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Digitization in Rail Transport

Janusz POLIŃSKI[1], Krzysztof OCHOCIŃSKI[2]

Summary
Digital transformation in the railway industry is an important element in the development of railways and should benefit commuters, railway operators, infrastructure managers and rolling stock manufacturers. The process of digitization applies to two domains, i.e. customer service and railway companies' operation. This paper aims to present previous efforts regarding the use of digital technologies in customer relations and in the field of operations and maintenance, which translates into the quality of services provided. This paper highlights important concepts of this domain with respect to passenger and freight transport, infrastructure, railway rolling stock and railway traffic management. It is also argued that the process of digitization needs properly trained staff. Examples of innovative initiatives of Polish and European railway companies are covered.

Keywords: railway transport, digitization, digitization of the railways

1. Introduction

Current economic changes are marked by a digital transformation, which is essentially about deploying and effectively using the solutions based on digital technologies. This allows changes to be made in the business models of many companies that lead to the launch of innovative products and services as well as new forms and methods of customer service. *Digital Transformatio*[3] is a complex process. Within the transport industry, the transformation changes existing management, planning and shipping processes, including the processes of monitoring and managing transport services.

As has been arguably pointed out [12], (...) *Implementing technological innovation in open, globally interconnected and intermodal transport systems, managed by a number of operators, logistics service providers, shippers, loaders, loading companies, recipients and customs agencies, is often a greater challenge than automating and robotizing closed manufacturing systems in smart factories.*

And (...) *digital transformation in the railway industry does not merely imply the use of new technologies in the business of operators, infrastructure managers and manufacturers catering to the railway industry. This transformation, instead, means a radical change to previous business models and mindsets that helps create added value for many stakeholders of the transport process and contributes to implementing new concepts of mobility.* (…) [21]

These are five major trends of digitization in the rail transport industry [21]:

1. *Connected Commuter* – With Internet access while travelling;
2. *Mobility as a Service (MaaS)* – Connected with easier journey planning;
3. Project Management as a service (PMaaS) – Proactive rolling stock maintenance based on data about the current usage of individual sub-assemblies, provided on an ongoing basis by digital systems, for greater reliability of the rolling stock;
4. Automation and integration of rail traffic management systems; GoA4 – *Unattended Train Operation* – A system in which all vehicles are started completely without any operating staff (the 4th level of automation);
5. *Internet of Trains* – Improving railway traffic safety, optimizing operating costs and improving service quality.

In 2015, the European Commission published a document "A Digital Single Market Strategy for Eu-

[1] Dr inż.; Railway Research Institute, Railway Track and Operation Department; e-mail: jpolinski@ikolej.pl.
[2] Eng.; Railway Research Institute, Railway Track and Operation Department; e-mail: kochocinski@ikolej.pl.
[3] Digital transformation shall not be thought of as mere digitization of information, which is essentially concerned with the digital form of information (0,1). The digital form of various kinds of content facilitates, among others, fast access to knowledge, and, thanks to the low costs, provides convenient conditions for innovative processes. Digitization of information is the first step within digital transformation.

rope." The strategy aims to lift the barriers in place that hinder Europe's digital growth. This new market shall help European companies grow globally and improve their product and service quality, reduce prices and provide customers with a greater range of products.

Poland was the originator behind the first summit of the European Commission dedicated to digital matters. During summit debates, heads of governments sought to unify their varying points of view. Poland's proposal to organize that summit was initially backed by 17 governments. This group was then joined by Bulgaria. The meeting was held on 29 September 2017 in Tallinn and attended by 28 leaders of state governments. This was an important element in the drive to deliver a positive digital agenda for Poland in the EU scale [5].

Between 2021 and 2027, the EU plans to launch the Digital Europe programme. The idea is to support the process of digitally transforming the European society and economy as well as benefiting EU citizens and businesses. It is also assumed that the programme will reinforce Europe's capabilities in key fields of digital technologies and boost their dissemination and absorption within the fields of public interest and in the private sector. The programme will encompass five specific objectives (as stated in chapter 3, paragraph 2) [26]:

1. "High-Performance Computing (HPC)"[4] – Pursued by supporting the EU ecosystem to provide necessary HPC and data capabilities and help Europe successfully compete on the global scale,
2. Artificial Intelligence (AI)[5] in Europe, including, among others, strengthening the centres that conduct AI tests and experiments in member states and bringing them into a single network,
3. 'Cybersecurity and trust' – This part of the programme is to stimulate the development of principal capabilities in order to protect the EU digital economy, society and democracy by supporting the EU's industrial capacity and competitiveness in the field of cybersecurity, and boosting private and public sectors' capacity to protect European citizens and enterprises against cyber threats, including support for the implementation of the EU Network and Information Security directive.
4. 'Advanced digital skills' – this part of the programme will support access of the present and future workforce to digital skills, especially with respect to HPC, AI, distributed ledgers (e.g. the *blockchain* technology) and cybersecurity by providing students, graduates and employees with opportunities to gain and develop such skills, regardless of their location (Fig. 1).
5. 'Implementation' – Optimum use of digital capabilities and interoperability.

