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LOGISTIC SUPPLY CHAIN MODELING IN THE ARMED FORCES: THEORETICAL APPROACHES AND OPTIMIZATION METHODS

Huseyn-Zada Karim
Baku State University, Baku, Azerbaijan

Talibov Aziz Mashalla
ScD, professor
İnstitute of Control Systems, Baku, Azerbaijan

Hashimov Elshan Giyas
ScD, professor
Azerbaijan Technical University, Baku, Azerbaijan
National Defense University, Baku, Azerbaijan

Summary. *This article examines the theoretical foundations and optimization methods of logistic supply chain management in the Armed Forces of Azerbaijan. It highlights the decisive role of logistics in modern warfare by analyzing lessons from recent conflicts and comparing military and commercial supply chains. The study emphasizes the importance of transport logistics systems and explores mathematical and algorithmic approaches including Mixed Integer Linear Programming (MILP), simulation models and game theoretic methods for enhancing efficiency, resilience and flexibility. Comparative analysis with international practices, particularly NATO standards and Industry 4.0 applications, reveals both strengths and areas for improvement in Azerbaijan's logistics model. The findings suggest that integrating scientific optimization methods and advanced technologies into logistic support systems can significantly strengthen combat readiness, ensure sustainable supply and improve resource utilization in both wartime and peacetime contexts.*
Keywords: *Military logistics; supply chain management; transport logistics systems; optimization methods; Mixed Integer Linear Programming (MILP); simulation models; game theory; NATO standards; Azerbaijan Armed Forces; defense capability.*

Introduction

In modern warfare, the role of logistic support is of decisive importance. Even the best operational plans may collapse if supply lines are weakened or disrupted. For example, during the Second Karabakh War in 2020, the Azerbaijani Armed Forces used unmanned systems to destroy enemy bridges, logistics hubs, and supply convoys, which led to the isolation of front-line units. In the 2022 war in Ukraine, the Russian army's logistical shortcomings and the disruption of its supply chain paralyzed operational capabilities on certain fronts - within a few weeks, more than 50 ammunition depots were destroyed, and the inability to deliver supplies to the front line significantly weakened the enemy's offensive potential. These experiences demonstrate that any army, including the Armed Forces of Azerbaijan, must possess an effective logistic support model to ensure sustainable combat capability.

For this purpose, the professional management of the supply chain within the armed forces and the optimization of transport-logistics systems are of exceptional importance. This article examines the theoretical foundations of the logistic model of supply in the Azerbaijani Armed Forces and presents approaches focused on optimization. Comparative analysis with existing international models in the field of military logistics and defense technologies will be conducted, and the application of optimization methods such as Mixed-Integer Linear Programming (MILP), simulation models, and game theory will be discussed. The aim of the article is to propose scientifically grounded solutions to enhance the efficiency of the military supply chain.

Military logistics and supply chain management

NATO defines logistics as the science of planning and executing the movement and sustainment of forces. Logistics encompasses the acquisition, storage, transportation, distribution, and disposal of weapons and ammunition; the transportation of personnel; construction and engineering support; maintenance and repair services; medical support; and many other functions. In modern management, the concept of logistics has expanded further to include the supply chain, which integrates the entire process from the producer to the end user. In the U.S. Department of Defense's 2010 Logistics Strategic Plan, the transition from traditional logistics to supply chain management (SCM) was emphasized. As a result, the DoD began to standardize its vast supply system through the Supply Chain Operations Reference (SCOR) model across the phases of planning, sourcing, production/maintenance, delivery, return, and support.

The objective of the military supply chain, unlike in the business sector, is not maximizing profit but ensuring the highest possible level of combat readiness. In other words, while commercial companies aim to optimize supply networks for cost efficiency, military logistics is primarily directed at ensuring operational readiness and minimizing shortages. In military supply chains, the main goal is not so much to minimize inventory holding costs but to prevent stock outs. Moreover, in wartime, the volume and type of demand are unstable and difficult to predict in advance; supply sources and routes frequently change, which makes them fundamentally different from the stable, demand-driven models used in the civilian sector. Consequently, military logistics managers must account for factors beyond their control (e.g., allied supplies or processes forming part of the civilian supply chain) and create buffer stocks to mitigate unexpected delays and losses. For example, in a volatile and uncertain environment, it becomes necessary to maintain additional stockpiles at field level - a practice that in commercial contexts often leads to the so-called "bullwhip effect."

