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Innowacyjne technologie transportu kolejowego wykorzystywanego przez Siły Zbrojne Rzeczypospolitej Polskiej

Innovative technologies of rail transport used by the Armed Forces of the Republic of Poland

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Abstract. Innovation in rail transport has a wide range of applications, which includes customer contact, train monitoring with modern internet-connected sensors and data analysis, as well as the use of artificial intelligence for route optimization, customer service management and vehicle maintenance. The presented issues constitute a research niche in the field of the use of innovations in military rail transport, which encourages research in this area. The article describes innovative technologies of rail transport used by the Armed Forces of the Republic of Poland. The subject of the research included in the article are the latest innovations in the field of rail transport technology and the analysis of their benefits and potential use by the Polish Armed Forces. These include intelligent control systems, infrastructure maintenance, innovative designs of trains and wagons. The aim of the article is to identify the advantages of innovative technologies and their potential application in the Polish Armed Forces. In order to achieve the objectives of the article outlined in this way, it is necessary to answer the following research questions: What innovative technologies of rail transport are used by the Polish Armed Forces? What are the prospects for the development of innovative rail transport technologies for defence purposes in Poland? What innovative solutions concerning the railway infrastructure in Poland could improve the safety of movements of troops by rail? The research hypothesis was adopted in the article: Innovative solutions in rail transport used by the Polish Armed Forces will effectively support the implementation of transports in the movement and transport subsystem (M&T). In order to verify the hypothesis, the following research methods were used: theoretical methods (analysis, synthesis, abstraction, inference, generalization) and the method of expert interview with representatives of the movement and transport subsystem. The presented approach allowed to analyse the problem from different perspectives, which makes it possible to conduct detailed research on this important and current issue.
Keywords: rail transport, innovations, armed forces, movement and transport, management

Abstrakt. Innowacyjność w transporcie kolejowym ma szeroki zakres zastosowań, który obejmuje kontakt z klientem, monitorowanie pociągów za pomocą nowoczesnych czujników połączonych z Internetem oraz analizę danych a także wykorzystywanie sztucznej inteligencji do optymalizacji tras, zarządzania obsługą klienta i utrzymania pojazdów. Przedstawione zagadnienia stanowią niszę badawczą w zakresie wykorzystania innowacyjnych technologii w wojskowym transporcie kolejowym, co skłania do prowadzenia badań w tym zakresie. W artykule scharakteryzowano innowacyjne technologie transportu kolejowego wykorzystywane przez Siły Zbrojne Rzeczypospolitej Polskiej. Przedmiotem badań zawartych w artykule są najnowsze innowacje w dziedzinie technologii transportu kolejowego oraz analiza ich korzyści i potencjalnego wykorzystania przez Siły Zbrojne RP. Zalicza się do nich: inteligentne systemy sterowania, utrzymanie infrastruktury, nowatorskie konstrukcje pociągów i wagonów. Celem artykułu jest zidentyfikowanie zalet innowacyjnych technologii oraz ich potencjalne zastosowanie w Siłach Zbrojnych RP. Realizacja tak zarysowanych celów artykułu wymaga udzielenia odpowiedzi na następujące pytania badawcze: Jakie innowacyjne technologie transportu kolejowego są wykorzystywane przez Siły Zbrojne RP? Jakie są perspektywy rozwoju innowacyjnych technologii transportu kolejowego dla potrzeb obronnych w Polsce? Jakie innowacyjne rozwiązania dotyczące infrastruktury kolejowej w Polsce mogłyby wpłynąć na poprawę bezpieczeństwa przemieszczeń transportem kolejowym wojsk? W pracy przyjęto hipotezę badawczą: Innowacyjne rozwiązania w transporcie kolejowym wykorzystywanym przez Siły Zbrojne RP będą skutecznie wspomagały realizację transportów w podsystemie transportu i ruchu wojsk. W celu zweryfikowania przyjętej hipotezy zostały zastosowane następujące metody badawcze: metody teoretyczne (analizy, syntezy, abstrahowania, wnioskowania, uogólniania) oraz metoda wywiadu eksperckiego z przedstawicielami podsystemu transportu i ruchu wojsk. Przedstawione podejście pozwoliło na przeanalizowanie problemu z różnych perspektyw, co stwarza możliwość przeprowadzenia szczegółowych badań tego istotnego i aktualnego zagadnienia.
Kluczowe słowa: transport kolejowy, innowacje, siły zbrojne, transport i ruch wojsk, zarządzanie

Introduction

The troop transport and movement subsystem are an extremely important element of the logistics system, playing a key role in guaranteeing the effective performance of tasks by the armed forces. It is a comprehensive subsystem, designed to ensure fast, efficient and safe movement of troops, military equipment and supplies. Not only does it provide the ability to move troops and equipment quickly, but it is also a key factor in the combat readiness of units and their ability to maintain an advantage over the enemy. This system should function in accordance with the current trends in the assumptions of the policy of sustainable socio-economic development. Therefore, it requires a certain amount of money and innovation.

