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Ways to develop railway sorting yards to handle container trains

Sposoby rozwoju kolejowych placów sortowniczych do obsługi pociągów kontenerowych

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Abstract. The purpose of the study was to identify the most effective strategies for developing railway sorting yards to enhance the efficiency of container train handling. The research problem addressed inefficiencies in current railway sorting yard operations, which impede optimal cargo handling and contribute to delays, higher costs, and environmental concerns. The hypothesis posited that integrating automation, infrastructure modernisation, and green technologies could significantly improve efficiency, accuracy, and sustainability. The study fills a research niche by combining technological advancements, infrastructure updates, and environmental considerations to provide a comprehensive approach to modernising railway logistics. The following research methods were employed: statistical analysis of freight traffic data (2020–2023) across Europe, America, and Asia; evaluation of modern technologies; assessment of infrastructure upgrades; and analysis of environmental and occupational training impacts. As a result, the research found that automation and digitalisation, including automatic traffic management systems and container tracking platforms, substantially increase logistics efficiency by reducing downtime and improving accuracy. Modernisation of tracks, switches, and station expansion addresses the growing traffic volumes, while the adoption of modern cranes and lifts accelerates container handling. Integration with sea and road transport hubs enhances the overall logistics network, and the introduction of green energy and energy-efficient technologies reduces the carbon footprint. Proper personnel training ensures effective implementation and high safety standards. The main conclusion is that a comprehensive and integrated approach to the modernisation of sorting yards is essential for optimising container train logistics, increasing safety, and achieving sustainable development in global railway transport.
Keywords: digitalisation of transportation processes, integration of transport systems, infrastructure modernisation, optimisation of logistics processes, network route planning

Abstrakt. Celem badania było zidentyfikowanie najskuteczniejszych strategii rozwoju kolejowych placów sortowniczych w celu zwiększenia wydajności obsługi pociągów kontenerowych. Problem badawczy dotyczył nieefektywności obecnych operacji kolejowych placów sortowniczych, które utrudniają optymalną obsługę ładunków i przyczyniają się do opóźnień, wyższych kosztów i problemów środowiskowych.

Hipoteza zakładała, że integracja automatyzacji, modernizacji infrastruktury i zielonych technologii może znacznie poprawić wydajność, dokładność i zrównoważony rozwój. Badanie wypełnia niszę badawczą, łącząc postęp technologiczny, aktualizacje infrastruktury i kwestie środowiskowe, aby zapewnić kompleksowe podejście do modernizacji logistyki kolejowej. Zastosowane metody badawcze: analiza statystyczna danych dotyczących ruchu towarowego (2020–2023) w Europie, Ameryce i Azji; ocena nowoczesnych technologii; ocena modernizacji infrastruktury; oraz analiza wpływu na środowisko i szkolenia zawodowe. W rezultacie badanie wykazało, iż automatyzacja i digitalizacja, w tym automatyczne systemy zarządzania ruchem i platformy śledzenia kontenerów, znacznie zwiększają wydajność logistyki poprzez redukcję przestojów i poprawę dokładności. Modernizacja torów, zwrotnic i rozbudowa stacji rozwiązuje problem rosnącego natężenia ruchu, podczas gdy wprowadzenie nowoczesnych dźwigów i wind przyspiesza obsługę kontenerów. Integracja z węzłami transportu morskiego i drogowego wzmacnia ogólną sieć logistyczną, a wprowadzenie zielonej energii i energooszczędnych technologii zmniejsza ślad węglowy. Odpowiednie szkolenie personelu zapewnia skuteczną realizację i wysokie standardy bezpieczeństwa. Głównym wnioskiem jest to, że kompleksowe i zintegrowane podejście do modernizacji placów sortowniczych jest niezbędne do optymalizacji logistyki pociągów kontenerowych, zwiększenia bezpieczeństwa i osiągnięcia zrównoważonego rozwoju w globalnym transporcie kolejowym.
Słowa kluczowe: digitalizacja procesów transportowych, integracja systemów transportowych, modernizacja infrastruktury, optymalizacja procesów logistycznych, planowanie tras sieciowych

