DOI 10.18.276/978-83-8419-053-1-34

28th European Conference on Artificial Intelligence (ECAI 2025)

OPPORTUNITIES FOR THE USE OF ARTIFICIAL INTELLIGENCE IN RAIL TRANSPORT

Arkadiusz Drewnowski[a], Paulina Dąbrosz–Drewnowska[b], Krzysztof Małachowski[c]

[a] *University of Szczecin, Institute of Management, Poland*
[b] *University of Szczecin, Institute of Management, Poland*
[c] *Bydgoszcz University of Science and Technology, Faculty of Management, Poland*

ABSTRACT

Purpose: *The aim of this article is to present potential areas of application of AI in railways. This includes applications in areas such as rail transport management, railway infrastructure, passenger and freight transport, rolling stock or employee training.*

Need for the study: *The importance of Artificial Intelligence (AI) technology is increasingly growing in both social and economic life. This technology is finding increasing application in large part by replacing human labour and improving the performance of tasks by machines. The application of AI in rail transport management contributes to improving its efficiency, safety and quality of transport.*

Methodology: *The following review article is based on literature and expert experience.*

Findings: *The conclusions indicate potential areas of application of AI in rail transport management, which may consequently contribute to an increase in the competitiveness of rail transport.*

Practical Implications: *The article may be helpful to learn about potential areas of AI application in rail transport.*

Keywords: Artificial Intelligence, rail transport, rail transport management, rail passenger and freight transport, rail infrastructure, rail simulators

Jel codes: L92; O31; O33

1. INTRODUCTION

Artificial intelligence (AI) is a field of knowledge that includes fuzzy logic, evolutionary computing, neural networks, artificial life and robotics. It is also the branch of computer science that deals with intelligence - the creation of models of behaviour and computer programs that simulate these behaviours (Bharadiya, 2023; Wiśniewski, 2019). The importance of artificial intelligence technology has been growing rapidly in recent years. This applies to both social and economic functioning.

Peer-review under responsibility of the scientific committee of 28th European Conference on Artificial Intelligence (ECAI 2025) and Intelligent Management Workshop.

Artificial intelligence (AI) is making a significant difference to operational efficiency in organisations and businesses. By automating processes, AI eliminates the need to manually perform routine and time-consuming tasks, allowing employees to focus on the more strategic and creative aspects of their work. Automated data processing systems, robotics and intelligent analytical algorithms speed up project delivery and improve the quality of services and products (Gibała, 2024; Parveen, Chadha, Kumar, Singh, 2022; Iyer, 2021).

Artificial intelligence (AI) is bringing dynamic changes to the transport sector, opening up new opportunities and transforming existing methods of operation and transport management. In the transport, forwarding and logistics industry, AI is already optimising processes, speeding up decision-making and streamlining operations (Skowroński, 2023). The benefits that the use of AI expresses in terms of improved safety, efficiency and quality of service, both in passenger and freight transport, are evident.

One of the priority directions for transport development worldwide, including in the European Union, is to strive for an intelligent, environmentally friendly and passenger-accessible transport system. An important role in this system is assigned to rail transport, as emphasised by the EU transport policy guidelines. At the same time, the radical and very dynamic changes in the environment resulting from the implementation of information and communication technologies require modifications to be made to the existing business models and passenger strategies of rail operators.

AI on the railways in Poland is still used to a small extent, but the prospects are promising. The implementation of global solutions, combined with changes to current legislation in the country, will in the long run result in a quantum leap in the importance of artificial intelligence in this branch of transport (Wiśniewski, 2019).

This article will present areas in rail transport where AI technology is already being used. Potential opportunities for further application of AI in railways will also be discussed. With the increasing demand for safer, more efficient and greener solutions, AI is becoming an important tool for the transformation of this transport sector.

The main areas in rail transport where AI technology is already being used and there are potential opportunities to increase its participation include:

- rail transport management
- railway infrastructure,
- railway traffic organisation and management,
- passenger transport,
- freight transport,
- rolling stock,
- training and further training of railway workers.

2. LITERATURE REVIEW

In recent years, with advances in the development of Artificial Intelligence, there has been increasing interest in its application to economic processes, including the transport sector. This also applies to rail transport. Numerous studies have been presented in the literature in recent years on the general application of AI to the organisation and operation of rail transport. (Auleytner, 2024; Fiszer, 2024; Gibała, 2024; Bharadiya, 2023; Skowroński, 2023; Parveen, Chadha, Kumar, Singh, 2022; Iyer, 2021).

Modern AI-based solutions can be applied to different areas of the rail transport sector's operations. One of the key application areas for AI in rail is the maintenance of railway infrastructure and rolling stock. Analysing data from sensors deployed on the line and rolling stock allows for early detection of malfunctions as well as prediction of potential failures, significantly reducing repair and downtime costs (Zhao, Qin, Liu, Xie, 2020).

Another important area of AI applications in rail transport is the area of railway infrastructure and rolling stock security. This is as much about the safety and correctness of the elements as it is about the physical security of these elements, i.e. protecting them from vandalism or theft (Majewski, 2024). This also applies to protecting the safety of travellers at railway stations or on trains or transported freight (Żłobicki, 2024; Wiśniewski, 2019). AI can also play an important role in improving physical security and protecting against cyber threats in rail traffic control systems, enabling early detection of hacking attacks and system errors (Gao, Li, Zhang, 2022).