Military logistics activities are carried out at the strategic, operational, and tactical levels. According to NATO's concept, logistics functions are divided into three categories: production logistics (planning, procurement, and production of weapons and equipment); in-service logistics (supply, storage, and maintenance of material in use by the armed forces); and operational/consumer logistics (direct support and sustainment of forces in combat areas). At the operational (consumer) logistics stage, functions such as the accumulation of supplies, storage at depots, transportation to the front line, and the removal of obsolete or damaged material are carried out. Due to this multi-level structure, logistical measures taken at the tactical level can directly influence strategic outcomes. Thus, as the effectiveness of logistical processes increases, the armed forces become more agile and resilient, gaining a strategic advantage. Conversely, weak logistical support can slow operational tempo and directly affect the outcome of a conflict. Possessing a highly efficient logistics system grants a country the capacity for long-term warfare and enhances strategic endurance.

The multi-level structure of military logistics, covering the stages from central depots to front-line units, is illustrated in the schematic model shown in Figure 1. The model presented in Figure 1 demonstrates a multi-tiered logistics network in the Armed Forces, beginning from central depots, moving through regional and unit-level warehouses, and ultimately reaching combat units. This fragmented structure can sometimes result in uneven distribution of resources, with oversupply in some directions and shortages in others. Therefore, modern military logistics concepts emphasize the necessity of integrating and optimizing such systems.

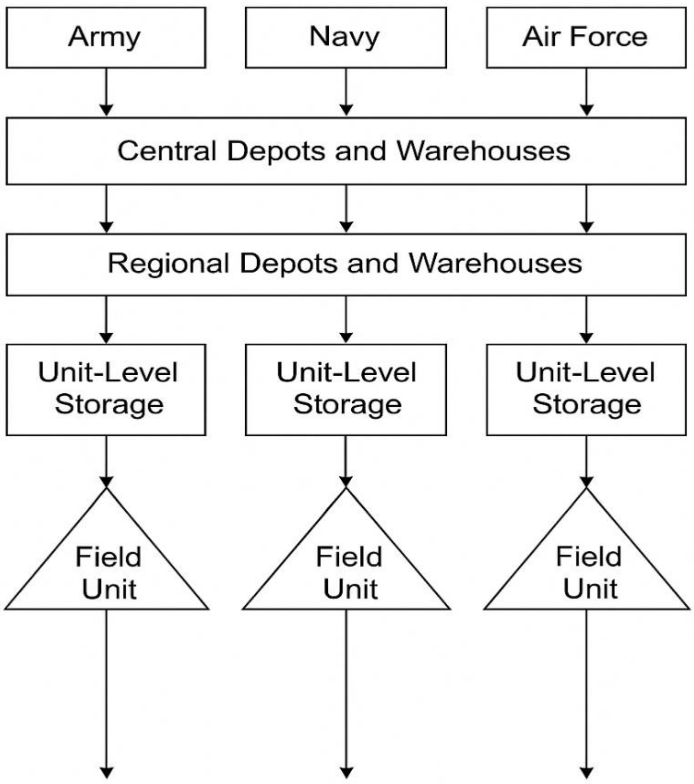

Fig. 1. Basic structure of a military supply chain

Table 1 below summarizes the main differences between commercial and military supply chains.

