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Conditions for the Application of Monitoring and Diagnostic Systems in Control and Telecommunications Systems

Abstract: The article concerns the essential conditions of the use of supervision and diagnostic systems in control and telecommunications systems. In the introduction, the factors aff ecting the correct functioning of the SRKI Systems were discussed, attention was also paid to the problem of interference. In the following part, the problem of reliability and safety of control systems, failure reporting systems, as well as technical diagnostics is characterized. Based on the research topic carried out as part of the National Center for Research and Development, solutions for a new technology for implementation on railway lines and a specifi cation of the structure of the support system were presented. Research models based on simulations, expert and statistical systems were indicated. The benefi ts of the project were indicated.

Keywords: Surveillance systems; Diagnostics; rm; Control; Telecommunication

Introduction

Human activity has introduced artificial shaping factors. As a result of the emergence of countless sources of radiation and interference, significant changes have occurred in the electromagnetic environment. The development of electrical engineering and electronics has led to the introduction of innumerable artificial sources of non-ionizing electromagnetic radiation, emitting fields over a very wide frequency range.

Modern control and telecommunication systems are expected, among other things, to feature miniaturization, limited power consumption, and high operational reliability. These constraints mean that the useful signal levels of devices used in SRKiŁ Systems (e.g., sensors, modules, etc.) may be comparable to the level of interference generated, for example, by stationary and mobile sources of interference (e.g., base stations, radio and TV stations, medium- and high-voltage power lines, transformer stations, household electrical appliances, traction vehicles, etc.).

For this reason, continuous diagnosis of the electromagnetic environment becomes very important whenever new devices and systems with high rated power are introduced, for instance when changing the power of a transformer station, using higher-power drive motors in traction vehicles, or increasing the transmitting power of mobile telephone base stations. The problem of electromagnetic interference first arose in the early days of radio broadcasting.

The proper functioning of SRKiŁ Systems depends on:

1. The reliability of individual components forming the system,
2. The internal reliability structure,
3. The adopted operational strategies,
4. Interference affecting operational processes.

SRKiŁ Systems, installed over extensive railway areas and in various buildings, are exposed to interference from moving objects (traction vehicles) and from the entire electrical and electronic infrastructure of the railway environment: traction power supply, power transformer stations, as well as other railway traffic control and telecommunication systems. A high level of interference may cause malfunctions in digital circuits and microprocessor systems that make up safety, control, and telecommunication systems.

Various frequencies and amplitudes of interference occur in railway areas. Electric traction and transformer stations generate low-frequency disturbances, while pulse devices used to start traction vehicles produce interference across a very wide frequency spectrum. The issue of interference immunity in safety and control systems—thus ensuring railway traffic safety—takes on particular importance when operators introduce high-power electric locomotives into service. The problem of interference appeared as early as the initial development of radio broadcasting.

Currently, in the railway sector, both analog and digital electronic devices are used. These devices themselves generate unintended electromagnetic fields during operation and are exposed to external fields generated by other devices. Broad concern about the adverse effects of electromagnetic fields across various frequency ranges on the human body and on the operation of electronic devices began when the European Union introduced a directive on electromagnetic compatibility (EMC). The determination of permissible conditions for the impact of external electromagnetic fields on the operation of electronic devices, as well as on equipment containing electronic circuits, is defined as electromagnetic compatibility.

The Railway Network as a Sustainable Mode of Transport

Rail transport is a part of sustainable mobility policy across the European Union. A global and comprehensive approach to introducing free competition within defined technical standards, safety regulations, and, above all, environmental protection requirements ensures ongoing efforts to implement innovative approaches aimed at increasing rail line accessibility, shortening service delivery times, and improving punctuality at destinations.

To guarantee the highest level of railway transport services and to effectively compete with road transport, it is necessary to improve continuous knowledge of the technical condition of all devices within railway traffic control systems.

A recent safety report prepared by the Office of Rail Transport [26] for 2019, covering railway lines managed by PKP Polskie Linie Kolejowe S.A., presents a list of indicators related to events that have the greatest impact on railway accidents and disasters. This document also provides data on safety at railway-road crossings, paying particular attention to category D crossings.

The construction of computerized railway network management centers (TEN) [25] will undoubtedly expand the range of transport services offered by rail as compared with road transport. Currently, global, intelligent railway traffic management systems are implemented through ERTMS [13]. However, the tasks performed do not extend to every type of railway operational point.

Reliability and Safety of Railway Traffic Control Systems

There is no doubt that the operated railway traffic control systems (abbreviated in Polish as *srk*), not only those intended for high speeds, must be safe and reliable. Reliability management for all types of technical systems is defined in the PN-EN 60300 standards series [22], covering basic concepts through guidelines for the application of reliability management procedures. Meanwhile, requirements concerning reliability, availability, maintainability, and safety (RAMS) for railway technical systems are covered by standards PN-EN 50126, 50128, 50129, and 50159 [23]. Detailed railway documents on RAMS usually address either RAM (i.e., reliability in its various dimensions) or safety understood as technical safety (*safety*), rather than the security of persons and property (*security*).

When analyzing reliability and safety, it must be remembered that the entire railway traffic control system is defined as a set of devices, adapted to the structure of the railway area, that perform automatic control or control with the participation of operators (e.g., dispatchers). These devices must be built in accordance with current regulations, and the subsystem also includes communications equipment and, where necessary, other support equipment as well as operators and the documentation they maintain.

A practical definition of a railway traffic control system (*srk*) is one that, under any operating conditions, ensures safe railway traffic control. Specifically, it should prevent head-on collisions of trains, prevent a train from running into the rear of another train, prevent collisions of trains on turnouts (including the incursion of railway vehicles from sidings onto main tracks), prevent derailments resulting from switch changing under a moving train, prevent collisions with road vehicles at railway-road crossings, and prevent exceeding speed limits or traveling beyond the end of a permitted route.

