17] regulations, issued in 1936, concerning the operation and maintenance of signalling and block equipment.

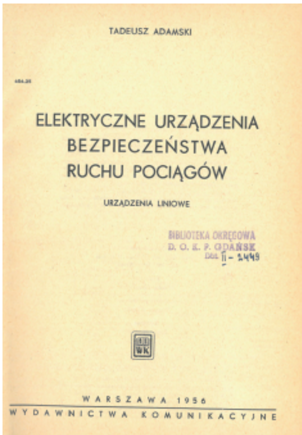


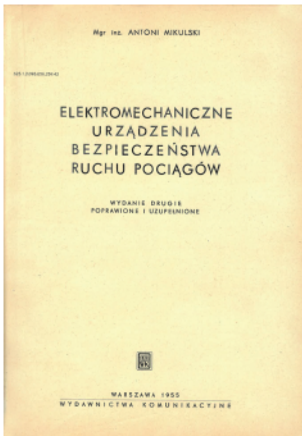
The Post-World War II Period – Before the Establishment of the Railway Research Institute

After the end of World War II, the situation on Polish railways was challenging, primarily due to the devastation of railway infrastructure, the destruction of rolling stock, and a shortage of specialists to operate the equipment and railway traffic. A significant portion of the railway network had previously been managed by German railways, which meant different regulations for railway operations and a distinct railway infrastructure, largely devastated as a result of wartime actions and post-war activities [looting]. During this period, interwar railway regulations were still in use, while efforts were made to inventory and reorganise the infrastructure. An example of such regulations includes "Signalling Regulations for Polish Railways No. E.1" (pol. „Przepisy sygnalizacji na kolejach polskich Nr. E.1") , which came into effect on 1 July 1946 and were approved by the decree of the Minister of Communications dated 7 August 1945, No. RT – 50/3/45 [18]. As a result of advancements in technology and the evolution of railway traffic management techniques, these regulations have undergone changes over time, but the fundamental principles of railway operations have remained unchanged. Publications were issued concerning the operation and maintenance of equipment, which also standardised the requirements for CCS systems. These publications were treated as operations and maintenance manuals for the installation of equipment adapted to the new requirements associated with railway traffic management. The currently applicable regulations for railway operation and signalling in Poland, "Regulation of the Minister of Infrastructure of 20 October 2023 amending the regulation on general conditions for railway traffic operation and signalling" [27], are a continuation of the principles contained in the interwar regulations.



During this period, new technical solutions in the field of railway control command and signalling equipment were developed, based on contemporary knowledge and utilising previously applied technical solutions, while also incorporating technological progress. The process of reorganising traffic control equipment in new locations also began. Examples of such publications include: "Electromechanical Train Traffic Safety Equipment" (pol. „Elektromechaniczne urządzenia bezpieczeństwa ruchu pociągów") by A. Mikulski [20] or "Electrical Train Traffic Safety Equipment" (pol. „Elektryczne urządzenia bezpieczeństwa ruchu pociągów") by T. Adamski [1].





These publications also served as textbooks for education in railway secondary technical schools and vocational schools. They were also used at universities specialising in railway traffic control engineering. To this day, these documents have not lost their significance, as some of the equipment described in them is still in service on Polish railways. Consequently, they are used as sources of information on the construction, operation, and maintenance of this equipment, although its operation is hindered by the lack of spare parts. This applies particularly to mechanical equipment, for which spare parts are made on order for specific applications in particular locations.

Research and Development Work in the Field of CCS Conducted at the Railway Research Institute

The Railway Research Institute (IK) was established in 1951 as the Railway Scientific and Research Institute, operating as a budget unit. In 1958, it was renamed the Central Railway Technology Research and Development Centre and simultaneously incorporated into the structures of the Polish State Railways. In 1987, it was renamed the Science and Technology Railway Centre (CNTK). Until the end of 1999, the Science and Technology Railway Centre was part of the Polish State Railways. From 2000 onwards, it was separated from the structures of the Polish State Railways (PKP) and functioned as a research and development unit. In 2010, it adopted the name Railway Research Institute (IK).

Following the establishment of the Railway Research Institute, the primary focus was placed on the development of rolling stock, railway tracks, general operational issues, and matters related to documentation. Initially, development work on railway control command and signalling equipment was conducted within the Operations Department and the Documentation Division.

