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A Single AI Platform for the Unification of Railway Transport Logistics Processes

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***Abstract*—This paper proposes the concept of a unified intelligent platform aimed at standardizing the logistics processes of railway transportation in Ukraine. The objective of this development is to automate transportation planning and optimize the utilization of railway resources. The proposed unified intelligent platform focuses on data exchange standardization and enhancing the efficiency of transport and logistics operations. The platform improves timetable accuracy, reduces transit times, and lowers overall logistics costs. The results obtained confirm the effectiveness of the approach, demonstrating the feasibility of integrating artificial intelligence technologies into modern railway infrastructure.**

Keywords—intelligent platform, rolling stock monitoring, automation of calculations, data integration, railway transport

I. INTRODUCTION

Over the last decade, business development in Europe has proceeded under the banner of implementing the provisions and principles of Industry 4.0 [1]. Today, the use of such 4.0 digital technologies as drones, artificial intelligence, cybersecurity, Big Data, Digital Twins [2], Logistic 4.0 [3], and 3D printing has already become an everyday reality. Artificial intelligence is the most accessible of these technologies for the average person. Thanks to its capabilities and availability, it has become possible to use AI for individual needs and the local automation of business structures.

Various scientific studies and industrial projects have confirmed the importance of implementing Industry 4.0 in the railway sector [4]. Despite numerous successful solutions in maritime and automotive logistics, the railway sector remains underexplored. Scientific publications related to the digital transformation of railway logistics largely focus on specific aspects, such as digital twin trains, operational applications for railway infrastructure management, or the intersection of artificial intelligence and cybersecurity [5, 6, 7]. Studies [8, 9] describe the implementation of digital twin technology for the European Train Traffic Control System (ETCS). The articles consider a multigraph approach to the formal description of railway infrastructure, which allows creating a digital twin of railway systems. The results of the verification of the ETCS digital twin confirm the effectiveness of such an approach in increasing the reliability of railway infrastructure management.

However, to date, no comprehensive solutions covering all stages of the logistics process have been proposed. In the next section, we review key research addressing this challenge.

Several digital solutions have been implemented at the European level to optimize railway logistics management. The European Rail Traffic Management System (ERTMS) and the Open Railway Freight EDI User System (ORFEUS) establish unified standards for railway traffic control and electronic document exchange. Additionally, the Path Coordination System (PCS) allows operators to synchronize schedules and reserve routes. However, these systems are primarily focused on traffic management and document standardization rather than comprehensive freight logistics. They do not fully address challenges such as rolling stock allocation, dynamic tariff optimization, multimodal transport integration, and real-time freight demand forecasting, which are key aspects for improving the international railway logistics market.

The idea for this work arose from the practical experience of personnel at a logistics company.

As part of the integration of the AI platform into the international railway logistics space, unification of rail transport logistics processes focuses on aligning data transfer formats and modules across various systems. Resolving technical discrepancies ensure compliance with safety and cybersecurity requirements, harmonizing terminology and classification systems. Adhering to EU legal norms and environmental standards, and facilitating interaction among all participants in logistics chains (from railways to startups and government institutions), taking into account the specifics of different markets and language barriers guarantee.

II. Methods for Integrating AI Platforms into the International Railway Logistics Space

In the context of introducing digital technologies, Ukraine's railway sector faces the need to implement new approaches to logistics management and data exchange among all market participants. The challenges of fragmented information systems, various data exchange formats, and the need for precise calculations are the main obstacles confronting the railway sector [10]. The proposed single intellectual AI platform (AI-platform) is an innovative solution aimed at standardizing data exchange and increasing the efficiency of transport and logistics operations.

II.A System architecture (conceptual design)

To ensure seamless integration with existing railway logistics systems in Ukraine and Europe, as well as to enhance transportation planning efficiency, the proposed AI platform is designed as a modular architecture consisting of four key functional components: the Data Integration Layer, AI Processing Core, Central Database, and Application/Service Layer. Each component performs specific tasks, collectively enabling real-time decision-making, predictive analytics, and optimized logistics operations.

The Data Integration Layer serves as the foundation for collecting, preprocessing, and standardizing data from various sources, including e.Portal UZ-Cargo, TMMap, GPS tracking systems, and historical logistics databases. By converting and unifying data formats (XML, JSON, EDIFACT), this layer ensures compatibility with European logistics standards such as ERTMS, ORFEUS, and PCS. This, in turn, facilitates automated data exchange among railway operators across different countries and enables integration into international logistics systems.

