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ICT for Rail Transport in Poland

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Summary
The aim of the article is to present the impact of the global development of IT and logistics systems on the planning and development of the ICT network for the needs of rail transport in Poland. The PKP PLK company is currently implementing the process of building a teletransmission network, primarily for the needs of the ERTMS system.
According to the author, the railway ICT network should be planned in such a way as to ensure the current and future needs of all railway companies in the field of data transmission, enabling, in the field of ICT services, the expansion of these companies to other types of transport.

Keywords: ICT networks for railways, network logical model, physical network model

1. Introduction

The dynamism of transport development and cooperation with other institutions and businesses mean that transport must not deviate from the global development trends in the application of ICT solutions. The common feature of IT systems and, in particular, of systems developed for transport, is that they cover large areas and must therefore use the data transmission network, which is one of the basic components of current IT systems. Transport is one of the logistics chain components which include:

- A multifunctional system of logistics services, and
- An integrated ICT system.

A prerequisite for the proper operation of the logistics centre is the transmission of up-to-date information between the aforementioned systems, which are increasingly interconnected and constantly being enhanced. Work is currently underway to find a systemic solution that will improve the efficiency of processes and develop logistics while, at the same time, achieving economic, social and environmental sustainability. This solution is to be the so-called "Physical Internet" (PI), which links the communication infrastructure using modular standardised loading units for transport and the exchange of data on ongoing logistics processes [3].

Developing IT techniques and technologies are now becoming a major and necessary business tool. It is particularly important to make use of all the IT technology potential in companies with a network structure. Such undertakings include almost all railway companies, as well as other rail and road transport companies.

The Internet of Things (IoT), which is already being developed in 5G technology, will be very important for the development and management of IT technology. It will enable better use of IT and telecommunications systems by providing new functionalities, increasing efficiency, automation and also by increasing the speed of transmitted data, necessary for making decisions in real time.

The Internet of Things will be used to manage, collect and transmit data between systems or devices equipped with computers connected to the Internet. This is a direction that offers an opportunity to develop intelligent rolling stock, Intelligent Transport Systems (ITS), and which will also support railway companies in the provision of transport services. The Internet of Things is a solution that supports and improves the acquisition of up-to-date data with fewer errors. Without the implementation of new, innovative solutions in transport companies in the near future, it will be difficult to achieve an improvement in economic performance and to remain on the market for these services.

The Internet of Things (IoT) is a field for the development of numerous innovations that can support not only transport companies, but also the customer and

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its business. This network has the best chance of integrating and cooperating different networks and IT systems. This is particularly important in the rail sector due to the nature of activities which concern the entire area covered by the services and involve the movement of means of transport, people and goods [3].

In Poland, rail transport should not only keep pace with the development of rail transport in Europe, but also with the development of other branches of land transport. One of the conditions for this development will be to have modern information and communication systems (*Cloud Computing, Big Data*, etc.), which will enable railway companies to cooperate not only with each other, but also with foreign partners, enable the introduction of new IT services for their customers and thus ensure that their transport needs are better met. In order to achieve these objectives, it is necessary to develop an appropriate ICT network with modern IT technologies, characterised by enhanced functionality and efficiency and decreasing investment and operating costs.

2. Premises for the development of an IT network project for PKP

The railway ICT network should be adapted to the structure of rail transport in Poland. This structure covers many infrastructure, freight and passenger transport companies, as well as companies providing appropriate services to these companies, such as telecommunications, IT and infrastructure maintenance services.

For many technical, operational, economic and organizational reasons, one common network should be built to meet the needs of all railway companies, which could be assisted by the creation of a holding of railway companies. The network should be open to development resulting from:

- The development of the railway network (e.g. designed railway lines related to the construction of the Central Communication Port, the so-called "spokes", reactivation of selected railway lines, changes in passenger traffic routes (growing trends), changes in freight traffic (reduced coal transport resulting from the need to reduce CO_2), and developing modal transport (e.g. Silk Road);
- Technical progress, such as the development of ICT networks; FRMCS, IoT, 5G networks, followed by 6G;
- Computerisation of the operation and maintenance of infrastructure and rolling stock (continuous monitoring);
- Development of device and system monitoring ensuring the security of railway areas (e.g. fire protection systems, "friend – foe" systems, AdHoc networks).

Before starting to develop an ICT network design, it is important to identify and establish the expectations of future network users in different time perspectives:

- In the first period after the network is put into operation;
- After long-term network operation (3–5 years), and
- In the long term (e.g. about 10 years).