Another field for the application of AI is the optimisation of timetables and traffic management, which can bring tangible benefits in terms of increasing line capacity and minimising delays (Chen, Song, Li, 2022).

Another area of AI use on the railways with significant application potential is the development of automated train guidance (Zhang, Li, Wang, 2021; Van Leijen, 2017).

AI can also be used to collect and analyse passenger transport data. This allows for more precise demand forecasting and personalisation of services. (Sun, Axhausen, Lee, Huang, 2020).

Another important area of possible application of artificial intelligence is training and further training, and simulations of the performance of infrastructure and rolling stock components. (Szuster, 2017). This includes training new railway employees or improving the work of existing ones. Examples include train drivers, where artificial intelligence can create scenarios for situations based on historical data or in-house (Niedzielski, Dyl, Niedzielska-Podlewska, 2023; Drewnowski, 2021; Combik, Michalik, 2020; Kunimatsu, Terasawa, Takeuchi, Tatsui, 2018; Drewnowski, Małachowski, 2018; Kozuba, Niedzielski, Maziarz, Drewnowski, Czapka, 2016; Kozuba, 2013). AI-enabled computer simulations also make it possible to dynamically adapt schedules to changing conditions such as breakdowns, weather conditions or changes in passenger and freight volumes. The possibilities of using AI can also apply to the simulation of the operation of various elements of railway infrastructure (Lisiecki, Szłapczyński, Chołodowicz, 2024), rolling stock (Naseri, Mohammadzadeh, Rizos, 2025; Bosso, Magelli, Zampieri, 2022) or even investment decision-making (Čamaj, Nedeliaková, Šperka, Ližbetinová, 2021).

Research to date indicates that AI is making a significant contribution to the transformation of the rail sector, offering new possibilities in terms of infrastructure and rolling stock diagnostics, safety, automation and traffic management, security or use in simulation and training.

3. METHODS

A literature review was carried out to explore the use of AI in rail transport. The aim of this review was to identify areas in railway operations where AI is already being used successfully, as well as potential areas where AI can still be applied. Available national and international literature on the use of AI in transport in general, as well as in specific transport modes, and in particular in rail transport, was analysed. An analysis of internet sources was also carried out with regard to expert statements on the application of AI in transport, including rail transport. On this basis, the following part of the article analyses the results obtained and reflects on the potential use of AI in rail transport, especially in those areas where it is not yet used or is still used to a limited extent.

4. RESULTS AND DISCUSSION

4.1. Rail infrastructure management

The management and maintenance of rail infrastructure is an important area where AI technology can be successfully applied to a large extent. In particular, it offers opportunities to improve safety, efficiency and to reduce and optimise the operating costs of railway infrastructure. Primary infrastructure areas where AI technology solutions can be applied include:

- rail road,
- overhead line,
- infrastructure safety.

One of the primary areas where AI can be applied is in the maintenance of the railway surface and substructure. This includes the acquisition of data and its analysis giving the possibility of making advance decisions on the repair and overhaul of infrastructure elements. This concerns both the day-to-day maintenance of these elements to ensure that they are in the appropriate condition required by the category of railway line concerned. It is also about planning well in advance the renovation or upgrading of this infrastructure. Sensors installed on tracks, switches or other traffic control devices can collect information on the status of these elements on an ongoing basis (in real time) and transmit it to the relevant databases. The AI then analyses this data and identifies (predicts) potential faults before they occur and recommends appropriate actions for the ongoing maintenance of these elements. This can allow preventive maintenance of these components to be carried out in a more efficient and preventive manner. It also reduces the risk of unexpected failures which, after all, can hinder or even seriously endanger rail traffic (e.g. rail accidents). For engineering structures such as bridges viaducts or tunnels, for example, by analysing sensor data AI can detect micro-damage and predict potential failures. In this way, preventive maintenance can be carried out, minimising the risk of costly repairs and failures later. Similarly, on the basis of current wear and tear analysis, AI can suggest in advance actions to be taken to prepare for the repair or modernisation of a given piece of infrastructure or railway track bed. This is important insofar as these issues must be implemented well in advance due to the need to create the appropriate documentation, as well as to ensure adequate financial resources and time due to the tendering procedures for selecting contractors for these works.

Another potential application area for AI on electrified lines is maintenance and overhead power supply. AI-enabled systems can analyse data from cameras and sensors in real time to detect problems in overhead lines. Automatic fault detection allows faults to be rectified more quickly, thereby reducing disruption to rail traffic. This is particularly important as the operation of a line by electric traction practically paralyses traffic on the line in the event of a breakdown, which, especially in the case of passenger services, can expose travellers to serious consequences (e.g. loss of connections with air transport. Also, thanks to AI, overhead power consumption can be optimised, adjusting power consumption according to the current traffic on the line. This reduces traction energy consumption, resulting in measurable cost savings.Intelligent systems can also control the use of renewable energy sources, such as photovoltaic panels located in railway stations.