In the literature on the subject, it was the first of the introduced definitions to define innovation as the establishment of new functions of production. This includes both the case of a new commodity and a new organizational form, such as a merger or the opening of new markets (Schumpeter, 1939, pp. 62). Innovation took into account the realization and practical application of the invention, not the mere fact of its creation. Solutions that are not applicable in real life could not be treated as innovations (Bukowska-Piestrzyńska et al., 2020, pp. 12). Railroads did not emerge because consumers took the initiative and expressed effective demand for their services, preferring them to mail stagecoach services. The vast majority of changes in the structure of consumer goods have been forced by producers on consumers.

The latter most often resisted the changes and had to be properly „educated" by the extensive psychotechniques of advertising (Schumpeter, 1939, pp. 47). In the last decade, rail transport has experienced many transformations.

The subject of the research included in the article are innovative technologies of rail transport used in the Polish Armed Forces. These include intelligent control systems, infrastructure maintenance, innovative designs of trains and wagons. The aim of the article is to present the latest innovations in the field of rail transport technology and to analyze their benefits and potential use by the Polish Armed Forces. The aim of the article is to identify the advantages of innovative technologies and their potential application in the Polish Armed Forces.

In order to achieve the objectives of the article outlined in this way, it is necessary to answer the following research questions: *What innovative technologies of rail transport are used by the Polish Armed Forces? What are the prospects for the development of innovative rail transport technologies for defence purposes in Poland? What innovative solutions concerning the railway infrastructure in Poland could improve the safety of movements of troops by rail?* Due to the research problems formulated in this way, the following research methods were used: theoretical methods (analysis, synthesis, abstraction, inference, generalization) and the method of expert interview with representatives of the movement and transport subsystem.

Literature review

The analysis of the literature shows that so far research has been conducted related to innovative technologies used in rail transport. There are numerous publications in the specialist literature on terminology and issues related to innovations introduced in rail transport. This literature has a significant impact on the development of rail transport.

It is worth noting that there is a large amount of research literature that focuses on the analysis of innovative technological solutions introduced in rail transport. These include the ultrasonic method for measuring residual stresses and detecting residual stresses in a railway wheel using the ultrasonic measurement method and estimating residual stresses by means of thermal-structural analysis (Strazovec et al., 2019, pp. 898–905) and innovative studies of rolling phenomena of wheels and rails (Strazovec et al., 2019, pp. 906-911). Research on the fabrication of load-bearing elements of the railway wagon body from circular pipes was also important (Fomin et al., 2021, pp. 1-20). Several research centres have also conducted research on the construction of models describing the demand for rail transport, as effective planning and optimisation of rail transport operations depends on effective and reliable demand forecasting (Borucka et al., 2021, pp. 354-363). Particularly noteworthy are also studies on the implementation of Industry 4.0 in rail transport, including

the use of digitization tools and state-of-the-art technologies (Gerhátová et al., 2020, pp. 23-30), (Ziółko et al., 2024, pp. 85-107) and the use of RFID technology (Fescioglu-Unver et al., 2014, pp. 1369-1380), (Liu et al., 2018, pp. 1013-1024). Many studies concern the implementation of the ERTMS system (Smith et al., 2012, pp. 79-87) and its further development (Kochan et al., 2018, pp. 249-262), as well as the automatic information transmission system (Kukulski et al., 2019, pp. 43-52). Also noteworthy is the prototype of a platform for loading trucks onto railway wagons (Krasoń W. et al., 2016, pp. 615-624).

It is worth noting that neither in Polish nor in the foreign industry literature there are studies directly addressing the utilization of innovative rail transport technologies by the Armed Forces of the Republic of Poland.