The assumptions and premises for the network to be designed should be consulted with specialists who are familiar with the current technology and its development and the technology for building ICT networks, and who should assess the feasibility of the assumptions made, both in technical and economic terms.

3. Assumptions for planning IT networks for PKP

Theoretically, planning an ICT network should start by creating a logical model of an ICT network and creating a physical model of the network on the basis of that model. In practice, the logical model should take into account the physical conditions on the ground, e.g. optical fibres with a total length of several thousand kilometres (and a capacity of 36 fibres) laid along railway tracks for the GSM-R system. They form a certain network architecture, which should be taken into account in the physical model of the ICT network. Another condition is (will be) the construction of high-speed railway lines related to the planned construction of the Central Communication Port (CPK).

3.1. Existing condition in the railway environment

Rail transport in Poland is handled by many commercial companies, but the most important group are companies of the PKP group, including PKP PLK, PKP IC, PKP Cargo and others, and each of these companies has its own plans, which do not necessarily have to be consistent with the interests of the other companies. Nor can the participation of companies in rail transport, which are not part of the PKP group and provide transport services for both freight and passenger traffic, be disregarded when using PKP infrastructure, such as Orlen and Fast City Rail. Another group of companies involved in rail transport are those that have their own infrastructure and rolling stock, e.g. LHS, Pomorska Kolej Miejska (Pomeranian Metropolitan Railway) and others. Transport services provided by railway companies may be divided into:

- Passenger traffic (local, regional, interregional, and long-distance traffic), and
- Freight traffic (PKP Cargo and many other carriers carrying various types of safe, hazardous or chemical materials).

These services may be provided thanks to the provision of appropriate infrastructure managed by PKP PLK, which also provides services in the field of rail traffic control and management.

Almost every company has its own priorities and different areas of interest (local, long-distance, passenger, freight, multi-modal and dedicated railway lines). Many transport companies operate and maintain their own infrastructure, e.g. holding stations, railway station buildings, and transshipment stations, such as Terespol – Małaszewicze (large area, cranes, gantries, trolleys, shunting locomotives, and warehouses). In addition, a feature of rail freight traffic is that it is usually provided for 'non-rail' operators, such as ports, mines, and chemical plants, which makes it necessary to exchange information between the carrier and operators.

Another group of systems, ensuring the safety of railway companies and customers, are land, railway infrastructure, rolling stock and passenger monitoring systems, as well as protection systems (fire, theft and burglary, and "friend – foe") and information systems (dynamic information for travellers, and timetables) [7].

In order to ensure the safety of passengers and transported goods, selected railway companies cooperate with state services (e.g. SOK, customs service, phytosanitary services, police, border guards, and emergency medical services), as well as with foreign partners to handle both passenger and freight traffic (e.g. border traffic, and multimedia traffic).

There are three main business areas in the railways:

1) Railway infrastructure;
2) Freight traffic, and
3) Passenger traffic.

Each of these areas has its own, uncoordinated business priorities spread across the different points of the rail network:

- Infrastructure – e.g. railway junctions and lines, viaducts, bridges and train control systems,
- Passenger traffic – e.g. stations in cities, rail traction units, wagons and multiple units,
- Freight traffic – e.g. freight stations, sidings, locomotives and freight wagons.

Many railway companies operate in these areas:

- The largest railway network operator in the infrastructure area is PKP PLK. Apart from this company, there are also other railway infrastructure operators, e.g. PKP SKM, PKM, PKP LHS, and PKP WKD.
- Several dozen companies have been registered in the area of freight transport, among which the leader is PKP Cargo, and large entities are Lotos Kolej, CTL Logistics and PKP LHS.
- Several companies have been registered in the area of passenger transport: the largest carriers include PKP Intercity, Przewozy Regionalne and Koleje Mazowieckie.

Railway transport companies (passenger and freight) operate throughout Poland or only on a limited territory, e.g. in a specific voivodeship or even only on a specific railway line. Therefore, the IT network should provide all topology and traffic requirements in these areas with an appropriate time horizon.