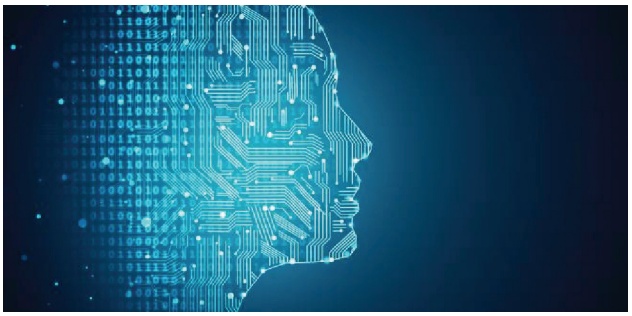

Fig. 1. More than half of all employees will need to significantly improve their skills and every 10th employee will have to be trained for more than a year [3], [photo: ShutterStock]

In the document on digitization entitled "Digital Trends in the Rail Sector," the Association of the European Rail Supply Industry has pointed out how digital transformation will increase railway passenger satisfaction, how the development of the logistics of freight transport should carry on and how transportation capabilities should be enhanced. Digital transformation of various enterprises concerns three basic fields of their operation [6]:

1) Nurturing mutual customer relations, mainly by identifying their needs, introducing various channels of communication with customers and launching self-service solutions;
2) Internal operational processes related to the existing infrastructure, work management and work environment, combined with performance monitoring;
3) An action model based on products and services delivered to specific markets.

All kinds of activities related to the process of digitization help bring Polish railway transport into the mainstream of the digital economy. This should benefit operators, infrastructure managers and rolling stock manufacturers. It is also worth mentioning that one of the most important assumptions of the EU transport policy is to make efforts to create a trans-

[4] HPC – *High Performance Computing* – The use of supercomputers and computing clusters to deliver complex and time-consuming computing tasks.
[5] AI – *Artificial Intelligence*.

port system that is smart, green and readily accessible to commuters, including railway passengers.

Many challenges faced by railway transport require implementation of the latest technologies across all fields of rail transport operations: production (delivery of transport services); rail traffic management; nodal and linear infrastructure development; and managing the transportation process. As far as this process is concerned, it is also worth bearing in mind the importance of qualified talents.

Until 2019, Poland's developing economy had been exposed to the process of globalization, integration and various kinds of limitations due to the need to preserve the natural environment. The relatively stable state funds and the fact that they were backed with external funds generated new needs and requirements for the transport system. Although those processes are facing new limitations these days, the state economy will need innovative railways. This industry needs to be interoperable, compete internally and externally to win customers, work with other fields of transport and use digital technologies.

What may also affect the digital transformation is the coronavirus pandemic. On 27 March 2020, the OECD announced that each month of economic stagnation means the annual GDP growth slows down by 2%. The EU has to address the impact of the pandemic on rail transport services. One of the advocates of this transformation is AllRail, the Alliance of Passenger Rail New Entrants in Europe. AllRail has stated that the present situation is unprecedented and its consequences cannot be alleviated with state funds only. AllRail claims that the EU financial support for the transport industry should address firstly the most ecological transport sectors [11].

The goal behind this paper is to present previous efforts regarding the use of digital technologies in customer relations and in the operational and maintenance realm, which helps improve the quality of services. Although digitization covers a broad range of issues, only some of them are covered herein. Some issues, such as cost forecasting, analysis of impediments to the process of digitization in Poland and the contribution of digitization to specific transport sectors, have been left out. These shall be covered by other dedicated publications.

2. Digital technologies in railway transport

Railway transport in Poland is of the most important transport sectors. However, in terms of the number of transport services, it has been losing out to road transport for many years. Due to the incommensurable growth of road transport services, railway transport continues to struggle against its competition. The winding down of some railway lines and the lack of a modern transport offering in the past made customers lose their confidence in this transport sector. As a result, the volume of goods and passengers transported has declined. What also contributed to this process are inadequate laws and competence among decision makers, undermining this transport sector even more.

The railway sector gradually regaining its stable position results from several factors. The most important ones are the modernization of the rail nodal and linear infrastructure; investing in modern rolling stock; improving the safety of transport services; and the use of innovative information technologies. The many infrastructural, technical and legal initiatives aside, the quality of railway operations also depends on the provision of digital services to the customers.

The range of mentioned initiatives helps us better understand the need to integrate railways with other means of transport. We can expect some push for this process due to the unpredictable consequences of the pandemic for the economy, something that is going to refashion our view of transport as a whole and the role of railway transport in it.

As regards the nodal infrastructure, the past several years have seen innovative train stations commissioned. These facilities use renewable energy sources and green solutions to reduce their operating expenses. This will play a huge role in the upcoming time of recession and financial hardship as the state will focus on other priorities.