Innovative rail transport technologies used by the Polish Armed Forces

Innovation in rail transport concerns many aspects of its functioning: contact with customers, monitoring of trains through the use of modern sensors connected to the Internet in order to detect, identify and locate the moving unit and send data to the recipient conducting specific analyses. The monitoring system uses the electronic power supply of the system that is the label of the object by the reader in order to identify the object. This system is called Radio-Frequency Identification (RFID). RFID is a technology that provides automatic, contactless identification of moving cargo using radio waves (Rosová et al., 2013, pp.26). The purpose of RFID systems is to store information that can be easily read. The tag can include m.in, information such as the type of object, the value of the load, weight, temperature, or the owner of the load. An RFID system consists of three basic components: a reader (transmitter/receiver), an antenna, and a radio frequency tag integrated with the antenna and transmitter/receiver (Rakhmangulov et al., 2016, pp. 533). Intelligent transport systems already operate a number of devices for monitoring the status of assets in transport, enabling their location and ongoing control of priorities to meet the needs of the consumer/recipient (Zaskórski, 2021, pp. 173-192). The use of sensor technology that uses radio waves to transmit data indicating the parameters of a moving train allows to determine the position and take a quick reaction in a situation requiring intervention.

From a policy perspective, over the last decade, the European Commission's (EC) 2011 Transport White Paper has set the framework for the development of transport policy at European Union (EU) level, including that for rail. In its ten headline goals for transport, the White Paper set a number of ambitious aims for the rail sector. These included goals to shift road freight to rail (and inland waterways), for the majority of medium distance passenger transport to go by rail, for an increase in the

number of high speed rail lines, for improved connections for rail to airports and seaports and for the deployment of the European Rail Traffic Management System (ERTMS) (Gkoumas et al., 2023, pp. 3634). This is another example of the use of innovative technologies in rail transport. It is an interoperable signalling system deployed on main lines and high-speed networks in Europe and beyond to provide the benefits of increased capacity, greater reliability, an open market for supply and improved safety (Steele et al., 2022, pp. 246). ERTMS comprises two systems: the European Train Control System (ERTMS/ETCS) and the Global System for Mobile Railway Radio Communications (ERTMS/GSM-R). ERTMS/ETCS ensures that the driver's work is controlled with an increased level of safety. The overarching objective of this system is to ensure interoperability with other rail transport management systems. As a result, trains can be moved on the networks of different infrastructure managers without the need to change locomotives and drivers (Wontorski, Dzierżak, 2021, pp. 370). The ERTMS system enables: increasing the level of safety of train traffic; increasing the capacity of the railway line; reducing the risk of accidents, refurbishing communication equipment and adapting to international standards; improving the quality of transport due to the possibility of launching additional services using it (Szymonik, 2013, pp. 147). The implementation of ETCS is of great importance from the perspective of building a common market for rail transport products and services by removing technical barriers on the EU rail networks. The implementation of this policy makes it possible to obtain European standards on lines covered by trans-European transport corridors running through the territory of Polish, as well as other countries (Sprawozdanie z funkcjonowania, 2021, pp. 160). According to legal requirements, ETCS is necessary for train running at speeds above 160 km/h or for one-man traction above 130 km/h.

An integral part of ETCS is the Global System for Mobile Railway Radio Communications (GSM-R). It is a railway variant of GSM digital mobile communications, designed for the transmission of data used as a data carrier for ETCS and dispatch systems and for voice communication with the driver (Jabłoński, Jabłoński, 2018, pp. 147). GSM-R is a centralised system and the Operation Management Centre (OMC) is responsible for its operation. Therefore, the linear infrastructure of the GSM-R system, i.e. base stations (BTS) located along railway lines, must be remotely monitored (the correct operation of radio, teletransmission and power supply devices, signaling, burglary and assault systems (IDS) is monitored, as well as the conditions in which these devices operate – temperature) (Gago, 2018, pp. 13).