3.2. Rationale for the development of ICT services in rail transport

Each railway company must develop in line with technical progress in its field of activity and keep pace with technical progress by introducing new services resulting from:

1. Development in terms of increasing the transport of goods, passengers, the size of the area served, increasing the speed of trains, and operating new facilities, e.g. the emerging Central Communication Port.
2. Development of techniques for the use and maintenance (operation) of infrastructure and vehicles through continuous monitoring of critical parameters of railway infrastructure (wear of railway track, strength of bridges, viaducts, and condition of contact lines) and mobile equipment (wear of rail traction units, wheels of wagons). In the future, it will be possible to automatically diagnose and maintain facilities, automatically assess the condition of railway tracks and electric traction on the basis of a large amount of collected data.
3. Introduction of new services for railway customers, e.g. dynamic timetables, ticket sales (fares or parcel transport), and monitoring of railway areas, e.g. yards in front of railway stations.
4. Cooperation with large railway customers and their IT systems, e.g. ports, international transport (Silk Road), and the Physical Internet.
5. Development of IT techniques at railway clients, in neighbouring railway managements (e.g. PKP Cargo operates in several Central European countries).
6. Development of monitoring techniques for IT networks and equipment [5].

These conditions will affect the volume of data streams transmitted over the ICT network. In the longer term, the introduction of systems for safer train control is being considered through:

- Automatic decision making on train speed based on weather data and object detection;
- Autonomous driving, which stops the trains, reduces speed or directs trains to other routes depending on the situation, and
- Train assistance systems by continuously monitoring the operation of drive units (energy-efficient operation, and timetable compliance) [8, 9].

For these reasons, the planned ICT network should be open to a continuous increase in the volume of transmitted data.

It is highly likely that the core network for rail transport will be a network operating in accordance with TCP/IP protocols, the so-called „Internet of Things" network. (IoT). This network has the greatest chance of integrating and cooperating various networks and IT systems, providing connections between data centres organised in the cloud model and users, equipped with any computer stations or any mobile devices that are connected to service servers via broadband Internet. This is particularly important in the rail sector due to the nature of activities which concern the entire area covered by the services and involve the movement of means of transport, people and goods.

Increasing the designed network resistance and survivability, i.e. the ability of networks to provide the desired quality of service even in the event of attacks (cybersecurity), large-scale disasters and other failures, is becoming a key issue. It can be concluded that the aim should be to create an information network platform that integrates different types of information, such as the monitoring of:

- Ground-based infrastructure;
- Condition of trains;
- Train traffic;
- Train travel conditions;
- Power demand;
- Passenger traffic volume on individual routes;
- Planned maintenance, and
- Geospatial data.

In order for railway companies to provide, for example, the services listed above, an appropriately designed ICT network is required, which will transmit (with the appropriate parameters) data to the IT systems necessary for the proper operation of those companies, as well as for cooperation with partners and customers.

4. Rationale for the IT network concept for PKP

IT network design should be a complete process that matches business needs with available technology to provide a system that will maximise the success of an organisation. The IT network for rail transport in Poland should include many companies that are separate economic operators and can compete and cooperate with each other, while taking care of their business interests (data confidentiality), very often using the same infrastructure. When designing an IT network for rail transport, it should be borne in mind that this is a 'network of networks', since each of the users of this network will have its 'own' separate IT network with the possibility of cooperating with other IT networks (rail or public). First, a logical concept of the IT network model should be developed, which presents the basic components, divided by the functions and structure of the system, while the physical model illustrates the devices and specific technologies and how they are deployed.

4.1. Logical network model

As experience shows, the knowledge of IT technology is not the same in each company, while the interests and requirements of individual companies vary. In order for a logical network model to be developed that takes into account the requirements of individual companies, a clear interpretation of the issues relating to the network functionality and the services provided by that network should be defined.

Each company should identify the location and size of the expected data streams, at least on the company's main routes, the types of data, processes and users that access or modify the data. This applies to both the backbone network of the company and the local area network (LAN). The collection of information from future users of this IT network will be used to develop the requirements and structure of the future IT network for rail transport in Poland. The logical network model should identify the relevant features of the network, such as:

- Traffic flow volume on individual (main) routes;
- The location of data sources and sinks and the location of databases and data warehouses;
- The desired link data rate;
- The properties of data streaming (priorities, traffic classes, and real-time applications), and
- Quality of Service (QoS) requirements for the network.

In order to calculate whether the offered link data rate is sufficient, in addition to knowing the traffic flow volumes, you should know:

- The number of data sources and sinks;
- Average station idle time between packets sent, and
- The time required to send a message after accessing the medium.

As mentioned, the design phase of the logical network model deals with the overall architecture, size, shape and interconnection of networks. Designing the network topology should include:

- Network scalability – the ability to introduce new applications, handling increased data traffic (what percentage of the traffic growth must be handled by the designed network), and the possibility of network expansion;
- Availability – the time for which a network is available to users, often expressed as a percentage of the uptime or mean time between failures (MTBF) and mean time to repair (MTTR) [11].