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Table 1

Key differences between commercial and military supply chains

Aspect	Commercial supply chain	Military supply chain
Objective	Maximization of profit, minimization of costs	Maximization of combat capability (readiness), minimization of shortages
Nature of demand	Relatively stable and predictable (based on market demand)	Unstable, volatile, and sometimes unpredictable (rapidly changing during conflict)
Network structure	Integrated, efficient distribution network (with minimal intermediaries)	Multi-tiered, separate logistic networks by service branch (difficult to integrate, risk of redundancy and delays)
Inventory management	"Just-in-time" principle, minimal stock levels (for cost savings)	Safety stocks and surplus reserves (maintaining additional supplies to ensure continuity in combat)
Key performance indicators (KPI)	Cost efficiency, delivery time, customer satisfaction level	Combat readiness, timeliness and sustainability of supply, minimization of losses and delays (e.g., equipment availability rate, supply coverage rate)
Procurement criteria	Price and efficiency-based (selection of the cheapest, most effective supplier)	Reliability and security-based (critical materials sourced locally or from allies, via fast and secure channels)

The role of transport-logistics systems

The role of transportation infrastructure and delivery systems in the supply chain of the Armed Forces is undeniable. In logistic support, two main aspects of transportation are distinguished -strategic and tactical transportation. Strategic transportation refers to the large-scale delivery of materiel and personnel from the point of origin to the theater of operations (rear bases near the combat zone), often involving intercontinental or long-distance movements of ammunition, equipment, and supplies. Tactical (operational) transportation, on the other hand, covers the movement of supplies from the operations theater directly to combat positions, that is, to front-line units. Tactical transportation is carried out with smaller units (e.g., company-level convoys), which may operate under enemy fire and therefore require additional protection and flexibility. This distinction shows that at the strategic level, the primary concern is the timely delivery of bulk supplies over long distances, while at the tactical level, the focus shifts to ensuring secure and rapid distribution along the "last mile."

The proper organization of transport networks and the integration of multimodal transport play a critical role in the supply system of the Armed Forces. To illustrate this, a typical structure of a regional logistics network is presented in diagram form (Figure 2).

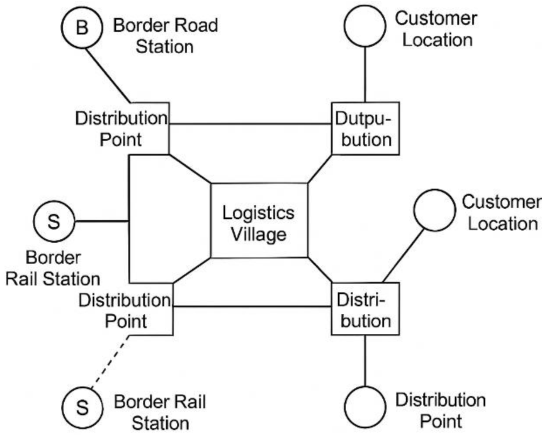

Fig. 2. **Logistics transport network configuration (example from a regional supply network)**

Figure 2 illustrates a network structure showing that the integration of road and rail connections through a logistics village (hub) enables more efficient distribution of supplies. Such a model serves to identify critical routes and optimize logistic flows.

In military operations, the establishment of bases, the organization of supply along lines of communication, and the creation of distribution networks are among the main challenges faced by logisticians. The infrastructural capacity and geographical conditions of a potential theater of operations directly affect supply planning. When distances are great or the road-transport network is underdeveloped, it becomes difficult to deliver supply convoys to their destination on time. In this regard, four factors known as the "4D" (Demand, Distance, Destination, and Duration) are considered during operational planning. These 4D parameters characterize the logistic requirements of each mission and help determine the scope, routes, and duration of supply planning. For example, in a short-term local operation, supply demand is relatively low and the duration short, whereas in a long-term operation conducted in a distant theater, demand is high, distances are large, destinations are dispersed, and the duration extended- factors that significantly affect the structure of the supply chain.

Recent studies on the improvement of the transport-logistics system of the Armed Forces of Azerbaijan show that establishing logistics centers is a promising approach to optimizing the supply process. Building supply-distribution hubs at optimal locations across the country can increase efficiency by reducing distances and centralizing the allocation of resources. Research by A.M. Talibov and others has proposed models to determine the optimal number and location of logistics centers to be used when redeploying troops to combat areas. In one study conducted in 2023, this location-allocation problem was solved based on cost-effectiveness criteria, and as a result, the most efficient placement of logistics centers along Azerbaijan's main highways was determined, taking into account movement trajectories. Such optimization allows for the rapid redistribution of reserves and faster delivery to troops via warehouses situated at the intersections of different supply routes. Additional benefits include reducing congestion in the logistic network, avoiding redundant supply operations, and minimizing overall transport costs.