A decisive factor in the ability to meet the needs for the use of rail transport for military transport is the existing rolling stock. During the practical implementation of transport tasks, passenger coaches, flatcars and covered wagons are used (Pawlisiak, Piękoś, 2019, pp. 131-141). An innovative solution in the field of rail transport, which has been used in the Polish Armed Forces, is the introduction of modern passenger carriages into the army's equipment. The decision to purchase military passenger

carriages, ordered by PKP IC from the H. Cegielski Rail Vehicles Factory in Poznań, is a manifestation of innovation and staying ahead of the competition. For the purpose of transporting soldiers, PKP Intercity ordered eight special passenger carriages. Six of them are non-compartmental, and two are compartmental, designed to transport a convoy. These wagons can be used not only on the territory of the Republic of Poland, but also in the railway network of the Czech Republic, Slovakia, Hungary and Romania. The maximum speed of a railway train using the above-mentioned is 200 km/h. Compartment cars are equipped with lying compartments (including double compartments), a bar space of a very good standard, LCD monitors and air conditioning. In addition, in order to ensure the best possible conditions of use, a special infrastructure for the maintenance of these wagons will also be put into operation. Currently, PKP Intercity has received all military wagons from the order commissioned by the Ministry of National Defence (NATO Allies, 2021).

The acquisition of eight so-called special wagons for the needs of the Polish Armed Forces will ensure the transport of soldiers (crews of the military equipment being moved) in military operational transports with heavy military equipment, as well as the protection of means of supply (ammunition, combat means) in military supply transports. Two **wagons, the so-called "guards",** will be used to transport guards and convoys protecting military supply transports, especially with ammunition and combat equipment. Their layout and equipment should meet the requirements of a mobile guardhouse. In connection with the above, compartments were planned in them allowing for guard duty in a three-shift system: for the shifts of guard, vigil and rest. These wagons should guarantee the self-sufficiency of the soldiers in terms of social and living conditions for a minimum of five days (Dobrosielski, 2018, pp. 90).

Compartment carriages performing "convoy" functions have compartments with four berths each, a manager's compartment with one berth, a table and a safe; a conference room with a table, 14 chairs and a gun rack; a built-in two-level bookcase with a firearms safe and a kitchenette, toilet cubicles, air conditioning, public address and audio-video system (with a DVD drive, SD/MMC/IMS card readers, USB ports, FM transmitter, LCD monitors and sound system) (PLN 64 million for echelon, 2017). The analysis shows that guard wagons for transporting soldiers are an innovative solution that will significantly improve the safety and comfort of military transport. This solution meets the requirements of modern transport and is an important step towards the future-proof protection of transported cargo.

Six **passenger wagons** intended for the transport of soldiers in military operational transports (Fig. 2) will be included as single wagons or groups of wagons for transports with military equipment (SpW). Each of them should provide the soldiers with self-sufficiency in terms of social and living for a minimum of three days. That is why they are equipped with a kitchenette with household appliances, which creates appropriate living conditions (Dobrosielski, 2018, pp. 90). The second-class

non-compartment carriages (Fig. 2) for the transport of passengers (soldiers) are equipped with seventy-two seats on the seats (with an electric socket at each seat), a kitchenette and two modular toilet cubicles, air conditioning and thermal insulation, a public address system and the same audio-visual system (PLN 64 million for echelon, 2017). Thanks to these wagons, soldiers will be provided with comfortable travel conditions, which is extremely important from the point of view of maintaining combat readiness. With such support, individuals will be able to focus on the task at hand, confident that transport will not be a limitation or risk for them.

Another innovative solution used in military rail transport is **the mobile railway ramp**. It enables the loading and unloading of rail military transports in areas without efficient railway infrastructure (NO-82-A204, 2017, pp. 5). Loading is possible after prior surface preparation, which does not require much effort – anywhere on the railway line. The ramp is attached to the rails by means of clamps, and to the wagon – by means of a draw-rod device. Such a solution does not cause damage to the railway infrastructure. The ramp is used in loading and unloading not only heavy military tracked vehicles, but also wheeled vehicles and heavy vehicles of the civilian market, as well as for pedestrian traffic. The mobile ramps are available in two versions: with a load capacity of 35,000 kg (RM-35) and 70,000 kg (RM-70) (OBRUM news). The ramp is suitable for ambient temperature ranges from 40°C to +70°C for cold, temperate, tropical dry and humid climate zones. The structural steel used ensures high strength of the ramp while maintaining a relatively low weight. Once installed, the ramp is attached to the rails by means of clamps, and to the railway wagon by means of a draw-rod device. Fold-out ramps are used to fill the voids between the ramp and the railway carriage and the ramp and the ground. An important element that increases the grip of vehicles moving on the ramp is the surface with transversely welded elements (herringbone). The individual segments are fastened by means of pins. The construction solution of the railway ramp does not cause damage to the road infrastructure and the vehicles being loaded and unloaded (Mobile Railway Ramp). An external lifting device is not required for efficient installation of the structure – the whole can be assembled/dismantled by human hands (the weight of one element does not exceed 100 kg). Each element can be successfully moved by the crew, and the transport of complex ramps does not require dedicated vehicles (Choroszy, 2022, pp. 34). As you can see, mobile ramps are extremely easy to use, allowing you to move quickly and adapt to changing battlefield conditions.