Security – protection of the organisation's ability to conduct its activities without interference from intruders who improperly access and damage equipment, data or operations (e.g. data may be intercepted, analysed, changed or deleted, user passwords may be compromised, and device configurations may be changed). The following factors are particularly dangerous for safety:

- Management – error, configuration, performance and safety management [4];
- Usability – the ease with which network users can access the network and its services;
- Adaptability – the ease of adapting the network to existing faults, changes in traffic patterns, additional business or technical requirements, new business practices and other changes.

An important feature of a network is its performance, which consists of the following common factors:

- Available band;
- Bandwidth;
- Bandwidth use;
- The traffic volume offered;
- Precision (adjustment to the traffic needs);
- Delay and change of delay, and
- Response times.

The bandwidth is also affected by other factors, such as [1, 12]:

- Package size;
- Intervals between packages sent out;
- Number of packages per second in the package transfer devices;
- Customer access time to CPU, memory and HD;
- Server access time to CPU, memory and HD;
- Network design (queues, congestion, and delays);
- Protocols;
- Distances;
- Errors, and
- Part of the day.

Creating a logical model of an IT network as a basis for creating a physical network model[2] is, on the one hand, based on understanding the requirements of the contracting authority. On the other hand, it depends on the capabilities of modern ICT networks and the size of the budget allocated by the contracting authority and the time taken to implement the network. When designing IT networks for the railways in Poland, there are additional design complications due to the different activities of railway companies – different business areas (e.g. passenger traffic, freight traffic), different areas of activity (regional transport, IC transport, activity abroad – PKP Cargo), and different fields of activity (infrastructure, transport, industry companies – e.g. telecommunications, IT). Each company has its own confidential interests and information about them may only be accessed by it. At the same time, companies operating in the railway industry have to cooperate with each other, e.g. PKP IC and PKP PLK. In addition, each company has different requirements for the services provided on the network. This means that the ICT network for railway companies in Poland should consist of many logical networks to which only specific companies have access. It is clear that the logical networks described should work in one physical model of IT networks.

According to the author, a team should be formed consisting of experts with knowledge of railway, IT and ICT issues, who will develop a set of network problems and interpretations for individual railway companies. This team should create, on the basis of previously developed questionnaires, logical models of ICT networks for individual companies, the so-called *Virtual Private Network* (VPN). On the basis of the VPN network models of individual companies, a logical network model for the railways in Poland should be created and developed, which will be the basis for the development of a physical IT network model for rail transport in Poland.

4.2. Physical network model

As has already been mentioned, the basis for the creation of a physical network model is a logical model that takes into account all the logical networks of the individual railway companies – the "logical network of the network". In order to create a physical model

[2] The term "network model" is understood to mean a "hardware and software" environment that meets all the requirements of the logical network model and takes into account, inter alia, the impact of the environment on the quality of service provided.

of an ICT network for Polish railways, the following paradigms should be adopted:
1) The ICT network for Polish railways will be based on a network of optical fibres already laid and currently being laid along railway lines for the needs of the GSM-R network (this also applies to newly-built railways – the "spokes" for the Central Communication Port);
2) DWDM technology will be used in optical fibres;
3) The data transmission technology will be implemented in the Ethernet standard[3], and
4) The network will work according to TCP/IP protocols in the 5G version.

The physical network model should have the following features:
- The network vulnerability to almost constant development and change;
- Network security, i.e. adequate protection of networks against hacker attacks and viruses;
- Network resistance to hardware and software failures, damage, human errors, disasters;
- Continuity after disasters;
- Support for time-dependent applications (support for real-time applications, e.g. control, VoIP) [10];

and take into account existing restrictions such as:
- Limited budget for the network construction;
- Staff designated to build and operate the network;
- Limited time to build the network, and
- The "policy" of companies in the ICT application.