Formally, work on the development of railway control command and signalling equipment began in the 1960s, with the establishment of the Railway Traffic Control Department at the Railway Research Institute. Later, the Department's scope was expanded to include issues related to communication and telecommunications. The Automation and Telecommunications Laboratory was established for this purpose, among others. During this period, the names of the Department changed, but the profile of its work remained practically the same. Its current name is the Railway Traffic Control and Telecom Department. In the remainder of this paper, the abbreviation CD will be used to refer to the department responsible for railway control command and signalling.

Initially, the work of CD focused on the technical development of CCS equipment and systems, as well as the evaluation of new solutions (both technical and organisational) introduced into operation. New solutions were developed both independently and in collaboration with other domestic and foreign entities. The developed CCS equipment and systems were also the subject of patents obtained by the Railway Research Institute (over twenty patents in the field of CCS equipment were granted).

In the 1980s, CD expanded its activities to include the formal evaluation and certification of products. The first official body aimed at evaluating products intended for use by the Polish State Railways was the Product Evaluation Committee (KOW). The majority of assessments issued by the Committee concerned CCS and communication equipment, which is why the secretary's office of this Committee was located within the CD. The Product Evaluation Committee evaluated several hundred products intended for use on the network of the Polish State Railways, and at that time, its approval was required for the authorisation of specific products, equipment, or systems for operational use.

Development Work

One of the first solutions developed by the Control Department was the SHP system (Samoczynne Hamowanie Pociągów – *Automatic Train Braking*). This system serves as a warning mechanism for train drivers approaching a railway signal. It belongs to the group of Automatic Warning Systems (AWS). AWS systems provide visual and audible warnings to the driver as the train approaches railway signals, level crossings, or temporary and permanent speed restrictions. The system operates by alerting the driver when the train passes a specific point on the track equipped with a sensor (known as a trackside magnet). The SHP system consists of a trackside sensor, an onboard sensor, and equipment installed in the vehicle (the SHP generator). Typically, the sensor is installed on the track 200 metres before a signal, while at stations, it is placed before the exit signal or/and route signal. The driver is informed via the illumination of a corresponding indicator, and after 3.5 seconds, an audible buzzer is activated (lasting up to 5 seconds). During this time, the driver must press the vigilance button, confirming their ability to operate the train. If this action is not taken, the vehicle will automatically initiate braking.

The SHP system was implemented across the entire Polish railway network. Initially, SHP was intended as an interim solution until it could be replaced by a three-frequency system, somewhat modelled on the Indusi system used by several railway administrations (e.g., DB, ÖBB). The three-frequency system provided the driver with information about the speed restriction indicated by the signal. However, research conducted at the Railway Research Institute revealed that the Polish railways could not adopt a system of sensors dependent on signal indications, primarily due to the theft of cables. The system was described by B. Świderski in the book "Point-Type Automatic Train Braking Devices" (pol. „Urządzenia SHP typu punktowego") [30],

detailing both its operational principles and maintenance requirements.

Another system developed by the Railway Traffic Control and Telecom Department at the Railway Research Institute in the 1960s was the automatic coded block signalling system with data transmission to the vehicle. The concept was based on the ALS (automatic locomotive signalling) system used on Russian railways. The system collected information from railway signal indications and converted it into an encoded electrical signal transmitted to the track. The signal encoding was carried out using a mechanical encoder. The signal from the track was received by the vehicle's antenna and decoded for the driver, displaying the signal indications on the dashboard. The onboard decoder was electronic, constructed using vacuum tubes. If the driver failed to respond to a speed restriction, particularly a stop signal, the traction vehicle would automatically initiate braking. However, the implementation of the system faced numerous challenges, the most significant being the onboard decoder. Vibrations on the vehicles caused instability of the contacts in the vacuum tube sockets, leading to their damage. Additionally, the mechanical trackside encoder resulted in inconsistent operation and coding discrepancies. Another issue was the reduced track bed impedance, especially during rain. This prevented the encoded signal from covering the full length of the track, as transistors and methods for stabilising track bed impedance were not available at the time. Had these technologies been accessible, the Polish railways would have had a highly advanced safety system for that era.

