

An electronic business model for the regulation of railway traffic and transport based on artificial intelligence

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ABSTRACT

The accelerated development of railway systems is based on modernization of infrastructure, interoperability of signaling and telecommunication systems, and digital transformation of operational processes. Modern railway traffic management requires efficient coordination between infrastructure systems, dispatch centers, rolling stock, and information technologies. Due to the complexity of railway operations, human errors may occur during traffic regulation and transport management. This paper presents an electronic business model for railway traffic and transport regulation based on artificial intelligence and advanced information and communication technologies. The proposed model integrates internal databases, intelligent algorithms, and digital communication systems into a unified platform for sustainable and safe railway traffic management. Particular attention is focused on the application of AI systems in decision-making processes, predictive analytics, automation, and operational safety. The paper also analyzes the advantages and limitations of AI implementation in railway systems and discusses future development trends in digital railway transport. Research results indicate that AI-based electronic business models can significantly improve operational efficiency, interoperability, safety, and sustainability in railway traffic regulation.

KEYWORDS

Railway traffic and transport, artificial intelligence, interoperability, electronic business, safety, sustainability

1. INTRODUCTION

Railway transport represents one of the most important components of sustainable transport systems. Modern railway infrastructure is increasingly based on advanced digital technologies, intelligent control systems, and interoperable communication networks. The modernization of railway systems requires the integration of signaling devices, telecommunication infrastructure, dispatch centers, electric traction systems, and rolling stock into a unified digital environment [1].

The development of Industry 4.0 technologies and digital transformation has significantly influenced railway traffic management. Artificial Intelligence (AI), Internet of Things (IoT), cloud computing, and big data analytics have become essential technologies in railway transport systems [2]. These technologies enable real-time monitoring, predictive maintenance, automated traffic regulation, and intelligent decision-making.

Modern railway systems require interoperability between different devices and infrastructures. Interoperability implies the ability of railway systems and subsystems to exchange information and operate without additional adjustments [3]. However, due to the complexity of railway operations and the large number of activities involved, human errors and operational interruptions may occur.

The application of artificial intelligence enables automation and optimization of many operational processes in railway transport. AI systems can analyze large volumes of operational data, predict failures, optimize schedules, and support dispatchers in traffic regulation [4]. The aim of this paper is to present an electronic business model for railway traffic and transport regulation based on artificial intelligence and digital technologies. Advanced technologies that can be applied in rail traffic and transport are shown in Table 1.

Table 1: Modern AI Technologies in Railway Systems

Technology	Application in Railway Systems	Main Advantages
Artificial Intelligence	Traffic regulation and predictive analytics	Increased efficiency and safety
Internet of Things (IoT)	Monitoring railway infrastructure	Real-time data collection
Big Data Analytics	Analysis of operational data	Improved decision-making
Cloud Computing	Data storage and communication	Centralized information management
Digital Twins	Simulation of railway operations	Predictive maintenance
Machine Learning	Failure prediction	Reduction of operational disruptions
Intelligent Dispatch Systems	Automated train control	Improved interoperability
Computer Vision	Monitoring railway crossings and stations	Increased operational safety

2. DIGITAL TRANSFORMATION OF RAILWAY SYSTEMS

Digital transformation in railway transport involves the integration of intelligent technologies into operational and business processes. Railway companies increasingly rely on advanced information systems to improve operational efficiency, safety, and sustainability [5].

Modern railway systems generate large volumes of data through signaling systems, onboard sensors, dispatch centers, and communication networks. These data can be processed using AI algorithms to improve traffic management and optimize operational processes.

The digital transformation of railway systems includes:

- intelligent traffic management;
- predictive maintenance;
- automated dispatching systems;
- digital communication platforms;
- real-time monitoring systems;
- electronic business operations.

One of the most important aspects of digital transformation is the development of intelligent transport systems (ITS). ITS technologies enable integration between railway infrastructure, trains, passengers, and operational management centers [6].

Artificial intelligence plays a key role in modern railway systems because it allows automation of repetitive tasks and supports operational decision-making. AI systems can detect anomalies in infrastructure conditions, predict equipment failures, and optimize train movement.

The European railway sector increasingly promotes digital railway strategies based on interoperability and automation. The implementation of the European Rail Traffic Management System (ERTMS) represents one of the most important examples of digital railway integration [7].

3. ARTIFICIAL INTELLIGENCE IN RAILWAY TRAFFIC REGULATION

Artificial intelligence systems are increasingly applied in railway traffic regulation and operational management. AI algorithms analyze operational data and support dispatchers in making optimal decisions in real time [8].