The Relationship Between Reliability and Safety

A railway traffic control system is an active safety system that, as a whole, must be safe. Its safety is achieved by applying two principles throughout the system's entire life cycle:

1. The *fail-safe* principle (i.e., the "failed-safe" principle).
2. The requirement to ensure a Safety Integrity Level (SIL) 4.

The fail-safe principle is widely used in railway transport. In the event of a failure, systems and devices may shift to an operational failure state but never to a safety failure state. For example, traffic control devices are designed so that when a fault occurs, instead of a green signal on a light signal, a speed-limiting signal (e.g., yellow) or even a "stop" signal may be displayed.

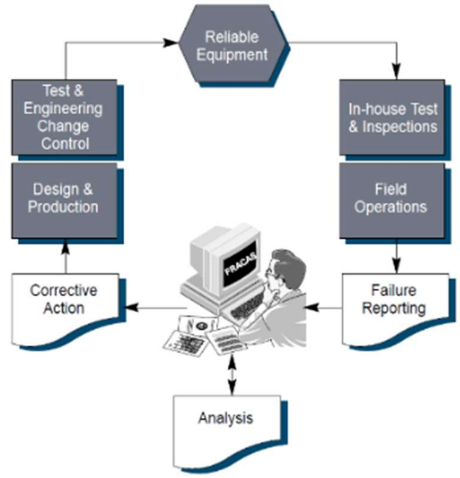
In developing a safety requirements specification, two types of safety requirements are distinguished:

- Functional safety requirements, to which the fail-safe principle is applicable and sufficient.
- Safety integrity requirements, for which a detailed analysis of the impact of random failures and systematic errors on equipment safety is necessary.

Random failures are those arising, for example, from material defects. Systematic errors are those arising from human errors, which may occur during various stages of a device's life cycle (e.g., design, manufacturing, or maintenance errors). In the first case, quality and reliability requirements are defined. In the second case, various procedural requirements are defined. Here, the FRACAS (Failure Reporting, Analysis, and Corrective Actions System) methodology must be used.

Failure Reporting, Analysis, and Corrective Actions System (FRACAS)

Failure Reporting, Analysis, and Corrective Actions System (FRACAS) (Fig. **1**) is a closed-loop feedback path in which the user and the supplier cooperate to collect, record, and analyze failures of both hardware and software. The user captures data on all problems and provides these data to the supplier.



1. FRACAS methodology.

All events or results deviating from the assumed nominal values that occur during operation and testing should be reported in accordance with the established procedure, which includes collecting and recording information for preventive or corrective maintenance, as well as the time needed to carry out these tasks. The data contained in the reports should be verified and forwarded on appropriate forms to the relevant hardware or software.

The next process is analysis, whose purpose is to determine the root cause of failure to the extent that the primary source of the nonconformity can be identified. The methods used in root cause analysis may include:

- Brainstorming
- Histogram
- Pareto Analysis
- FMEA
- Trend Analysis
- Fault Tree Diagram
- Cause-and-Effect Diagram

The results and conclusions are documented, and **corrective actions** should be taken. A plan should be developed and implemented to **eliminate or reduce** the number of repeated failures. In the event of **systemic failures**, it is necessary to **redesign, perform simulation work, and conduct approval testing** before placing the system back into operation. The system is constantly learning.

Reliability of Railway Traffic Control Systems

Confirmation of compliance with SIL 4 requirements, through a safety case for the entire railway traffic control system, is carried out so that the probability of a dangerous failure—based on the reliability of the entire system—remains lower than the tolerated hazard rate per hour and per system function**.** For SIL 4, the value of this probability factor is less than 10^(-8)**.** In practical terms, this means that, statistically, such a functional failure should not occur more often than once every 10,000,000 hours of continuous operation.

To meet requirements for systematic failures, such systems are equipped with remote diagnostic systems that continuously monitor the correct operation of the system. In some technical solutions, remote diagnostics is an integral part of the system.

When analyzing how railway traffic control device failures affect operations, a particularly useful parameter is train delays caused by these failures. Input data for such an analysis come from information collected for the ERTMS RAMS analysis, included in a document defining reliability and safety requirements for the European Rail Traffic Management System. According to that document, a train is considered delayed if its delay exceeds 1 minute over its entire route. The following probabilities are assumed:

- The probability of a train being delayed is 15%
- The probability that the cause of the delay is a technical failure is 40%
- The probability that the technical failure is a control system failure is 30%
- The probability that the cause within the control system is failure of the European Rail Traffic Management System is 15%

Available data on control system failures allow us to assume that the probability the cause of a control system failure:

- Is damage to occupancy control devices or systems: 10%
- Is the inability to set a turnout in the correct position: 5%
- Is damage to interlocking systems (signal boxes, block devices): 3%
- Is a signal on a light signal requiring an emergency speed restriction (e.g., bulb burnout or an emergency speed restriction resulting from the signal displayed on a crossing warning sign): 65%
- Is damage to a safe driving control system (e.g., the system for transmitting electronic movement authority to vehicles): 15%
- Is some other control system failure: 2%

Therefore, the probability that a train will be delayed due to a light signal failure is approximately one hundredth of one percent:$Po=0.15\times0.4\times0.3\times0.65=0.011$
over the entire train route, taking into account all light signals encountered along that route.

Main Components of a Traditional Signaling and Control System are:

- Train detection devices
- Track circuits
- Axle counters
- Mass detectors
- Safety systems
- Cab signaling
- Interlocking
- Operating rules
- Fixed signals
- Mechanical signals
- Color light signals
- Route and speed signaling
- Block signaling
- Centralized traffic control
- Timetabling and train sequencing

The most important elements to monitor in signaling and control systems are:

- Point (switch) drives
- Signaling systems
- Track circuits
- Axle counters
- Railway-road crossings

Diagnostic System for Devices and Technological Processes

A fundamental issue in reliability and operational considerations is determining the reliability function R(t)R(t)R(t). The simplest way is to analyze the operation of a device or technological process and note occurrences of failures, their frequency, and their causes. On this basis, one can determine key reliability parameters, such as:

- Probability of operation
- Failure rate
- Expected mean time between failures (MTBF)
- Mean time to repair (MTTR)
- etc.