Various indicators are considered to improve the efficiency of military transport processes. Studies show that, within the framework of automotive-technical support, criteria such as the loading efficiency of vehicle fleets, minimizing empty mileage, centralized delivery, and route optimization are of particular importance. Multi-criteria optimization models built on these indicators not only enable more efficient use of transport resources and reduction of transport costs but also improve the timeliness and reliability of the supply process. For example, a model proposed in Azerbaijan simultaneously considers economic, technical, and tactical parameters, aiming to ensure on-time delivery of loads, operational readiness of troops, and optimal allocation of limited transport assets. By incorporating dynamic real-world constraints (such as the capacity of the road network, vehicle load limits, and security risks) this model seeks to guarantee the execution of military transport without delays and with minimum risk. As a result, the optimization of transport-logistics systems makes the supply activities of the Armed Forces more timely, efficient, and reliable.

Optimization Methods and Algorithms

The improvement of military logistics systems widely relies on mathematical models and algorithms. Optimization approaches play a crucial role in determining the optimal structure of supply networks, allocating reserves, selecting transportation routes, and making other critical decisions. Below, some of the main optimization methods applied in the supply processes of the Armed Forces are examined.

Mixed-Integer Linear Programming (MILP). MILP is one of the most widely applied approaches for the mathematical modeling and optimization of military logistics problems. Through MILP, decision-making problems at almost all levels of the supply chain can be solved: optimal location of depots and bases, routing optimization of transport loads, planning of inventory levels across different time periods, production-distribution scheduling, and more. For example, in a study of the supply network of the Korean military, researchers used a MILP model to minimize total supply costs by determining the optimal number and locations of logistic consolidation centers. This model aimed to integrate the multi-tiered supply network separately managed by three different service branches (army, navy, air force) and demonstrated quantitatively the benefits of creating joint logistic centers instead of maintaining separate depots. The results showed that, since the primary objective of military supply chains is minimizing shortages rather than reducing inventory costs, location-allocation decisions must be based on different criteria compared to civilian models.

The MILP approach applied to the optimization of military logistics networks is a multi-component framework consisting of input parameters, objective functions, constraints, and output decisions. A conceptual model representing this structure is depicted in Figure 3.

As shown in Figure 3, the schematic model clearly demonstrates that MILP creates a multi-level decision-making framework for logistics optimization. Here, input parameters (such as demand forecasts, transport options, capacity, and costs) are processed under defined objective functions, and then, under the influence of constraints, optimal decisions (such as route selection, vehicle assignment, and scheduling) are obtained. Such a model enables risk reduction and more efficient use of resources in military logistics systems.

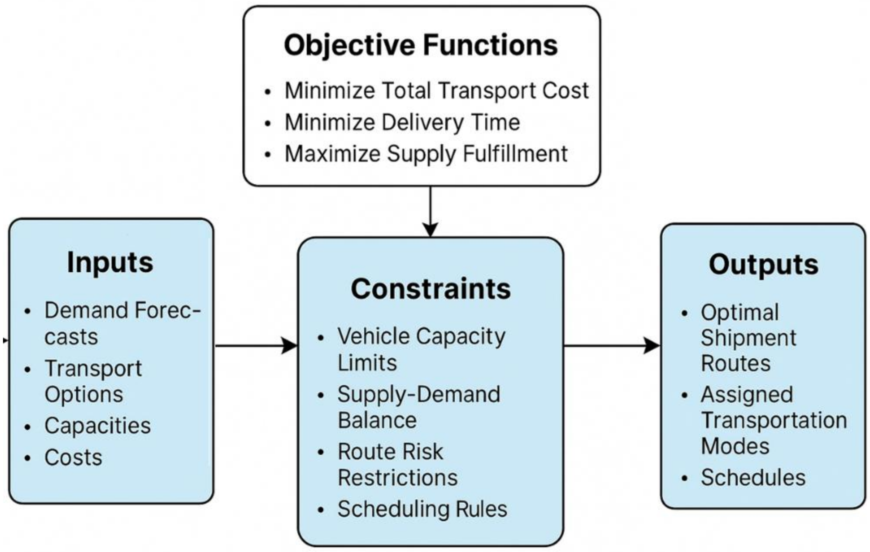

Fig. 3. Mixed-integer linear programming (MILP) model structure for logistics optimization

