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THE ROLE OF ARTIFICIAL INTELLIGENCE IN THE DEVELOPMENT OF RAIL TRANSPORT

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Abstract

Artificial intelligence plays a revolutionary role in modern transport systems. The article discusses the role of artificial intelligence in railway transport and its potential impact on the sector. This article presents different types of artificial intelligence technologies used in this sector, explores the advantages of artificial intelligence in this field, and discusses the challenges associated with using artificial intelligence in rail transport. Artificial Intelligence is revolutionary in rail transport systems by enhancing efficiency, safety, and overall performance. There are several ways in which AI influences rail transport and its impact on the cognitive load of human resources. These factors are examined in this article.

Keywords

Artificial Intelligence, Rail Transport, Rail Industry, Digital Automatic Coupling, Cognitive Load

1. Introduction

Rail transport is a mode of transportation that involves the movement of passengers and goods on wheels of vehicles running on railway tracks. It is a widely used and efficient means of mass transit and freight transport. The fundamental components of rail transport include:

Railway Tracks: Fixed tracks made of steel or other materials that guide the train and provide a stable path for its movement (*Shi et al., 2023*).

Train: A connected series of rail vehicles (such as locomotives and wagons) that move along the tracks as a single unit (*Waters, 2007*).

Locomotive: A powered railway vehicle that provides the motive power for a train. Locomotives are typically fuelled by electricity, diesel, or steam (*Babcock, Bunch, 2007*).

Cars or Wagons: Non-powered rail vehicles coupled and pulled by a locomotive. They can be designed for the transportation of passengers or cargo, depending on the type of service.

Human Resource: Nowadays, human labour is essential in the maintenance and operation of train services (*Crawford, Kift, 2018*).

Rail transport is known for its efficiency, particularly in moving large quantities of goods over long distances. It is also a popular mode of commuter transportation in many urban areas. The advantages of rail transport include lower fuel consumption per ton mile, reduced traffic congestion, and lower environmental impact compared to other modes of transportation. However, it requires significant infrastructure, such as well-maintained tracks, stations, and terminals. Rail transport is one of the world's oldest and most important modes of transport. Since its establishment, it has played a vital role in passenger and freight transport and is an important part of the transport system. However, the rail sector faces many challenges, including increasing competition from other modes of transport, ageing infrastructure and safety concerns. To address these challenges, the rail industry is turning to artificial intelligence technologies to improve its operations and provide better customer service.

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2. Applications of AI in rail transport

Artificial intelligence (AI) can revolutionise rail transport, and this paper explores the potential role of artificial intelligence in developing this field through the outstanding publications:

Artificial intelligence has played an increasingly important role in the development of rail transport, offering numerous benefits that improve efficiency, safety, and overall operations. Here are some key areas where artificial intelligence has influenced the development of rail transport.

Predictive maintenance: AI is used to analyse vast amounts of data from sensors on trains and tracks to predict potential equipment failures before they occur. This proactive approach helps schedule maintenance activities, reduce unexpected breakdowns, and minimise disruptions. As a result, maintenance crews can focus their efforts more efficiently, reducing the cognitive load associated with reactive problem-solving (*Yao et al., 2023*).

Autonomous trains: AI algorithms are employed in automatic train control systems. These systems can optimise train schedules, manage traffic, and ensure safe distances between trains. Human operators can concentrate on more strategic decision-making tasks by automating certain control functions, reducing the cognitive burden associated with routine operations (*Niu, You, 2022*).

Enhanced safety and security: Artificial intelligence-powered video analytics and sensor technologies can monitor and detect potential security threats or safety hazards in railway infrastructure. This helps prevent accidents and ensure the safety of passengers and rail personnel. AI contributes to digital signalling systems that enhance traffic management efficiency on rail networks. These systems can dynamically adjust train schedules based on real-time conditions, minimising delays and improving traffic flow. This reduces the cognitive load on human operators who would otherwise need to manage and adapt to changing circumstances manually. AI-powered safety systems, such as Positive Train Control (PTC) and collision avoidance systems, enhance safety by monitoring and controlling train movements. These systems can automatically apply brakes or take other corrective actions in emergencies, reducing human operators' cognitive load to react quickly to potential hazards (*Hartong, Goel, Wijesekera, 2011*).

Optimised operations and scheduling: AI algorithms optimise crew schedules, ensuring that human resources are allocated efficiently. This helps minimise fatigue and stress among railway personnel and ensures that the right personnel are available when needed.

Passenger experience: AI is also employed to improve passenger services, including ticketing, customer service chatbots, and personalised travel recommendations. This can reduce the cognitive load on staff dealing with routine inquiries and transactions.

Energy efficiency: Artificial intelligence can reduce energy consumption and optimise energy use in rail systems. Through data analysis and predictive modelling, artificial intelligence can help develop energy-efficient strategies and reduce the environmental impact of rail transport.