The AI Processing Core is the central analytical unit of the system, responsible for demand forecasting, tariff optimization, and rolling stock management. By leveraging machine learning models, the platform can analyze historical freight trends, predict future demand, dynamically adjust tariff policies, and determine optimal transportation routes, minimizing costs and transit time. In addition to AI-driven algorithms, the system incorporates rule-based decision mechanisms that ensure compliance with regulatory requirements, technical standards, and safety protocols. This guarantees system reliability and predictability, even in cases of operational disruptions or sudden changes in logistics processes.

The Central Database functions as the primary data repository, accumulating both structured and unstructured information, including real-time cargo status, historical transport records, and predictive analytics outputs. To maintain data integrity and security, this component employs encryption mechanisms, multi-level access control, and automated anomaly detection. These measures reduce the risk of unauthorized access, data loss, or tampering, which is crucial for ensuring cybersecurity compliance in the railway sector.

To provide user-friendly interaction, the Application/Service Layer offers intuitive access interfaces for logistics operators, railway companies, and regulatory authorities. This layer includes:

- Web-based dashboards with interactive visualization of analytics and transportation status.
- Mobile applications for iOS and Android, enabling real-time cargo tracking and monitoring.
- RESTful APIs that facilitate seamless integration with third-party solutions, such as cargo tracking startups and multimodal transportation providers.

These functional components incorporate specialized subsystems that expand the platform's capabilities. For instance, the AI Processing Core includes dedicated subsystems for demand forecasting, dynamic pricing optimization, and rolling stock allocation, while the Data Integration Layer consists of data conversion, validation, and synchronization mechanisms for external railway logistics infrastructures. This architectural approach ensures scalability, adaptability to diverse market conditions, and seamless interoperability with both national and international railway networks.

By enabling automated data exchange and AI-driven recommendations, the proposed system will enhance operational efficiency and decision-making across all levels of railway logistics management.

II.B. Artificial Intelligence Methods and Algorithms

To enhance the efficiency of railway logistics management, the AI platform is planned to incorporate methods for demand forecasting, tariff optimization, rolling stock distribution, and route planning, ensuring adaptive real-time decision-making.

Demand forecasting will be implemented using Long Short-Term Memory (LSTM) networks, which analyze historical data to identify seasonal trends, economic cycles, and potential delays. For short-term forecasting, Autoregressive Integrated Moving Average (ARIMA) models will be used, providing more interpretable results.

Tariff optimization will leverage reinforcement learning methods (Q-learning) to dynamically adjust pricing based on demand, market fluctuations, and operational costs, ensuring a balance between competitiveness and profitability.

Rolling stock distribution will be managed using genetic algorithms, which iteratively improve planning efficiency, along with constrained optimization, which accounts for regulatory requirements, technical constraints, and wagon maintenance schedules.

Route optimization will utilize graph algorithms (Dijkstra, A)* to determine the shortest paths while considering traffic conditions, weather factors, and transport connections. Additionally, Markov decision processes can be applied to predict alternative routes.

The system will support continuous learning, with algorithms automatically updating based on new logistics data and market changes. Thanks to transfer learning, the platform will seamlessly adapt to different regions without requiring a substantial amount of new data.

It is proposed, in the 1st stage, to organize a pilot project for the use of the AI-platform in the Ukrainian market. In the 2nd stage, as part of the HE project PhDs-Rail, the AI-platform could be integrated with European transport and logistics systems, thereby boosting the competitiveness of railway logistics,

promoting the growth of international trade, and strengthening Ukraine's economic ties with EU countries. In the 3rd stage, this development could be introduced into international markets for digital logistics systems.

It should be noted that a study of this scope requires extensive expert support and a multidisciplinary approach. Collaboration with the PhDs-Rail project partners, research institutions, and startups can ensure a continuous influx of innovations and contribute to the development of highly qualified professionals for the transportation sector. Establishing an open Application Programming Interface (API) for the AI platform enables startups – such as those focused on AgTech, IoT, blockchain, and cargo tracking systems – to develop additional solutions that enhance the platform's functionality (Table I). Joint engagement with industry, universities, and innovative companies promotes the creation of an innovation-friendly environment, in which knowledge and ideas are transformed into tangible solutions for the logistics field.