As far as traction vehicles are concerned, innovative solutions aim to leverage new sources of energy (e.g. gas and hydrogen-powered engines) and autonomous trains, operated without a driver (Fig. 2).

Fig. 2. Autonomous train high-speed railway between Beijing and Zhangjiakou [17]

Based on the literature on the digitization of the railways, one can say that the implemented solutions address two realms (of improvements):

- Customer service;
- Functioning of railway companies and of the entire railway industry.

Numerous strategic documents made by railway companies[6] devote ample attention to boosting the process of digitizing transport services. The automation and digitization of processes should help reduce maintenance costs and make rational infrastructural investments (installing innovative devices and technologies), and this will make access to infrastructure less expensive.

2.1. Passenger transport

Real-time information provided to customers is of great importance in passenger transport services. Such information helps passengers make choices about the right means of transport, safety and available services before, during and after their journey. For the provided information to meet today's requirements, (...) *it should be clear, precise, reliable and reach the right addressees to ensure effective travelling* (...) [15].

As regards passenger transport services, the Polish Masterplan [13] argues that (...) *the efforts to implement a networked information system for passengers are of special significance to all industry segments. These efforts have been initiated by PKP Telekomunikacja Kolejowa, which has launched a pilot project implementing the SITKol system for notifying railway passengers. The project will provide a journey planner* (...), and passengers will be able to combine railway services with other means of transportation (tram, bus or subway), as expected by those visiting large metropolitan areas.

To guarantee the efficient transmission of information, various types of innovation regarding media, required types of content and content delivery are being constantly implemented. Some relevant features have been defined in the specifications of interoperability. The effective use of digital technologies in the process of building desired relations with passengers largely rests on understanding their needs and preferences and the capacity to communicate with the service provider. It is important to consistently expand all kinds of self-service solutions, from ticket purchase to full train availability to all passengers. Therefore, new technologies to support customer relations should be designed with the consideration of the broadest range of expectations possible. These comprise:

- Frequency of train journeys tailored to the size of the commuter stream;
- Regular minutes for cyclical train departure times for easier memorizing;
- Integrating railway journeys with other means of transport;
- Competitive journey duration compared to other means of transport;
- Comprehensive information provided with various carriers and media;
- Acceptable cost, considering passenger's purchasing power and service quality;
- Flexible fares;
- Ease of ticket purchase, various payment methods available;
- Highly comfortable and safe travel, including personal safety (on the train, at railway stations and at the stops), enjoyable surroundings;
- Available extra services: luggage, parking, hotel, catering and tourist services etc. [15].

Digital technologies are also used by operators to improve their own reporting and forecasting operations and transport service planning. A report from 2018 entitled "Digital transformation of the railways" [21] points to several main trends of further digitization progress in passenger railway transport, namely:

- Smart railway stations;
- Smart ticket systems;
- Mobile apps with real-time information on train traffic;
- Dynamic notification systems in passenger train stations;
- Apps to facilitate multimodal journey planning;
- On-board high-speed Internet access for passengers (3G/4G, and 5G in the future) – the concept of a connected passenger.

The remaining part of this article presents various examples of how the digitization of notifications for railway passengers has been used in Poland.

Notifications can be delivered via the iSMS messaging system, an app for mobile devices (phones, tablets and netbooks etc.). One of the features of this system notifies interested passengers about important events and the resulting actions taken by the railway operator. The information is delivered in the form of text messages directly to mobile phones or as push notifications within the said app itself. With the wide popularity of mobile phones, the information can

[6] The German Masterplan for Rail Freight Transport (Masterplan Schienengüterverkehr 2017) considers digitization of this industry as the main driving force behind its growth.

reach virtually everyone concerned. Passengers can be notified via an ICT system[7] made available to the operator. Passengers using these services do not incur any costs.

In the Polish market, a free-of-charge text messaging system is used by a number of users/clients of passenger rail operators. Users can also download an app called *Komunikator iSMS*, which provides access to a larger amount of information than a short text message does. The app allows rail operators to send text messages of up to 10,000 characters, videos, files and photos. Passengers can voice their opinions with surveys and opinion polls or by responding to notifications sent by the carrier. The Komunikator iSMS app is available at Google Play [18] and allows operators to notify passengers about:

- Train delays;
- Failures, acts of nature or planned repairs;
- Pricing and promotional campaigns;
- Timetable changes;
- Emergency transport services;
- Changes to the rules of reduced fares;
- Acceptance of tickets for a given route by various transport operators;
- Traffic problems due to weather conditions;
- Railway festivities;
- Special trains, promotional campaigns.