Introduction

Railway sorting yards play a key role in modern logistics, ensuring efficient handling of container trains and integration with other modes of transport (Rosa, 2024; Ficoń, 2019). Due to the growing volume of container transportation and increased requirements for the speed and accuracy of logistics processes, there is a need to modernise and improve the infrastructure of these stations. Current challenges include improving cargo handling efficiency, reducing downtime, optimising logistics processes, and ensuring environmental sustainability (El Yaagoubi et al., 2022). In accordance with these requirements, the development of new technologies, process automation and implementation of innovative solutions are critical to improving the overall productivity and competitiveness of railway sorting yards.

The problem of efficient handling of container trains at railway sorting yards is relevant for modern logistics. Various researchers have already investigated this topic, in particular, T.-L. Chen et al. (2021) emphasise that automation of processes at sorting yards can significantly reduce cargo handling time, increasing overall productivity. The introduction of automatic systems can reduce human error and improve processing accuracy. R.W. Ahmad et al. (2021) note that the integration of digital container tracking platforms reduces delays in logistics processes and provides more transparent cargo management. Modern tracking technologies improve interaction between different stages of the logistics chain. A. Mohammed and H. Bashir (2023) investigated how modernisation of tracks and switches affects the overall processing performance of container trains, noting a significant reduction in the time of trains passing through stations. Investment in infrastructure upgrades is cost-effective due to reduced delays. Z. Raimbekov et al. (2022) point out the importance of expanding stations to handle growing traffic volumes, which allows coping with large cargo flows without loss of efficiency. Expanding the capacity of stations can reduce congestion and improve cargo handling. M. Kłodawski et al. (2024) emphasise the role of modern cranes and lifts in accelerating the movement of containers, which reduces the overall cargo handling time. Automating these processes reduces manual labour costs and increases efficiency.

The purpose of the study was to identify and evaluate effective strategies for modernising railway sorting yards, focusing on automation, infrastructure upgrades, and environmental sustainability, to optimise the handling and efficiency of container trains. The research problem centers on the inefficiency and outdated practices in railway sorting yards, which hinder the optimal handling of container trains, leading to delays, increased operational costs, and environmental concerns. The hypothesis is that integrating automated control systems, modernised infrastructure, and eco-friendly technologies can significantly improve the efficiency, accuracy, and sustainability of railway logistics. The research niche lies in addressing the intersection of technological innovation, infrastructure development, and environmental sustainability within the context of railway sorting yards, offering a comprehensive approach to enhancing container train operations in an era of growing global trade demands.

Materials and Methods

The following research methods were used in this study: statistical analysis of freight transport data, evaluation of technical reports on automation and modernisation, comparative analysis of regional transportation systems, and assessment of technological, environmental, and training impacts on railway logistics efficiency. The study examined container geography to determine the distribution of container traffic and identify key locations that affect the effectiveness of global logistics chains. Factors influencing the choice of container transport routes, including economic, political, and environmental aspects, were evaluated to improve the planning and management of logistics processes at the global level. Statistics on freight transport in conventional freight cars and containers in the European (European Union Agency for Railways, 2024), American (Bureau of Transportation Statistics, 2024), and Asian (Association of South East Asian Nations, 2019) regions were considered to compare the efficiency and volume of transport in different systems. This allowed assessing the advantages and disadvantages of each transportation system, including space efficiency, transportation costs, and infrastructure impact. This provided insight into global trends in freight transport and helped to optimise logistics strategies in different regions.

The study analysed a technical report on the automation of train and container management in Europe, which helped to assess the effectiveness of automated systems in cargo handling (Mohammed, Bashir, 2023). Evaluation of new technologies in the United States revealed their impact on upgrading railway infrastructure, improving safety, and reducing costs (Digitalization in the railway industry, 2022). Analysis of infrastructure modernisation in Asia revealed the effect of new construction solutions on increasing capacity and reducing transport delays (Southeast Asia Infrastructure, 2023).