The use of artificial intelligence may also relate to ensuring an adequate level of safety of the railway infrastructure. This could include the automatic inspection of railway infrastructure to make it safer to operate. AI-equipped drones can monitor tracks, bridges and tunnels, analysing the condition of the infrastructure and detecting, for example, damage, landslides, obstacles along the route, unauthorised (illegal) trespassers on railway land or acts of vandalism, and automatically send alerts to the relevant services. This enables inspections to be faster and more precise. By optimising patrol routes, AI can enable more effective prevention efforts, minimising the risk of crime without the need to increase the number of patrols. This, in turn, can improve safety and reduce delays on the railway. The implementation of modern artificial intelligence technology can contribute to safer railway infrastructure (Majewski, 2024).

Systems with AI can also contribute to improving safety at single level crossings. The situation in this respect varies and depends on the category of railway line. For high-speed lines, double level crossings (viaducts) are even required. For trunk lines, the elimination (in the case of modernisation) of single level crossings is also recommended. However, single level crossings are still common on trunk lines. These are now equipped with automatic (self-acting) crossing signals supplemented additionally with barriers (half-way barriers) closing the crossing on the right-hand side of the road. The warning is activated when a train approaches the crossing using activation systems located on both sides at a suitable distance from the crossing. The approaching train, depending on the direction of travel, acts on the switching device. The device registers and transmits the signal of the approaching train to the control device, which activates the light and sound signals on the signals located on both sides of the wheeled road and the closure of the barriers also takes place. The end of the effect of the passing train on the system installed in the tracks behind the crossing causes the warning to be released and the barriers to open. AI can analyse data from cameras at level crossings, optimising the timing of lowering and raising barriers and warning of potential hazards, such as vehicles stopped on the tracks. This is particularly important at level crossings on lower category lines, where there may be crossings without barriers, or even where only a road sign (the so-called St Andrew's Cross) informs the driver of the crossing. The installation of cameras there and the use of AI can significantly improve road safety. At the same time, it should be remembered that road users are the main cause of accidents at single level crossings.

4.2. Organisation and management of railway traffic

Artificial intelligence (AI) in the organisation and management of rail traffic can significantly improve the efficiency, safety and punctuality of services.

One of the most important applications of AI in the organisation and management of rail traffic is the optimisation of train movements. This tool can be particularly useful for those managing and directing train traffic (dispatchers and traffic officers). AI algorithms can analyse train traffic data in real time, allowing dynamic schedule management and minimising delays. Forecast models help predict potential disruptions, such as breakdowns or the impact of weather conditions, allowing for dynamic responses to situations and better route planning and dynamic timetable adjustments. AI can, for example, stop traffic, call emergency services and communicate information to passengers. AI can also analyse ongoing train delays and propose alternative solutions. In the event of breakdowns or accidents, AI can direct trains to alternative routes or optimise transfers, reducing passenger waiting times.

AI systems can also successfully support the work of dispatchers overseeing rail traffic in a selected area. AI helps in decision-making by suggesting the best solutions based on data analysis. It can also manage the sequence of crossings and the cooperation between different railway operators or automatically control traffic control devices and signals or level crossings. In addition, AI can analyse historical data, so it can detect recurring traffic problems and suggest optimisation measures.

4.3. Passenger transport management

Artificial intelligence (AI) has the potential to make a significant contribution to improving the passenger experience in rail transport, enhancing safety and the quality of journeys. Particularly in passenger transport, the potential application of AI seems particularly broad.

In recent years, the greatest progress in passenger rail transport in Europe can be observed in the creation of a transparent communication system with the customer through the following measures (Drewnowski, Małachowski, 2018):

- carrier websites have been expanded and upgraded,
- mobile applications with real-time train traffic information and the possibility to purchase a ticket are created, the functionality of which is extended with additional services,
- modern dynamic passenger information systems are being implemented at railway stations and stops.

Important areas of application for AI in passenger service include travel safety and its continuous monitoring both on trains and in stations. AI can analyse data from cameras and sensors, helping to manage traffic at stations and on trains. AI can monitor passenger flow at stations and platforms, predicting congestion and suggesting optimal travel paths. It can also support dynamic signage and passenger information systems. By analysing images from surveillance cameras, AI can detect dangerous situations or suspicious behaviour in advance. Facial recognition systems can also help improve passenger safety. This is particularly relevant in the current situation with the ever-present risk of possible terrorist activities occurring in various modes of transport. So far, the greatest restrictions have been introduced in air transport. However, it should be remembered that rail transport can also be exposed to this danger. Therefore, the use of AI in this area can significantly increase the safety of rail travel. Systems using AI can also monitor passenger behaviour, e.g. identifying those in need of assistance and automatically alerting emergency services.

AI can also be helpful in the ongoing analysis and optimisation of timetables. AI can analyse data on passenger traffic and occurring later in real time to dynamically adjust timetables to these situations. This helps to minimise delays, quickly suggesting alternatives to minimise disruption to rail traffic. Chatbots and virtual assistants can also assist passengers in real time, providing information on delays or schedule changes. This is all the more important as, in passenger traffic, any delay or waiting for delayed trains (so-called connecting trains) is always frowned upon by passengers. Any unplanned extension of the journey time is perceived by the passenger as a personal loss of time, which translates into a negative evaluation of the carrier. This rarely takes into account whether the passenger is actually at fault or whether it is a random situation. Systems using AI can also analyse passenger behaviour, such as identifying those in need of assistance and automatically notifying emergency services.