Train tickets can also be purchased with an app called *SkyCash*. The idea behind the app was devised by a Swedish IT specialist and quickly spotted by Polish investors, who bought the software rights. *SkyCash* is the largest Polish virtual wallet and lets users buy tickets for urban transportation (available in 70 cities), regional trains, PolRegio trains and PKP Intercity trains (long-distance services) and pay for inner city car parks [18, 23]. Tickets of the rail operator PKP Intercity are available from the app's home screen. The main section of the screen features an icon with the carrier's logo. The user can touch it to activate the journey planner. You need to set the departure date and the first and final stations and then parameters such as the number of tickets, type of discount and the ticket class. To complete the transaction, the user picks a payment method (*SkyCash* account or a payment card) and accepts the transaction. The ticket is automatically saved at the 'Ticket inspection' tab. Then, you can show it to a ticket inspector, even wirelessly. *SkyCash* is currently available for smartphones with Android and iOS systems[8]. The app can be downloaded at Google Play and App Store. The user needs to type in the name of the app and install it on their phone. This is, however, a mobile app that needs Internet access to work [18].

The IC Mobile Nawigator mobile app (Fig. 3) has been developed by PKP IC for the users of mobile devices. The app lets users access PKP Intercity's timetable, check for delays and save planned journeys. It also provides up-to-date information on promotional offers and any travel-related issues (e.g. information

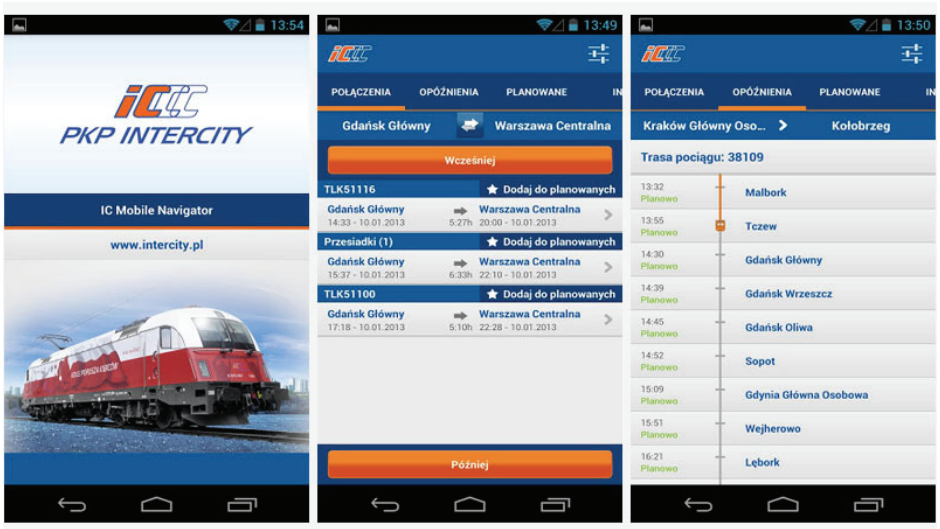

Fig. 3. Examples of screens displayed in the IC Mobile Nawigator app [7]

[7] Polish law defines an ICT system as a set of IT devices and software working together to allow a network-dedicated end device to process, store, send and receive data via telecommunication networks.

[8] iOS – An operating system developed for mobile devices such as iPhone, iPad and iPod *touch* by Apple, under the current name since 2010.

about ticket purchase methods, lost property procedures etc.). This provides ongoing access to information about the punctuality of the PKP Intercity trains (just as InfoPasażer does). A click on the icon of a given train reveals details of the set of train cars. A passenger who does not know the way to the railway station can use a feature that will identify their location and navigate them right to the station. Additionally, a selected train can be saved in the "Planned" tab, where departure and arrival times for the coming days can be updated by the user without entering the departure and arrival stations again [7, 18]

There are many other apps related to passenger transport services used in the Polish railways:

- Bilkom – Used by PKP IC, among others, for EIC ticket sales.
- jakdojade.pl – A journey planner designed with urban transport in mind; it covers railways in individual metropolitan areas. This app compiles various means of transport to help the user reach their destination).
- CallPay Usługi – Used on Silesian railways.
- moBilet – A payment app designed to buy transport tickets and pay for car parks. It covers Arrive RP railways (selected routes in the Kuyavian-Pomeranian Region).
- SKM KomPas – An app for those using PKP SKM in Trójmiasto. The app lets users check current railway timetables and search for desired journeys. The offline mode allows passengers to use the app without Internet access. The app allows the user to check current ticket prices for specific journeys. The alert feature notifies passengers about the upcoming time of departure for their journey. Via the app, SKM customers receive notifications about the current situation on the routes. Some journeys can be added to 'favourites', which greatly facilitates journey searches.

Another aspect of digitization in railway passenger transport is that operators have come to accept digital IDs. In mid 2019, the director of the Railway Transport Bureau called on PKP Intercity to accept digital IDs. During ticket inspection, the largest Polish operator used to accept regular IDs only. The director of the Railway Transport Office has recommended the acceptance of mTożsamość with the mObywatel app, too. At present, every name-assigned ticket holder can prove their identity with the app.

