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Sribna Ye. V. [1; ORCID ID: 0000-0002-6676-0606],
Candidate of Economics (Ph.D.), Associate Professor,
Stupnytskyi V. V. [2; ORCID ID: 0000-0001-8845-7643],
Candidate of Economics (Ph.D.), Associate Professor

[1]National University of Water and Environmental Engineering, Rivne
[2]Dubno Branch Higher Education Institution «Open International University of Human Development «Ukraine»

ECONOMIC AND MATHEMATICAL MODELS OF LOGISTICS CONTINUITY UNDER CONDITIONS OF INSTABILITY

The increasing instability of economic environments has significantly intensified the vulnerability of logistics systems and highlighted the importance of ensuring logistics continuity under constrained conditions. This article aims to substantiate the role of economic and mathematical modeling as a theoretical tool for analyzing logistics continuity in situations characterized by uncertainty, limited resources, and infrastructural constraints. The study focuses on the conceptualization of logistics continuity not as an optimal outcome, but as a feasible system state determined by economic and capacity limitations. The research applies a theoretical economic and mathematical approach to represent logistics systems as constrained flow networks, where continuity is ensured through minimum flow requirements and feasibility conditions. The proposed framework formalizes the relationships between logistics costs, system capacities, and continuity thresholds, allowing for the identification of feasible operating regions under conditions of instability. The results demonstrate that maintaining logistics continuity may require accepting higher logistics costs; however, such costs are economically justified due to the prevention of systemic disruptions and long-term economic losses. The findings emphasize that economic and mathematical modelling supports continuity-oriented logistics decision-making by enabling the prioritization of critical flows and rational allocation of limited resources. The study contributes to the development of theoretical foundations for logistics management under instability and provides a basis for further research on adaptive and resilient logistics systems.

Keywords: logistics continuity; economic and mathematical modelling; instability; logistics systems; resource constraints.

Formulation of the problem. In the modern global economy, logistics systems play a critical role in ensuring the continuity of production, distribution, and consumption processes. The growing complexity of supply chains, combined with increasing exposure to extreme disruptions such as economic crises, infrastructure failures, and large-scale systemic shocks, has significantly heightened the vulnerability of logistics networks. Disruptions in logistics flows can lead to supply shortages, rising operational costs, production delays, and a decline in economic stability at both microeconomic and macroeconomic levels.

The problem is further exacerbated by the high level of uncertainty and resource constraints that characterize extreme disruption conditions. Traditional logistics management approaches, which are primarily designed for stable operating environments, often prove insufficient when confronted with sudden and severe disturbances. As a result, ensuring logistics continuity under extreme disruptions has become a pressing challenge for economic systems, requiring the development of adaptive, resilient, and analytically grounded decision-making tools. In this context, the lack of formalized approaches capable of quantitatively assessing logistics system performance and continuity under extreme conditions represents a significant scientific and practical problem. This situation raises critical questions regarding the applicability of economic and mathematical models for evaluating logistics resilience, optimizing resource allocation, and minimizing losses caused by systemic disruptions.

Analysis of recent research and publications. The issue of logistics continuity under disruptive conditions has attracted growing scholarly attention in recent years, reflecting its increasing relevance in logistics, supply chain management, and applied economics. Researchers have explored various dimensions of this problem, including supply chain resilience, risk management, and adaptive logistics strategies [1; 2]. A significant body of research focuses on the concept of logistics and supply chain resilience. Scholars emphasize the ability of logistics systems to absorb shocks, adapt to changing conditions, and recover from disruptions. Studies highlight the role of flexibility, redundancy, and diversification in maintaining logistics continuity under adverse conditions. Authors such as Christopher and Peck underline the importance of resilience-oriented logistics design as a response to systemic uncertainty [3].

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Another research stream addresses the application of economic and mathematical models in logistics management. Researchers propose optimization models, network flow models, and scenario-based approaches to analyse logistics system performance under constraints. These models are used to minimize costs, optimize transportation routes, and allocate limited resources efficiently during disruptions [4; 5]. Quantitative modelling enables a more accurate assessment of logistics risks and supports evidence-based decision-making. Recent publications also examine scenario analysis and stress-testing methods as tools for evaluating logistics continuity under extreme conditions. Scholars argue that scenario-based modelling allows for the comparison of alternative logistics strategies and the identification of critical vulnerabilities within supply chains [6]. However, despite these advances, existing studies often focus on specific disruption types or isolated logistics elements, lacking a comprehensive economic-mathematical framework for ensuring logistics continuity under extreme systemic shocks. Overall, the literature indicates a growing recognition of the importance of quantitative modelling in logistics continuity research, while also revealing gaps related to the integration of economic and mathematical approaches in complex and highly uncertain environments.