AI systems can also be useful in the ticketing and seat-booking process and in optimising travel routes. The introduction of AI into passenger services allows for better personalisation of services. This is particularly important in today's booming transport market, where the individualisation of passenger service is becoming one of the carrier's significant competitive advantages.Intelligent systems using AI can analyse travellers' preferences and suggest optimal connections, adjust ticket prices according to demand and streamline the seat reservation process. The system can dynamically allocate seats in carriages according to the number of passengers. Advanced systems can analyse the distribution of passengers in the carriages and suggest optimal seats to avoid congestion (Drewnowski, Małachowski, 2018).

With AI, passengers can receive personalised recommendations on routes, optimal transfers or dynamic ticket prices. Intelligent chatbots can assist passengers with ticket purchases, connection searches and bookings. AI can also assist with dynamic ticket pricing, which may be of particular interest to transport operators keen to make the most of the seats on offer on trains. AI analyses demand and adjusts ticket prices in real time, optimising train occupancy. It can also participate in personalising offers to the individual passenger. The system analyses travel history and passenger preferences, being able to suggest the best routes and promotions. It provides suggestions for the best seats on the train, convenient transfers or attractions along the route.

AI can also be used in automated customer service centres. AI can handle customer requests, answering questions about tickets, delays or additional services. It can also send passengers information about timetable changes, delays or alternative routes. AI can facilitate international communication, such as in mobile apps for tourists (real-time translation). AI can also recognise emotions in customer service. Voice or image analysis can help respond quickly to upset passengers and improve service quality. AI-enabled voice assistants and mobile apps can facilitate navigation at train stations and on trains, helping, for example, blind people or tourists.

Also while driving, AI systems can enhance the travel experience. AI can suggest movies, music or audiobooks based on passenger preferences (intelligent entertainment systems). AI can control temperature, air conditioning, lighting and other parameters in the carriages, adapting them to the needs of the passengers. Chatbots can also be used for train catering. Passengers can order food and drinks from the mobile app without visiting the dining car.

Finally, AI can support the integration of railways with other modes of transport. AI can synchronise trains at transfer stations or, for example, with public transport or taxis (optimising transfers). AI can also be used in dynamic passenger information systems. AI can provide updated travel information in real time.

4.4. Freight transport management

Artificial intelligence has great potential in the optimisation of rail freight traffic. Among its most important areas of application are route optimisation and timetable adjustment. AI can analyse large data sets, taking into account weather conditions, track traffic and transport demand. This allows it to dynamically adjust and optimise routes and timetables, minimising delays and operational costs.

AI can predict the demand for wagons and optimise their allocation. Particularly beneficial use of AI can concern the organisation of empty wagon transports. This applies in particular to dispersed transports (single wagons or small groups of wagons) where, after unloading, wagons are allocated to subsequent loads, with the best solution being such an allocation that the transport of the empty wagon is as short as possible (Zalewski, Siedlecki, Drewnowski, 2004). The use of AI can significantly support the decisions of wagon dispatchers in the allocation under subsequent loads based on the received transport demand.

AI can also be of great help in organising freight marshalling. By marshalling trains we mean trains that are put together at the starting station from wagons that have a single destination station or a common final technical (marshalling or shunting) station, i.e. they cover the journey from the starting station to the final station without exchanging wagon groups at intermediate stations. There are several types of marshalling. Depending on where the wagons are loaded and how the marshalling train is put together, there are marshalling routes (Zalewski, Siedlecki, Drewnowski, 2004):

- consignment - made up of wagons loaded by one or more consignors at one or more loading points and handed over to the railways at one delivery point;
- graded - put together by the railway from compact groups of wagons, loaded by one or more shippers at one station and handed over to the railway at several transfer points, or at several stations;
- technical - put together by the railways from wagons appearing at random, loaded at the marshalling yard and arriving in loaded condition by trains subject to marshalling..

AI can support the formation of marshalling trains at the starting stations by predicting in advance the potential wagons that can form a marshalling train. Especially is ot relevant for technical marshalling. AI can predict well in advance whether there will be enough wagons in the trains arriving at a technical station to put together a marshalling train, which allows for earlier organisational preparation for this task. It should be noted in this connection that marshalling transport brings considerable economic benefits to the rail freight operator, manifested in a reduction in the amount of shunting work and a more intensive use of the transport fleet over time. Both types of benefits are primarily the result of a reduction in the number of switching stations for freight wagons on the journey from consignor to consignee. AI can also control automated loading and unloading systems at terminals and cargo points, for example by analysing data in real time. This reduces downtime at terminals, increasing the efficiency of freight transport.

