Технічні науки

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FEATURES OF UNINTERRUPTED DELIVERY OF BULK MATERIALS IN THE CONSTRUCTION OF ROADS, OVERPASSES, AND HIGHWAYS

Summary. *This study examines the features of ensuring uninterrupted delivery of bulk materials required for the construction of roads, overpasses, and highways. The analysis covers technological and organizational aspects of transportation, logistics strategies, and supply chain management approaches in this field. Particular attention is given to the integration of digital technologies, such as IoT, ERP, and SCM systems, to optimize delivery processes, reduce costs, minimize losses, and enhance construction efficiency. Based on a literature review, the study formulates the hypothesis that implementing an integrated digital platform in the logistics of bulk materials can ensure the sustainability and quality of construction projects. The methodological framework includes a systematic analysis and a comparative literature review, allowing for the identification of a scientific gap. The findings of this study may be of interest to researchers and postgraduate students specializing in transport logistics, innovative construction technologies, and supply chain optimization, as it provides an in-depth analysis of uninterrupted bulk material delivery dynamics in the context of modern infrastructure projects. Additionally, the results may be useful for practicing engineers and experts in government regulatory bodies seeking to implement advanced methods to improve reliability and economic efficiency in large-scale road, overpass, and highway projects.*

Key words: *uninterrupted delivery, bulk materials, road construction, logistics, supply chain, digital technologies, innovative approaches.*

Introduction. In modern road infrastructure construction, ensuring the uninterrupted delivery of bulk materials is a critical factor for the success of large-scale projects such as roads, overpasses, and highways. Bulk materials, including crushed stone, sand, and gravel, constitute a fundamental component in road construction technology, and their timely supply directly affects project timelines, the quality of constructed infrastructure, and overall economic efficiency. With the increasing volume of road construction and stricter environmental safety requirements, the organization of effective bulk material logistics is becoming increasingly relevant.

The study of infrastructure development challenges demonstrates that the issue of ensuring uninterrupted delivery of bulk materials in large-scale road projects is closely intertwined with broader socio-political and economic processes. Research on urban corridorization, presented in the works of Tassadiq F. et al. [1] and Tassadiq F. [2,3], emphasizes the necessity of a comprehensive understanding of government policy mechanisms, land-use regulations, and compensatory measures in the context of post-colonial transformations. The authors highlight that legislative and institutional frameworks significantly shape the conditions for establishing sustainable logistics chains, including those related to bulk material delivery, which becomes particularly relevant in the implementation of major infrastructure projects.

At the same time, the study by Müller-Mahn D. [4] offers a different perspective on the challenges associated with transport corridors. Lamarque H. [5] further develops this perspective by analyzing competition and circulation processes along transport corridors, demonstrating how local and global interests influence the organization of material flows and, consequently, the efficiency of logistics systems in road construction.

Additionally, the global research focus on integration processes in the context of both traditional and modern transportation networks has been advanced in the works of Mayer M. and Zhang X. [6], as well as Ngo T. W. and Hung E.P.W. [7]. These studies examine transformations accompanying the shift from traditional trade routes to contemporary global integration models, where reconfigurations of socio-spatial structures and the development of informal exchange mechanisms contribute to new logistics solutions. Such a reassessment of traditional approaches establishes conceptual parallels with bulk material delivery challenges, where integrating innovative transport technologies and adaptive management models becomes a key factor in ensuring the sustainability of infrastructure systems.

Despite the diversity of analytical approaches, contradictions remain in interpreting the interconnections between government regulation, economic competition, and logistical resilience. At the same time, issues directly related to the methodology for ensuring uninterrupted delivery of bulk materials for road, overpass, and highway construction remain insufficiently addressed in the existing literature. This gap necessitates further empirical analysis and the development of specialized solutions to optimize transport chains in this sector.

The objective of this study is to examine the features of organizing uninterrupted delivery of bulk materials in road, overpass, and highway construction, with a focus on integrating technical, logistical, and organizational aspects.

The scientific novelty of the research lies in analyzing the feasibility of a model that combines technical, organizational, and logistics components, which would not only minimize downtime and material losses but also enhance the overall efficiency of construction projects.

The research hypothesis posits that applying a comprehensive approach to bulk material supply organization, incorporating modern digital technologies,

monitoring systems, and process optimization, can lead to significant cost reductions and improved construction quality.

The methodological framework of the study includes a systematic analysis and a comparative literature review, allowing for the identification of a scientific gap.

1. Technological and organizational aspects of bulk material delivery

In large-scale road construction and the implementation of major infrastructure projects, such as roads, overpasses, and highways, ensuring the uninterrupted delivery of bulk materials is a strategically important task. The efficiency of transportation directly affects the quality of road surfaces, construction timelines, and overall project costs. Modern research indicates that optimizing technological and organizational processes within the supply chain not only reduces material losses but also improves energy efficiency and environmental safety in construction.