One of the fundamental components of CCS systems are track and turnout occupancy detection devices. Detection can be achieved in various ways, such as using track circuits and axle counters or loop circuits. The Control Department conducted extensive work on these systems, culminating in the introduction of new devices into operation. Several types of track circuits powered by 50 Hz alternating current were developed. They exhibited significant durability against fluctuations in track bed resistance influenced by changing weather conditions. They utilised new types of impedance bonds that stabilised the track bed resistance and were resistant to high traction return currents. These developments were supported by theoretical analysis and practical experiments, as described by F. Puderecki in the book "Track Circuits Implemented on the Polish State Railways" (pol. „Obwody torowe stosowane na PKP") [26]. Simultaneously, for monitoring the occupancy of automatic block signalling sections longer than 1200 metres, centre-fed track circuits were developed, tested, and implemented. These allowed the extension of track circuits to 2400 metres, which was sufficient for all block sections used on the Polish railways. The new types of track circuits were deployed across the Polish railway network. For operational purposes, a document titled "Guidelines for Track Circuits Implemented on the Polish State Railways" (pol. „Karty instrukcji obwodów torowych stosowanych na PKP") [11] was prepared by A. Białoń. This document became the operations and maintenance manual for track circuits used on the Polish railways, and remains in use to this day on the Polish railway network.

In the 1970s, work began on jointless track circuits. The reason for initiating these efforts was the frequent damage to insulated block joints and the high costs associated with their installation and maintenance. Jointless track circuits operating in two frequency bands: 1.5 kHz to 3 kHz and 7 kHz to 15 kHz – were developed, tested, and implemented. Jointless track circuits operate without insulated block joints (used in conventional 50 Hz track circuits). The boundaries of these circuits are determined by electrical joints. Jointless track circuits operating in the lower frequency range utilise a signal modulated at 50 Hz, while those in the higher frequency band use a continuous (unmodulated) signal. A significant achievement was the development of a jointless track circuit for railway turnouts—a unique solution among all railway administrations worldwide. Jointless track circuits continue to be used on the Polish railway network to this day.

For the purpose of detecting the passage of a traction vehicle through a specific point on the network, such as activating a level crossing, jointless track circuits operating with a continuous signal in the frequency range of 19 kHz to 50 kHz were developed in collaboration with the company ZWUS. These circuits are characterised by their short length (up to a few metres) and the ability to detect the direction of travel. They remain in use on the Polish railway network.

In the 1990s, a version of jointless track circuits was developed for the Warsaw metro. One of the differences in these circuits is their greater resistance to traction return currents, which in the metro are at least five times higher than on surface railways. The developed, tested, and evaluated jointless track circuits, as well as special conventional circuits, continue to be used in the metro on both Line I and Line II.

In the 1970s, a special trackside sensor was also developed to detect the passage of rolling stock through a specific point on the railway network. It was intended to replace the previously used mechanical Neptune-type sensor. The solution involved the use of a reed relay (Herkon relay) in a special magnetic assembly mounted to the rail. The sensor was tested in both laboratory and field conditions. After a positive evaluation, it was implemented for operational use as a sensor to monitor passage through a specific point, as well as to activate automatic level crossing signalling.

[4] PKP/PKP IC trains to UZ Rava-Ruska station ran between 2000 and 2005 (the line was closed between 1944 and 1996).

An interesting area of research undertaken by the Control Department at the Railway Research Institute was the use of loop track circuits for occupancy detection. The principle adopted was that a vehicle entering a monitored track section would change the operating frequency of the loop circuit, which was implemented as a cable loop laid on the rail foot. This solution, not used anywhere else in the world, achieved partial success. The loop circuit for straight track sections functioned correctly, but when applied to railway turnouts, the solution did not always operate reliably-effective monitoring of the necessary connections in the turnout area was lacking. Due to these maintenance challenges, the solution was not implemented for operational use.

In the 1970s, the Traffic Control Department at the Railway Research Institute began work on the application of electronic components (semiconductors, digital circuits, and integrated circuits) in CCS systems. It was a progressive and relevant course of action for that era. Electronics were utilised, for example, in the previously described designs of jointless track circuits, as well as in the SHP system.

One example of the application of digital electronic circuits in CCS systems is the MS-type inter-station block system, developed by the CD. The block system, constructed using prototype digital circuits available on the Polish market, was intended to replace the relay-based inter-station block systems previously in use. Despite being operationally tested and offering a greater number of functions, as well as simple and intuitive operation, the MS block system was not adopted for widespread use. One reason was the limited availability of digital electronic components, as well as concerns among operators regarding the use of such circuits.