TABLE I. INNOVATIONS THAT CAN BE IMPLEMENTED THROUGH APIS

Innovation sphere	Possible API functions	Examples of technologies	Benefits for logistics
AgTech	- Temperature and humidity sensors - Drones for cargo monitoring	- Connecting sensors to the platform - Remote monitoring of cargo status	- Increased cargo safety - Reduced losses due to product spoilage
IoT	Smart Containers - Intelligent Tracking Devices	- Integration of IoT devices - Processing of large data sets	-- Optimization of logistics operations - Increasing forecasting accuracy
Blockchain	- Secure Transaction Systems - Decentralized Data Storage	- Real-time cargo tracking - Geolocation data analysis	- Reducing fraud risks - Improving trust between partners
Tracking systems	- GPS and RFID - Monitoring platforms	- Historical data analysis - Automatic route adjustment	- Reducing transportation delays - Improving customer service
AI/ML analytics	- Demand forecasting algorithms - Route optimization	- Historical data analysis - Automatic route adjustment	- Resource saving - Increasing the efficiency of infrastructure use

Main functions of the AI-platform

A. Automation of calculations and data analytics

The AI-platform integrates information from the TMmap (a software package used to display freight train routes and calculate shipping charges, employed on the railways of Ukraine, the Baltics and Europe) and other sources for an expanded analysis of tariffs, transportation durations, and optimal wagon use. By applying artificial intelligence and the aforementioned data, the platform provides more accurate calculations and forecasts, automate routine operations, and increase the efficiency of rolling stock management, taking into account demand, wagon conditions, and market changes. It should be noted that AI is able to:

1) help process enormous volumes of information, including historical transportation data, seasonal demand fluctuations, and market forecasts;
2) optimize routes and reduce the number of empty wagons;
3) contribute to reducing CO_2 emissions;
4) automatically select optimal transportation routes during peak periods.

B. Intelligent rolling stock monitoring

The AI-platform creates a centralized database on rolling stock belonging to various owners. As a result, on an interactive AI map that displays the location of wagons and other logistics management data in real time, users can obtain up-to-date information on the positions of wagons. The platform is be able to analyze market data taking into account the route, cargo type, wagon condition, and demand, thereby facilitating the optimal use of wagons and improving logistics processes for the entire logistics market. Future integration with other modes of transportation is also possible, allowing the AI map to display not only wagons but also motor vehicles and ships for building multimodal routes. In addition, through this AI map with built-in artificial intelligence, it is planned to automatically determine the optimal rolling stock for transporting goods at minimal cost.

Currently, similar databases exist only in fragmented form and are partially regulated or not regulated at all, accessible to a limited number of users. The platform solves this problem by providing a single state-regulated resource, which becomes an important tool for both businesses and the railway company, while ensuring a high level of cybersecurity to protect data and prevent potential threats [11].

This module could also include a system for real-time analysis of railway hub congestion, accounting for the number of freight wagons, arrival schedules, infrastructure conditions, and current operating conditions. Based on this data, AI is planned to automatically suggest rerouting flows to avoid overloading specific sections or stations. This reduces freight wagon downtime and improve overall operational efficiency.

C. Integration with the "e.Portal UZ-Cargo" electronic portal

The platform closely interacts with the "e.Portal UZ-Cargo" for the centralized exchange of electronic documents among market participants [12]. This ensures the automation of document creation and storage processes, as well as optimizes interactions between clients and JSC "Ukrzaliznytsia." Integration with the portal allows clients to receive real-time updates on transportation status, reduces the time spent on document processing, and lowers labor costs.

D. Forecasting market conditions and dynamic tariffs

Forecasting market conditions and dynamic tariffs is planned to leverage AI algorithms that utilize statistical information from past periods, including demand for various types of cargo during specific months or seasons, changes in transportation costs, and more. Real-time data such as order

volumes, fluctuations in raw material prices, and macroeconomic indicators are also considered.

The construction of predictive models allows the system to identify hidden patterns and relationships in market dynamics through machine learning and deep learning techniques. The module automatically adjusts tariff rates based on the forecasted demand levels, the state of the competitive environment, fuel costs, and other resources.

III. Results

The implementation of the AI-platform provides market participants with numerous benefits, such as resource and time savings, improved calculation accuracy, and optimized logistics processes. Thanks to automation, the time required for contract approvals is reduced, and the client is able to receive transportation status updates and process the necessary documents through the platform in just a few minutes. As of December 2024, the developers of "e.Portal UZ-Cargo" have already automated the process of concluding and renewing contracts with the Main Information and Computing Center.

Since the system has not yet been deployed, pilot testing can already be planned to assess its effectiveness in real railway logistics conditions. The initial testing phase can be conducted as early as 2025 on selected Ukrainian railway routes, where the AI platform will be integrated with existing logistics management systems such as e.Portal UZ-Cargo and TMMap.