Contemporary transport vehicles designed for bulk material delivery include specialized dump trucks, conveyor systems, and combined transport units. These vehicles are characterized by high payload capacity, automated cargo condition monitoring systems, and integrated telematics modules for tracking routes and vehicle status [1,3]. A key direction in technological development is the implementation of information-analytical systems that enable real-time monitoring of transportation parameters, including speed, load levels, residual material volume, and equipment condition. Advanced GPS monitoring systems and IoT sensors ensure precise planning and coordination of deliveries, reducing the risk of delays and errors during loading and unloading operations [2]. Additional research in logistics automation highlights the necessity of integrating digital twins of transport systems, which help predict potential disruptions and optimize delivery routes.

The organization of bulk material delivery involves not only technical solutions but also the structuring of efficient logistics processes. At the current

stage, particular attention is paid to planning and coordinating all supply chain links, from raw material extraction to its direct use at the construction site [1,4]. The key elements of organizational management include:

- Supply planning and inventory management. Forecasting the demand for bulk materials, considering seasonal and regional factors, allows for optimized warehouse stock levels and synchronization of construction site schedules with delivery timelines.
- Integration of digital platforms and monitoring systems. The use of information systems based on ERP and SCM platforms ensures supply chain transparency, automates route coordination, enables real-time schedule adjustments, and minimizes downtime.
- Quality and safety control systems. Loading and unloading operations must comply with strict safety and quality standards, achieved through automated monitoring systems (such as video surveillance and pressure sensors) and regular audits and maintenance of transport equipment [2,7].

For a better illustration of the comparative characteristics of key types of transport vehicles used for bulk material delivery, Table 1 presents a summary of their specifications.

Table 1

Comparative analysis of specialized vehicles for the delivery of bulk materials [1-3]

Vehicle type	**Payload capacity (tons)**	**Average speed (km/h)**	**Automation and control systems**	**Advantages**	**Limitations**
Dump truck	20–40	60–80	GPS monitoring, load level sensors	High mobility, versatility	Limited maneuverability in confined spaces

Vehicle type	Payload capacity (tons)	Average speed (km/h)	Automation and control systems	Advantages	Limitations
Conveyor system	Up to 100	15–30	Automated flow control	Low material loss, stable delivery	High capital investment, fixed placement
Combined transport unit (Modular)	30–50	50–70	Integrated IT platforms, telematics	Flexibility in use, adaptability	Complex maintenance requirements

Addressing the challenges of bulk material delivery requires the integration of modern technological solutions with well-structured organizational processes. Advanced transport vehicles equipped with digital monitoring and automation systems, combined with effective supply chain management, ensure high reliability and efficiency of deliveries. This, in turn, reduces time and material costs, lowers environmental impact, and enhances the quality of road infrastructure construction. Further research in this area should focus on developing integrated models that combine the technical specifications of transport vehicles with organizational supply chain management methods, enabling the establishment of new standards in large-scale infrastructure construction.

2. Logistics strategies and supply chain management

In the context of rapidly developing road construction and large-scale infrastructure projects, optimizing the supply chain for bulk materials becomes a priority. Efficient supply planning, synchronization of production and construction schedules, and real-time inventory management contribute to cost reduction, minimize downtime, and ensure the continuity of construction processes. The integration of digital platforms such as Enterprise Resource Planning (ERP) and Supply Chain Management (SCM) systems enables the creation of transparent and adaptive logistics systems capable of adjusting routes

and delivery schedules in real time, forecasting demand, and responding promptly to changing conditions.

One of the key challenges in bulk material logistics is accurately predicting demand at construction sites while considering seasonal fluctuations, project-specific requirements, and regional production characteristics. Demand forecasting allows for the optimization of warehouse inventory, reducing the risk of temporary supply shortages and excessive stock accumulation. Modern planning models, based on time series analysis and machine learning methods, account for multiple factors influencing demand and create adaptive inventory management systems [3,6].

Synchronizing bulk material deliveries with construction schedules is another crucial aspect of supply chain management. Ensuring timely material availability to maintain uninterrupted construction workflows requires close coordination between suppliers, transportation companies, and project managers. Organizational solutions in this context include joint planning, real-time information exchange among supply chain participants, and the use of specialized software solutions that integrate data on current inventory levels and production schedules. Such systems help reduce the likelihood of delays due to shortages or excess inventory and optimize the utilization of transportation resources.

The application of digital technologies represents one of the most promising directions in logistics management. IoT sensors, GPS monitoring, automated route planning systems, and analytical platforms enhance transparency across all supply chain stages [1; 2]. These technologies facilitate real-time information exchange among stakeholders, minimize response time to unforeseen disruptions, and improve overall logistics efficiency. ERP systems play a vital role in integrating data on inventory, orders, and routes, while SCM platforms optimize supply management.

To provide a clearer understanding of logistics strategies and supply chain management methods, Table 2 presents a comparative analysis of key

approaches, their descriptions, advantages, and limitations, allowing for an assessment of their applicability in bulk material delivery.