Finally, it is worth emphasizing that innovative rail transport technologies are necessary to develop the logistics potential of the armed forces. The armed forces strive to continuously improve their transport system in order to be prepared for any challenges they may encounter. Thanks to the introduction of the ERTMS network, modern passenger coaches for transporting soldiers, guard wagons and mobile railway ramps, the Armed Forces have gained new opportunities in terms

of efficiency, flexibility and safety of troop movement, as well as creating conditions for maintaining combat readiness of troops. At the same time, this ensures better protection of troops as well as military equipment during military operations.

Prospects for the development of innovative rail transport technologies

Conducting scientific research and R&D works related to rail transport is a key issue for the development and efficiency of this branch of transport. This requires cooperation between military units and specialized research centers that focus on the introduction of modern technologies. With increasing demands for both safety and efficiency of military rail transport, there is a growing need for R&D capabilities that can contribute to the creation and implementation of innovative technological solutions. Only through such measures will it be possible to ensure optimal use of the potential of rail transport in military service.

The Railway Research Institute (IK) in Warsaw has a significant impact on the development of innovative solutions and their implementation in rail transport, which has a significant impact on shaping innovation policy in Poland. This research institute has been active for more than seventy years in the field of rail transport. The priority tasks of the CI include: substantive support for entities, decision-makers, transport organisers, carriers, investment projects, improving the competences of staff in the broadly understood transport sector and improving safety in transport (Barcikowska, 2022, pp. 27). Thanks to intensive research and tests conducted by the Railway Research Institute, it is possible to develop innovative solutions that increase safety, efficiency and comfort in rail transport. The institute not only analyzes existing technologies, but also tries to develop completely new ones that can transform the rail sector. The activities of the Railway Research Institute are not limited only to research and testing. The training and education of railway industry workers also plays an important role. By conducting specialized trainings, the Institute contributes to the improvement of knowledge and skills of people associated with rail transport, which in turn translates into better quality and efficiency of the entire sector.

Nowadays non-military factors, which support and complement military actions, play an increasingly important role in the understanding of security (Kurek, 2021, pp. 5-24). The introduction of modern technologies in military rail transport will bring a number of benefits, including m.in lower maintenance costs, reduced costs of urgent repairs, better planning based on real-time information about the condition of the rail vehicle, greater operational availability of rail vehicles and greater reliability during use (RFID na szynach, 2021). As part of the work processes, it is possible to monitor the time of their implementation, the materials used and spare

parts. This allows you to plan and finance the necessary maintenance activities more efficiently. Using multivariate statistics and analysis modules, it is easy to obtain forecasts of investment and operating costs in the perspective of days, months or years, taking into account various decision options (Przemysł 4.0, 2021). The use of electronic means to exchange regulatory information can reduce administrative costs for economic operators and can increase the efficiency of competent authorities. Both economic operators and competent authorities would have to take the necessary steps to enable the electronic exchange of freight regulatory information (eFTI) in a machine-readable format via information and communication technology platforms (eFTI platforms), including the purchase of the necessary equipment (Regulation (EU), 2020). With the introduction of IoT (Internet of Things) technology, it is possible to monitor and analyze various operating parameters such as fuel consumption, technical condition or wear of spare parts. This allows for more efficient fleet management and scheduling of regular inspections and maintenance, which in turn leads to a reduction in operating costs. The use of modern technologies in the planning of military rail transport and the operation of railway vehicles brings many benefits. In addition to optimizing the planning process, it also helps to reduce costs and increase safety. As a result, the armed forces can concentrate on the performance of their tasks, confident that rail transport is effective and efficient.