The reliability parameters of a system—depending on whether the system is renewable or non-renewable and on the type of failure assessment—are shown in Fig. **2**.

Parametry niezawodnościowe:

MTTF - średni czas do uszkodzenia – dla systemów nieodnawialnych;
MDTF - średni dystans do uszkodzenia – dla systemów nieodnawialnych;

MTBF - średni czas pomiędzy uszkodzeniami – dla systemów odnawialnych;
MDBF - średni dystans pomiędzy uszkodzeniami – dla systemów odnawialnych.

Ocena typu awarii oraz MTBF – niezawodność

Kategoria awarii	Typ awarii systemu	Efekt w eksploatacji	MTBF (w godz., latach lub km)
Generalna	Całkowita awaria	Eksploatacja niemożliwa	
Ważna	Awaria krytycznego elementu funkcjonalnego	Eksploatacja awaryjna 1	
Drugorzędna	Awaria niekrytycznego elementu funkcjonalnego	Eksploatacja awaryjna 2	
Pomijalna	awaria nieistotnego elementu funkcjonalnego	Normalna eksploatacja	

2. System reliability parameters

In the case of complex technical systems, reliability is determined by numerous factors whose significance and impact on the day-to-day operation of technical resources we are not fully able to understand or estimate. This results from the inability to conduct sufficiently detailed analyses and modeling of both the production process and reliability phenomena. An additional problem is that the processes themselves, carried out dynamically, are stochastic in nature and do not allow for complete modeling or prediction—even if reliability policies are strictly followed. Therefore, regardless of the level of technical awareness, an essential component of the maintenance process is the use of diagnostic systems for devices and technical systems. Standard practice includes the use of measurement systems for drive overloads and permissible operating temperatures of devices and their control systems.

The results of operational diagnostics make it possible to generate information related to the current servicing of devices for:

- Operators—information about the machine's efficiency level and expected periods of trouble-free operation,
- Maintenance services—indicating the location of a failure and its cause.

Thanks to this approach, it is possible to continuously perform tasks for monitoring device conditions and diagnosing them, which—given the adopted reliability model describing the analyzed technical process—enables a direct assessment of the state of the ongoing process. It also allows the detection and identification of device failure states as well as the determination of their location and causes. Any state or phenomenon leading to failure is indicated in these systems by an appropriate alarm. The failure detection signal is also relayed to the operator or system dispatcher. Such actions help to limit the effects of potential failures or prevent them altogether.

Knowledge of signals and symptoms that indicate the condition of the diagnosed object includes both signals inherently connected with its operation and signals generated, for example, in artificially induced states. In this case, familiarity with methods of signal generation, processing, and the creation of diagnostically oriented symptoms of the object's condition becomes necessary. The use of such symptoms is particularly significant in technical diagnostics. Observation of the residual processes that accompany the functioning of objects can be employed according to the basic model assuming a clear relationship between the technical condition and the intensity of residual processes, such as vibration, noise, or thermal radiation. Generally, this intensity is not directly measurable, so the technical condition is inferred indirectly on the basis of measurable symptoms associated with these residual processes.

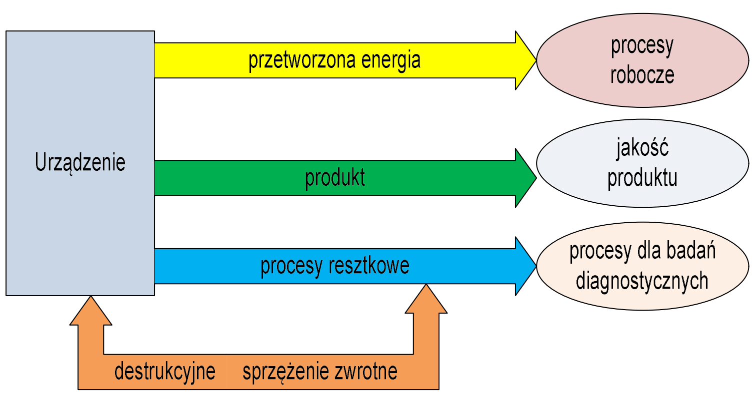
Technical Diagnostics of Devices

To ensure that devices remain in a constant state of readiness, they must undergo continuous observation. One must observe and locate any potential damage or wear in device components and then repair any detected faults. To plan and carry out maintenance processes properly, it is crucial to obtain relevant information about the device. Such information must be reliable, show the current state of the devices, and provide forecasts of their future states. This information is gathered using technical diagnostics methods.

Carrying out diagnostics involves assessing the device's condition indirectly by comparing measured diagnostic signals against their nominal values. These diagnostic signals are called *symptoms*, which allow one to detect the presence of a fault. Diagnostics relies on these symptoms to enable an evaluation of the technical condition of the diagnosed device.

Device condition can be evaluated through:

- Continuous or periodic monitoring of parameters related to working processes,
- Qualitative assessment of the product or the outcome of the device's operation,
- Observation of parameters in residual processes.



3. Parameters used to assess the condition of the device

Fundamental Tasks in Technical Diagnostics

- Examining, identifying, and classifying failures that develop over time, along with their symptoms,
- Developing methods needed to examine and select diagnostic symptoms,
- Issuing a diagnostic decision regarding the condition of the diagnosed device as well as any preventive measures to be taken.

To arrive at a diagnosis, it is necessary to perform activities that make it possible to recognize the current condition of the device and assess its past and future states. In the methodology of diagnostic testing, the following stages are distinguished:

- Checking the device's condition,
- Evaluating that condition and its consequences,
- Locating and isolating any failures,
- Forecasting future states of the device.

Once these stages are completed, the following processes become possible:

- Diagnosing – determining the device's current condition,
- Genealogizing – reconstructing the device's operational history,
- Forecasting – determining possible future states of the device.