In the 1980s, the KHP system (Train Braking Control – Kontrola Hamowania Pociągów) was also developed. It was an extension of prior SHP system designs and efforts to implement the three-frequency Indusi system for digital speed control, using specialised semiconductor circuits and coded block signalling with data transmission to the vehicle. The KHP system enabled the transmission of nine signal indications to the driver's cab, allowing for the control of permissible speed based on these indications. The transmission was achieved by receiving an encoded electrical signal from the track and converting it into indications in the driver's cab and control of the permissible speed. The transmission took place along the entire length of the line but required appropriate track infrastructure modifications (such as installing specific insulation and short circuits in the rail infrastructure). The system was operational for over a year on an approximately 100-kilometre section of the Coal Trunk-Line However, it was not implemented for widespread use on the Polish railways. It can be considered a precursor to systems such as EBICAB or ETCS.

In the 1980s, work began on the development of a digital system for transmitting data from the trackside to the traction vehicle, known as CPI (cyfrowe przekazywanie informacji – *digital data transmission*). The concept of the system was developed, and its implementation was initiated. The system was intended to be fully electronic. One of the more interesting proposed solutions was the transmission of data using so-called radiating cables. Tests were conducted with positive results on the PKP network in collaboration with the Railway Technical Centre in Derby (United Kingdom).

Also in the 1980s, the Control Department began work on the design of automatic block signalling (ABS) system. This was primarily driven by the need to increase the capacity of lines on major transport routes. The work started with the development of a three-aspect ABS system (Eac), utilising track occupancy detection systems. Initially, these were conventional track circuits, including mid-point fed track circuits, and later jointless track circuits. Signal transmission between railway signals was carried out via cables using appropriate voltage levels. After laboratory, field, and operational testing, the Eac-type automatic block signalling system (ABS) was approved for widespread use on Polish railways. The first major installation of the ABS system took place on the CMK line (over 200 km of double-track line). After a period of operation, it became apparent that a four-aspect ABS system was needed to further increase capacity. Developing such a system required the creation of an assembly to trigger flashing lights on the railway signal. This assembly was intended to replace the unstable relay-based flasher that used mercury to short-circuit the contacts. Such an electronic assembly was developed, tested, and implemented in operation. The challenge in designing the flasher assembly was to ensure it met safety requirements (*fail-safe*) and to produce a safety case for it. At the time, this was pioneering work for Polish railways. The flasher assembly was successfully developed and implemented in operation, and a safety case was prepared for it. The four-aspect automatic block signalling system remains in use on Polish railways to this day. Axle counters are also used for the detection of block section occupancy.

In the 1980s, the type FELB automatic block signalling system, produced by a Danish company, was tested in Poland. It was an electronic block signalling system with digital signal transmission between railway signals. Like all CCS equipment, the FELB-type automatic block signalling system had to meet fail-safe requirements, including the development of a safety case. Interestingly, this proof was prepared by a team of nearly thirty employees of the Danish company over almost five years. It was one of the first safety cases developed for electronic CCS systems. The results of operational testing of the FELB-type automatic block signalling system confirmed its suitability for Polish railway conditions, but it was not widely implemented. After several years of operation on the test site near Tczew Station, it was dismantled. Work on this block signalling system allowed railway specialists to gain a closer understanding of the application of electronics in CCS equipment, which later facilitated the easier implementation of electronic systems into operation.

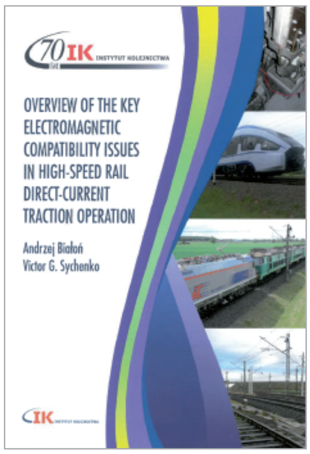
Currently, the Control Department has been carrying out tests on electronic automatic block signalling systems for several years, as well as independent safety assessments of these systems. Tests and assessments are carried out for both domestic and foreign manufacturers. Numerous tests and evaluations of systems have been conducted, and after positive assessments, these systems were installed on railways in other countries (Lithuania, Turkey, Bosnia and Herzegovina, Slovakia, Czech Republic, Serbia) also meeting the specific requirements of the railway administrations in those countries.