One of the innovative solutions being analysed for introduction in rail transport is the „Intelligent Video Monitoring of Containers" (IMW) project. The idea behind the innovative project is to develop an installation enabling the provision of a package of monitoring services, including: intelligent analysis of monitoring data allowing for risk estimation and forecasting of maintenance costs, using real-time data on the technical condition of wagons and related geolocation data; detection of defects in freight wagons through vibration diagnostics and a network of sensors (bearing temperature sensors, tank gas pressure sensor); forecasting failures and defects and carrying out preventive actions (Inteligentny monitoring wizyjny) In view of the above, intelligent video surveillance of containers would be of inestimable value for military needs. Through the use of advanced technologies such as artificial intelligence, image recognition and data analysis, it would be possible to effectively manage and control military transport and logistics. Smart monitoring would make it possible to precisely track containers, identify potential threats, as well as respond quickly to emergencies. The monitoring infrastructure would also be able to record and analyse signs of unusual behaviour, which would make it possible to protect against acts of sabotage or the seizure of containers by unauthorised persons.

Another innovative solution of the Railway Research Institute is Project IN2STEMPO „Innovative solutions in future stations, energy metering and power supply", which is part of the three issues of the Shift2Rail program. Shift2Rail is the first European rail initiative that aims to find relevant research and innovation and market-based solutions to integrate new and existing advanced technologies and

create innovative products that can be implemented in rail transport. IN2STEMPO is part of the main objectives of the Shift2Rail project and focuses on: reducing product lifecycle costs, improving reliability and punctuality, while increasing capacity, as well as improving rail interoperability and passenger satisfaction. The „IN2STEMPO Smart Power Supply" project is intended to contribute to the development of a smart rail network based on the development of a unique railway power grid. This new rail network is designed to integrate smart energy metering, innovative electronic power components, energy management and an energy storage system. This new concept is expected to lead to the improvement and optimisation of: the load on railway traffic, energy costs and the system of safe energy supply. On the other hand, the aim of the „IN2STEMPO Intelligent Energy Metering" project is to implement a non-invasive, intelligent network of measurement sensors in the railway system. The applications used use an energy analysis process to improve the decision-making process. Other possible applications include preventive maintenance plans, asset management, and lifecycle cost control. The third theme is „IN2STEMPO Future Stations" aimed at improving the customer experience and sense of security at railway stations. Research focuses on improving crowd management at large stations, station appearance and associated elements, train accessibility and new ticketing technologies (Innovative solutions). On the basis of the conducted analysis, it is concluded that the introduction of innovative solutions of the IN2STEMPO project would also contribute to increasing the capabilities for the Polish Armed Forces. In the context of the evolution of today's world, where technology and innovation play an increasingly important role in the military area, the IN2STEMPO project gives Poland a chance to be a leader in this field.

By reviewing and analysing the literature, research on the IT application has shown that IT tools are characterized by continuous evaluation, adapting to the progress in the field of computer science. This specificity is an effective solution, especially in the era of 5G technology, Industry 4.0 and the Internet of Things (Zabrocki, Bartosiewicz, 2020, pp. 5-18). Moreover, this research can also be applied to innovative rail transport technologies, which allows to predict a promising future for the development of IT applications in these fields.

The chapter on the prospects for the development of innovative rail transport technologies shows how many opportunities await us in the future. A research centre such as the Railway Research Institute plays a key role in the pursuit of innovative development of rail transport. Its importance lies not only in conducting research, but also in putting innovative solutions into practice. Its experts and teams of scientists are key players who contribute to the competitiveness and change of the rail sector. Therefore, their efforts should be recognised and supported in order to ensure the sustainable development of innovative rail transport technologies and to contribute to improving the quality and efficiency of this important mode of transport.

Innovative solutions in the field of railway infrastructure in Poland improving the safety of troop movements

Innovative solutions applied in the construction of rolling stock include the production of multifunctional, interoperable locomotives, suitable for operation in several countries. They are adapted to different train signalling and control systems and meet different safety criteria. In addition, they are used in both passenger and freight transport (Zamkowska, 2010, pp. 299). Rolling stock manufacturers also offer solutions to eliminate differences in parameters on different railway lines: locomotives powered by electricity of different voltages, bogies with devices that allow for automatic change of track gauge (Markusik, 2011, pp. 118). Multi-purpose locomotives are capable of transporting both military equipment and other goods, allowing for optimal use of these machines. Additionally, their ability to navigate a variety of tracks and difficult terrain conditions makes them ideal for military transport to the alliance's eastern flank, where there is a wider wheelbase.

