

BRIDGES AND TUNNELS: THEORY, RESEARCH, PRACTICE

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YE. E. ARUTIUNIAN^{1*}, Y. V. SAMOVAR²

^{1*}Department of Urban Construction and Architecture, Zaporizhzhia National University, 226 Sobornyi ave., Zaporizhzhia, Ukraine, 69006, tel. +38 (095) 599 11 56, e-mail arytynyanevgen@gmail.com, ORCID 0000-0002-0502-6651

²Department of Industrial and Civil Engineering, Zaporizhzhia National University, 226 Sobornyi ave., Zaporizhzhia, Ukraine, 69006, tel. +38 (098)325 39 06, e-mail jaroslavsumovar@gmail.com, ORCID 0009-0007-8704-5461

OPTIMIZATION OF ORGANIZATIONAL AND TECHNOLOGICAL PROCESSES IN CONSTRUCTION THROUGH THE IMPLEMENTATION OF MODERN TOOLS IN THE SYSTEM OF TIMELY RESOURCE PROVISION FOR CONSTRUCTION PROJECTS

Purpose of the research is a comprehensive theoretical and methodological substantiation and the development of practical recommendations for optimizing the system of resource provision in construction through the integration of logistical strategies into the processes of organizing construction production. The objective involves the formation of a holistic concept for managing material, information, and financial flows within a construction project, the substantiation of mechanisms for synchronizing work execution schedules with resource supply schedules, as well as the determination of conditions for minimizing total logistical costs without disrupting the technological sequence of construction. **Methodology** of the research includes systemic, process-oriented, and comprehensive approaches to the analysis of construction production organization. The study applies methods of economic analysis and synthesis, comparative analysis of traditional and logistical approaches, structural and functional modeling of flow processes, optimization methods, and elements of economic and mathematical modeling to formalize the cost minimization problem. The method of expert evaluation is also used to identify priority directions for improving the resource provision system. **Findings** of the research consist in the development of a conceptual model for integrating logistical strategies with methods of organizing construction processes, the improvement of approaches to planning resource requirements based on the synchronization of material flows with construction schedules, and the formulation of an economic and mathematical model for optimizing supply while taking into account supplier constraints, storage capacities, and time lags. The feasibility of transitioning from fragmented supply management to an integrated logistical system that ensures inventory reduction, downtime minimization, and increased rhythmicity of construction production is substantiated. **Originality** of the obtained results lies in the substantiation of an integrated approach to construction resource provision as a component of the overall project management system, as well as in the formalization of the relationship between organizational methods of construction and logistical optimization tools. **Practical value** of the research lies in the possibility of applying the proposed models and recommendations in the activities of construction enterprises in order to enhance their competitiveness, ensure production continuity, and promote the rational use of resources.

Keywords: construction organization; resource provision; logistics in construction; material flows; cost optimization; supply chain management; schedule planning; economic and mathematical modeling; efficiency of construction production

Introduction

Modern construction operates under conditions of high competition, market instability, limited resources, and increasing requirements for the timing and quality of project implementation. Additional complicating factors include inflationary fluctuations, price dynamics of construction materials, energy resources, and transportation services, as well as the strengthening of regulatory require-

ments regarding safety, environmental compliance, and energy efficiency of facilities. In such conditions, construction enterprises are forced to operate in a highly adaptive mode, responding quickly to changes in the external environment and minimizing the impact of risks on business performance (Арутюнян, І. А., & Арутюнян, Є. Е., 2021; Арутюнян, 2022; Арутюнян, & Коваленко, 2024).

A distinctive feature of the construction indus-

try is its project-based nature: each facility has individual technical and economic parameters, a unique configuration of production processes, and specific resource requirements. At the same time, the duration of project implementation may range from several months to several years, which complicates long-term planning and coordination of supply. Uncertainty regarding delivery times, potential transportation delays, interruptions in material production, or changes in project documentation directly affect the rhythm of work execution (Aloini, Dulmin, Mininno, & Ponticelli, 2012; Zhang, & Yu, 2021).