Table 2

Logistics strategies and their characteristics [1; 2; 7]

Strategy	Description	Advantages	Limitations
Just-in-time (JIT)	Timely material delivery with minimal inventory	Reduced storage costs, increased flexibility	High dependency on supplier and transport reliability
Coordination with construction schedules	Synchronization of deliveries with construction phases	Ensures continuous operations, reduces downtime	Requires close collaboration among project participants
Digital platform integration	Use of ERP/SCM systems and IoT technologies for monitoring and planning	Increased transparency, real-time response to changes	High initial implementation and training costs
Adaptive planning	Use of analytical and predictive models for inventory adjustments	Improved forecast accuracy, reduced excess inventory risks	Requires continuous algorithm and data updates

Effective supply chain management for bulk materials requires a comprehensive approach that includes accurate demand forecasting, close coordination of delivery schedules with construction activities, and the integration of modern digital technologies. Implementing these strategies helps reduce costs, improve delivery efficiency, and maintain stability in construction processes. Future research in this field should focus on developing adaptive information systems capable of real-time logistics flow analysis and optimization, contributing to new standards for supply chain organization in large-scale infrastructure projects.

3. Experience in foreign practices and innovative approaches

In recent decades, various countries have actively implemented innovative solutions for organizing the delivery of bulk materials in large-scale infrastructure projects. This experience has facilitated the development of comprehensive

approaches that combine modern information technologies, the integration of transport corridors, and advanced supply chain management models. These innovations not only contribute to reducing logistics costs but also ensure uninterrupted deliveries, which are essential for the timely completion of construction projects [2; 6].

One of the most prominent examples of foreign practices is the implementation of infrastructure corridors under China's Belt and Road Initiative (BRI), where systematic planning and the integration of transport and logistics systems enable the creation of continuous supply routes for construction materials and other infrastructure-related products. Similar principles are applied in the European Union, where transnational transport corridor projects under the TEN-T program ensure supply coordination, standardization of technological processes, and the use of digital monitoring systems [1].

In the United States and Canada, there is also a growing trend toward the adoption of comprehensive logistics solutions. Integrated inventory and route management systems, based on ERP and SCM platforms, allow for real-time adjustments to delivery schedules in response to construction process dynamics and seasonal demand fluctuations [3].

Among the innovative solutions implemented internationally, the following can be highlighted:

- Digital twins and IoT technologies. The development of digital models of transport systems (digital twins) enables real-time tracking of cargo conditions, prediction of potential disruptions, and optimization of delivery routes. IoT sensors installed on transport vehicles and within logistics centers collect high-precision data, enhancing the transparency of the entire supply chain.
- Modular transport systems. In countries with highly developed infrastructure, such as Germany, modular transport solutions are actively used. These systems combine different types of transport (dump trucks, railway

platforms, container shipments) into a unified logistics network, allowing for cost optimization and minimizing waiting times during material transfers [4,6].

- Integrated information systems. The use of specialized ERP and SCM platforms facilitates seamless data exchange between suppliers, carriers, and project managers. These systems enable quick responses to fluctuations in demand and optimize warehouse and transportation resource utilization [1].

Table 3 below presents a comparative analysis of foreign practices in bulk material delivery, highlighting innovative solutions and key implementation outcomes.

Table 3

Comparative analysis of foreign practices and innovative approaches [1; 3; 4]

Region/country	Practical example	Innovative solutions	Key results
China	Belt and Road Initiative (BRI)	Integration of transport corridors; digital twins; IoT systems	Reduction in logistics costs, improved delivery reliability
European Union	TEN-T corridors	Process standardization; ERP/SCM platforms; interstate coordination	Increased routing efficiency, reduced delays
United States and Canada	Integrated logistics systems	Modular transport solutions; automated inventory management	Optimization of warehouse usage, reduced downtime

International experience demonstrates that a comprehensive approach to bulk material delivery—incorporating digital technologies, transport corridor integration, and modular transport systems—can significantly enhance logistics efficiency in large-scale infrastructure projects. The use of ERP and SCM platforms ensures supply chain transparency and real-time responsiveness to changes in construction processes, while innovative solutions such as digital twins and IoT technologies help minimize disruptions and reduce costs. Future

development in this field should focus on adapting these solutions to country-specific conditions, enabling the creation of integrated logistics management models that ensure uninterrupted deliveries and the long-term sustainability of construction projects.

Conclusion. The conclusion summarizes the findings of the conducted study, which provided a comprehensive analysis of the features of bulk material delivery for the construction of roads, overpasses, and highways. The research demonstrated that transportation efficiency and loss minimization depend on the integration of modern technological solutions and organizational processes, as supported by data from other studies. Moving forward, it is recommended to implement pilot projects that integrate the proposed digital and organizational solutions into real-world construction logistics systems.

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