Another solution is to equip it with modern control devices and on-board computers, thanks to which, for example, the driver obtains information on the optimal speed on each section of the route, as well as the acceleration and deceleration of the train, so as to minimize the energy consumption needed to run trains according to the timetable (Zamkowska, 2010, pp. 299). Thanks to modern equipment, the driver also has access to information about the tracks, signalling and possible difficulties on the route. This allows you to react quickly and minimize the risk of delays. The use of modern technologies allows you to minimize losses that were previously an inseparable part of travel. These actions are a step towards more sustainable rail transport, benefiting our environment and future generations.

In the current vision of transport policy, innovation is an integral part of the sustainable development of transport. New technologies make it possible to make the most of the opportunities offered by individual means of transport while minimizing their negative impact on the natural environment. This applies both to passenger transport, where the aim is to increase speed while ensuring an appropriate degree of safety, and to shorten travel times. As a result, at distances of up to 300 km, rail transport can compete with air transport in terms of the total time needed to complete the transport process (Wulgaris, 2019, pp. 89-90). It should be emphasised that the elements of intelligent management of transport systems facilitate the development of other spheres in society, ensure the emergence of new market relations and increase the level of possible needs of the population (in particular the transport system). Digital transport technologies are taking the commercial component to a new level, as they allow for earlier recognition of vehicle breakdowns or qualitative statistical analysis of the operation of the transport system (Rudakova et al., 2021, pp. 2). In addition, the development of intelligent traffic management systems makes trains run more efficiently, reducing fuel consumption and further

reducing emissions of various pollutants. Another important aspect is the reduction of noise, which can be achieved through the use of better insulated sound attenuation systems. Moreover, new technologies in rail transport are leading to increased energy efficiency and a reduction in the consumption of natural resources. Trains are using increasingly sophisticated energy recovery systems, including regenerative braking, photovoltaics and wind energy.

According to the analysis of information received during expert interviews with representatives of the transport and troop movement subsystem, in order to reduce the costs of construction and maintenance of railway loading points, a wider use of mobile railway ramps may be considered. Planning their location should be made with a view to the needs of the peaceful functioning of the armed forces, defensive in states of state defense readiness and in times of war. However, it is also important to select convenient places for the installation of these ramps in advance. With proper planning and use of mobile rail ramps at strategic loading points, steps can be taken to reduce construction and maintenance costs while providing the necessary security for rail logistics operations.

In addition, it can be concluded that there is a need to analyse the railway transport network in terms of meeting the allied requirements regarding the freedom of movement of the Polish Armed Forces and allied reinforcement forces on the territory of the Republic of Poland. To this end, in cooperation with railway infrastructure managers, predefined force displacement lines with high readiness for action should be selected and elements that require further adaptation should be identified. The prioritisation of these activities should take into account the operational needs of allied forces. This analysis will make it possible to make optimal use of the rail transport network, increase the mobility of the armed forces and ensure the efficient movement of allied troops if necessary. As a result, the Polish Armed Forces will be able to effectively support allied operations and maintain a high level of interoperability.

The next step is to take concrete actions to strengthen the role of rail transport in the country's integrated transport system. There is an urgent need to fill the gaps in the main lines (trunks) of the TEN-T network, which are crucial for the smooth flow of freight and passenger transport in our country. In particular, it is necessary to improve the infrastructure on railway lines, which are elements of connections between seaports and regions particularly important for national security in the interior of the country. Allocating adequate budgetary resources for these investments will be crucial for developing the potential of rail transport. It is also necessary to establish dialogue and cooperation with the entities responsible for the railway line and seaports in order to ensure consistency of action and optimisation of the use of the transport system.

According to experts, the focus on improving rail transport links also plays an important role. It is of great importance both at European level and for the Baltic

Sea area. Improving these connections will significantly improve accessibility and communication opportunities in the region, both internally and internationally. However, the implementation of these priorities should also be consistent with the objectives of improving the ability of the Polish Armed Forces to move troops by rail both within the country and abroad in Europe. Increasing the ability to move troops through rail transport will provide the Republic of Poland with greater security and enable better cooperation with allies within the framework of NATO commitments.

An important complement to the ability to transport troops by rail may be investments by infrastructure managers and carriers, which are aimed at modernising both the infrastructure and rolling stock (modernisation and purchase). Thanks to such investments, it will be possible to use it for transport for both civilian and military purposes. New and modernized railway lines enable the fast and safe transport of soldiers, military equipment and other important assets. Experts emphasise that it should not be forgotten that investments in the purchase of modern rolling stock will also significantly contribute to the improvement of transport capacity. Modern trains and wagons equipped with modern safety and comfort systems make civil and military transport more efficient, fast and safe. The modernisation of the railway infrastructure and the modernisation of the rolling stock will also make it possible to increase the capacity of the rail network and thus increase transport capacity. This, in turn, will result in faster and more efficient delivery of the necessary means of transport and military support in crisis situations and conflicts.