Under these conditions, a key factor for the success of a construction enterprise is the effective organization of processes, particularly in terms of timely provision of construction resources. Rational resource management involves the clear coordination of work schedules with the supply schedules of materials, structures, products, and equipment. It also includes the optimization of inventory levels, minimization of transportation costs, and ensuring continuity of the production cycle (Nolz, 2021; Войтович, Поколенко, & Смельянова, 2023).

Insufficient coordination of supplies, misalignment of work schedules and material flow, and irrational formation of stocks lead to downtime of equipment and labor, cost overruns, extended construction duration, and reduced competitiveness of the enterprise. Moreover, excessive inventory results in the immobilization of working capital, increases the risk of material spoilage or loss, while resource shortages create a threat of contract breaches and the application of penalty sanctions.

Therefore, to address the challenges of optimizing construction organization in terms of timely provision of construction resources, a modern and relevant tool-logistics – is employed. Logistics is considered not only as a function of supply or transportation but as an integrated system for managing flow processes, encompassing material, information, and financial resources at all stages of project implementation (Полусмяк, Павлюк, & Косач, 2024; Садовяк, 2024).

The application of logistics as a contemporary tool for managing material, information, and financial flows in construction becomes particularly relevant in the context of economic digitalization and the implementation of integrated information systems. The logistical approach allows for the integration of supply, transportation, storage, and

resource utilization processes into a single system focused on minimizing total costs and maximizing efficiency. At the same time, synchronization of material movement with work schedules is achieved, ensuring the rhythm of the production process and increasing its controllability (Войтович, Поколенко, & Смельянова, 2023).

The implementation of logistical principles facilitates the transition from fragmented management of individual operations to a systemic approach encompassing the entire lifecycle of a construction project – from resource planning to project completion and commissioning. Such integration allows not only the optimization of costs but also increased transparency of managerial decisions, reduced uncertainty, and enhanced strategic stability of the enterprise in the long term (Son, Duy, & Dat, 2021).

Thus, logistics serves as a key instrument for transforming the traditional construction organization model into an innovative one oriented toward efficient resource utilization, adherence to project timelines, and the achievement of high levels of economic performance (Polat, & Arditi, 2005; Терещенко, & Євтушенко, 2024).

Purpose

The purpose of this research is the comprehensive theoretical, methodological, and practical substantiation of the principles for optimizing construction organization in terms of timely resource provision through the implementation of modern logistical approaches, aimed at enhancing the efficiency of managing material, information, and financial flows within the framework of construction project implementation.

Achieving this goal involves:

- the systematization of existing approaches to construction resource management and the identification of their limitations under modern economic conditions;
- the clarification of the economic essence of logistics as an integrated tool for managing flow processes in the construction industry;
- the formation of a conceptual model of the relationship between construction process organization methods and logistical strategies;
- the development of economic, mathematical, and organizational mechanisms for optimizing the supply, transportation, and storage of construction resources;

- the substantiation of ways to reduce total logistical costs while ensuring the continuity of work execution;
- the determination of conditions for increasing the adaptability of construction enterprises to changes in the external environment through the integration of logistical principles into project management systems.

Thus, the aim of the research is not only to conduct a theoretical analysis of logistical approaches but also to develop practically oriented recommendations for their implementation in the activities of construction enterprises, with the goal of ensuring the rhythm of the production process, reducing the duration of the construction cycle, and enhancing the overall competitiveness of the construction industry.

Methodology

The construction process is characterized by high resource intensity. The main types of resources include material resources (construction materials, structures, equipment), labor resources (workers, engineering and technical personnel), technical resources (machines, mechanisms), and financial resources. The effectiveness of a construction project directly depends on the level of coordination between the quantities, timing, and location of the use of these resources (Nolz, 2021; Полусмяк, Павлюк, & Косач, 2024).

A distinctive feature of construction is the territorial dispersion of sites, the uniqueness of each project, the significant duration of the production cycle, and its dependence on external factors (climatic conditions, transportation infrastructure, etc.). This creates complexity in supply planning and necessitates a systematic approach to managing resource flows (Войтович, Поколенко, & Смельянова, 2023).