Similarly, optimization models that take into account the dynamic conditions of wartime operations also exist. For instance, a dynamic MILP model has been developed to address the problem of locating and relocating supply units as the front-line advances. In this model, the relocation of several combat-support units across different time periods, the selection of safe positions, and the planning of supply volumes are optimized simultaneously. The objective function seeks to minimize total risk, measured by indicators such as the volume of unmet demand, the probability that a supply site will be exposed to enemy threats, and the operational downtime caused by relocation. Such models are typically solved with exact methods for small- and medium-sized problems, but as problem size grows, hybrid methods become necessary. For the above-mentioned dynamic location problem, the authors developed an efficient hybrid genetic algorithm that produced near-optimal solutions. This demonstrates that integrating meta-heuristic algorithms within the MILP framework is practically essential for the optimization of complex, large-scale military logistics systems.

Simulation Models. In military logistics planning, simulation approaches are indispensable for accounting for real-world uncertainties and system dynamics. Using Discrete Event Simulation (DES) and Agent-Based Modeling (ABM), supply processes can be replicated in a virtual environment and the behavior of the logistics system observed under different scenarios. Simulation models make it possible to represent random events that may occur on the battlefield (e.g., demand fluctuations, transportation delays, infrastructure damage, equipment breakdowns, etc.). As a result, it becomes possible to evaluate in advance how effective the solutions proposed by an optimization model would be in real-world conditions.

For example, in one two-stage integrated method combining optimization and simulation, solutions obtained through MILP can be tested in an agent-based

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simulation environment. Such integration helps compensate for the shortcomings of optimization by reflecting the complexity of real systems. Through such approaches, decision-makers can stress-test existing logistic plans under worst-case scenarios and take preventive measures where necessary. In general, simulation models are an important component of military logistics decision-support systems, complementing optimization algorithms and enabling more resilient and synergistic solutions.

In the analysis of military logistics systems, simulation approaches and game-theoretic models play an important role. To demonstrate their application, an example of a logistics system constructed in a simulation environment is presented in Figure 4.

Figure 4 illustrates a simulation model that makes it possible to track the dynamics of logistic processes and identify weak links in the network. When such simulation is combined with game-theoretic approaches, the resilience of military supply under uncertain and contested conditions can be evaluated more effectively.

Game theory applications. In environments where enemy threats are present, logistics planning can be modeled through game theory. In this approach, the selection of supply routes is considered alongside the probability that the adversary may attack those routes. The problem of optimizing a logistics system in a contested environment can be formulated as a two-player confrontation: one side seeks to execute logistics support as effectively as possible, while the other attempts to disrupt it (e.g., by attacking convoys or destroying roads). To mathematically describe this interaction, two-player zero-sum game models are employed.