Another challenge for the development of CCS systems was station equipment. With the increasing use of electronics in CCS systems, modernisation of station equipment on Polish railways also began. The work started with the modernisation of existing relay-based equipment by adapting the traffic controller's interface to electronic components. The interlocking layer continued to be implemented using relays. This led to the creation of "hybrid" station systems, which, after laboratory and field-testing and the development of safety cases, were put into operation. An example of such systems is the OSA-H type system. These efforts were later continued with the aim of replacing the interlocking layer of station equipment with electronic components, primarily driven by the industry producing CCS equipment in collaboration with the CD. The challenge lay in developing safety cases and validating these solutions. Validation was carried out, among others, by the CD. Currently, the Control Department carries out tests for certification purposes and conducts independent safety assessments for electronic station systems from various manufacturers. After a positive assessment, these systems are approved for use on Polish railways and by other railway administrations. The Control Department has tested and assessed station-based traffic control systems designed to meet both pan-European requirements and the specific requirements of individual railway administrations. Following such testing and assessment, the systems could be installed on Polish railways, as well as in Belarus, Lithuania, Turkey, Slovakia, Bosnia and Herzegovina, and Serbia.

In the 1960s, an automatic level crossing signalling system was constructed in the Control Department. Testing methods, including safety tests, were developed on this occasion for the automatic level crossing signalling system. The design used relays and made it possible to use it on double- and single-track railways. At the time, this was a very modern universal crossing signalling solution in comparison to those used by other railway administrations. COB 58 and COB 63 automatic level crossing signalling system were widely used for several decades on railway lines in Poland. Even today, one can still find single pieces in operation on the Polish railway network.

In the later years of the 20th century, CD employees participated in the construction of relay-electronic and electronic automatic level crossing signalling systems developed by the Polish industry. The experience gained in the development of COB-type automatic level crossing signalling allowed for the application of this crossing's operating principle in new solutions. To this day, CD evaluates various new automatic level crossing signalling systems designs from different manufacturers. Some of these solutions, in addition to meeting safety requirements, must also fulfill specific requirements of particular railway administrations. The evaluation of automatic level crossing signalling systems has been conducted, among others, for the needs of Lithuanian, Turkish, Slovak, Serbian, and Belarusian railways.

Since the 1970s, the Control Department has been working on the compatibility of rolling stock with CCS equipment. The main concern was the impact of electrical and electromagnetic interference generated by rolling stock on CCS equipment. It turned out that the equipment most sensitive to interference were track occupancy detection devices (track circuits, axle counters) and information transmission circuits that use cables. A method has been developed to test and determine the values of permissible interference parameters. These methods were adopted for use within the UIC (Committee A 122 of the ORE) as well as within the OSJD. In 1982, interference limit values were developed and applied to Polish railways [12]. In 1999 [10] and 2011 [3] these values were updated and introduced into the List of the President of the Office of Rail Transport (UTK) as mandatory requirements of the Polish railways. The findings of these works are described in the book by A. Białoń and V.G. Sychenko entitled "Electromagnetic compatibility of direct-current traction energy at the high-speed operation" [8].



In the 1990s, the development of an interoperable railway traffic management system (European Rail Traffic Management System - ERTMS) and its ETCS (European Train Control System) subsystem began in Europe. Representatives of the Control Department were involved in the work carried out at UIC and European Union level from the very beginning. The result of this work was the development of functional and system requirements for ERTMS and ETCS. These requirements became mandatory in the European Union. Their successive iterations were published in the Technical Specifications for Interoperability, as documents applicable on the Community's railways. CD also carried out work on the implementation of the ERTMS system in Poland. One of the first studies on ERTMS was a study by Italfer entitled "Pilotowa instalacja ERTMS na linii E-20 Kunowice Warszawa" [25], in the development of which CD employees also had a significant contribution. In 2007, the concept for the implementation of ERTMS in Poland was complete. The National Implementation Plan for ERTMS, developed by CD in cooperation with representatives of all railway "services", was approved by the Polish government as binding in March 2007. This plan, with minor corrections, was used in the creation of subsequent versions of the National Implementation Plan for the Technical Specification for Interoperability "Control Command and Signalling".

The Control Department began testing and evaluating the implementation of the ERTMS system on the Polish railway network. Methods and test programmes for the ERTMS system were developed for the approval and certification of the system and its components. This concerned both the ETCS and GSM-R system. The test programmes developed at ZS were adopted for use by the Office of Rail Transport. One of the most important issues was the development of country-specific variables [6], which were adopted for use on the Polish railway network. Compatibility tests for on-board and trackside equipment of the ETCS system (ESC) were also developed in 2020 and, with minor adjustments, are still in force today. Works on the practical implementation of ESC testing have also begun. Appropriate agreements and contracts for ESC testing on testbeds complying with the test specifications have been established. These activities have become a model for the conduct of ESC tests by other units. More than half of the ESC tests conducted in Poland were carried out by CD.