Traditional methods of supply organization, based on maintaining large stocks of materials on the construction site, are economically inefficient under modern conditions. They lead to the immobilization of working capital, increased storage costs, and risks of material spoilage or loss. Therefore, there is a need to optimize the resource provision system based on modern management concepts (Арутюнян, I. A., & Арутюнян, С. Е., 2021; Арутюнян, & Коваленко, 2024).

Logistics in construction represents a system for managing material, information, and financial

flows from suppliers to the end consumer (construction site) to ensure their timely and economically justified movement (Арутюнян, 2022).

The main principles of the logistical approach are:

1. Systematic and integrated processes.
2. Focus on minimizing total costs.
3. Synchronization of material and information flows.
4. Ensuring the required level of service.
5. Flexibility and adaptability to changes in the external environment.

The application of logistics in construction implies the formation of a unified logistical system encompassing suppliers, transport organizations, warehouses, construction sites, and enterprise management structures. Such a system ensures clear coordination among all participants in the process.

Material flows in construction are characterized by a large variety of resources, varying supply frequency, and uneven consumption. Optimizing these flows involves (Садовьяк, 2024):

- rational planning of supply volumes;
- determining the optimal batch size;
- minimizing transportation costs;
- reducing inventory levels;
- shortening delivery times.

One of the key tasks is determining an economically justified inventory level. Excessive stocks lead to higher storage costs, while shortages cause downtime and delays. The use of logistical models allows achieving an optimal balance between these extremes (Полусмяк, Павлюк, & Косач, 2024).

In particular, the application of the Just-in-Time principle, which provides for the delivery of materials directly to the point of use, is appropriate. In construction, this reduces the required storage area on site and decreases working capital tied up in inventory. Modern logistics is impossible without an effective information system. Information flows ensure planning, control, and coordination of resource movement. In construction, it is essential to integrate work schedules with material supply schedules (Садовьяк, 2024).

The use of digital technologies, automated management systems, and resource planning software allows for (Polat, & Arditì, 2005):

- real-time tracking of material stocks;
- forecasting resource requirements;
- controlling delivery timelines;

- analyzing deviations from planned indicators.

Integrating logistical modules with project management systems creates conditions for increased transparency and controllability of resource provision processes.

Transportation costs constitute a significant portion of construction product costs. Therefore, optimizing transport logistics is an important direction for improving efficiency.

The main tasks of transport logistics are:

- selecting optimal delivery routes;
- rational use of transport vehicles;
- aligning transportation schedules with work schedules;
- minimizing vehicle idle time.

Rationalizing transport flows reduces transportation costs, shortens delivery times, and increases supply reliability. The efficiency of a logistical system largely depends on the level of interaction with suppliers (Table 1). Establishing long-term partnerships allows for:

- ensuring supply stability;

- harmonizing quality standards;
- optimizing payment terms;
- reducing order fulfillment time.

A strategic approach to supplier selection involves evaluating reliability, financial stability, production capacity, and logistical capabilities. Implementing a supplier assessment system helps reduce supply disruption risks.

Implementing a logistical approach in construction organization provides a comprehensive economic effect manifested in:

- reducing total supply and storage costs;
- shortening the construction cycle;
- increasing labor productivity;
- decreasing work-in-progress volumes;
- enhancing enterprise competitiveness.

Reducing downtime due to material shortages directly affects adherence to construction schedules. Timely project completion improves the enterprise's reputation and expands its market opportunities.

Table 1

Comparison of traditional construction organization methods with logistical approaches