The main applications of AI in railway traffic regulation include:

- train scheduling optimization;
- predictive maintenance;
- intelligent signaling systems;
- automated traffic control;
- risk assessment and safety management;
- energy consumption optimization.

AI systems process information from multiple sources simultaneously, including sensors, dispatch centers, GPS systems, and communication networks. Based on these data, intelligent systems can identify potential operational risks and propose corrective actions.

Machine learning algorithms are particularly important because they can identify patterns in operational data and predict future events. For example, AI systems can predict delays, equipment failures, or traffic congestion based on historical and real-time data [9].

Another important application is predictive maintenance. Traditional maintenance approaches are based on predefined schedules, while AI-based predictive maintenance uses real-time data analysis to determine the actual condition of infrastructure and rolling stock.

AI technologies also improve passenger information systems and communication processes. Intelligent systems can automatically provide information about train schedules, delays, and alternative transport solutions.

Despite numerous advantages, the implementation of AI in railway systems also presents challenges:

- cybersecurity risks;
- reliability of AI algorithms;
- high implementation costs;
- data privacy concerns;
- interoperability between different systems.

Therefore, railway companies must establish appropriate standards and regulatory frameworks for AI implementation.

4. ELECTRONIC BUSINESS MODEL IN RAILWAY TRANSPORT

Electronic business (e-business) represents the application of digital technologies and information systems in business operations. In railway transport, e-business models support communication, operational management, logistics, ticketing systems, and infrastructure monitoring.

The proposed AI-based electronic business model consists of the following components:

- Centralized database;
- AI analytical module;
- Communication infrastructure;
- Intelligent dispatch center;
- User interface;
- Security and monitoring system.

The centralized database stores operational information related to trains, infrastructure, traffic schedules, maintenance activities, and passenger services. The AI analytical module processes operational data and generates recommendations for traffic regulation.

The intelligent dispatch center represents the core of the system. It integrates operational data from multiple sources and enables real-time monitoring of railway traffic.

The model also supports interoperability between railway companies and infrastructure managers. This interoperability enables efficient information exchange and coordination between different railway systems.

Electronic business models contribute to:

- reduction of operational costs;
- increased safety;
- improved communication;
- better passenger services;
- optimization of logistics processes;
- sustainable transport development.

Cloud computing technologies further improve scalability and accessibility of railway information systems. Railway operators can access operational information from different locations and coordinate activities more efficiently.

4.1. Case Study: AI-Based Predictive Railway Traffic Regulation Using ERTMS and Intelligent Dispatch Systems

To demonstrate the practical applicability of the proposed electronic business model, a case study based on AI-supported railway traffic regulation within an ERTMS environment is presented. The case study analyzes the implementation of artificial intelligence technologies for predictive maintenance, intelligent dispatching, and operational optimization in modern railway systems [7], [8].

The analyzed model is based on the integration of:

- ERTMS signaling systems;
- IoT infrastructure sensors;
- centralized cloud databases;
- AI analytical modules;
- intelligent dispatch centers;
- real-time communication systems [1], [5].

The operational architecture of the system is shown through the interaction between railway infrastructure, dispatch centers, and AI analytical platforms. Sensors installed on railway infrastructure continuously collect operational data related to:

- rail temperature;
- vibration levels;
- train speed;
- braking systems;
- signaling equipment status;
- energy consumption [6].

The collected data are transmitted through communication networks to a centralized database where machine learning algorithms analyze operational conditions in real time [2], [8].

- The AI system performs:
- anomaly detection;
- delay prediction;
- predictive maintenance;
- automatic route optimization;
- operational risk assessment [4], [9].

A simplified operational workflow is presented below:

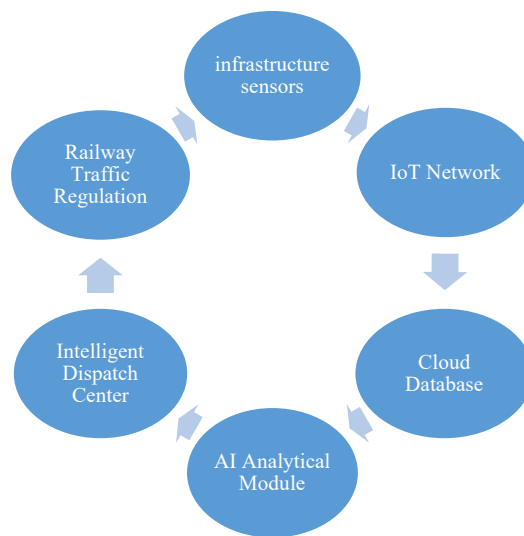


Figure 1: Operational workflow

The case study compares operational performance before and after AI implementation.