As noted in [10], the past few years in the railway passenger transport have seen more and more websites being expanded and upgraded and a number of mobile apps providing precise data on train travel, potential delays and track disturbances. For these transport services, (...) *there are plans to develop smart systems that will assess various journey scenarios with different means of transport, facilitate booking and ticket purchase, considering accessibility, congestion, changes to traffic organization and unexpected events.*

In European passenger railway transport, the last few years have seen many railway managers introduce simple systems to communicate with customers. The goal behind these has been to adapt railway operators' websites for the disabled, provide commuters with mobile apps with full real-time data on train traffic, and ticket purchase functionalities, including for other integrated means of transport. These apps are constantly being expanded and upgraded. In EU countries, successful digitization efforts are being conducted by the DB AG Group, which has established a special purpose entity DB Systel. The latter has developed a cloud platform for the DB AG Group that can also be used by other service providers in the transport market.

An example of innovative solutions related to digitization in the Russian Federation are the Sapsan trains running between Moscow and St. Petersburg. Their passengers can access the Internet and use film and music resources. They can also access details of cultural events in both cities, take a virtual trip around the train and learn more about the railway. Passengers can order meals from the restaurant car from wherever they are on the train. The app allows them to book a hotel room, rent a car, order a taxi, a city guide or buy tickets for other means of transport, including airline tickets. Since this paper covers solutions addressed to passengers only, innovative solutions that support the railway operators themselves have been deliberately left out.

2.2. Freight transport services

In the White Book of 2011, the European Commission set the goal for railway and waterway transport to take over 30% of the cargo transported with road transport services at distances of up to 300 km. By 2050, this share should be increased to 50%. Supporting these goals and the reduction of CO2 emissions aside[9], consistent efforts to take cargo from roads to railway tracks reduce road congestion and hazards related to the transportation of hazardous goods as well as heavy and bulky ones. The progress

[9] EU documents often refer to CO_2 reduction as decarbonization.

so far in the EU states has not been enough. The average share of railways in freight transport is ca. 18%; to meet the provisions of the White Book, the efficiency and quality of the railway transport needs significant improvement [22].

To strengthen the competitiveness and quality of freight railway transport services, various solutions offered by digital technologies should be implemented and greater commitment towards technical and technological innovation is needed.

In Poland, the railway freight transport market is composed of three transport segments, differing in terms of their market shares and potential to grow. It consists of:

- The stable segment of trainload services;
- The segment of wagon and wagon set services – in decline;
- The fast-growing segment of intermodal services (mainly connected with the transport of containers).

Although, as per the Polish transport policy, freight transport is part of the multimodal transport system, it does not play a key role in it. This is so despite PLN 66 billion being spent to upgrade the railway transport infrastructure under the EU's current financial perspective. However, the efforts made in this respect raise hopes for a reversal of the previous negative trends [12].

In Poland, the dominant rail freight operator is PKP Cargo. Besides this operator, the market consists of several dozen other licensed operators providing freight transport services.

Planning freight railway transport services requires arrangements to be made between many parties. These are facilitated by various IT systems, partially or fully automating many of the business processes [14]. Effective planning of freight rail transport is a very complex process that depends on many variables, the values of which should be known in real time. The staff responsible for these processes should know, for instance, the ongoing location of locomotives, wagons, the availability of drivers and of the linear infrastructure. Any changes related to the availability of the resources destroy the whole process and the planning process needs to be restarted. IT systems prevent this by optimizing rail freight transport planning based on the availability of resources, business orders and digital waybills, such as CIM, SMGS and CIM/SMGS. Starting a freight train needs several actions [14]:

- Business activities – Business enquiries, offers, calculations, planned freight contracts, and cost settlement;
- Controlling activities – The system constantly monitors the profitability of transport services against the calculated planned expenses;
- Strategic planning – Weekly / monthly train timetables based on transport orders placed by customers;
- Operational planning – Delivering transport services; staffing; defining the geographical location of a wagon and locomotive and planning the arrival of the rolling stock at the destination;
- Technical activities – Monitoring technical inspections of locomotives and wagons and their subassemblies in the event that they have their own technical inspection cycle;
- Personnel activities – Monitoring work time, rights and licenses of the locomotives, and health check-ups (in order to start a locomotive, the driver needs to have a valid driving licence, a certificate demonstrating their familiarity with the given locomotive and show that they are "familiar with the given route").

IT support technologies and related innovation needed for freight transport are related to the following issues [2]:

- Smart systems for managing freight transport services;
- Implementing low-cost freight transport solutions;
- Furthering automation of freight reloading based on exact knowledge of the situation related to the cargo location and its destination;
- Improving logistics services that leverage the capacity of the digital technology to obtain data and information, e.g. to track freight transport services in real time;
- Eliminating travel of empty rolling stock.