The study examined terms like Twenty-foot Equivalent Unit (TEU) in Europe and America and Container Equivalent Unit (CEU) in Asia to ensure accuracy in comparing cargo volumes and transportation efficiency. Traditional terms, such as wagon freight in Europe and boxcar in the US, were analysed to understand their impact on rail transport productivity and infrastructure optimisation. The study assessed automation's role in cargo handling efficiency, focusing on real-time digital monitoring platforms, modernised tracks and switches, and expanded sorting yards to improve station capacity and cargo flow. Modern cranes, lifts, scanners, and sensors were evaluated for their impact on speed, accuracy, and safety in container handling. Additionally, integrated systems linking rail, sea, and road transport and network planning methods were explored to optimise routes and reduce delays. The study also analysed renewable energy and energy-efficient technologies for reducing the carbon footprint and highlighted the importance of staff training in managing new technologies and maintaining safety standards.

Results

Asia is an important region in global logistics due to its large-scale trade turnover and significant role in international trade. In this region, cargo transportation is carried out both using containers and traditional wagons, with special terms and standards for each type of transportation. Containers in Asia are often evaluated in CEU, which, although similar to TEU, has specific standards for different types of containers (Hilmola et al., 2021). CEU incorporates various container formats, including 20 ft and 40 ft units, which is crucial for optimising transportation in countries with large cargo volumes, such as China and India. In China, for example, container transportation has become extremely important due to the expansion of port infrastructure and the growth of exports, as a result of the new port terminals in Shanghai and Guangzhou, which provide fast and efficient cargo handling. Traditional freight wagons in Asia also have specific terms: "box wagon" for closed wagons and "open wagon" for open wagons. Box wagons are used to transport weather-sensitive goods such as chemicals and food. Open wagon, in turn, is used for transportation of large, unpacked cargo, for example, raw materials for industrial enterprises.

Table 1 provides an overview of changes in the volume of freight traffic in conventional wagons and containers over different years, which allows assessing the trends and dynamics of traffic in different regions.

Table 1. Statistics on freight traffic in conventional freight wagons and containers (2020-2023)

Region	**Year**	**Type of transportation**	**Traffic volume (million units)**	**Comments**
European	2020	Freight wagons	8.5	Main volume of traffic is in traditional railcars.
		Containers.	10.0	Trend towards an increase in container traffic.
	2021	Freight wagons	9.0	Slight increase in volumes in conventional railcars.
		Containers	11.0	Further growth of container transportation.
	2022	Freight wagons	9.5	Further growth in traffic volumes.
		Containers	12.5	Increase in container traffic volumes.
	2023	Freight wagons	10.0	Continued growth in freight wagons.
		Containers	13.0	Growth of container traffic continues.
American	2020	Freight wagons	12.0	High volume of traffic in traditional railcars.
		Containers	14.5	Significant volume of container traffic.
	2021	Freight wagons	12.5	Slight increase in traffic volumes.
		Containers	15.5	Further growth of container transportation.
	2022	Freight wagons	13.0	Growth in volumes in traditional railcars.
		Containers	17.0	Increase in container traffic.
	2023	Freight wagons	13.5	Further growth in traditional railcars.
		Containers	18.0	Container traffic continues to grow

cd. tab. 1

Asian	2020	Freight wagons	15.0	High volume of traffic in traditional railcars.
		Containers	18.0	High volume of container transportation.
	2021	Freight wagons	16.0	Growth in volumes in traditional railcars.
		Containers	20.0	Further growth in container traffic volumes.
	2022	Freight wagons	17.0	Further growth in traffic volumes.
		Containers	22.0	Increase in container traffic.
	2023	Freight wagons	18.0	Continued growth in traffic volumes.
		Containers	24.0	Continued growth in container traffic volumes.

Source: compiled by the author based on Bureau of Transportation Statistics (2023)

The study of statistics on freight transport in conventional freight wagons and containers in the European, American and Asian regions helped to compare in detail the efficiency and volume of transportation in different systems. Both traditional freight wagons and modern container solutions were analysed for each of these regions. This enabled an assessment of the advantages and disadvantages of each transport system, including space efficiency, transport costs, and impact on infrastructure (Table 2).