Table 2: Operational Performance Before and After AI Implementation

Operational Indicator	Traditional System	AI-Based System
Average train delay	12.4 min	4.8 min
Infrastructure failures per year	18	7
Energy consumption	100%	83%
Dispatcher reaction time	5-8 min	1-2 min
Predictive maintenance capability	Limited	Advanced
Operational safety level	Medium	High

The obtained results indicate that AI-based systems significantly improve operational efficiency and safety. Predictive analytics enables early detection of infrastructure failures and reduces operational disruptions [4], [9].

One important aspect of the case study is predictive maintenance. Traditional maintenance systems are based on fixed maintenance intervals, while AI-supported maintenance continuously evaluates the actual condition of infrastructure components. Machine learning algorithms process historical and real-time operational data to identify potential failures before they occur [9].

In addition, intelligent dispatch systems improve interoperability between railway operators and infrastructure managers. AI-supported traffic regulation enables dynamic optimization of train routes and minimizes operational conflicts in real time [3], [7].

The implementation of digital twins further improves operational management. Virtual simulation models allow railway operators to test different traffic scenarios and optimize operational processes before applying changes to real railway systems [5], [11].

Despite the advantages, several implementation challenges were identified [10]:

- high initial investment costs;
- cybersecurity risks;
- interoperability issues between legacy systems;
- need for employee digital training;
- regulatory and legal limitations.

However, long-term operational benefits significantly outweigh implementation challenges. The application of AI technologies contributes to [1], [10], [11].

- improved punctuality;
- increased infrastructure reliability;
- reduced operational costs;
- better passenger services;
- sustainable railway transport development.

The presented case study confirms that AI-based electronic business models can significantly improve railway traffic regulation and transport management within modern digital railway systems.

5. SAFETY AND SUSTAINABILITY ASPECTS

Safety represents one of the most important priorities in railway transport. AI technologies significantly contribute to improving operational safety through real-time monitoring, predictive analytics, and automated decision-making [10].

AI systems can identify abnormal operational conditions and issue warnings before accidents occur. Computer vision systems are increasingly used for monitoring railway crossings, stations, and railway infrastructure.

Another important aspect is sustainability. Railway transport is considered one of the most environmentally friendly transport modes. Digital technologies and AI systems contribute to sustainable railway operations through:

- optimization of energy consumption;
- reduction of operational disruptions;
- efficient traffic management;
- reduction of greenhouse gas emissions.

AI-based optimization algorithms can reduce unnecessary train stops and improve energy efficiency. Intelligent traffic management systems also reduce congestion and improve punctuality.

However, sustainability also requires long-term investments in digital infrastructure and employee training. Railway companies must continuously improve digital competencies and technological capabilities.

6. FUTURE DEVELOPMENT TRENDS

Future railway systems will increasingly rely on autonomous technologies, intelligent communication networks, and advanced AI systems. The concept of “smart railways” involves full integration of digital technologies into operational and business processes [11].

Future trends include:

- autonomous trains;
- digital twins of railway infrastructure;
- 5G communication systems;

- AI-driven predictive analytics;
- blockchain-based logistics systems;
- intelligent passenger services.

Digital twins will enable simulation and optimization of railway operations in virtual environments. This technology will significantly improve predictive maintenance and infrastructure management.

Autonomous railway systems are also expected to become more common in the future. AI technologies will enable trains to operate with minimal human intervention while maintaining high safety standards.

Cybersecurity will remain a critical issue due to the increasing dependence on digital technologies. Railway companies will need advanced cybersecurity strategies to protect operational data and communication systems.

7. CONCLUSION

Artificial intelligence and digital technologies are transforming railway traffic regulation and transport management. Modern railway systems increasingly depend on intelligent information systems, interoperability, and automation.

The electronic business model presented in this paper demonstrates how AI technologies can improve operational efficiency, safety, sustainability, and interoperability in railway systems. Intelligent dispatch systems, predictive maintenance, and automated traffic management significantly reduce operational risks and improve service quality.

Despite the advantages of AI implementation, challenges related to cybersecurity, interoperability, and ethical issues remain important. Successful digital transformation requires continuous investment in digital infrastructure, employee education, and regulatory development.

Future railway systems will increasingly integrate AI technologies, autonomous operations, and intelligent communication systems, contributing to safer, more efficient, and sustainable railway transport.

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