There are many different IT systems that support rail freight services. One of them is the system from RAILSoft Business Solutions, used for 19% of the freight weight transported by railways in Poland. This system is integrated with other systems that support waybills, filed data etc. As a result, railway operators may approve train arrivals and generate waybills. The system allows work to be conducted in the multi-enterprise model – businesses can access an overview of shared resources, have access to planned trains, and can file business contracts regulating terms of payment for transport services with their customers. The system supports the automation of a number of activities that have been previously conducted by hand. Businesses can provide mutual services with the use of the common 'Train planning' module, which provides planning flexibility and makes customer service more efficient [14].

Implemented in 2013–2016, the FOSTER-RAIL project [2] demonstrated that cooperation and coordination of activities related to digitization across Europe

can provide great opportunities to boost the competitiveness of freight rail transport services by means of:

- New technical and structural solutions of freight wagons;
- The use of new loading and unloading technologies and systems;
- Providing and deploying pan-European measures to coordinate, manage and use freight transport services;
- Launching smart freight terminals and logistics centres involving railways to ensure timely and efficient distribution of goods;
- Developing a new range of freight services, among others, involving the use of passenger transport services to transport light cargo;
- Continuous development of information services for railway freight transport services – enabling tracking, management and procuring cargo for shipping.

As announced in the opinion of the European Economic and Social Committee, item 3.2.2.2. of the document [16], during the TEN-T Days in Rotterdam (2016), the railway industry adopted a joint declaration entitled "Sector Statement". The Sector Statement presents measures that should be undertaken to improve international rail freight transport in Europe and facilitate digitization of this transport industry internationally. The statement included 10 priority actions [19] that are expected to be implemented by 2024[10], namely:

- **Harmonization of freight train timetable procedures /** TTR programme[11]/ – In the EU, this extensive programme will be gradually implemented in three steps:
  - In 2020, three European railway networks launched a pilot IT system within the shared section of the TEN-T line to test innovative timetabling components, such as: business terms; personnel management and IT systems in place[12];
  - Within the timetable 2020/2021, the pilot study will be expanded to include the Austrian railway network;
  - A common timetabling process based on the TEN-T network shall have been fully implemented by 2025.
- **New concepts of Requests for Capacity (RFC)**
- **Improving the coordination of previous Temporary Capacity Restrictions** /TCR/. Temporary capacity restrictions, caused, for example, by renovation works, create an important task that provides for safe train operations along bypass routes and ensures the proper state of the infrastructure. For a limited period of time, though, the restrictions limit the capacity available to railway traffic. To offer reliable times of transport along bypass lines, the railway sector needs to arrange for methods to ensure the minimum impact of TCR on railway traffic. Modernization should also be optimized to minimize the losses due to this process [20].
- **Wider use of the Path Coordination System (PCS).** The web-based app optimizes international path coordination by ensuring that path requests and offers are harmonized among all involved parties. The system processes ad hoc path requests for the current timetable as well as path requests for the next annual timetable [20].
- **Harmonization of border procedures.** The lack of border harmonization is one of the main obstacles to railway freight traffic in Europe. This priority provides a new opportunity to challenge the national way of thinking and acting, which is the case among all EU states. The priority is to find fast, interoperable solutions that will help address current problems along with IT systems [20].
- **Train tracking and Estimated Time of Arrival /** ETA/. Three European projects are committed to improving the exchange of train-related information from the first to the last kilometre of the path. The issues addressed under this priority are related to the compliance with standards defined under the TSI TAF interoperability specification (train ID, message format and data exchange), legal support for developing a pan-European data exchange solution and the role of stakeholders, including intermodal operators [20].
- **Priorities, funding and monitoring TEN-T /** RFC/ parameters. EU member states and their rail

[10] The data presented in the report of 2018 [20].

[11] Further information about the programme can be found on the website ttr.rne.eu.

[12] To address market needs, infrastructure managers designed a process composed of 5 components: a capacity strategy – a common European strategy with harmonized general access to the TEN-T network; temporary capacity restrictions – improved and harmonized; a transport capacity model – a model of timetables developed with the participation of, among others, applicants to facilitate planning and notification of available capacities; capacity requests for the TEN-T line – developing an annual timetable for the whole traffic for which particulars are known; and expected additional trains to be incorporated in the traffic for which particulars will be known shortly before the train start-up operation.

infrastructure managers are obliged to implement the parameters defined for the TEN-T network by 2030 [20].
- **Implementation of ERTMS.** While waiting for the review of the regulations that define the ERTMS planned for 2022, a process underway in several member states, the member states' supervisory bodies should be working with infrastructure managers to evaluate and deliver a more ambitious digital programme to upgrade the traffic management and signalling system with the use of ERTMS as a standard platform providing adequate safety and interoperability [20].
- **Monitoring the quality of transport services**[12]**.**
- **Corridor Information Document (CID).**

2.3. Infrastructure

Digitization initiatives in this field should help the railways widely adopt a smart infrastructure, which forecasts and notifies its status and uses automatic maintenance, which translates into the quality of services. To deliver consistent improvements in the reliability, availability and maintainability of European railways, infrastructure-related systems and support services should be based on three domains [2]:
- **Reliable and damage-resistant infrastructure**, which requires innovation and pan-European solutions, among others, to improve the process of planning maintenance works, reduce the number of unplanned events and failures and optimize the process of resuming traffic after planned or unplanned activities;
- **Smart infrastructure,** requiring implementation of a variety of devices and sensors to secure more and more data and ascertain the current and expected status of infrastructure, which should create "the capacity to manage accidents before they occur";
- **Situational awareness**, based on real-time analysis of data and information to avoid costly failures and the need to deliver maintenance works; this data is provided to support the process of making operational decisions, especially regarding information on security, safety and planned works.