One of the issues developed at CD was the issue concerning marshalling yards. A lot of work has been carried out on modernising and automating the work at marshalling yards. Work was carried out on the application of track brakes, the automation of control of switches, and the control of occupancy of the directional track. The first significant result of this work was the development, testing and implementation of a computerised automation system at Lublin Tatary station, one of more than 100 marshalling yards. The station was commissioned in the mid-1970s and continued to operate with Odra 1305 computers until 2010.

A challenge for CD was the Warsaw Metro. For Warsaw Metro, as mentioned earlier, various new types of track circuits (jointless, standard and using axle counters) were developed and put into operation; what is more, acceptable interference parameters were developed for them. An interesting solution was the only jointless track circuit for a track crossing known in the world. Work on track circuits was carried out in the 1980s and 1990s. For Warsaw Metro, tests were also carried out for the approval of a SOP-type automatic train protection system. These tests were carried out on lines I and II of the Warsaw Metro. The results of the tests allowed minor adjustments to be made to the SOP system, and also contributed to the CD's final positive opinion on the system. A number of tests were also carried out for Warsaw Metro regarding the interference caused by the trains and its impact on trackside equipment, including track occupancy detection devices.

Work on significant components of CCS equipment, such as switch drives and indicators, was also one of the issues addressed in the work carried out at the CD. Methods for testing, evaluating and controlling switch drives were developed. Tests were carried out on the drives of various manufacturers, on the basis of which opinions were given on their safe operation, their acceptability for use, and suggestions for maintenance. Work on signalling has focused on both the technical solutions for railway signals, including methods of controlling them, and the proposed new signalling system for use on Polish railways. Several new solutions for controlling the display of lights on railway signals have been developed, tested, and implemented into operation.

Another challenge has been the use of non-incandescent light sources (e.g., light-emitting diodes) in railway signals. It became necessary to develop new methods for evaluating these solutions, including safety assessments of the systems. Work on the use of non-incandescent light sources has been ongoing since the beginning of the 21st century. Some solutions are already in operation, but widespread implementation across the Polish railway network will still require some time.

Development work and standards

Since the beginning of the Control Department, work has been carried out to recognise certain physical phenomena relevant to the conditions and applicability of CCS equipment. An example of this is the transmission range of electrical signals in the railway track. In the 1970s, studies concerning the attenuation of electrical signals by the track as a function of frequency were carried out. The studies were used in the development of track circuits, including jointless ones. Another example is the study of electrical resonances in overhead lines. In the 1990s, such studies were carried out both on the PLK railway network and on the testing yard of the Railway Institute in Bychowo near Żmigród. This made it possible to use the results of these studies in determining the permissible parameters of interference from electric traction devices and their effect on CCS equipment, as well as in determining the permissible parameters of overvoltages affecting CCS and humans.

In the 2010s, studies were carried out on the propagation of lightning impulses in overhead line and railway track. These studies made it possible to quantify and qualitatively determine the attenuation of the catenary and the railway track during the propagation of lightning impulses. In part, the phenomenon of signal reflections from the end of the overhead line and the superposition of these signals was also investigated. In part, the phenomenon of signal reflections from the end of the overhead line and the superposition of these signals was also investigated. These studies were used in the development and evaluation of a collective traction structure bonding system for a DC overhead line. This was "pioneering" research on a European scale.

Further work carried out by CD was related to the determination of RAMS (*Reliability*, *Availability*, *Maintainability*, *Safety*) parameters for CCS equipment. The assessment methods and parameters called RAMS developed in the 1990s were applied on the PKP PLK S.A. network. The experience gained from the safety-related work concerning RAMS allowed for an easier entry into the independent safety assessment of CCS systems (ISA) in accordance with current standards.

In the 1980s and 1990s, CD carried out work on defining the principles of operation after railway accidents. It also proposed a range of necessary investigations on the basis of which the causes of a railway incident (accident) involving CCS equipment could be determined.

In 2010, the "Standardy techniczne szczegółowe warunki techniczne dla modernizacji lub budowy linii kolejowych do prędkości $V_{max} \leq 250$ km/h" (Technical standards – Detailed technical conditions for modernisation or construction of railway lines up to $V_{max} \leq 250$ km/h) were implemented for use on the PKP PLK railway network [7]. The standards were developed at the Railway Institute. They concerned all railway sectors, including CCS equipment: they defined requirements and indicated detailed technical parameters to which the equipment should conform. The standards were amended and supplemented several times (the last time in 2022).