AI can analyse cargo flow and optimise intermodal transport. AI in intermodal terminals can significantly support their work by optimizing the planning of transhipment operations, including the analysis of data on the movement of means of transport of individual modes of transport. This can enable the optimization of loading and unloading schedules of cargo units, which can minimize or even eliminate downtime and queues. AI can also quickly recommend alternative solutions, e.g. in the event of a catenary failure and the resulting disruptions to traffic. AI can also support the management of warehousing and storage of cargo units in the terminal, e.g. how to best position containers to facilitate their quick loading and shorten the transhipment time. AI can also support the control of autonomous vehicles transporting containers in the terminal, by optimizing their movement routes, which can also reduce the risk of potential collisions. It can also support supervision of the technical equipment of the terminal, e.g. by ensuring that loading devices are serviced on time. It can also optimize energy consumption at the terminal by adjusting its consumption to the current volume of work. An important task in which AI can be used is the management of security in the terminal area. Vision systems supported by AI can automatically detect unauthorized persons in the terminal area or other threats (e.g. the beginning of a possible fire), unauthorized persons in the terminal area or incorrect operations.

AI can also help control the collation and marshalling of freight trains at freight shunting and marshalling yards. The use of AI can primarily concern the optimization of the shunting and marshalling of freight trains. During shunting, AI can support the directing of groups of wagons to a selected track on a directional group. AI also allows for the optimization of the management (planning) of the movement of shunting locomotives and station workers, as well as reducing the wear of infrastructure elements (e.g. track brakes). This allows for the minimization of the number of necessary shunts (saving fuel costs), shortening the shunting and marshalling time of trains, optimizing the order of train substitution or adjusting the station work plans on an ongoing basis in the event of delays or changes in arriving trains. Systems based on AI algorithms can also forecast what numbers of wagons and what types of cargo will appear at the station in the coming days. This allows for more effective planning of the work of people and resources and optimal use of track groups and the working time of the hump at the station.

With AI, it is also possible to develop technology for autonomous goods trains, especially those running long distances, preferably in low-urbanised areas. This can minimise human error and optimise energy consumption. Currently, autonomous trains can only operate on isolated lines. An example of this is the Rio Tinto autonomous goods train in Australia running on a 100 km-plus freight rail line located in a desolate area. This allows for lower costs, more energy-efficient train journeys and the elimination of complicated logistics related to train operation by employees such as drivers (Van Leijen, 2017). In the case of autonomous trains, the problem is still unforeseen events that may occur in the area near the railway line (e.g. people crossing the tracks in prohibited places). Therefore, for now, such solutions only apply to non-urbanized areas, as in the case of Rio Tinto.

4.5. Rolling stock management

Artificial intelligence can significantly improve the safety and efficiency of rolling stock operations, while reducing operational costs. Among the most important applications of AI in rolling stock is the maintenance of rolling stock (locomotives and wagons). AI systems can continuously monitor the condition of rolling stock through the use of continuous sensors. Advanced algorithms analyse data from sensors on wagons and locomotives, detecting the first signs of wear and tear on equipment predicting failures based on the data. This allows maintenance to be scheduled at the right time. Early detection of faults and prevention of failures (e.g. wear on wheels, brakes, engines). This also allows preventive maintenance to be carried out reducing the risk of delays and downtime.

AI can also be used to optimise fuel and energy consumption. AI algorithms can analyse the speed, gradient and load of the train and carry out an analysis of how the train is driven and make recommendations for economical vehicle operation (e.g. eco-driving, optimisation of fuel or electricity consumption). Also, AI-enabled vision systems can support the driver's reactions to hazards (e.g. detecting obstacles on the track in advance). AI can also analyse the driver's behaviour in real time, warning of fatigue or dangerous manoeuvres.

The next step in the development of railways is the implementation of autonomous trains (ATO - Automatic Train Operation). Thanks to AI technologies, it is possible to control trains without the involvement of drivers, which increases safety and precision in traffic. AI-based systems can analyse the environment, detect obstacles and dynamically adjust speed, reducing the risk of collisions and improving energy efficiency. There are currently more than 800 km of autonomous metro lines operating worldwide (most in France). Driverless vehicles also run on airport rail lines or monorail lines (Wiśniewski, 2019).

4.6. Training and further training of railway staff management (railway simulators)

Rapidly accelerating technical and technological progress and the related introduction of modern technologies into economic and social life determine the activities for raising the qualifications of employees in enterprises. On the one hand, this is a forced action resulting from the need to familiarise and introduce employees to the operation of modern machinery, equipment or applications. On the other hand, modern technologies provide an opportunity to test and improve the skills of employees in scenarios that could not be carried out within the framework of analogue systems (Drewnowski, 2021).