Comparison Criterion	Traditional Construction Organization Methods	Logistical Approaches (Strategies)
Conceptual Basis	Fragmented management of individual processes	Systemic, integrated approach to flow management
Resource Planning	Planning with creation of large stockpiles	Planning based on accurate demand forecasting
Inventory Management	Creation of safety and excessive stocks	Optimization of stock levels, minimization of warehouse inventory
Supply Organization	Periodic large batch deliveries	Flexible small-batch deliveries according to schedule
Synchronization with Work Schedule	Partial or delayed coordination	Full integration of supply schedules with the construction timeline
Information Support	Mostly paper-based or fragmented accounting	Unified information system for managing resource flows
Response to Changes	Low adaptability, long adjustment cycles	High flexibility and rapid response to changing conditions
Transportation Management	Separate planning of transport operations	Optimization of routes and vehicle loading within a unified system
Supplier Interaction	Short-term contracts, price-oriented	Long-term partnerships, strategic collaboration
Cost Control	Analysis of individual cost items	Management of total logistical costs
Risk Level of Downtime	Increased due to untimely deliveries	Reduced through synchronization of flows
Construction Cycle Duration	Often exceeds planned timelines	Shortening of project execution timelines
Use of Working Capital	Significant freezing of funds in inventories	Rational use of financial resources
Organizational Structure	Hierarchical, separated divisions	Integrated flow management structure
Strategic Orientation	Focus on completing individual stages	Focus on optimizing the entire project lifecycle

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Despite significant advantages, the implementation of logistical approaches is associated with certain challenges, including:

- insufficient personnel training;
- lack of modern information systems;
- resistance to change from management;
- instability of supply markets.

To overcome these limitations, comprehensive measures are required to enhance staff qualifications, modernize information infrastructure, and develop logistical thinking at all management levels.

The further development of logistics in construction is associated with the introduction of digital technologies, automation of planning and control processes, and the use of analytical tools for resource demand forecasting.

Significant potential lies in integrating logisti-

cal processes with modern project management methods, which enables comprehensive optimization of construction timing, cost, and quality.

Traditional construction organization methods are characterized by localized process management and a focus on creating inventory as a means of risk mitigation (Войтович, Поколенко, & Емельянова, 2023). In contrast, logistical approaches involve the systemic integration of material, information, and financial flows, which allows for cost minimization, reduction of construction timelines, and improved efficiency in resource utilization (Table 2).

Thus, the implementation of logistical strategies transforms the construction organization model from reactive to proactive, ensuring adaptability, cost-effectiveness, and competitiveness (Son, Duy, & Dat, 2021).

Table 2

Correspondence of Logistical Approaches to Construction Process Organization Methods

Construction Process Organization Method	Corresponding Logistical Approach / Strategy	Nature of the Relationship
Flow Method of Construction Organization	Continuous logistics; Just-in-Time; integrated coordination of material flows	Ensures uninterrupted movement of materials and rhythm of the production process
Flow-Sequential Method	Resource planning; synchronization of supply with work schedule; batch optimization	Aligns sequence of work with material deliveries, reducing downtime
Contract-Based (Subcontractor) Method	Contract management; strategic sourcing; supplier evaluation	Links delivery timelines and volumes with subcontractor resources
Sequential Method	Material flow planning; buffer stocks; monitoring and tracking of resources	Ensures sequential execution of work and maintenance of required material stock
Coordination of Work Schedules and Supplies	Integrated planning systems; digital material tracking	Synchronizes supply schedules with work schedules for optimal project rhythm
Monitoring of Resource Consumption	Real-time tracking systems; digital information platforms	Allows control of material usage and operational adjustments
Supply Risk Management	Predictive analytics; buffer optimization; contingency planning	Minimizes risks of delays, shortages, or changing supply conditions
Cost Control and Efficiency Improvement	Total cost optimization; flow analysis; lean logistics	Enhances economic efficiency and reduces storage and transportation costs
Integration with Project Management Systems	ERP and software platforms; flow process integration	Ensures full coordination of logistics and project management
Adaptation to External Changes	Flexible logistics; dynamic rescheduling; adaptive strategies	Provides rapid response to changes in market, climate, or regulatory environment

The table presented demonstrates that logistical approaches do not replace the methods of construction process organization but serve as a tool for their optimization and efficiency enhancement. Each construction organization method can be reinforced with an appropriate logistical strategy, ensuring:

- synchronization of work execution and resource supply;

- reduction of total costs;
- minimization of downtime;
- increased adaptability to changes;
- shortening of the construction cycle duration.

Thus, the integration of logistical approaches into the construction organization system creates the prerequisites for forming a modern construction project management model.

Findings

The article presents a simplified mathematical model for optimizing the timely provision of construction resources based on a logistical approach:

1. General Problem Statement.

The purpose of the modeling is to minimize the total logistical costs of a construction project while ensuring timely completion of works and uninterrupted resource supply.