In 2021, the Railway Institute developed railway standards for the Central Transport Port – CPK [28]. In the Control Department, the following were developed:

- Volume VI.1: Control Command and Signalling – Basic Equipment
- Volume VI.2: Control Command and Signalling – European Train Control System ETCS,
- Volume VII.3: Devices for the Detection of Rolling Stock Failure Conditions (DSAT),
- Volume XI: Electromagnetic Compatibility (EMC).

The standards developed defined the requirements for CCS equipment and systems and showed the detailed technical parameters that the equipment should meet.

In 2021, the Department developed standards for the procurement of rolling stock, focusing on CCS equipment. The standards were developed on behalf of the Ministry of Infrastructure and are currently being used.

Another challenge for the ZS was to develop standards for interfaces between CCS equipment. The work, conducted within the framework of the Joint Undertaking of the National Centre for Research and Development and PKP Polskie Linie Kolejowe S.A. BRIK – Research and Development in Railway Infrastructure, was completed in 2022 with a study defining the requirements for interfaces between CCS equipment subsystems and their design guidelines [29]. Interface models and their simulators were also developed and tested in laboratory and in operation. These requirements, interface simulators and design guidelines should lead to standardisation of interfaces between each manufacturer's systems, subsystems and CCS equipment. For the development of the requirements, analyses of the documentation of the interfaces of the CCS equipment applied by various manufacturers were used. These standards were adopted for use by PKP PLK S.A.

Test methods for CCS equipment were also developed in the Control Department; they were also amended and supplemented due to technical and technological changes, their digitisation and issues concerning CCS equipment.

In the 2020s, work on the cyber security of CCS equipment operated on the rail network in Poland began in the Control Department. Both the principles of cyber security of CCS equipment and methods for its verification were developed. The principles related to cyber security are described in detail in publications: Pawlik M. "Referencyjny model funkcjonalny wspierania bezpieczeństwa i ochrony transportu kolejowego przez systemy z transmisją danych" [24] and

Pawlik M. "Railway Safety, Security and Cybersecurity. Comprehensive Approach to Safety of the Guided Transport Systems" [23].

Certification of rail traffic control equipment

The issue of approval of equipment has always been present in the work carried out by CD. Initially (1950s and 1960s), these were opinions on specific equipment and systems. From the 1960s to the 1980s, an opinion from the Product Evaluation Committee (Komisja Oceny Wyrobów) at the Control Department (Zakład Sterowania) of the Railway Research Institute was required for the approval of the equipment.

From the 1990s onwards, work, regulated by national and international requirements, on the development of safety case began. Safety cases were developed for components, subsystems and rail traffic control systems. The developed safety case required validation. This assessment of safety case was conducted at CD for both in-house developed and safety case developed by other entities e.g. manufacturers. Nowadays, an Independent Safety Assessment (ISA[2]) is required by both national and international regulations. Safety case and ISA are used when assessing the safety of railway components and CCS systems, as well as their safe integration.

In the 1990s, the need for the use of certificates, which are one of the conditions for the authorisation of CCS equipment and systems, began. CD is actively involved in the development of certificates and also carries out the necessary tests in this regard. This work requires those developing the certificates to have a very good knowledge of the design principles of CCS equipment as well as knowledge in the field of safety.

Collaboration with Other Entities and International Cooperation

CD collaborates with numerous organisations and research centres specialising in railway matters, both domestically and internationally. One of the key organisations is the International Union of Railways (UIC – established in 1922), which brings together railway boards from the majority of countries worldwide. Employees of CD have participated in UIC activities, as well as in the development of UIC requirements (known as flashcards). These flashcards are recommended for the design of all railway equipment, including CCS. One of the organs of the UIC was the Office of Research and Experimentation (ORE), established in 1950 and transformed in 1992 into ERRI, the European Regions Research and Innovation Network). The purpose of these international institutes is to carry out research for standardisation and projects coordinated by the UIC. CD staff participated, among other things, in work on: warning of workers on the railway track, identification of the completeness of the train, application of thyristors to rolling stock, interference generated by rolling stock and traction substations and their impact on CCS equipment, and work on the application of the ERTMS system. Many of the studies later used by ORE and ERRI to create recommendations and flashcards by UIC were conducted.