Formulating the article goals. The goal of this article is to develop and analyse economic and mathematical models aimed at ensuring logistics continuity under extreme disruptions. The study seeks to formalize logistics system behaviour under conditions of uncertainty and resource constraints, assess the impact of disruptive factors on logistics performance, and propose modelling approaches that support the optimization and resilience of logistics systems. The results are intended to contribute to the improvement of analytical tools for logistics management and to support decision-making processes in conditions of systemic instability.

Economic and mathematical modelling constitutes an essential analytical instrument for studying logistics systems under conditions of instability, where traditional deterministic planning approaches lose their effectiveness. Instability in logistics is manifested through unpredictable changes in demand, disruptions of transport and infrastructure networks, limited availability of resources, and heightened operational risks. In such an environment, logistics systems require not only operational flexibility but also analytically grounded mechanisms for maintaining continuity and economic sustainability.

A defining feature of economic and mathematical modelling in unstable logistics environments is its capacity to structure complex economic relationships in a formalized manner. Logistics systems can be represented as interconnected networks of flows, costs, capacities, and constraints, enabling the identification of systemic dependencies and vulnerabilities. This formalization is particularly important under instability, where even minor disruptions may generate disproportionate economic consequences across supply chains.

Another important characteristic of economic and mathematical modelling in logistics is its emphasis on constraint-oriented analysis. Under unstable conditions, logistics decision-making is limited by reduced transport capacities, constrained inventories, time delays, and financial restrictions. Unlike classical optimization models that assume relatively stable parameters, models designed for instability explicitly incorporate constraints as central elements. This allows for the assessment of feasible logistics configurations rather than purely optimal ones, which is more consistent with real-world conditions of systemic stress.

In conditions of instability, economic and mathematical modelling shifts its analytical focus from efficiency maximization toward continuity preservation and system resilience. The objective of logistics management evolves from minimizing costs to ensuring acceptable levels of system functioning under adverse conditions. Modelling tools thus serve to evaluate trade-offs between cost increases and the preservation of logistics flows, supporting economically rational decision-making in volatile environments.

A further feature of economic and mathematical modelling in logistics under instability is its suitability for generalized and scenario-based analysis. Theoretical models enable the examination of different instability scenarios—ranging from moderate disruptions to severe systemic shocks—without reliance on detailed empirical datasets. This abstraction is particularly valuable when reliable data are unavailable or rapidly changing, allowing for the development of adaptive strategies and contingency planning frameworks.

From a practical standpoint, the application of economic and mathematical modelling enhances strategic logistics planning and risk management. By identifying critical logistics links, bottlenecks, and resource constraints, such models support informed decision-making aimed at sustaining logistics continuity. Consequently, economic and

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mathematical modelling contributes to strengthening the adaptive capacity of logistics systems and improving their ability to function under prolonged instability.

Table

Specific Features of Economic and Mathematical Modelling in Logistics under Conditions of Instability

Aspect of modelling	Characteristics under stable conditions	Characteristics under conditions of instability
Planning horizon	Long-term, predictable	Short- to medium-term, adaptive
Primary objective	Cost minimization and efficiency	Continuity preservation and resilience
Role of constraints	Secondary, often flexible	Central and binding
Treatment of uncertainty	Limited, often ignored	High, explicitly considered
Data requirements	Detailed and stable datasets	Generalized or scenario-based data
Model outcomes	Optimal solutions	Feasible and robust solutions
Practical application	Operational optimization	Strategic planning and risk management

Logistics continuity under conditions of instability can be formally represented through an economic and mathematical framework based on constrained system functioning. In unstable environments, logistics systems operate under limited resources, reduced infrastructure capacity, and increased uncertainty, which necessitates a formalized representation of trade-offs between costs and continuity requirements. In this context, economic and mathematical modelling provides a structured analytical basis for capturing the interactions between resource limitations, system capacities, and minimum continuity thresholds. Such a framework enables the abstraction of logistics system behaviours from specific operational details and allows for the generalization of continuity conditions applicable to various forms of instability. As a result, logistics continuity can be examined not only as an operational objective but also as an economically conditioned system property determined by quantitative constraints and strategic priorities.