The most advanced in the use of simulators in training systems is air transport, which for decades has used a range of simulators in its pilot training processes, both military and civilian (Kozuba, 2013). In 1909, the Antoinette aircraft manufacturing company developed a training device that mimicked the cockpit of an aeroplane for flight instruction – the Antoinette Trainer. The Antoinette Trainer was one of the first truly synthetic flight simulation motion platforms. This platform consisted of two half-sections of a barrel mounted and moved manually to represent the pitch and roll of an aeroplane (Hayes, 2005). The outbreak of the First World War and the effective use of aviation on the battlefield, accelerated the development of solutions for training military pilots. One solution was the Ruggles Orientator, developed in 1917. Ruggles Orientator. The structure, placed on a wheeled platform and rotating vertically and horizontally, mimicked a pilot's cockpit. In 1927, an American, Edward Link, developed the Link Trainer, also known as the Blue Box. Based on electromechanical solutions, this simulator simulated turbulence and disturbances occurring during flight. During the Second World War, 500 000 pilots were trained on these simulators. After the war, it was widely used in military pilot training in the United States (Niedzielski, Dyl, Niedzielska-Podlewska, 2023). Another widely used aircraft simulator was The Link D2 Trainer, developed in about 1937, fitted with movable ailerons, rudder and elevators. The cockpit was instrumented with compass, altimeter, rate of climb indicator, airspeed indicator, turn and bank indicator, radio compass (Hayes, 2005).

Rail transport relied in the construction of railway simulators on the successful experience of air transport. It is worth noting at this point that Poland can be counted among the forerunners in the use of simulators in the training of train drivers, as it had already organised a Central Training Centre (Centralny Ośrodek Szkolenia Maszynistów) in Warsaw for train drivers using a steam locomotive simulator before the Second World War. The simulator used, developed by the PKP[3]. Psychotechnical Testing Office (Biuro Badań Psychotechnicznych PKP), was successfully used for psychotechnical training of train drivers. In line with the popular trend of using psychology in the world of work, analysing work, its productivity and safety, the bureau introduced psychotechnical testing of railwaymen and candidates for railway safety jobs in a bid to eliminate the number of railway accidents (Pisarski, 1974). Thanks to the use of these modern methods, the number of railway accidents has been reduced by 56% in a few years (Budkiewicz, Kączkowska, 1978).

[3] PKP - Polish State Railway

Simulators are today an essential part of the process of training and improving the skills of train drivers. Their role will grow with the increasing digitalisation of the railways and the entry of a new generation of workers into the market. They are used to the virtual world and modern train driver training should be adapted to this. Experience shows that training on simulators is more engaging and at the same time more effective. The trainees not only acquire knowledge faster, but also consolidate it better, which translates into their readiness to work in a dynamic railway environment (Szuster, 2017).

Simulators are a useful addition to the training process, especially during the first stage of the driving licence course, and once obtained, allow driving techniques to be improved during periodic courses (Combik, Michalik, 2020). The use of simulators is also supported by lower operating costs compared to training with real vehicles in real traffic (Kozuba, Niedzielski, Maziarz, Drewnowski, Czapka, 2016).

The current use of AI in railway simulators can significantly increase the realism, training efficiency and skill analysis of drivers and railway staff. AI in rail simulators can allow for increased training realism, but also for infrastructure testing, optimised driving and better interaction with the environment.

With AI, advanced simulations of driving conditions can be generated. AI can control train traffic and modify traffic signals depending on the situation (Kunimatsu, Terasawa, Takeuchi, Tatsui, 2018). It can also generate realistic weather conditions (rain, snow, fog) affecting driving conditions and visibility and dynamically make changes to weather conditions. AI can also dynamically create random (crisis) events that may occur during driving, such as brake failures, obstacles on the track, fire in the depot, electrical traction failure, passenger evacuation or sudden human intrusion. AI can generate simulations of damage to traction, switches or traffic control systems. It can also map the condition of the railway superstructure, which affects driving comfort. AI can also simulate other train sets on the route in a realistic way, e.g. delays, signal changes.

In the training of drivers and other personnel, AI can generate individual training scenarios, with AI analysing the user's skills and adjusting the simulation's difficulty level to suit them, as well as assessing errors and learning progress. AI can monitor driving style, such as braking too sharply or driving uneconomically, and then suggest corrections. It is worth noting that today, in addition to the most common simulators for train drivers, simulators dedicated to employees in other positions directly related to the operation and safety of railway traffic are increasingly being implemented using virtual reality technology. Such a simulator makes it possible to see how a trainee will perform his or her duties in stressful and abnormal situations, while the use of AI makes it possible to simulate the work of, for example, a crossing supervisor, signalman or traffic warden.

AI can also create simulations for optimising fuel and electricity consumption in traction vehicles. As an eco-driving training, AI can simulate conditions for optimal train driving to save fuel or electricity. In addition, it can also analyse driving economy, i.e. indicate when to slow down to avoid sudden braking, and optimise the use of the recuperative braking system.

With AI, it is also possible to simulate realistic situations of interaction between a railway employee and passengers and staff. In simulating passenger behaviour, AI can generate different types of passengers (e.g. those in a hurry to get on the train, those requiring assistance, those who are rowdy). Simulations of on-board incident handling activities can also be created. AI can create emergency scenarios, e.g. a passenger falling asleep, aggressive behaviour, lost luggage. AI can also map traffic and crowding on platforms at peak times to practice controlling passenger movement at stations.

Simulators can also successfully combine AI with the use of Virtual Reality (VR) or Augmented Reality (AR) for realistic training. AI can analyze the driver's reactions in a full VR environment, or it can overlay rolling stock condition information onto a real image for operating training using AR for technicians and drivers.