To successfully deliver the planned initiatives related to the process of digitization in the above-mentioned fields, it is recommended that the industry should constantly seek to deliver and maintain the infrastructure in a new or better way. The initiatives in this field should primarily regard [2]:
- The use of innovative materials, such as graphene, metal foam and recycled materials;
- The use of new processes and technologies, such as nanotechnology and biotechnology;
- Modularization of infrastructural components;
- Supporting management processes with database information on buildings and other structures;
- Monitoring and automating the processes of efficient maintenance;
- Reducing costs across service life;
- Surveying railway tracks and rail damages;
- Use of new railroad switch solutions, which are more reliable and allow higher speeds;
- Delivering infrastructural solutions to address current and future challenges, such as climate changes and severe weather phenomena, the consequence of global warming.

One of the notable examples of using recycled materials in the railway infrastructure is the following Russian solution. In 2014, the manufacturing of 'smart sleepers' [9] completely made of recyclable plastic waste started in Russia. Successfully tested at the Shcherbinka Test Site, the composite sleepers are nearly three times as light as concrete ones and last three times as long as wooden ones. They also offer load-bearing capacity that is twice as high and do not emit toxic substances. As the sleepers are made of a dielectric, they are not exposed to electrical corrosion and greatly reduce vibration. Additionally, such sleepers minimize the ongoing maintenance costs and the number of repairs and can also be used on bridge spans and at railroad switches. Currently, they are used for all kinds of rail transport services (tram, subway and railroad tracks).

The sleepers have digital markers attached to them during the manufacturing process that encode the geographical location of a sleeper upon track assembly. Every sleeper also has a plate that enables railway data to be encoded. While installing a sleeper within a track, the so-called control points[13] are installed every 100 metres at an appropriate distance from the sleeper, and special markers are put on the rail foot, the sleeper plate and the sleeper itself (Fig. 4). This section is determined using geographical coordinates with a 10 mm tolerance and related to the control point.

[12] Based on 15 KPIs [20].
[13] Control point – a field point with a location defined with coordinates under an applicable two-dimensional Cartesian coordinate system and with the height defined under the applicable elevation system of the national spatial reference system.

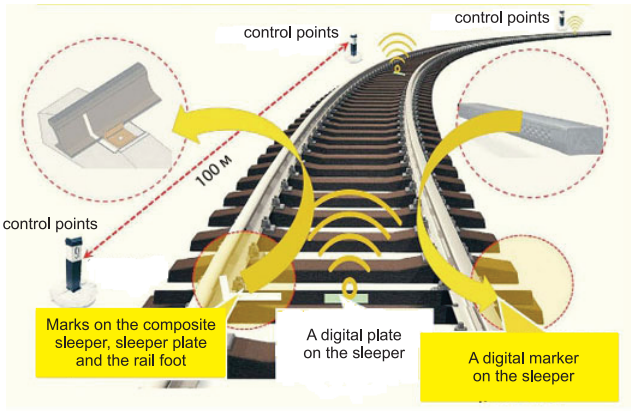

Fig. 4. A model of railway tracks with intelligent sleepers [9]

During cyclical diagnostic drives, analytical systems of the survey wagon attached to the passenger train detect and mark the locations where railway tracks need to have their placement adjusted. Survey data, as well as verification data, is juxtaposed with control points rather than kilometres, (as opposed to regular sleepers) and digitally saved. They can be used by road machines for precise positioning during repair works and to reposition railroad tracks without running extra drives to take measurements. The information obtained during diagnostic drives is used while planning infrastructure repair and maintenance works. In the future, the use of digital composite sleepers may lead to the introduction of fully unmanned, robotized digital systems and technologies for diagnosing tasks and rail infrastructure maintenance [9].

Digital technologies are also used by many European railway managers to determine the structure gauge. Survey wagons are used for this purpose – their survey equipment can take measurements at the speed of up to 120 km/h. The highly precise results are used to codify railway tracks for the needs of intermodal transport and to transport oversized cargo.