The ICT networks associated with the operation of railway companies should be designed in such a way that they are resistant, i.e. capable of providing the desired service even in the event of hacker attacks, large-scale disasters and failures. This concept of resistance depends on survivability, which is the ability to maintain communication on the network despite the correlated failures that arise from large-scale attacks and disasters and when telecommunications channels are overloaded, disrupted and there are unpredictable delays. The following factors should be taken into account when designing the network:
1. Deficiencies in network design are inevitable; a perfect system cannot be built, and the challenges and risks that occur during standard network operation cannot be prevented.
2. It is necessary to understand proper operation in the environment in which the network operates and the requirements of individual applications implemented in this network. We can infer when the network is at risk only by understanding the proper functioning of the network.
3. The network should be prepared for the detection and possible neutralization of undesirable events that may interfere with the proper operation of the network. Such events are inevitable during the operation of the network.
4. A reaction of the network to undesirable events (e.g. failures) and ensuring resistance by:
   - Ensuring the correctness of performed operations;
   - Return to standard operation;
   - Diagnosing root causes, and
   - The application of appropriate remedial measures [2, 12].

According to various opinions, the resistance of the network depends primarily on its physical topology. In the case of a railway ICT network, the geographic topology of the network is related to the topology of the railway lines along which optical fibre cables are and will be laid (right of way). Moreover, the headquarters of railway companies are usually linked to railway areas by telecommunications. Therefore, it can be predicted that the geographical topology of the physical ICT network will enable the construction of a resistant ICT network for railway companies.

5. Ascertainment

1. Creating a logical model of an IT network as a basis for creating a physical network model is, on the one hand, based on understanding the requirements of the contracting authority. On the other hand, it depends on the capabilities of modern ICT networks and the size of the budget allocated by the contracting authority and the time taken to implement the network.
2. When designing IT networks for the railways in Poland, there are additional design complications compared to public networks, because this network will not only be associated with ensuring the safety of employees, rolling stock and railway infrastructure, but also with ensuring public safety (safety of passengers on railway premises and on trains, safety of goods transported and stored – safe and hazardous, and safety at railway crossings).

[3] The success of solutions based on the Ethernet standard consists of many factors, including the ease of implementation, reliability, ability to adopt new technologies and relatively low implementation cost.

3. The activities of railway companies are different – different business areas (e.g. passenger traffic, freight traffic), different areas of activity (regional services, IC services, activities abroad), and different fields of activity (infrastructure, transport, professional companies, e.g. telecommunications, IT).
4. Each company has its own confidential interests which may only be accessed by it. These companies, operating in the railway industry, have to cooperate with each other (e.g. PKP IC and PKP PLK).
5. Each company has different requirements for the services provided on the network. This means that the ICT network for railway companies in Poland should consist of many logical networks to which only specific companies have access. It is clear that the logical networks discussed will work in one physical model of IT networks.
6. In order to create a physical network model, it is necessary to develop a logical network model that takes into account all the logical networks of individual railway companies – the „logical network of the network."
7. There should be a team consisting of experts with knowledge of railway, IT and ICT issues, who will develop a set of network problems and interpretations for individual railway companies. This team should create, on the basis of previously developed questionnaires, logical models of ICT networks for individual companies, the so-called VPN.
8. On the basis of the VPN network models of individual companies, a logical network model for the railways should be created and developed, which will be the basis for the development of a physical IT network model for rail transport in Poland.

6. Conclusions

The developing IT techniques and technologies are now becoming a major and necessary business implementation tool. It is particularly important to make use of all the IT technology potential in companies with a network structure. Such undertakings include almost all railway companies, e.g. PKP PLK, transport companies (passenger and freight) as well as other rail and road transport companies.

Rail transport in Poland should not only keep pace with the development of rail transport in Europe, but also with the development of other branches of land transport. One of the conditions for this development will be to have modern ICT systems (*Cloud Computing, Big Data, IoT*, etc.), which will enable railway companies to cooperate not only with each other, but also with foreign partners, enable the introduction of new IT services for their customers and thus ensure that their transport needs are better met. In the longer term, it will be possible to provide IT services for private entities, e.g. for multi-modal and road transport, create an Internet for land transport (unmanned rail vehicles, autonomous road vehicles) and then create an ICT network for the "Physical Internet" (PI).

The ICT network for rail transport, which is organically adapted to work with many different IT systems, while taking into account European trends and standards, should also be susceptible to meeting the requirements for cooperation (integration) with networks of economic sectors affecting the possibility of 'surviving' in crisis situations, i.e. power generation, road transport and fuel markets.

The dynamism of transport development and cooperation with other institutions and businesses mean that transport must not deviate from the global development trends in the application of ICT solutions. Railways cannot be a heritage park of IT systems only because of the environment and cooperation with it. The Polish railway ICT network should be in line with the ICT network development directions in Europe, both in the wired and wireless part (frequency band, and technology) in order to cooperate with the ICT systems of other railway managements.

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