Infrastructure planning and management: Artificial intelligence can assist in the planning and management of railway infrastructure, including the design of new rail lines, maintenance of existing infrastructure, and the identification of areas for improvement.

Integrating artificial intelligence in the development of rail transport can revolutionise the industry, improving operational efficiency and safety and creating better customer experiences. While AI brings numerous benefits to rail transport, it is crucial to consider the human-machine interface and provide adequate training for personnel to understand and trust AI systems. Additionally, human oversight is often essential to handle unexpected situations and ensure the ethical and safe operation of the railway system. The successful integration of AI in rail transport requires a collaborative approach that considers both technological and human factors.

Several types of artificial intelligence technologies are used in rail transport. There are several types of ITS (Intelligent Transportation Systems) technologies. Machine learning is an artificial intelligence that allows machines to learn from data without being explicitly programmed (*Borsodi and Takács, 2022*). This technology is used in rail transport to develop predictive maintenance models that can help prevent breakdowns and reduce downtime. Another important type of artificial

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intelligence technology is computer vision. Computer vision is artificial intelligence that allows machines to recognise and interpret visual data, such as images and video (*Fedorko, 2021*). Computer vision is being used in rail transport to develop intelligent video surveillance systems that can help improve safety and security (*Ulewicz et al., 2019*).

3. Benefits

3.1. The Benefits of Using Artificial Intelligence in Rail Transport

There are many advantages to using artificial intelligence in rail transport. One of the most important ones is increased safety. Artificial intelligence technologies, such as predictive maintenance models and intelligent video surveillance systems, can help identify potential safety hazards and prevent accidents before they happen. Another benefit is increased efficiency. Artificial intelligence technologies can help optimise rail operations, reducing delays and improving customer service. In addition, artificial intelligence can help reduce costs by reducing the need for manual labour and optimising the allocation of resources. In the rail sector, artificial intelligence can support research and development in several ways, including (*Tang et al., 2022*):

- Predictive modelling and simulation: artificial intelligence can help researchers develop predictive models and simulations that simulate different scenarios and outcomes. For example, machine learning algorithms can be used to analyse data from railway systems – such as train schedules, traffic patterns, and weather conditions – to predict potential problems and improve the efficiency of railway operations (*Liu et al., 2023*).
- Data analysis and decision-making: artificial intelligence can help researchers and engineers analyse large amounts of data to make informed decisions. Machine learning algorithms can identify patterns and correlations in the data, allowing researchers to make predictions and recommendations based on the data (*Lieophairot, Rojniruttikul, 2023*).
- Autonomous systems: artificial intelligence can also be used to develop and optimise autonomous systems for rail operations. For example, artificial intelligence can be used to develop algorithms that allow trains to operate autonomously, reducing the need for human intervention.
- Optimising resources: Artificial intelligence can be used to optimise the use of resources in railway operations. Machine learning algorithms can be used to analyse train schedules, maintenance schedules and other operational data to identify areas where resources can be optimised, for example, to reduce downtime or increase efficiency.
- Risk management: Artificial intelligence can help researchers and engineers identify potential risks to rail operations and develop strategies to mitigate them. For example, machine learning algorithms can analyse train accident data to identify patterns and potential risks.

In summary, artificial intelligence can be a useful tool to support research and development in the rail sector, helping to improve efficiency, safety and reliability.

3.2. Digital Automatic Coupling

Digitalisation is one of the most important steps in properly taking advantage of new opportunities. An essential element of this is the introduction of digital automatic coupling (DAC). Digital Automatic Coupling (DAC) is a concept and technology aimed at improving the efficiency and automation of coupling and uncoupling railway vehicles (such as wagons). It involves the use of digital communication and control systems to automate the process of connecting and disconnecting railcars. The traditional coupling method involves manual labour, where railway workers physically connect and secure the couplings between train cars. Digital automatic coupling seeks to replace or augment this manual process with automated, digitally controlled mechanisms. Digital automatic coupling technology can improve the efficiency of rail transport in several ways:

- Faster and more efficient coupling: the DAC technology enables faster and more efficient coupling and uncoupling of rail wagons. This can reduce the time needed to load and unload cargo and improve the overall efficiency of rail operations.
- Increased safety: DAC technology can improve safety by providing more accurate and up-to-date information on the position and movement of train wagons. DAC can help reduce the risk of collisions and other accidents (Takacs, 2023; Mekonnen et al., 2023).
- Real-time tracking: DAC technology can enable real-time tracking of the position and movement of trainsets, allowing control centres to make more informed decisions on train scheduling, routing, and other operational issues. This can help reduce delays and improve the overall efficiency of rail operations.
- Increased capacity: DAC technology can increase the capacity of rail wagons by enabling more accurate coupling and uncoupling. DAC can help reduce the number of wagons needed to transport a given amount of freight, improving efficiency and reducing costs.

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- Better planned maintenance: DAC technology can improve maintenance operations by providing real-time information on the components and performance of rail wagons. This can help maintenance teams identify and repair potential problems faster, reducing downtime and improving efficiency.