The model is based on the integration of:

- the construction work schedule;
- material resource requirements;
- costs for procurement, transportation, and storage;
- constraints of suppliers and warehouses.

2. Introduction of Notation.

Indices:

$i=1, 2, \dots, n$ – type of construction resource;

$t=1, 2, \dots, T$ – time period (day, week);

$j=1, 2, \dots, m$ – supplier.

Parameters: D_{it} – the need for resource I during the period, t ; C_{ij}^p – purchase price of resource I from the supplier, j ; C_{ij}^t – transportation costs per unit of resource; C_{ij}^h – storage costs of a resource unit for the period, t ; S_{ij} – maximum supply from the supplier, j ; W_i – warehouse capacity for the resource, I ; L_{ij} – delivery hour (lag).

Variable models: x_{ijt} – volume of the order of resource i from supplier j in the period, t ; I_{it} – remaining resource I in the warehouse during the period, t .

3. Target function.

We minimize total logistics costs:

$$\min Z = \sum_{i=1}^n \sum_{j=1}^m \sum_{t=1}^T (C_{ij}^p + C_{ij}^t) x_{ij} + \sum_{i=1}^n \sum_{t=1}^T C_i^h \cdot I_{it} \quad (1)$$

The target function includes:

1. Procurement costs.
 2. Transportation costs.
 3. Storage costs.
 4. Restriction system.
- #### 4.1 Inventory balance.

$$I_{it} = I_{it-1} + \sum_{j=1}^m x_{ij,t-L_{ij}} - D_{it} \quad (2)$$

Ensures compliance with material balance.

4.2 Ensuring scarcity-free

$$I_{it} \geq 0 \quad (3)$$

Eliminates resource shortage (prevention of downtime).

4.3 Supplier capacity limitations

$$x_{ijt} < S_{ij} \quad (4)$$

4.4 Storage capacity limitations

$$I_{it} < W_i \quad (5)$$

4.5 Non-negativity of variables

$$x_{ijt} \geq 0 \quad (6)$$

$$I_{it} \geq 0 \quad (7)$$

5. Model Expansion (Logistics Strategies).

5.1 Inclusion of the downtime penalty.

If a deficit is allowed, a variable is introduced

B_{it} – the volume of unmet need:

$$Z = \sum_{i=1}^n \sum_{j=1}^m \sum_{t=1}^T (C_{ij}^p + C_{ij}^t) x_{ij} + \sum_{i=1}^n \sum_{t=1}^T C_i^h \cdot I_{it} + \sum_{i,t} P_i \cdot B_{i,t} \quad (8)$$

where P_i – downtime penalty.

5.2 Tipu Model Just-in-Time

A minimum stock limit is added:

$$I_{it} \leq \epsilon \quad (9)$$

where ϵ – permissible minimum safety stock.

5.3 Multi-criteria optimization.

You can consider:

- minimizing the duration of construction;
- minimizing risk;
- minimizing environmental costs.

Then a vector objective function is formed:

$$\min(Z_1, Z_2, Z_3).$$

Economic interpretation. The proposed model allows:

- to determine the optimal supply schedule;
- to minimize logistics costs;
- to avoid downtime caused by resource shortages;
- to optimize the use of warehouse space;
- to align supplies with the construction

schedule.

The model is formulated as a linear programming problem and can be solved using the simplex algorithm or modern optimization software packages.

Originality and practical value

Originality of the obtained results lies in the substantiation of an integrated approach to construction resource provision as a component of the overall project management system, as well as in the formalization of the relationship between organizational methods of construction and logistical optimization tools. Practical value of the research lies in the possibility of applying the proposed models and recommendations in the activities of construction enterprises in order to enhance their competitiveness, ensure production continuity, and promote the rational use of resources.

Conclusions

Optimization of construction organization in terms of timely resource provision is one of the key factors in enhancing the efficiency of construction enterprises. Traditional supply management methods do not provide an adequate level of flexibility and cost-effectiveness in the context of the modern market.