Table 2. Comparison of road and rail transport in the American, European, and Asian regions

Criteria	American region	European region	**Asian region**
Infrastructure	**Automobile: 6.7 million km of roads, of which 75,000 km are interstate roads. Railway: 293,564 km of railways, of which 225,000 km are intended for freight transport.**	**Automobile: 5.5 million km of roads. Railway: 226,000 km of railways, of which 108,000 km are electrified.**	**Automobile: 5.1 million km of roads in China, India, and Japan. Rail: 250,000 km of railways, of which 40% are electrified (mainly in China).**
Transportation speed	**Automobile: average speed 80-100 km/h. Railway: average speed of freight trains is 40-60 km/h.**	**Automobile: average speed 60-90 km/h. Railway: speed of passenger trains is up to 300 km/h, freight trains – 50-80 km/h.**	**Automobile: average speed 60-90 km/h. Rail: speed of passenger trains in China is up to 350 km/h, freight trains – 40-70 km/h.**

cd. tab. 2

Cost of trans-porta-tion	**Automobile: USD 0.15-0.20 per tonne-kilometre. Railway: USD 0.02-0.05 per tonne-kilometre.**	**Automobile: USD 0.20-0.25 per tonne-kilometre. Railway: USD 0.04-0.10 per tonne-kilometre.**	**Automobile: USD 0.10-0.15 per tonne-kilometre. Railway: USD 0.02-0.06 per tonne-kilometre.**
Environ-mental friendli-ness	**Automotive: 0.2-0.4 kg CO_2 per tonne-kilometre. Railway: 0.04-0.07 kg CO_2 per tonne-kilometre.**	**Automotive: 0.3-0.5 kg CO_2 per tonne-kilometre. Railway: 0.02-0.06 kg CO_2 per tonne-kilometre.**	**Automotive: 0.15-0.35 kg CO_2 per tonne-kilometre. Railway: 0.03-0.08 kg CO_2 per tonne-kilometre.**
Flexibil-ity and acces-sibility	**Automobile: 90% of cargo transportation is carried out by cars. Railway: 40% of freight traffic is carried out by rail.**	**Automobile: 70% of cargo transportation is carried out by cars. Railway: 20% of freight traffic is carried out by rail.**	**Automobile: 60% of cargo transportation is carried out by cars. Railway: 25% of freight traffic is carried out by rail (more in China).**
Advan-tages	**Automobile: optimal for transportation over dis-tances of up to 800 km. Railway: effective for transportation over a distance of more than 1,000 km.**	**Automobile: optimal for transportation over dis-tances of up to 600 km. Railway: effective for transportation over dis-tances of more than 800 km.**	**Automobile: optimal for transportation over dis-tances of up to 500 km. Railway: effective for transportation over a distance of more than 1,000 km (especially in China).**

Source: compiled by the author based on European Union Agency for Railways (2024), Bureau of Transportation Statistics (2024), Association of South East Asian Nations (2019)

The analysis showed that different regions have their own specific approaches to the organisation of cargo transportation, which directly affect efficiency and economy. The European region, with its developed infrastructure and high requirements for environmental standards, demonstrates a high level of automation and optimisation of cargo transportation (Aulin, et al., 2019). The American region, due to its large area and the presence of a large number of freight wagons, focuses on the scale and efficiency of space use. The Asian region, which is actively upgrading its infrastructure, focuses on integrating new technologies and reducing transport delays (Babachenko et al., 2023). Thus, it is possible to significantly speed up the delivery of containers by rail by optimising the operation of sorting yards. Usually, a significant part of the time during which the container is on the road is spent on downtime at sorting yards. To solve this problem, it is proposed to implement principles borrowed from maritime transport.