4. Challenges and potential threats

4.1 Challenges for the application of artificial intelligence in rail transport

Thus, DAC technology can improve rail transport efficiency, safety and reliability through faster and more efficient interconnection, real-time monitoring and more accurate information on the position and movement of train sets.

While introducing DAC has clear benefits, it may not be widespread shortly. This is because rail transport is fragmented. Separate departments are responsible for traction, passenger transport, freight and infrastructure management. As these outsourced companies are economically independent, there is no common interest. Passenger and freight wagons must be equipped with DAC equipment, so the costs would logically be linked to these departments. However, the profits are expected to be realised by the infrastructure provider. Understandably, the companies operating and servicing the wagons do not want to spend around €20,000 per wagon, as they will never profit. At the same time, the company that maintains and manages the infrastructure does not want to spend money upgrading wagons owned by another company. Another difficulty is that the profitability of old freight wagons is very uncertain.

To solve this problem, the companies in the different areas would have to work together, but none is interested in doing so separately. However, the social benefits are unquestionable so top-down legislation could be the solution. It is important to note that this investment does not make sense in small steps, and the benefits can only be realised if everyone simultaneously moves to the new system. This is, of course, the most important thing for international traffic. It is also important that standardised switching equipment is introduced.

As with the economic benefits (*Evans, 2013*), this is the only way to maximise the potential of artificial intelligence. The resulting increase in capacity could also significantly reduce passenger and freight traffic on roads, reducing emissions (*Torok and Sipos, 2022*).

4.2. Potential threats to the application of artificial intelligence in rail transport

While digitalisation can bring many benefits to rail transport, potential threats must be addressed. Some of the main risks of digitalisation for rail transport are outlined below (*Török, 2023*):

- Cybersecurity risks: As rail systems become increasingly interconnected and rely more and more on digital technology, they may become more vulnerable to cyberattacks. This could include attacks against rail IT systems, control systems or trains. Cybersecurity threats can disrupt rail operations, compromise passenger safety, and cause significant financial losses.
- Reliance on technology: While digitalisation can improve the efficiency and reliability of rail services, it also means that rail companies rely more on technology. This means that significant disruption to rail operations can occur in the event of a technological failure (*Hussain, Zefreh, Torok, 2018*).
- Job losses: using digital technology in the rail sector could lead to job losses as automation and artificial intelligence take over some of the tasks previously done by humans. This could have a significant impact on workers and their communities.
- Privacy concerns: As digitisation generates large amounts of data about rail passengers and operations, there are concerns about how these data are collected, stored and used. There is a risk that this data could be misused or hacked, leading to privacy breaches and other negative consequences.
- Infrastructure Challenges Digitisation requires significant investments in IT infrastructure and communication networks, which can be costly and time-consuming. Railway operators may need to upgrade their infrastructure to support digitalisation, which may disrupt the implementation phase.

Recognising the potential threats of digitalisation in rail transport is essential, and measures must be taken to mitigate them. This includes investing in cyber security, ensuring that workers are properly trained and protected, addressing data protection concerns, and carefully managing the introduction of new digital technologies.

Despite the many benefits of artificial intelligence in rail transport, its implementation faces several challenges. One of the biggest challenges is the cost of implementing artificial intelligence technologies. Implementing artificial intelligence requires significant investments in hardware, software and personnel. Another challenge is the lack of standardisation in the industry. Standardised data formats and communication protocols are needed to integrate different artificial intelligence systems. Finally, privacy and security concerns may also arise. For example, intelligent video surveillance systems raise concerns about using personal data and the potential for misuse.

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5. Summary

In conclusion, artificial intelligence plays an increasingly important role in the development of rail transport. The benefits of artificial intelligence, including improved safety, greater efficiency, and cost reduction, make it a promising technology. Despite the challenges, the future of artificial intelligence in rail transport is promising. Artificial intelligence technologies are expected to continue to play an important role in the development of rail transport, and new technologies and applications will emerge over time. One area of particular interest is using artificial intelligence in autonomous trains. Autonomous trains could revolutionise rail transport, improving safety and efficiency while reducing costs. Another interesting area is artificial intelligence in customer service, where chatbots and virtual assistants are being developed to improve the customer experience.

Rail transport has been a vital mode of transport for both people and goods for many years, but it faces many challenges, such as competition from other modes, ageing infrastructure and safety risks. Artificial intelligence-based technologies can revolutionise rail transport by improving efficiency, reducing costs, and increasing safety. Machine learning and computer vision are among the technologies based on artificial intelligence used in rail transport. Artificial intelligence can support research and development in the rail sector in several ways, including predictive modelling and simulation, data analysis, autonomous systems development, resource optimisation, and risk management. Digital automatic coupling (DAC) technology can further improve the efficiency of rail transport through faster and more efficient coupling, improved safety, real-time monitoring, and increased capacity. However, the fragmentation of the rail sector may limit the deployment of DAC technology shortly.

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