This phase will serve as an evaluation of the system's ability to improve transport planning, resource allocation, and decision-making efficiency in the railway sector.

During the pilot phase, key performance indicators can be used to measure the system's impact:

Accuracy of demand forecasting – assessed by comparing predicted cargo volumes with actual transportation data.

Reduction in wagon idle time – evaluated by analyzing past and real-time rolling stock utilization.

Effectiveness of train schedule optimization – measured through quantitative and qualitative indicators of improvements achieved due to AI-based planning.

The results of this pilot phase will provide crucial insights for further system refinement and potential large-scale deployment. Based on the collected data, adjustments will be made to AI algorithms, integration processes, and user interfaces to enhance overall performance and interoperability with European railway networks.

The practical advantages of the AI-platform are:

1. When creating a commercial proposal, the platform automatically selects the necessary data, which reduces the time required for document preparation and ensures a competitive rate for the client.
2. Real-time wagon monitoring enables immediate determination of load levels and ensures optimal distribution of wagons, increasing the efficiency of rolling stock usage.
3. Seasonal increases in transportation demand cause wagon shortages, and by using historical data and forecasts, AI can identify peak load periods and automatically suggest wagon allocation.

Additionally, the AI-platform is planned to integrate:

I. A rolling stock repair management module that allows concluding contracts with wagon repair companies, automatically generating repair requests, and automatically uploading notifications to the database regarding the need for wagon repairs, the repair status, or return to service. This solution significantly increases the efficiency of freight rolling stock maintenance, reduce downtime costs, and also enhance transportation safety.

II. A module for regular and rapid checks of knowledge and/or professional skill acquisition for employees in the railway transport sector. It could be expanded to include both knowledge acquisition in the Ukrainian transport industry and integration of EU knowledge bases and experience. This would include holding meetings for representatives at all hierarchical levels from various transport spheres to exchange experiences and develop common standards, thereby promoting the harmonization of logistics management processes and implementing best European practices.

Cybersecurity module, as the system is planned to process large volumes of sensitive information about logistics processes, transportation routes, wagon technical characteristics and other data. The cybersecurity module ensures information protection, detection of potential threats, and prevention of cyberattacks, adhering to modern international standards. The main functions of such modules generally include:

1) data encryption to ensure confidentiality;
2) systems for multifactor authentication (MFA), that platform access requires several levels of verification;
3) real-time threat monitoring and detection, which allows the analysis of network traffic in real-time, identifying anomalies and potential cyberattacks;
4) a backup and recovery system with a principle of geo-redundancy;
5) the use of blockchain technologies to ensure the immutability of critical data (e.g., transportation status or financial documents).

IV. Discussion

The proposed intelligent AI platform, built on the basis of artificial intelligence, has significant potential to increase the efficiency and transparency of logistics operations in the field of railway freight transportation. It enables the optimization of management and data exchange between the railway company and other market participants. This ensures a high level of reliability and resource savings, allow for quick adaptation to market changes, and enhances the safety of freight transportation.

Integration with European transport and logistics systems such as ERTMS [13], ORFEUS (Open Railway Freight EDI User System), which has demonstrated a significant reduction in document processing time. PCS (Path Coordination System), enabling operators to unify schedules and route reservations for freight transportation, and RailData fosters synergy with international markets, facilitate the adaptation of Ukraine's railway transport to European standards, and advance Ukraine's

integration into a unified European logistics space. Primarily, this concerns the compatibility of data formats and transmission protocols. Each of the aforementioned systems has its own specifications and requirements for electronic document management (Table II). To avoid discrepancies in the classification of routes, railcars, and cargo types, it would be prudent to implement unified directories or develop converters that automatically transform different data formats and ensure their synchronization.

TABLE II. COMPARISON OF EXISTING RAIL LOGISTICS MANAGEMENT SYSTEMS

System	Features	Advantages	Disadvantages
TM-Map	Displaying routes of freight trains	Integration with other systems	Limited functionality
e.Portal UZ-Cargo	Centralized exchange of electronic documents	Document workflow automation	The need for manual data entry
ERTMS	Unified standard for European railways	Compatibility with European systems	High implementation cost
ORFEUS	Simplification of document processing	Reduction of document processing time	Limited functionality
PCS	Unification of schedules and route reservations	Route optimization	Need for integration with other systems

It is necessary to take into account several decisive factors, including:

1) Compliance with European safety standards and legal regulations. Each EU member state requires stringent oversight of environmental protection, data security, and transparency in logistics operations. The AI platform should be adapted to these conditions, ensuring both the proper processing of transportation data and creating the conditions for an uninterrupted exchange of information with governmental bodies.