Technical Diagnostics of Railway Traffic Control Devices

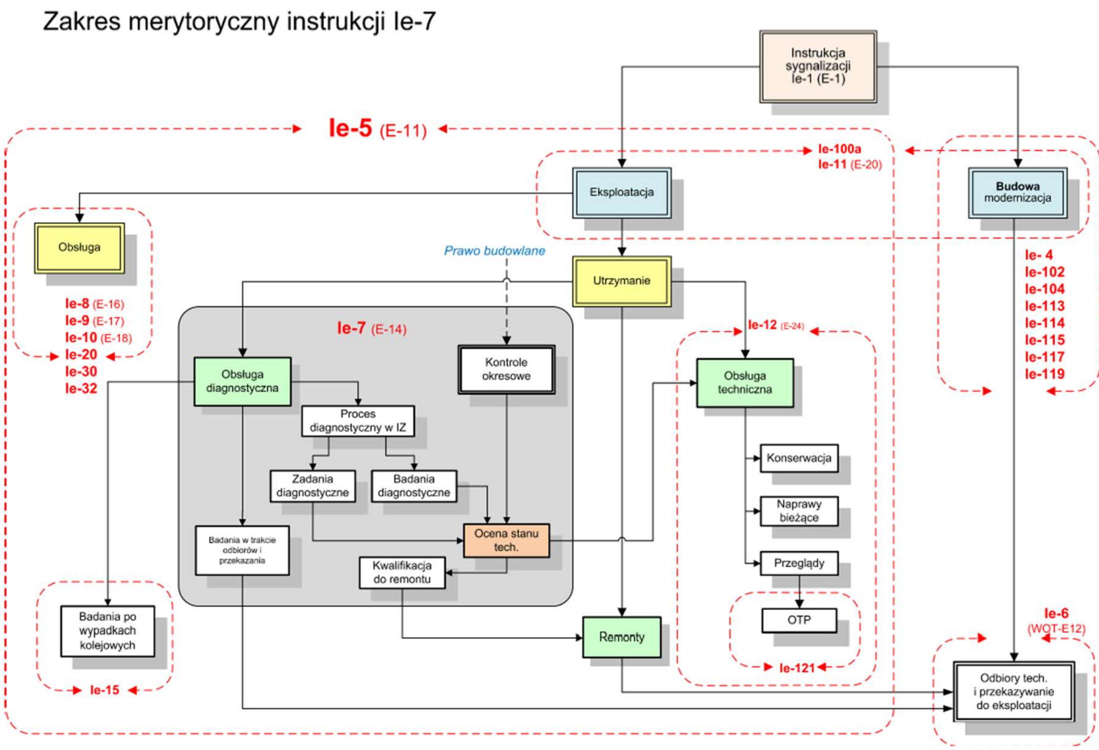
The primary diagnostic objective for railway traffic control devices (*srk*) is consistently to ensure safety and the operational reliability of train traffic on the railway line.

Disregarding computer-based techniques, the diagnostic process is largely carried out manually, using appropriate measuring instruments. This type of diagnostics is referred to as a preventive activity aimed at avoiding malfunctions. *Srk* devices undergo diagnostic tests that determine their degree of wear, so that the necessary repair measures can be taken and the technical conditions for further operation of the devices can be established, together with an assessment of their maintenance level.

When defining diagnostic testing criteria for railway traffic control devices, attention should be paid to the requirements and technical guidelines found in documents such as:

- The Technical and Operational Documentation (DTR) for *srk* devices,
- The Technical Guidelines for building railway traffic control devices – *Ie-4 Instruction* [15],
- Technical Acceptance and commissioning guidelines for railway traffic control devices – *Ie-6 Instruction* [16],
- Maintenance and Inspection instructions for *srk* devices – *Ie-12 Instruction* [14].

Diagnostics of railway traffic control devices itself is based on internal Instruction Ie-7 [17], issued by PKP PLK SA, which describes the diagnostic process in the following stages: planning, diagnosing, technical analysis, formulating a diagnosis, and drawing conclusions for the continued use of *srk* devices. This also includes documenting the process (e.g., test and measurement results), as illustrated in Fig. **4**.



4. The substantive scope of diagnostics of railway control devices from Instruction Ie-7.

Remote Diagnostics of SRK Devices

With the development of IT and telecommunications technologies, it has become possible to continuously monitor the operation of railway traffic control (*srk*) devices in real time from certain distances (so-called *remote diagnostics*). Remote diagnostics is successfully employed at the Maintenance and Diagnostics Center (CUiD), which is located in the premises of the Local Control Center (LCS). From an IT standpoint, the CUiD consists of hardware and software for collecting diagnostic data from any *srk* system and storing them in local databases.

The CUiD's primary tasks include:

- Ongoing monitoring,
- Collecting and
- Presenting diagnostic information regarding the condition of control devices and systems within the LCS area of responsibility.

5. Operator panel in the CUiD in the LCS room, Mińsk Mazowiecki

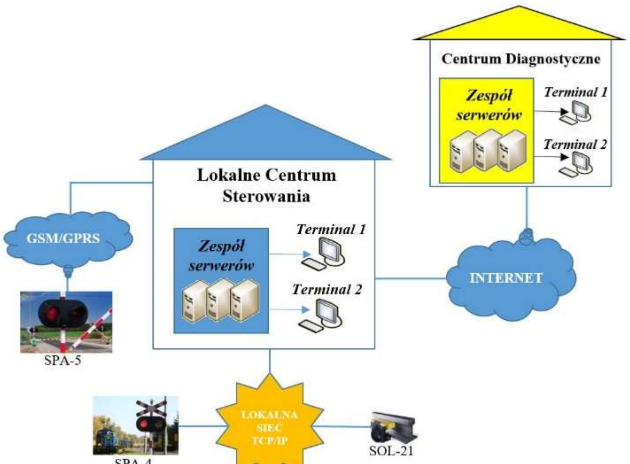
An interesting LCS solution is the modern system implemented in Drzewica, on the Tomaszów Mazowiecki–Radom line section. Zakłady Automatyki KOMBUD from Radom installed a family of modern railway traffic control (srk) systems there, known as MOR. The primary srk system in use is the MOR-2 remote control system, which provides an extended view of operating states, automatic scheduling of rail traffic, dispatcher control, train run analysis with automatic recording, electronic train announcements, and communication between traffic dispatchers. All the elements installed at the Drzewica LCS are equipped with comprehensive mechanisms for monitoring device operation, autonomous fault detection, and remote diagnostics.