The implementation of a logistical approach enables the formation of an integrated system for managing material, information, and financial flows, ensuring the synchronization of supply processes with construction work execution. The application of modern logistical tools contributes to cost reduction, shorter construction timelines, increased reliability of supplies, and strengthening the competitive position of the enterprise.

Thus, logistics functions not only as a supporting activity but as a strategic management tool for construction production, providing comprehensive optimization of resource provision and creating prerequisites for sustainable industry development.

The developed economic-mathematical model reflects an integrated logistical approach to managing the resource provision of a construction project. Its application allows a transition from intuitive planning to formalized optimization-based management, ensuring cost reduction, increased supply reliability, and adherence to project timelines.

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Є. Е. АРУТІОНЯН^{1*}, Я. В. САМОВАР²

^{1*}Кафедра міського будівництва і архітектури, Запорізький національний університет, проспект Соборний, 226, Запоріжжя, Україна, 69006, тел. +38 (095) 599 11 56, ел. пошта arutyunyan@gnail.com, ORCID 0000-0002-0502-6651

²Кафедра промислового та цивільного будівництва, Запорізький національний університет, проспект Соборний, 226, Запоріжжя, Україна, 69006, тел. +38 (098) 325 39 06, ел. пошта jaroslavsumovar@gmail.com, ORCID 0009-0007-8704-5461

ОПТИМІЗАЦІЯ ОРГАНІЗАЦІЙНО-ТЕХНОЛОГІЧНИХ ПРОЦЕСІВ БУДІВНИЦТВА ШЛЯХОМ ВПРОВАДЖЕННЯ СУЧАСНИХ ІНСТРУМЕНТІВ У СИСТЕМІ СВОЄЧАСНОГО РЕСУРСНОГО ЗАБЕЗПЕЧЕННЯ БУДІВЕЛЬНИХ ПРОЄКТІВ

Метою дослідження є комплексне теоретико-методологічне обґрунтування та розроблення прикладних рекомендацій щодо оптимізації системи ресурсного забезпечення будівництва шляхом інтеграції логістичних стратегій у процеси організації будівельного виробництва. Мета передбачає формування цілісної концепції управління матеріальними, інформаційними та фінансовими потоками в межах будівельного проєкту, обґрунтування механізмів синхронізації графіків виконання робіт із графіками постачання ресурсів, а також визначення умов мінімізації сукупних логістичних витрат без порушення технологічної послідовності будівництва. **Методикою** є системний, процесний та комплексний підходи до аналізу організації будівельного виробництва. У роботі використано методи економічного аналізу та синтезу, порівняльний аналіз традиційних і логістичних підходів, структурно-функціональне моделювання поточкових процесів, методи оптимізації та елементи економіко-математичного моделювання для формалізації задачі мінімізації витрат. Також застосовано метод експертних оцінок для визначення пріоритетних напрямів удосконалення системи ресурсного забезпечення. **Результати** дослідження полягають у розробці концептуальної моделі інтеграції логістичних стратегій з методами організації будівельних процесів, удосконаленні підходу до планування потреб у ресурсах на основі синхронізації матеріальних потоків із календарними графіками робіт, а також у формуванні економіко-математичної моделі оптимізації постачання з урахуванням обмежень постачальників, складських потужностей і часових лагів. Обґрунтовано доцільність переходу від фрагментарного управління постачанням до інтегрованої логістичної системи, що забезпечує зниження рівня запасів, скорочення простоя та підвищення ритмічності будівельного виробництва. **Наукова новизна** отриманих результатів полягає в обґрунтуванні інтегрованого підходу до ресурсного забезпечення будівництва як складової загальної системи управління проєктами, а також у формалізації взаємозв'язку між організаційними методами будівництва та логістичними інструментами оптимізації. **Практичне значення** дослідження полягає у можливості використання запропонованих моделей і рекомендацій у діяльності будівельних підприємств з метою підвищення їх конкурентоспроможності, забезпечення ритмічності виробництва та раціонального використання ресурсів.

Ключові слова: організація будівництва; ресурсне забезпечення; логістика в будівництві; матеріальні потоки; оптимізація витрат; управління ланцюгами постачання; календарне планування; економіко-математичне моделювання; ефективність будівельного виробництва

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