2) The difference in track gauge. The difference in track gauge (1520 mm in Ukraine versus 1435 mm in most European countries), which affects the transshipment process and route planning. Having suitable algorithms within the platform enables consideration of the time and cost required for all existing technologies, thereby facilitating the calculation of the optimal solution.

3) Language barriers, since different railway networks employ distinct terminology and coding systems. Nevertheless, automated translation tools and coordinated specialized terminology directories make it possible to standardize designations of routes, tracks, stations, and cargo types. This aspect is particularly relevant at the stages of document approval and during real-time messaging throughout the transportation process.

Automated Infrastructure Monitoring Module – This module should analyzes the condition of tracks, switches, and the catenary network using drones and sensors. The system is capable of detecting defects, assessing wear levels, and forecasting the need for repairs or upgrades. It enables timely maintenance, reduces accident risks, and prevents speed restrictions. Automating this process enhances transportation safety and improves the efficiency of infrastructure utilization

Geospatial Analytics and GIS Integration Module – This module provides real-time visualization of rolling stock locations along with additional geodata, such as connection points with other modes of transportation or repair depots. It s optimizes transportation management, minimize costs, and ensure efficient logistics planning.

The proposed AI platform has significant potential in the international market. For large-scale implementation, such a platform must comply with EU transport regulations, adapt to various railway infrastructure standards, and ensure compatibility with existing European platforms such as ERTMS, ORFEUS, and PCS. One of the main challenges will be achieving seamless interoperability between national and international railway operators, particularly given the differences in track gauges and operational protocols.

From an economic perspective, AI-driven optimization is expected to generate significant cost savings and efficiency improvements. By enhancing rolling stock allocation, reducing downtime, and improving demand forecasting, the platform could help lower transportation costs by approximately 10–15%. Additionally, better route planning and resource management could lead to a substantial reduction in CO_2 emissions, making railway transport more sustainable.

If we consider the railway logistics market in Ukraine, a unified open platform would enable JSC "Ukrzaliznytsia" to transition to a more transparent freight transportation policy, positioning UZ as a more competitive and self-sufficient logistics operator. Moreover, it would strengthen the country's integration into the European transport system by aligning data management with international standards.

It is essential to consider that the platform is being designed with secure data exchange and compliance with cybersecurity requirements in mind. However, some private logistics companies may hesitate to share operational data due to competitive concerns. Overcoming this barrier will require a clear regulatory framework and incentive structures to encourage data sharing and collaboration.

Overall, this solution represents a promising step toward the digital transformation of railway logistics. However, for full-scale implementation in Europe, further pilot testing, regulatory adjustments, and international cooperation will be necessary.

V. CONCLUSIONS

The proposed AI platform represents a promising tool for the unification of logistics processes in Ukraine's railway transport. Its development is based on advanced Industry 4.0 technologies, enabling the resolution of key sectoral issues such as the lack of standardized data exchange, fragmented information systems, and low resource utilization efficiency.

The initial phase of platform implementation at the national level facilitates the creation of a unified database for rolling stock, automate calculations and data analytics, optimize transportation routes, and reduce CO_2 emissions. Through integration with the electronic portal "e.Portal UZ-Cargo," the platform provides transparent and prompt document management for all market participants.

The 2nd phase, involving the potential integration of the platform with European transport and logistics systems such as

ERTMS and RailData, may contribute to aligning Ukraine's railway infrastructure with European standards. This should enhance the competitiveness of Ukrainian railway logistics, foster growth in international trade, and strengthen economic ties with EU countries.

Further development of the platform, including modules for rolling stock maintenance management, workforce training, and support for multimodal transportation, will significantly improve the efficiency and safety of freight transportation by railways.

One of the key areas for future development could be the enhancement of AI itself. As AI continues to evolve, it gains a deeper understanding of context, improves models for better comprehension of language, intentions, and emotions. Additionally, it autonomously learns (AutoML) and becomes multifunctional (Multimodal AI).

Expanding the system's capabilities to support integration with maritime port and road logistics will be important step toward creating a fully interconnected transport ecosystem. Further research will also focus on improving cybersecurity mechanisms to ensure data integrity and compliance with international standards, as well as developing AI-based risk assessment models to predict and mitigate potential railway disruptions.

The innovative solutions implemented within the AI platform lay the groundwork for the future digital transformation of railway logistics and for Ukraine's integration into a unified European logistics space.

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