5. Equipping LCS Drzewica with modern solutions for managing railway traffic.

5.

Bombardier Transportation Polska has implemented the SDZ-2 Remote Diagnostic System. This system is computer-based and is designed to collect diagnostic information from multiple railway traffic control (srk) devices simultaneously. Data obtained from the linear srk devices under diagnosis are processed and displayed in a clear format on the diagnostic panel monitor at the Maintenance and Diagnostics Center (CUiD). Depending on the service area and the number of monitored devices, the SDZ-2 system uses servers located on one or several computers.

Thanks to its open architecture, the SDZ-2 system can concurrently monitor various linear srk systems with different purposes. It also seamlessly monitors systems developed by Bombardier Transportation Polska, such as the SHL 12 automatic line block system, the SPA-4 or SPA-5 automatic level crossing signaling systems, or the SOL-21 track section occupancy detection system.



7. Example configuration of the SDZ-2 Remote Diagnostics System

Description of a new technology, ready for implementation on railway lines managed by PKP Polskie Linie Kolejowe S.A.

The research topic carried out under NCBiR by the research team of Kazimierz Pułaski University of Technology and Humanities in Radom, entitled: "System for collecting operational data and analyzing reliability and safety of railway automation systems", received the Minister of Education and Science Award in 2021.

Description of the solution

The project implemented by the consortium concerned a fundamental issue related to railway safety and covered the topic of applied research in the field of reliability of railway traffic control devices (srk). The research aimed to improve methods for making operational decisions, which are a crucial factor in increasing railway traffic safety. These activities included issues of operating traffic control devices and systems in terms of methods for assessing and classifying their technical condition, modeling processes carried out during operation, and algorithms for decision-making in the servicing process.

Information about the condition of technical devices, events occurring in the operation system, and the progress of individual processes is key to making effective operational decisions. The identification of the process of managing the operation and servicing of srk systems at PKP PLK, the analysis of the servicing system structure, internal documents regulating the servicing process of devices, and the applied maintenance strategy allowed for formulating and confirming the rationale for attempting to solve research problems such as:

- Developing a method for the effective use of diagnostic test results,
- Developing a method for solving decision-making problems in the operation process by proposing procedures to support decision-making.

A number of new research topics also required consideration, including:

- Analysis of processes carried out in the operation system, including determining probability distributions, for instance for times of correct operation,
- Modeling activities and processes carried out in the operation system using methods appropriate for these purposes,
- Developing a model of the operation process of srk devices as a sequence of events and actions causing changes in their technical condition.

PKP PLK SA's needs were diagnosed by achieving the following objectives:

- Collecting acquired operational data and analyzing them using IT tools,
- Verifying the assumptions and solutions adopted for the implementation of decision support in managing the operation process of srk systems in the area of making decisions concerning the physical implementation of selected processes and activities, and in particular the rational use of srk devices, maintaining and restoring serviceability, materials, spare parts, diagnosing device condition, examining the nature of destructive processes, modernizing devices, replacing or possibly decommissioning them,
- Preparing and developing implementation assumptions for introducing, at the infrastructure manager PKP PLK, the *System for the Analysis of Operational Data in Railway Automation (SADEK)* as a unified software platform for maintenance needs, covering the status of srk devices and subsystems from sections or junctions of the railway network.

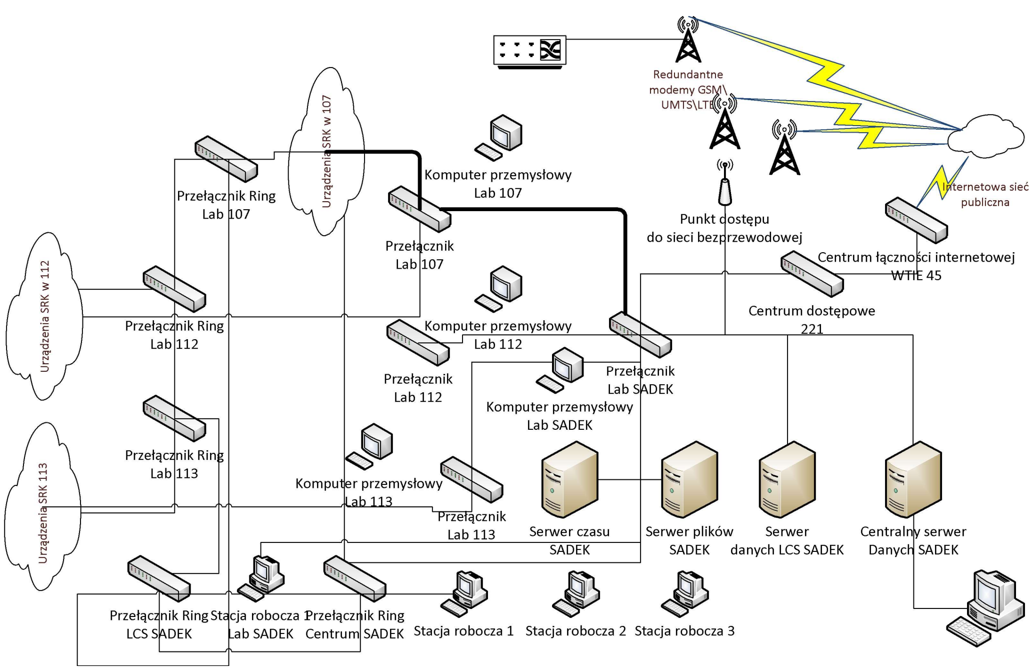
The research work, assumptions, and design solutions related to srk systems operated within the railway infrastructure of PKP PLK, i.e.:

- Systems securing traffic at railway-road crossings,
- Interlocking systems,
- Station devices,

- Line blocks,
- Track-to-vehicle interaction devices,
- Systems for remote control of primary layer devices on a line section.