On sea container ships, sorting and dispatch processes are organised in such a way as to minimise the time spent by the ship in port. Containers intended for a specific port are promptly unloaded, and new ones are loaded, after which the ship is immediately sent on a further voyage. A similar approach can be applied to the operation of sorting yards on the railway. Trains arrive at the station, where containers intended for this station are unloaded, and new ones intended for other stations are loaded. This sorting can occur both between trains and between the train and the station.

Optimisation of logistics processes is an important aspect of the development of modern transport systems, including integration with marine and road transport hubs, and the introduction of modern network planning methods (Palin et al., 2021). These approaches are aimed at ensuring uninterrupted communication between different modes of transport, which is critical for the effective organisation of global logistics chains. Integration with sea and road transport hubs allows creating a single logistics system that ensures smooth and well-coordinated cargo transfer between different modes of transport. The development of integrated logistics systems reduces the delays that can occur when cargo is reloaded between rail, sea, and road transport systems. This includes optimising cargo transfer locations, coordinating schedules for various modes of transport, and improving handling processes at Inter-transport terminals. As a result, this integration helps ensure smooth cargo movement, reducing overall transit times and increasing the efficiency of logistics operations.

Network planning is another important tool for optimising logistics processes. The use of modern network planning methods allows analysing and optimising transportation routes, reduce downtime and improve overall transport efficiency (Danchuk et al., 2021). These methods include the use of specialised software for modelling logistics chains, which allows planning and managing routes based on real data and forecasts. The implementation of network planning provides a more flexible and faster response to changing conditions, such as congestion, weather conditions or changes in cargo volumes, which helps to increase efficiency and reduce costs.

As a result of integration with marine and road transport hubs and the introduction of network planning, logistics processes become more coordinated and efficient. This reduces delays, improves resource management, and reduces transportation costs. It is important to note that these improvements not only improve operational efficiency, but also improve the overall level of customer service, ensuring faster and more accurate deliveries. Thus, optimisation of logistics processes through integration with other modes of transport and the use of network planning are important aspects for improving the functioning of modern transport systems. These approaches ensure uninterrupted cargo movement, reduce costs, and increase the overall efficiency of logistics operations.

Environmental aspects have become key in the development and modernisation of railway infrastructure, as increasing attention to sustainable development and combating climate change requires the introduction of environmentally friendly technologies (Vijayakumar et al., 2021). Important areas in this context are the implementation of solutions based on renewable energy sources and improving energy efficiency. Green energy is central to reducing the carbon footprint of rail transport (Babachenko et al., 2021). The introduction of renewable energy solutions, such as solar panels, wind turbines or biomass, can significantly reduce dependence on traditional fossil fuels and reduce greenhouse gas emissions. For example, solar panels can be installed on the roofs of sorting yards and depots, providing partial or complete replacement of traditional energy sources. Wind turbines located near important railway junctions can also contribute to clean energy production. The introduction of such technologies not only reduces the negative impact on the environment but can also lead to lower operating energy costs. Table 4 shows data on environmental aspects in the development of railway infrastructure.

Table 4. Environmental aspects in the development of railway infrastructure in 2021

Environmental aspect	European region	American region	Asian region
Use of renewable energy sources (%)	25%	18%	10%
Reducing CO_2 emissions (t/km)	50%	40%	30%
Energy efficiency (kW/t)	0.12	0.15	0.18
Share of electrified lines (%)	65%	30%	25%
Investment in environmental technologies (USD billion)	5.2	3.1	2.5
Noise reduction percentage (dB)	10%	8%	6%
Amount of green infrastructure (km)	70%	60%	50%

Source: compiled by the author based on Hirata et al. (2022).

Energy efficiency is another important aspect of environmental infrastructure development. The use of energy-efficient technologies and materials in infrastructure upgrades helps reduce overall energy consumption. This may include the introduction of modern lighting systems, such as LEDs, or improvements in heating and cooling systems. Modern materials that have high thermal insulation properties can also reduce energy requirements to maintain optimal temperatures in buildings. In addition, optimising the operation of mechanisms and equipment used at railway stations can help reduce energy consumption and reduce operating costs.