AI can also be used in the development of simulators for designing rail routes. AI can be used to test new track layouts, where AI can simulate traffic on a newly designed route, assessing its efficiency. It can also analyze potential critical points, i.e. predict places where potential collisions, slowdowns or congestion of rail traffic may occur.

5. CONCLUSION

As it results from the considerations presented in the article, the use of artificial intelligence in rail transport opens up new possibilities for the operation of the railroads and can significantly contribute to revolutionizing this branch of transport. The use of AI can apply to practically every area of activity of this transport sector. Of course, AI is currently only entering the functioning of social and economic life, however, it is already visible that its importance will deepen with each year and this trend is already unstoppable. This also applies to railways.

The article presents both the already used AI applications on the railroads but focuses primarily on the potential possibilities of its further application in the functioning of rail transport. As technology develops and modern AI systems are integrated, we can expect an increase in the safety, efficiency of operation and quality of services provided on the railway, also taking into account important ecological issues. The consequence of the widespread implementation of AI systems may be the implementation of the long-standing assumptions of the European Union's transport policy for the growth of this mode of transport in passenger and freight transport.

Funding: Co-financed by the Polish Minister of Science under the "Regional Excellence Initiative".

REFERENCES

Auleytner, A. (2024). *Sztuczna Inteligencja na Torach: Wymogi Aktu o Sztucznej Inteligencji*. Retrieved from https://www.dzp.pl/publikacje/1502-sztuczna-inteligencja-na-torach-wymogi-aktu-o-sztucznej-inteligencji (17.03.2025).

Bharadiya, J.P. (2023). *Artificial Intelligence in Transportation Systems. A Critical Review*. American Journal of Computing and Engineering. Vol.6, Issue 1, p. 35-45.

Bosso, N., Magelli, M., Zampieri, N. (2022). *Simulation of wheel and rail profile wear: a review of numerical models*. Railway Engineering Science, No. 30(4), DOI: 10.1007/s40534-022-00279-w.

Budkiewicz, J., Kączkowska, J. (1987). *Z dziejów psychologii stosowanej w Polsce do roku 1957, ze szczególnym uwzględnieniem poradnictwa zawodowego*. Wydawnictwa Uniwersytetu Warszawskiego, Warszawa, p. 109.

Combik, P., Michalik, M. (2020). *Rola ćwiczeń symulacyjnych w procesie szkolenia i doskonalenia zawodowego maszynistów*. Magazyn Kultury Bezpieczeństwa, UTK, Warszawa.

Chen, H., Song, X., & Li, Z. (2022). *Reinforcement Learning Approaches for Train Traffic Management*. Transportation Research Part C: Emerging Technologies, No. 134, p. 103483.

Čamaj, J., Nedeliaková, E., Šperka, A., Ližbetinová, L. (2021). *The planning of investment activities in field of railway transport with suport of simulation tools*. Transportation Research Procedia, No. 53.

Drewnowski, A. (2021). *Problems related to the implementation of a complex training system and professional development of train drivers using traction vehicle simulators in the Polish railway transport*. Procedia Computer Science, Vol. 192, DOI: 10.1016, p. 4486.

Drewnowski, A., Małachowski, K. (2018). *Wykorzystanie technologii cyfrowych w relacjach z klientem przez kolejowych przewoźników pasażerskich w Polsce*. Prace Komisji Geografii Komunikacji PTG, No. 21(3), p. 78-84.

Fiszer, K. (2024). *Sztuczna inteligencja na kolei. Czy jej rola bywa przeceniana?* Retrieved from https://www.rynek-kolejowy.pl/wiadomosci/sztuczna-inteligencja-na-kolei-czy-jej-rola-bywa-przeceniana-121344.html (17.03.2025).

Gao, S., Li, M., Zhang, X. (2022). Deep Learning-Based Intrusion Detection for Railway Signalling Systems. Journal of Rail Transport Planning & Management, No. 21, p. 100316.

Gibała, M. (2024). *AI w transporcie. Czy to ma sens?* Obserwator logistyczny. Retrieved from https://obserwatorlogistyczny.pl/2024/07/29/ai-w-transporcie-czy-to-ma-sens/ (17.03.2025).

Hayes, M.J.D. (2005). *Atlas: A novel kinematic architecture for six DOF motion platforms*, Transactions of The Canadian Society for Mechanical Engineering, 29(4), DOI:10.1139/tcsme-2005-0047, p. 4.

Iyer, L.S. (2021). *AI enabled applications towards intelligent transportation*. Transportation Engineering, No. 5. DOI: 10.1016/j.treng.2021.100083.