The new technology project: “collecting operational data and analyzing the reliability and safety of railway automation systems”. The project was carried out in 8 stages, which included:

1. Preparation of equipment, hardware base, and research tools. The following srk systems and devices were connected:
   - EbiLock 950 computer station equipment system with STC object controllers,
   - EbiScreen 2 computer system station master’s workstation,
   - SHL-12 two-way computer line block,
   - SPA-5 computer automatic crossing signaling,
   - SOL-21 axle counter system for detecting unoccupied track sections,
   - EAA-5 turnout drive,
   - EHA-22 5-aspect signal,
   - EHZ-7 road signal,
   - EHZ-5 driver’s warning signal.
2. The following activities were carried out:
   I. Construction of a fiber-optic network in the building of the Faculty of Transport and Electrical Engineering, ensuring full integration of the laboratories used in the project, and connection to the MAN network, along with testing connections within the prototypes and transmission protocols implemented in the task.
   II. Development of prototypes of devices for collecting data from digital interfaces and sending telegrams in an ETHERNET network. Methods of ensuring safety in the diagnosed railway automation subsystems.
   III. Analysis of secure transmission (encryption) protocols in open systems.



8. General structure of the computer network and srk devices in the WTiE laboratories, connected for research purposes and to develop the assumptions of the created System for the Analysis of Operational Data in Railway Automation (SADEK)

The diagnostic data read are sourced from the following:

a) srk devices installed in the Scheidt & Bachmann Polska Sp. z o.o. laboratory, established during the project as SRK113 devices, or from srk devices originating from the Bombardier Transportation laboratory, designated as SRK w 112 devices, created prior to the implementation of this project. The data recorded in this way are local in nature—they come from systems installed in the laboratories of the Kazimierz Pułaski University of Technology and Humanities in Radom,

b) the second source of diagnostic data is the continuously recorded data from srk devices located on an actual railway line, coming, for example, from Local Control Centers (LCS). The transmission of these data is based on the public internet network, using software dedicated for this purpose, for instance in the form of automatically generated emails containing diagnostic data, or using wireless technologies such as GSM, UMTS, and LTE modems,

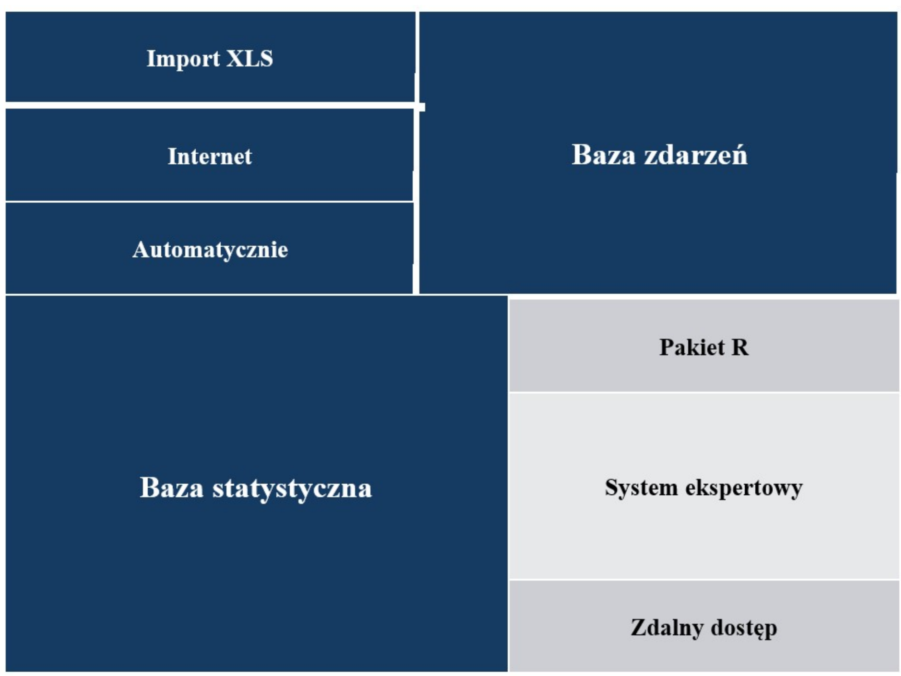
c) the third source of data is information on failures and repairs of individual srk devices located on the railway line, recorded by the personnel servicing these devices. Until now, this information had been stored in paper form. Currently, it is collected in electronic form, which will greatly automate the process of obtaining this type of data,

d) the fourth type of data consists of data generated by a program that enables simulation of failures. The failures are generated on the basis of failure distributions derived from real data.

Specification of the structure of the operation support system

An analysis of railway traffic control systems was carried out to determine the requirements for system complexity (the number of devices in the railway network) and the structure and scope of recorded operational data. The specifications for the structure of a railway automation operation support system were defined. Requirements for the complexity of the operational system of railway automation devices were developed.

The assumptions for the functional structure of the SADEK system are presented in Fig. **9**.



9. Functional structure of the SADEK system

Data on the condition of srk devices are entered into the event database in three ways:

- XLS import – the system has an implemented mail server and client for automatic file import and conversion to the database format,
- Internet – the E 1758 electronic logbook with all its functions,
- Automatically – from actual devices through diagnostic interfaces.

Information from the event database is periodically retrieved by the monitoring program and, after initial verification and processing, is sent to the statistical database. The information in the statistical database is processed using the R package. Statistical distributions are developed and placed in the appropriate fields of the database. Based on both primary data and statistics, the implemented expert system predicts the future condition of devices. Maintenance services can access statistics and conclusions from the expert system remotely.

Reliability Research Models

The task was carried out through the specifications of:

- Reliability models for crossing automation systems, station devices, and line block devices,
- Operational models of railway automation systems, taking into account repairable and non-repairable components. In particular, specifications of reliability tests for repairable and non-repairable systems, as well as specifications of the set of operational states and the scope of reliability testing for srk systems.