Let the logistics system be represented as a network of logistics flows. The volume of logistics flow is denoted as x_i, where i=1,2,…,n represents individual logistics channels or routes. The total logistics cost of system functioning under instability can be expressed as:

$$C = \sum_{i=1}^{n} c_i x_i ,$$

where c_i denotes unit logistics costs associated with the i-th flow. Under conditions of instability, unit costs tend to increase due to capacity constraints, longer routes, and elevated risk levels.

Logistics continuity is ensured if the system satisfies minimum flow requirements necessary for maintaining economic functioning. This condition can be represented as:

$$\sum_{i=1}^{n} x_i \geq Q_{min} ,$$

where Q_{min} is the minimum aggregate logistics volume required to preserve continuity of economic processes.

At the same time, logistics systems under instability are subject to resource and capacity constraints, which can be formalized as:

$$x_i \leq K_i ,$$

where K_i represents the maximum feasible capacity of the i-th logistics channel under unstable conditions.

An important result of the theoretical analysis is the identification of the feasibility region of logistics continuity. Unlike classical optimization models that aim to determine a single optimal solution, instability-oriented modelling focuses on identifying a set of feasible solutions that ensure continuity while respecting system constraints:

$$\mathcal{F} = \left\{ x_{i \left| \sum_{i=1}^{n} x_i \geq Q_{min,0 \leq x_i \leq K_i} \right.} \right. .$$

This feasible region reflects the adaptive potential of the logistics system and defines the boundaries within which logistics continuity can be maintained despite adverse conditions.

From an economic perspective, the results indicate that maintaining logistics continuity may require accepting higher total logistics costs. This trade-off can be expressed through the continuity–cost relationship:

$$\mathrm{C} = \int (Q_{\min}), \frac{dC}{Q_{min}} > 0 ,$$

which implies that higher continuity requirements are associated with increased logistics expenditures. However, such cost increases are

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economically justified, as they prevent systemic disruptions and larger macroeconomic losses.

Thus, the economic and mathematical representation developed in this study confirms that logistics continuity under instability is determined not by cost optimality, but by the ability of the system to operate within feasible boundaries defined by continuity constraints, capacity limitations, and resource availability. The obtained theoretical results allow for a generalized interpretation of logistics continuity as an economically constrained equilibrium rather than an optimal state. Under conditions of instability, logistics systems do not strive for cost minimization in the classical sense; instead, they aim to remain within a feasible operating zone that ensures the minimum acceptable level of logistics performance. This shifts the analytical focus toward identifying stability thresholds beyond which logistics continuity can no longer be maintained.

The analysis confirms that logistics continuity is strongly dependent on the structural configuration of logistics flows and the degree of flexibility embedded in the system. Systems characterized by diversified routes, reserve capacities, and adaptable resource allocation mechanisms demonstrate a wider feasibility region and greater tolerance to instability. Conversely, highly centralized and rigid logistics structures exhibit a narrow feasibility space, making them more vulnerable to extreme disruptions.

From an economic perspective, the results emphasize that the preservation of logistics continuity generates long-term economic benefits that outweigh the short-term increase in logistics costs. While higher continuity requirements lead to increased expenditures, the avoidance of systemic breakdowns, supply shortages, and production interruptions significantly reduces aggregate economic losses. Thus, continuity-oriented logistics strategies should be considered economically rational under conditions of persistent instability.

Theoretical modelling also highlights the role of prioritization in logistics decision-making under unstable conditions. When resources and capacities are limited, logistics continuity can be achieved by prioritizing critical flows that support essential economic functions. Economic and mathematical representations provide a structured basis for defining such priorities and for evaluating their economic implications in a consistent manner.

Finally, the results indicate that economic and mathematical modelling serves not only as an analytical tool but also as a conceptual framework for understanding logistics behaviour under instability. By formalizing relationships between costs, capacities, and continuity constraints, modelling supports the development of adaptive logistics strategies and enhances the strategic resilience of economic systems.