Another organisation with which the Railway Institute (including CD) cooperates is the OSJD (*Organisation for Cooperation between Railways*), which brings together countries formerly active in the Comecon. Initially, the Railway Institute was represented by PKP (Polish State Railways), whereas now, after the separation of IK from PKP structures, it is an affiliated member. During the twentieth century, OSJD carried out many studies, the results of which were used in developing recommendations for use in associated countries. CD staff were involved in the development of a railway signalling system to be implemented on the railway networks of member countries. This system has not been fully implemented in any of the railway administrations. The issues that the OSJD dealt with from the 1970s to the 1990s concerned the use of thyristors in railways. CD staff coordinated research carried out by the various railway boards and defined the scope of this research. In addition, they were involved in work relating to CCS equipment (testing, requirements, maintenance), and assisted colleagues dealing with rolling stock and traction power supply in determining the impact of new developments in these areas on CCS equipment.

CD also cooperated with railway centres of various railway administrations. One example is the cooperation with the VUZ Institute of the Czech Railways and Incertrans of the Romanian Railways in the field of interference. The scope of this cooperation included joint research into interference generated by rolling stock and its effects on CCS equipment. In the

[2] ISA (*Independent Safety Assessment*) is designed for railway systems and is a process carried out by independent assessors who verify that the railway architecture meets safety standards and that it operates in a way that minimises the risk of accidents or incidents.

field of applications of CCS equipment, cooperation was carried out with the institutes: Incertrans, VUŻ, WNIIŻT and WNIIAS (Russia) and the Yugoslav Railways Institute.

Within the framework of cooperation with foreign centres, cooperation with railway universities is important. A typical example is the cooperation with DIIT (Dnipro National University of Railway Transport named after academician V. Lazaryan, Dnipro (Ukraine). There has been cooperation with this institute concerning studies on interference generated by DC and AC traction, surges generated by rolling stock, as well as in the field of CCS (track circuits).

Joint research on interference was carried out, several scientific conferences on electromagnetic compatibility were organised, as well as conferences on energy optimisation, safety and logistics (Energy – optimal technologies, logistics and safety on transport). Certification training was also provided for DIIT staff. The result of this collaboration was a co-authored monograph by A. Białoń and V.G. Sychenko entitled "Злектромагнитная совместимость тягового электроснабжения постоянного тока при скоростном движении" [5]. At the same time, the director of Railway Institute and an employee of CD were honoured with the title of honorary professor of DIIT. Cooperation also took place with the University of Žilina (formerly Vysoká škola dopravy a spojov) in the field of safety of railway control command and signalling equipment. For almost twenty years, an employee of CD was a member of the Slovak state diploma examination board at this university. One of the results of this cooperation was a joint publication by Bialoń A., Rástočný K., Nagy P., Mikulski J., Młyńczak J. entitled "Prvky zabezpečovacích systémov" [4].

The cooperation of the CD with national centres dealing with railway issues has continued all the time since the establishment of the Department. We cooperate with the following universities: Warsaw University of Technology, Silesian University of Technology, Gdansk University of Technology, Cracow University of Technology and University of Radom.

Popularisation of knowledge

The work carried out at the Control Department has been published in various technical journals and also presented at conferences related to rail transport. More than 500 papers on rail traffic control were presented at conferences. An example of such a journal was the monthly magazine "Railway Automation, Traffic Control, Communications, Information Technology" (pol. „Automatyka Kolejowa, sterowanie ruchem, łączność, informatyka"), published by the PKP in the post-war period (until 1990), in which the results of the CD's work on new solutions in the field of railway control command and signalling were published. Another example of this type of magazine is the supplement, published by the monthly magazine TTS Technika Transportu Szynowego, on TSR (Telecommunications and Traffic Control) tail traffic management system, in which the results of the work carried out at the CD were also published.

The research results from the work carried out at CD have been published in "Railway Reports" (pol. „Problemy Kolejnictwa") and in the Railway Institute's Works (pol. „Prace Instytutu Kolejnictwa") published by the Railway Institute. Another form of publication of the work carried out at CD and the knowledge in the field of rail traffic control are book publications and monographs. Examples of this are publications on interoperable traffic control system, [13, 14, 16, 21, 22] cyber security systems [23, 24] or vehicle positioning [32]. An important part of the dissemination of railway knowledge was the "Lexicon of railway terminology" (pol. „Leksykon terminow kolejowych") [2] published in 2011, in which many terms were edited by employees of the Control Department.

Many publications by CD employees have also appeared in foreign publications. Examples of this are, for example, publications in DIIT publications (Dnipro National University of Railway Transport named after academician V. Lazaryan – Dnipro, Ukraine): Nauka Ta Progresu Transportu (CD employee is a member of the programme board), Elektrifikacija transporta, Elektromagnitnaya sovmiestimost (CD employee is a member of the academic board).

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