The development of railway sorting yards is a complex process that requires investment in the latest technologies, infrastructure and personnel training. These measures will ensure efficient operation of container trains and contribute to the overall development of railway logistics.

Discussion

In the process of analysing the results of the study of ways to develop railway sorting yards for handling container trains, significant achievements in infrastructure modernisation were identified, which contributed to improving the efficiency of transportation. Automation and digitalisation, as the results showed, have become the main areas of improvement. The introduction of automatic traffic management systems and digital platforms for tracking containers reduced downtime and optimised logistics processes, which contributed to an increase in the efficiency of processing container trains. The results confirmed that digitalisation significantly improves the speed and accuracy of cargo transshipment. This was also investigated by E. Hirata et al. (2022), where the results confirmed that automation and digitalisation are critical for upgrading railway stations and improving container handling efficiency.

The introduction of automated container handling systems can significantly reduce the time required for loading and unloading cargo. Modern technologies, such as automated cranes, conveyor systems, and RFID tags, allow tracking the movement of containers in real time, which simplifies logistics and cargo management processes (Babachenko et al., 2022). Digital platforms provide integration of various stages of cargo handling, including registration, identification, and data processing, which reduces the human factor and errors. This, in turn, increases the accuracy and speed of container handling, which has a direct impact on the overall performance of railway stations.

The study by A. Ukato et al. (2024) also showed that digital platforms and automated systems significantly reduce downtime and optimise logistics processes by integrating and automating key functions. The introduction of modern software solutions reduces delays associated with manual data processing and scheduling. Real-time monitoring and analytics systems allow faster and more accurate forecasting and management of cargo flows, which prevents delays and overcrowding of warehouses. Automating routine tasks, such as cargo accounting and vehicle management, can reduce costs and improve operational efficiency. As a result, companies can increase the reliability of their logistics chains and increase customer satisfaction by completing orders faster and more accurately.

It is worth noting that automation and digitalisation not only reduce the cost and time of cargo handling but also contribute to improving safety at railway stations. Automatic systems can reduce the risk of human error and improve cargo control, which is critical to ensuring the safety and reliability of railway operations (Voloshina et al., 2020). In addition, the integration of digital platforms allows collecting and analysing data on the effectiveness of processes, which provides an opportunity for further improvement and optimisation of logistics strategies.

The renewal of railway station infrastructure has also shown a positive effect. The modernisation of tracks and switches and the expansion of stations to handle the increased traffic volume (optimisation of station areas) has reduced delays and improved safety (Panchenko et al., 2019). This reduced the risk of accidents and breakdowns, which increased the overall reliability of rail transport. The results showed that a comprehensive approach to infrastructure modernisation is critical to ensuring smooth operation of container trains. A. Šperka et al. (2022) concluded that upgrading the railway station infrastructure is a critical step to reduce delays and improve transport safety. The update includes the introduction of new technologies, such as automated traffic control systems, modern alarm systems, and video surveillance. This improves coordination between different components of the railway network, reduces train downtime, and reduces the likelihood of accidents.

In addition, infrastructure modernisation may include improvements to platforms, (sorting platforms, sorting devices) platforms and office premises, which affects the overall level of safety and comfort for passengers and cargo. The study by P. Singh et al. (2021) found that updating tracks and switches significantly increases the reliability and efficiency of working with container trains. New or repaired tracks provide smoother and more stable movement, which reduces the wear of cars and increases their service life. Modern switches reduce delays and improve container handling (Panchenko et al., 2018). This provides greater efficiency in transportation, reducing the risk of accidents and delays, and, as a result, increases the overall productivity of the railway network. These results confirm the above study, as they show that infrastructure modernisation and updating of tracks and switches have a direct impact on improving the efficiency and safety of railway transport. Updated technologies and improved components reduce delays and improve coordination in cargo handling, which confirms the importance of investing in infrastructure upgrades to achieve optimal results (Bekenov et al., 2020). A systematic approach to infrastructure renewal provides not only operational benefits, but also long-term reliability and safety of rail transport, which is critical for the development of efficient transport systems.