Kozuba, J., Niedzielski, P., Maziarz, W., Drewnowski, A., Czapka, B. (2016). *Możliwości wykorzystania szkoleń symulacyjnych maszynistów w transporcie kolejowym w aspekcie analizy benchmarkingowej systemu szkoleń pilotów w transporcie lotniczym*. Ekspertyza wykonana na zlecenie Urzędu Transportu

Kolejowego, Szczecin– Dęblin.
Kunimatsu, T., Terasawa, T., Takeuchi, Y., Tatsui, D. (2018). *Train opreation/passenger behavior simulator under moving block signalling system*. Quarterly Report of Railway Technical Research Institute, Vol. 59, No. 3.
Lisiecki, P., Szłapczyński, M., Chołodowicz, E. (2024). *Automatyczna generacja wirtualnych elementów infrastruktury kolejowej*. Pomiary Automatyka Robotyka, No. 2, DOI: 10.14313/PAR_252/119.
Majewski, F. (2024). *Sztuczna inteligencja na polskiej kolei. AI Shield ma zwiększyć bezpieczeństwo*. Retrieved from https://300gospodarka.pl/news/sztuczna-inteligencja-na-polskiej-kolei-ai-shield-ma-zwiekszyc-bezpieczenstwo/ (17.03.2025).
Naseri, R., Mohammadzadeh, S., Rizos, D.C. (2025). *Rail surface spot irregularity effects in vehicle-track interaction simulations of train-track-bridge interaction*. Journal of Vibration and Control, Vol. 31(5-6), DOI: 10.1177/10775463241232024.
Niedzielski, P., Dyl, K., Niedzielska-Podlewska, K. (2023). *Symulatory w edukacji - ujęcie historyczno-modelowe*. Zeszyty Naukowe Akademii Górnośląskiej, No. 7, DOI: 10.53259/2023.7.09, pp. 101-102.
Parveen, S., Chadha, R.S., Kumar, P., Singh, J. (2022). *Artificial Intelligence in Transportation Industry*. International Journal of Innovative Science and Research Technology, Volume 7, Issue 8, pp. 1274-1278.
Pisarski, M. (1974). *Koleje polskie 1842-1972*. Warszawa, p. 73.
Skowroński, D. (2023). *Pociąg „Sztuczna Inteligencja" odjeżdża*. Transport manager. Retrieved from https://transport-manager.pl/artykuly/pociag-sztuczna-inteligencja-odjezdza (17.03.2025).
Symulator do szkolenia osób związanych z prowadzeniem i bezpieczeństwem ruchu kolejowego. (2021). Retrieved from https://kurier-kolejowy.pl/aktualnosci/38266/symulator-do-szkolenia-osob-zwiazanych-z-prowadzeniem-i-bezpieczenstwem-ruchu-kolejowego.html (17.03.2025).
Symulatory w kolejnictwie – skąd czerpać wzorce? (2017). Retrieved from https://kurier-kolejowy.pl/aktualnosci/30387/symulatory-w-kolejnictwie---skad-czerpac-wzorce.html (17.03.2025).
Sztuczna inteligencja w transporcie kolejowym. (2021). Retrieved from https://wartowiedziec.pl/komunikacja-i-transport/59766-sztuczna-inteligencja-w-transporcie-kolejowym/ (17.03.2025).
Sztuczna inteligencja zmieni funkcjonowanie kolejnictwa. (2021). Retrieved from https://www.cire.pl/artykuly/materialy-problemowe/186464-sztuczna-inteligencja-zmieni-funkcjonowanie-kolejnictwa (17.03.2025).
Sztuczna inteligencja zwiększy bezpieczeństwo na kolei. (2024). Retrieved from https://naukawpolsce.pl/aktualnosci/news%2C100055%2Csztuczna-inteligencja-zwiekszy-bezpieczenstwo-na-kolei.html (17.03.2025).
Sun, L., Axhausen, K. W., Lee, D. H., Huang, X. (2020). *Understanding Passenger Flow Patterns in Public Transit Using Smart Card Data*. Transportation Research Part C: Emerging Technologies, No. 121, p. 102876.
Szuster, L. (2017). *Symulatory: rozwój i bezpieczeństwo transportu kolejowego*. Retrieved from https://raportkolejowy.pl/symulatory-rozwoj-i-bezpieczenstwo-transportu-kolejowego/ (17.03.2025).
Van Leijen, M. (2017). *Pierwszy w pełni autonomiczny pociąg w Australii*. Retrieved from https://pl.railfreight.com/business/2017/10/05/pierwszy-w-pelni-autonomiczny-pociag-w-australii/?gdpr=accept/ (17.03.2025).
Wiśniewski, Z. (2019). *Sztuczna inteligencja na torach i dworcach*. Retrieved from https://raportkolejowy.pl/sztuczna-inteligencja-na-torach-i-dworcach/ (17.03.2025).
Zalewski, P., Siedlecki, P., Drewnowski, A. (2004). *Technologia transportu kolejowego*. Wydawnictwa Komunikacji i Łączności, Warszawa, pp. 207-210.
Zhang, J., Li, Y., Wang, F. (2021). Deep Learning for Automatic Train Operation: Methods and Applications. IEEE Transactions on Intelligent Transportation Systems, No. 22(6), pp. 3481–3492.
Zhao, Y., Qin, Y., Liu, Y., Xie, M. (2020). *A Review of Predictive Maintenance: Intelligent Diagnosis and Prognosis Systems Based on Data Analysis*. IEEE Access, No. 8, pp. 59377–59397.
Żłobicki, P. (2024). *Straż Ochrony Kolei sięgnie po rozwiązania oparte na sztucznej inteligencji*. Retrieved from https://kgsok.pl/straz-ochrony-kolei-siegnie-po-rozwiazania-oparte-na-sztucznej-inteligencji/ (17.03.2025).