Conclusions

Analysing the issues of innovative technologies of military rail transport, it appears that innovative technologies used in rail transport have become tools thanks to which modern logistics develops. The aim of acquiring innovative technologies used in military rail transport is to increase the freedom of movement of the Polish Armed Forces and allied forces, to strengthen them with rail transport and to improve the social conditions for the transport of soldiers.

Strengthening the transport potential and the possibility of mobility in a short period of time are important factors in building the country's defence capabilities. Innovative technologies of rail transport make it possible to reduce the operating costs of the armed forces, which is important for optimising the use of available financial resources. Switching to greener energy sources in rail transport, such as hybrid or electric drives, also contributes to reducing the negative impact on the environment.

In the context of a dynamically developing world, innovative technologies in rail transport are an important element in the development of our armed forces. Their introduction allows for effective adaptation to the changing geopolitical realities and

taking quick and adequate actions to defend the interests of the Republic of Poland. Therefore, it is necessary to continue to invest in rail transport technologies as a key element in the modernisation and development of the armed forces.

Taking on the challenges of introducing new technologies in the rail transport sector is inevitable. However, like all innovations, these also have their limitations. It is often associated with high investment costs. For example, upgrading and automating railway infrastructure may require significant financial investment, which can be a major obstacle for the country. In addition, such solutions require the adaptation of the existing railway infrastructure. For example, the introduction of electric trains may require the installation of overhead contact lines on existing routes. This can be a difficult and expensive task, especially on old railway lines. What's more, the adoption of new technologies takes time for research, testing, and improvement. It is not possible to introduce new technologies immediately without proper preparation and real-world trials. This may require a long time to implement them.

The use of innovative technologies may also require the abandonment of old technology, leading to the phasing out of legacy solutions. This can cause difficulties for companies that have invested heavily in older technologies. In addition, the use of new technologies may be met with social resistance or lack of acceptance by users. For example, the use of autonomous trains may raise safety concerns for passengers and drivers. It is imperative to provide adequate support and public education to increase the acceptance of new technologies. The implementation of new technologies in the rail transport sector may face many limitations, but it should be remembered that the opportunities offered by innovation often exceed these limitations.

Innovative technologies of rail transport are used in the Polish Armed Forces, which confirms the subject of research presented in this article. This is confirmed, among others, by the receipt by PKP Intercity of the first of the wagons ordered by the Ministry of National Defence in 2021 and dedicated to the Polish Armed Forces. Eight wagons for the Ministry of National Defence were built by FPS H. Cegielski. These are six second-class special wagons without compartments for transporting people (soldiers) and two second-class special wagons with compartments for transporting convoys (Osiak, 2023, pp. 108). According to experts, the use of modern passenger coaches and mobile railway ramps will be an important complement to innovative technologies for the armed forces. In addition, the key solution is to plan the wider use of mobile railway ramps and to select convenient places for their installation in advance, both for the needs of the peaceful functioning of the armed forces and in times of crisis and war. These activities cannot be carried out on the basis of improvisation, but they require proper preparation and planning in order to be able to make the best use of the potential of railway ramps. Such their use will reduce the costs of construction and maintenance of railway loading points. Investments by infrastructure managers and carriers aimed at modernising railway

infrastructure and rolling stock are also important. The capabilities obtained in this way will strengthen the eastern flank of the North Atlantic Alliance.

To sum up, innovative technologies used in rail transport have become tools thanks to which modern logistics develops. Modern solutions in the field of military rail transport are of great importance both for the effectiveness of military operations and for ensuring the safety of soldiers. That is why armies around the world, including Poland, are investing more and more financial resources in this area, focusing on the development of innovative solutions and technologies. Finally, it should be emphasized that innovations and technologies that enable faster and safer delivery of supplies and equipment to the front line improve the effectiveness of military operations and increase their chances of victory. Innovative rail transport technologies used by the Polish Armed Forces are an important factor in the development of our country's defence potential. Thanks to this system, it is possible to quickly and effectively move troops and equipment over long distances, which is important in the event of crisis situations, conflicts and peacekeeping operations.

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