In addition:

- A set of reliability parameters was defined for the tests of renewable components with a finite repair time, useful for railway automation systems,
- A method was developed to assess the correctness of railway traffic control systems operation, taking into account operational and reliability parameters for a mathematical reliability model.

This part of the task involved the following analyses:

- Functional analysis of actual srk devices within the impact zone of a Local Control Center (LCS),
- Specification of the functions of a Local Control Center in managing train traffic,
- Technical characteristics of train control and traffic management systems,
- Analysis of srk system equipment and railway traffic management in a selected, existing Local Control Center,
- Analysis of the reliability structures of railway automation systems,
- Analysis of the reliability structures of technical systems with the possibility of adaptation for railway automation systems.

Based on the above specifications, simulation models of railway traffic control systems were developed for reliability research.

Technical Condition of the Examined srk System Devices

The current technical condition of the srk devices under study was determined based on a set of characteristic features. It was assumed that most types of device failures generate certain associated features (corresponding to certain measurable physical quantities), on the basis of which it is possible to determine the type of failure or the absence of any failure. Each device's state is described by a redundant number of features, some of which may not reflect its actual condition. Therefore, it is necessary to select a representative set of features and determine their patterns and ranges. A method based on the developed simulation reliability model for individual srk devices was used to isolate these representative features. Another method was also presented that allows feature extraction based on data from real srk devices on a railway line. It uses genetic algorithms and a statistical classifier, specifically its implementation in the form of an SVM (Support Vector Machine) classifier.

Database Design and Collection of Operational Data

A design for the installation and configuration of server and database systems dedicated to collecting operational data was carried out. The chosen technology was based on Microsoft SQL 2012 methodology running under the Microsoft Windows Server 2012R2 operating system. A virtual environment based on VMWare technology was used.

Using the results obtained in previous stages, database table structures were developed for collecting operational data from individual srk systems. In addition, a database was created to store data from the electronic logbook EP1758 developed as a subsystem of SADEK. A program was developed for converting data stored in electronic form (Excel format) to the SADEK database format.

The planned implementation activities were carried out in the following steps:

1. Designing the database, installing and configuring server systems based on a Microsoft environment,
2. Installing the database server and the necessary components,
3. Configuring the database environment in the Microsoft SQL Server management system,
4. Developing the concept of table structures for each srk system,
5. Creating data import programs.

The registration and analysis of operational data were implemented through the acquisition of operational data. From the available data, those useful for the research were selected. A program working with the automatic data conversion tool was developed and launched, allowing the automatic transfer of data from the EP1758 electronic logbook and their automatic saving in the dedicated database. Then, testing was carried out on the program for automatic data transfer and the automatic data conversion tool working with it.

Modeling and Simulation

Statistical analyses of operational data were performed. For each available subsystem, probability density distributions for correct operation times and repair times were determined. For this purpose, a program was written in the R package. It performs the following tasks:

- Connects to a dedicated database to retrieve operational data assigned to individual subsystems,
- Based on the operational data, determines—using the Maximum Likelihood (ML) method—the parameters of the distributions for each subsystem,
- Conducts a goodness-of-fit test for the distribution parameters obtained using the Maximum Likelihood method against the assumed types of distributions. Two methods are used for this purpose: Kolmogorov–Smirnov and Anderson–Darling.

Statistical Research, Inference Rules Database

Inference rule databases were created for the expert system. To develop these rules, data used to verify the functional performance of the selected srk system—provided by one of the manufacturers—were used. Thus, an expert system was created that allows automation of the functional verification process of the above-mentioned srk system. Previously defined inference rules were applied to implement it. The correct operation of this system was also verified using test data.

Expert system

As part of the design assumptions for the system supporting the operation of srk devices, an electronic version of the E 1758 logbook was created, and a plan was proposed for introducing this version in stages to replace the currently used paper-based E 1758 document.
This will enable:

- Systematizing and codifying the records of disruptions in railway traffic,
- Creating a "remote" access channel for the personnel managing railway traffic to records of significant events in railway traffic,
- Tightening procedures for access to servicing, technical maintenance, supervision, and control at traffic posts,
- Automating the processes of analyzing failures, punctuality of train runs, and classifying delays,
- Providing traffic posts with a tool that simplifies the registration process for service personnel behavior, the operating condition of devices, as well as automatically "transferring" records to related documentation,
- Providing supervisory personnel with a tool for analyses characterizing the performance of srk devices and railway traffic management.

It will also allow for the following:

- A synthetic description of the traffic post's location, its equipment with railway traffic control (srk) devices, and the area it covers,
- A register of the maintenance personnel authorized to carry out certain operations on srk devices at a given post,
- A register of personnel authorized to perform work on turnouts cooperating with srk devices,
- Recording:
  - Disruptions in and failures of railway traffic control devices,
  - Situations in which train movements are conducted under substitute signals and written orders,
  - Imposed and canceled restrictions in train traffic,
  - Use of special commands for operating railway traffic control devices,
  - Access to locked and sealed railway traffic control devices,
  - Work on removing disruptions in the operation of railway traffic control devices,
  - Reasons for the occurrence of disruptions in the operation of railway traffic control devices,
  - Information on maintenance work carried out on railway traffic control devices,
  - Information on introduced changes in the configuration and operation of railway traffic control devices,
  - Information on checks performed on railway traffic control devices.

The following basic functionalities of the designed data registration system were made available:

- Description of the traffic post's location and its srk equipment,
- Registration of authorized maintenance personnel,
- Registration of personnel authorized to perform work on turnouts,
- Registration of srk devices at the post,
- Registration of srk device disruptions,
- Registration of srk device maintenance operations.