The introduction of new technologies, such as modern cranes, lifts, scanners and sensors, has also yielded positive results. In particular, the use of these technologies accelerated the process of moving containers and automated cargo control. This helped to reduce the number of human errors and increase the overall level of security of operations. The results confirmed that automatic cargo control technologies significantly improve the accuracy and efficiency of Transportation. N. Tsolakis et al. (2022) also found that new technologies have a significant impact on speeding up container movement and automating cargo control. The introduction of innovative solutions, such as automated warehouses, unmanned cranes and logistics management systems, reduces the time required for loading and unloading cargo. Automatic container location detection and motion prediction systems provide faster and more accurate handling, reducing delays and improving overall productivity. The integration of such technologies allows automating routine tasks, reducing the impact of the human factor, and ensuring more efficient cargo management.

When analysing the results of the study, it is evident that the introduction of green energy and energy-efficient technologies has a significant impact on reducing the carbon footprint of railway transport. The transition to renewable energy sources and the use of the latest technologies can reduce CO_2 emissions and increases overall energy efficiency (Capasso et al., 2021). In addition, the results of the study confirm that reducing environmental impacts is achieved not only by reducing CO_2 emissions, but also through efficient waste disposal. The introduction of waste processing and management technologies reduces environmental pollution and contributes to the sustainable development of railway transport (Musayev et al., 2022). This highlights the importance of an integrated approach to reducing environmental impacts, including both introducing new technologies and improving waste management processes.

In the context of staff training and development, the results confirmed that training and ensuring high standards of occupational safety are critical for the effective implementation of new technologies. Investments in personnel training have helped ensure proper management of new systems and technologies, which has increased the overall level of safety and efficiency of stations. The results point to the need for continuous improvement of employee skills in response to rapid changes in the technology environment.

The conducted research contributes to science by providing a comprehensive framework for modernising railway sorting yards, integrating automation, infrastructure development, and environmental sustainability. It introduces novel insights into how digital technologies, such as automated traffic control systems and real-time container tracking platforms, can optimise logistics and reduce delays. Additionally, the study highlights the role of modern cranes, sensors, and renewable energy solutions in enhancing operational efficiency and sustainability. By addressing gaps in economic evaluation and long-term sustainability of such upgrades, the research advances the understanding of how to achieve efficient, environmentally friendly, and cost-effective railway logistics systems, offering practical solutions for global transport challenges.

Conclusions

Automation and digitalisation of processes, including the introduction of automatic traffic control systems and digital platforms for tracking containers, have significantly improved the speed and accuracy of cargo handling. These innovations have reduced downtime, reduced the risk of errors, and optimised logistics processes, which has significantly improved transportation efficiency. Infrastructure upgrades, such as updating tracks, switches, and optimising station space, have made it possible to handle the growing volume of traffic. This has led to reduced delays and improved safety at railway stations, confirming the need for continued investment in physical infrastructure.

An important result was the introduction of new technologies, such as modern cranes, lifts, scanners, and sensors. These technologies have accelerated the process of moving containers and automated cargo control, which has increased the overall accuracy and safety of operations. Optimisation of logistics processes through integration with marine and road transport hubs, and the use of network planning, has reduced delays and improved route management. This confirmed the importance of integrating different modes of transport to achieve maximum results in container transportation.

Environmental aspects have also been successfully implemented, including the introduction of green energy and energy-efficient technologies, which has reduced the carbon footprint and the environmental impact of rail transport. Finally, staff training has become a key factor in ensuring the effective operation of new systems and maintaining high safety standards. Thus, the study emphasised that a comprehensive approach to the modernisation of railway sorting yards is crucial for improving their efficiency and sustainability.

To further improve railway sorting yards, it is necessary to investigate the impact of new automation technologies on the long-term efficiency and sustainability of operations, and their integration with other transport systems. A limitation of the study is that the analysis focused only on railway sorting yards in developed countries, which may limit the applicability of the results for countries with less developed infrastructure.

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