2.4. Rolling stock

The use of innovative IT systems and digital access to abundant data have significantly facilitated the process of maintaining rolling stock. Many components of locomotives, traction units and even passenger wagons have digital elements installed on them to monitor their technical condition. The information sent to cloud computing centres facilitates the early detection of potential failures and reduces the consequences of damage that may interfere with traffic. As aptly noted [2], (...) *thorough notification about components that are likely to fail soon allows up to 100% of the rolling stock capacity to be ensured since the issues can be repaired when vehicles are out of operation to avoid potential failures. This helps provide high reliability of the system, which decreases the need for an operating reserve (usually kept at the level of 5–15%) and makes the use of the rolling stock more efficient* (…).

It is no surprise that the leading manufacturers of the rolling stock offer customers a number of digital services that essentially help them conduct real-time monitoring of the vehicle location and the condition of their sub-assemblies and remotely feed the diagnostic data to the essential devices, providing, among others, data visualization and identification of the reasons of the defects.

With the savings gained through digitization of the rolling stock and the greater safety that comes with it, this process will develop alongside advancing technical progress and innovation in the processes of diagnosing assemblies and sub-assemblies in real time.

The German railways are the leaders in this respect. Thanks to the cooperation with companies that are leaders of the *Internet of Things*, or IOT for short, the TechLOK[14] project will have provided 2000 locomotives with certified on-board computers by the end of 2020. They will monitor the proper operation of the most important assemblies and sub-assemblies of the vehicles in real time and pass this information to the monitoring and decision-making centres. The data from diagnostic sensors will be passed to those centres, regardless of whether a given vehicle is located inside or outside Germany. The on-board computers work with ground servers to prepare for maintenance and repair activities.

Further development of this form of monitoring will come with a departure from the regular methods of diagnosing and repairing vehicles. This will raise the capacity of the vehicles and the quality of transport and will help companies save some of the funds earmarked for vehicle maintenance.

As part of the German railway digitization programme, 25,000 freight wagons have been fitted with devices monitoring the position of wagons throughout the rail system (Fig. 5). These wagons will have been provided with full digitization equipment by the end of 2020.

[14] TechLOK – A project using diagnostic data in a smart way to support ongoing maintenance, cyclical maintenance and repairs of DB Cargo's rolling stock.

Fig. 5. Device monitoring, among others, wagon position within the rail network [25]

2.5. Rail traffic management

Digitization of this very important field of railway transport is connected with managing train traffic in real time. The use of new digital technologies is altering the previous model, one that consists of managing the traffic of trains travelling within a network divided into regular blocks. The future train traffic that will make use of digital technologies should be based on a block with a length defined digitally. This will facilitate short distances between trains, or actually their "virtual coupling". Such a solution will increase the capacity of the railroad infrastructure in place and make the provision of transport services more flexible. Under the present circumstances, this can be achieved by a combination of ERTMS with innovative, full automation of train operation.

In the past few years, it has been argued [2] that real-time train traffic management needs the deployment of new technologies and innovation in at least the following fields:

- Autonomous train operation;
- Precise positioning of the trains within the network;
- Smart train operation (including green driving to help protect the environment);
- Reduction in operating expenses.

The efforts to digitize railway traffic management on the European scale are connected, among others, with fast and simple integration of train traffic management systems and interoperability. It is important that any systems employed meet the required levels of safety and are capable of delivering uninterrupted operation under the conditions of changing risks. In this respect, the key realms in which new technologies and innovation should be deployed are:

- Secure connectivity, especially increased security of GSM-R,
- Cyber security – making adaptations to pan-European and common signalling languages and providing security to the greater network connectivity among distributed systems.

Innovative solutions are also expected to be deployed in order to strengthen the resilience and cut the recovery time after any critical situation within the railway network (e.g. following an accident or a disaster).

3. Conclusions

Digitization of the railways is a necessary commitment that has a positive impact on the state economy. It will be of great importance at the time of recovering from the havoc wreaked by COVID-19. The digital support for this transport sector will result in:

- Greater reliability thanks to the use of new technologies and systems supporting the quality of provided services;
- Greater bandwidth of the existing railway lines, which will help increase the number of provided transport services (with some of the road freight services to be taken over by the railroad freight);
- Lower operating expenses for the maintenance and repair of the rolling stock;
- Improving the international railway traffic by means of the interoperability of the systems in place;
- Reducing the emission of pollutants.

Delivering and continuing the tasks related to digitization of the railways by consistently implementing innovative solutions and new technologies requires access to high-quality, trained and qualified human resources across many different railway sectors. Without proper training, it will not be possible to deliver the adopted goals, which is why flexible forms of advanced training (to help managers meet the requirements related to continuous development) should be complemented with the commitment to grow a pool of talents, developed by means of higher education based on partnerships between industry and the providers of educational services. It is also worth considering the need to develop a concept of the 'European PhD in railway transport'[15], including detailed guidelines for such a doctoral degree and the path to obtain it in the future, e.g. with the involvement of European railway institutes.

[15] For example, the DETRA project points to the possibility of gaining such a degree in transport, and under the Polish classification of scientific fields, a PhD degree can be obtained in the field of civil engineering and transport, currently the closest to the railway industry.

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