Method of project implementation

Full use of the SADEK system will enable integration with external systems, which include, among others:

- SWDR – System Wspomagania Dyżurnego Ruchu (Train Dispatcher Support System),

- SEPE – System Ewidencji Pracy Eksploatacyjnej (Operational Work Recording System),
- Optionally SMUE – System Monitorowania Urządzeń Elektroenergetycznych (Power Equipment Monitoring System),
- Other possible systems, such as:
    - D831 (turnout inspection log),
    - A GIS (Geographic Information System), locating on a map:
        - The track layout, srk devices, and dangerous locations,
        - Cubic buildings containing devices such as signal boxes, cabinets, containers.

Integration should be implemented using web services. Integration with external systems is a developmental requirement. This will require the use of an additional integration server capable of handling various applications running in different software and system environments.

Impact of the project on improving safety

The fundamental factor in increasing railway traffic safety is the use of appropriate operational methods necessary to maintain srk devices in a functional state, as well as improving operational decision-making methods (reliability and maintenance) for railway traffic control systems regarding planning the servicing of these systems and procedures in emergency situations.

Decision-making support and the provision of IT tools to all responsible units in PKP PLK's Safety Management System – Procedure SMS-PW-01 – excerpt concerning OTP.

Assessment of the effectiveness of system solutions

The technical benefits of implementing the project include:

- Increased safety of operated srk systems,
- Obtaining uniformly systematized information on the course of railway traffic across the entire railway network,
- Enabling "remote" monitoring of the operation and maintenance of srk devices and the activities of operating and maintenance personnel,
- Providing collected real operational data on railway traffic control devices at traffic posts to the SADEK system.

The business benefits of implementing the project include:

- Reduced time to access information from traffic posts,
- And also the possibility of:
    - Faster response at the management level to emerging threat situations,
    - Developing alternative solutions for railway traffic in the event of disruptions,
    - More efficient use of existing technical and information resources at PKP Polskie Linie Kolejowe S.A.

Source materials

[1] Dyduch J. inni: "Innowacyjne systemy sterowania ruchem" Monografia 147,WPR Radom,2010

[2] Dyduch J. Paś J. Rosiński A.: „Podstawy eksploatacji transportowych systemów elektronicznych" WPR Radom,2011

[3] Dyduch J. Pawlik M.: "Systemy automatycznej kontroli jazdy pociągu" Wyd.II,WPR Radom,2011

[4] Dyduch J., Kornaszewski M.: Systemy sterowania ruchem kolejowym. Wyd. Politechniki Radomskiej, Radom 2003

[5] Dyduch J., Moczarski J.: ”Podstawy eksploatacji systemów SRK” Wyd. Pol. Radomskiej 2008.II wydanie
[6] Dyduch J., Pawlik M.: Systemy automatycznej kontroli jazdy pociągu. Wyd. Politechniki Radomskiej, Radom 2002
[7] Dyduch J., Rosiński A.: Proces eksploatacji systemów nadzoru. Prace naukowe „Transport” nr 1(17) Politechnika Radomska, Radom 2003
[8] Dyduch J.: Decision process In the exploitation of the railway traffic control systems. Archives of Transport v.13, Warszawa 2001
[9] Dyduch J.: Efektywność systemów sterowania ruchem. Tom II, KBM PAN, PWN Warszawa 1990
[10] Dyduch J.: Model niezawodnościowo – funkcjonalny systemu sterowania ruchem kolejowym. Zagadnienia Eksploatacji Maszyn, z. 1-2, PWN, Warszawa 1987
[11] Dyduch J.: Ocena funkcjonowania transportu kolejowego w 2003 r. Problemy Kolejnictwa, z. 139, Warszawa 2004
[12] Dyduch J.: Transportation system certification with respect to EU approval Transport Engineering, XIVt, Nr. 2S Vilnius, 1999
[13] ERTMS, European rail, Traffic Management System. System zarządzania europejskim ruchem kolejowym
[14] Instrukcja Ie-12, „Instrukcja konserwacji, przeglądów oraz napraw bieżących urządzeń sterowania ruchem kolejowym”, PKP Polskie Linie Kolejowe SA, Warszawa 21.12.2017
[15] Instrukcja Ie-4, „Wytyczne techniczne budowy urządzeń sterowania ruchem kolejowym”, PKP Polskie Linie Kolejowe SA, Warszawa 30.12.2019
[16] Instrukcja Ie-6, „Wytyczne odbioru technicznego oraz przekazywania do eksploatacji urządzeń sterowania ruchem kolejowym”, PKP Polskie Linie Kolejowe SA, Warszawa 19.05.2020
[17] Instrukcja Ie-7, „Instrukcja diagnostyki technicznej i kontroli okresowych urządzeń sterowania ruchem kolejowym”, PKP Polskie Linie Kolejowe SA, Warszawa 30.01.2018
[18] PN-EN 50126:2002, Zastosowania kolejowe – Specyfikacja niezawodności, dostępności, podatności utrzymaniowej i bezpieczeństwa
[19] PN-EN 50128:2011, Zastosowania kolejowe – Systemy łączności, przetwarzania danych i sterowania – Oprogramowanie kolejowych systemów sterowania i zabezpieczeń
[20] PN-EN 50129:2007, Zastosowania kolejowe – Systemy łączności, przetwarzania danych i sterowania – Elektroniczne systemy starowania związane z bezpieczeństwem
[21] PN-EN 50159:2011, Zastosowania kolejowe – Systemy łączności, sterowania ruchem i przetwarzania danych – Łączność bezpieczna w systemach transmisyjnych
[22] PN-EN 60300-1:2006, Zarządzanie niezawodnością – Część 1: Systemy zarządzanie niezawodnością
[23] PN-EN 60300-2:2006, Zarządzanie niezawodnością – Część 2: Wytyczne zarządzania niezawodnością
[24] Projekt realizowany przez UTH Radom: „System gromadzenia danych eksploatacyjnych i analizy niezawodności i bezpieczeństwa układów automatyki kolejowej”, nr PBS/A6/29/2015
[25] TEN, Trans-European Transport Network. Transeuropejska sieć transportowa
[26] Urząd Transportu Kolejowego „Raport w sprawie bezpieczeństwa”, Warszawa 2020