Conclusion. The study demonstrates that economic and mathematical modelling provides an effective theoretical framework for analysing logistics continuity under conditions of instability. In contrast to traditional logistics approaches focused on cost optimization, continuity-oriented modelling emphasizes the importance of maintaining feasible system functioning within constrained economic and infrastructural environments. This shift in analytical perspective allows logistics continuity to be interpreted as an economically conditioned equilibrium rather than an optimal state. The results confirm that logistics systems operating under instability are primarily limited by resource availability, infrastructure capacity, and minimum continuity requirements. Economic and mathematical representations enable the formalization of these constraints and support the identification of feasible operating regions within which logistics systems can sustain essential flows. Such an approach contributes to a deeper understanding of system resilience and adaptive potential in volatile conditions. It is established that ensuring logistics continuity may require accepting higher logistics costs; however, these costs are economically justified by the prevention of systemic disruptions, supply shortages, and broader macroeconomic losses. Continuity-oriented logistics strategies therefore represent a rational response to persistent instability, balancing short-term expenditures against long-term economic stability. The findings highlight the practical value of economic and mathematical modelling as a decision-support tool for logistics planning and risk management. By enabling the prioritization of critical flows and the rational allocation of limited resources, modelling enhances the capacity of logistics systems to operate under uncertainty. The results of this study can serve as a theoretical basis for further research aimed at developing adaptive logistics strategies and improving the resilience of economic systems facing extreme disruptions.

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Срібна Є. В. [1; ORCID ID: 0000-0002-6676-0606],
к.е.н., доцент,
Ступницький В. В. [2; ORCID ID: 0000-0001-8845-7643],
к.е.н., доцент

[1]Національний університет водного господарства та природокористування, м. Рівне
[2]Дубенська філія вищого навчального закладу «Відкритий університет розвитку людини «Україна», м. Дубно

ЕКОНОМІКО-МАТЕМАТИЧНІ МОДЕЛІ ЗАБЕЗПЕЧЕННЯ БЕЗПЕРЕРВНОСТІ ЛОГІСТИКИ В УМОВАХ НЕСТАБІЛЬНОСТІ

Зростання рівня економічної нестабільності в сучасних умовах суттєво підвищує вразливість логістичних систем і актуалізує проблему забезпечення безперервності логістичних процесів за наявності ресурсних, інфраструктурних та економічних обмежень. Порушення функціонування логістики негативно впливає на стійкість підприємств, регіонів і національних економік, зумовлюючи необхідність переосмислення традиційних підходів до управління логістичними

системами. Метою статті є обґрунтування ролі економіко-математичного моделювання як теоретичного інструменту аналізу безперервності логістики в умовах нестабільності, що характеризуються високим рівнем невизначеності, обмеженістю ресурсів та зниженням пропускної спроможності логістичної інфраструктури. У дослідженні безперервність логістики розглядається не як оптимальний результат функціонування системи, а як досяжний допустимий стан, сформований під впливом економічних і потужнісних обмежень. У межах теоретичного підходу логістичну систему подано у вигляді мережі потоків з обмеженою пропускною спроможністю, для якої безперервність забезпечується виконанням мінімальних вимог до обсягів логістичних потоків. Запропонована економіко-математична інтерпретація дозволяє формалізувати взаємозв'язки між логістичними витратами, наявними ресурсами та пороговими значеннями безперервності, а також визначити область допустимих рішень функціонування системи в умовах нестабільності. Результати дослідження свідчать, що забезпечення безперервності логістики зазвичай супроводжується зростанням сукупних логістичних витрат, однак такі витрати є економічно виправданими з огляду на запобігання системним збоям, дефіциту постачання та довгостроковим макроекономічним втратам. Застосування економіко-математичного моделювання сприяє обґрунтованій пріоритезації критичних логістичних потоків і раціональному розподілу обмежених ресурсів. Практична цінність отриманих результатів полягає у можливості їх використання в стратегічному плануванні логістики та управлінні ризиками в умовах нестабільного економічного середовища. Дослідження формує теоретичне підґрунтя для подальшого розвитку адаптивних і стійких логістичних систем.

Ключові слова: безперервність логістики; економіко-математичне моделювання; нестабільність; логістичні системи; ресурсні обмеження.

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