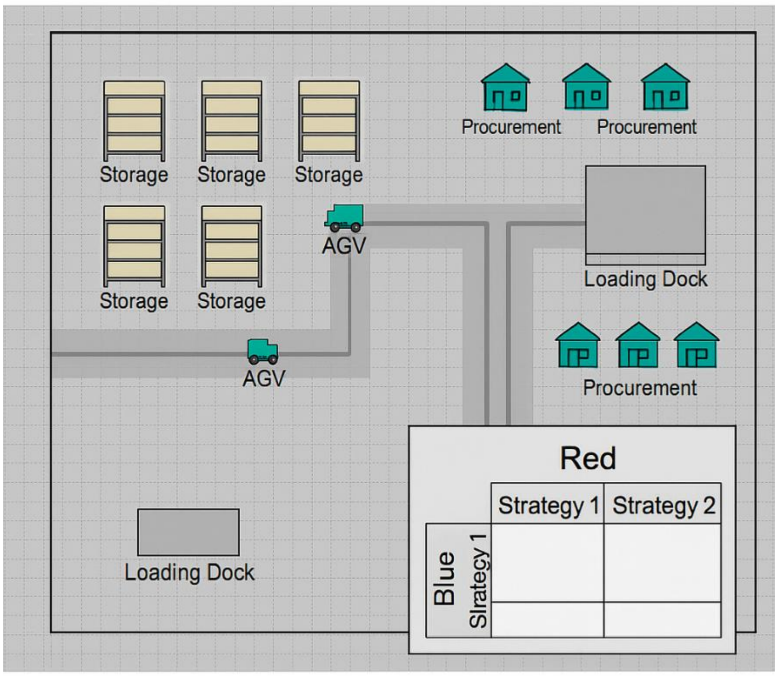

Fig. 4: **Simulation of a logistics system (screenshot of a discrete-event simulation model)**

For instance, a representative model that accounts for enemy interdiction of supply is the Contested Logistics Game. In this model, Nash equilibrium is applied between the logistics plan and the adversary's attack plan, meaning optimal strategies for both sides are determined at equilibrium. The logistics system is modeled as a graph (such as a road network), incorporating the transportation of loads by various means (e.g., trucks, trains, aircraft), as well as storage possibilities (e.g., holding reserves at intermediate depots). The adversary, in turn, has the ability to cut certain edges (routes) in the graph. To solve the problem, an iterative double-oracle algorithm is proposed: in this method, for a fixed defender strategy, the adversary's best attack strategy is computed (as an MILP solution), and vice versa, for a fixed adversary strategy, the defender's best logistics plan is obtained (again a MILP solution). This process continues until equilibrium is reached. The model is tested under various scenarios and can even be applied on real maps. Such game-theoretic approaches demonstrate that supply routes planned with prior consideration of potential enemy attacks are more resilient, yielding significant advantages compared to naïve logistics plans (i.e., those constructed without accounting for the adversary). Future research in this field may also extend to contested logistics in cyberspace (e.g., information-logistics networks), since in modern warfare cyber supply channels are as much a target as physical supply chains.

It should be noted that the application of optimization tools is not limited to MILP, simulation, and game theory. Depending on the specific problems of military logistics, other methods such as multi-criteria decision-making (AHP, ANP), graph theory (e.g., network flow models), support vector machines (e.g., for demand forecasting), and various artificial intelligence techniques are also employed. However, the focus of this article is on the optimization of the supply model of the Armed Forces, with the methods mentioned above being the most relevant in this context.

Comparison with international experience

There are many lessons that the Armed Forces of Azerbaijan can draw from international experience in improving their logistic support model. Advanced militaries have tested innovative solutions and established standards in the field of logistics over many years. For example, at the strategic level, NATO has developed joint planning and information-sharing mechanisms to coordinate the logistics activities of member states. In NATO's *Resilient Sustainment* strategy, particular emphasis is placed on increasing the resilience and flexibility of supply chains. Armies such as the German Bundeswehr are seeking to enhance efficiency by applying elements of the Industry 4.0 revolution (IoT sensors, automation, robotic technologies, etc.) in their logistics systems. The U.S. military is testing innovations such as autonomous trucks (Leader-Follower convoy systems) and warehouse robots-technologies that reduce personnel requirements and prevent casualties in high-risk zones. At the same time, leading armies have begun using artificial intelligence algorithms for processing large volumes of logistic data to support rapid decision-making (e.g., demand forecasting, predictive maintenance of equipment, and analytical models for supply planning). Such technological adaptations improve the transparency of logistic processes but also create new vulnerabilities. Highly automated systems are potentially exposed to cyberattacks, which compels militaries to safeguard both digital and physical supply chains.

When compared with international models, both strengths and areas for improvement emerge in Azerbaijan's logistics system. As in many post-Soviet armed

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forces, a certain degree of centralization in logistic functions exists in the Azerbaijani Armed Forces, but full adoption of NATO-style integrated supply chain management has not yet occurred. During joint exercises and peacekeeping missions, Azerbaijani logistics have demonstrated flexibility; however, gaps remain in modern standards such as asset visibility and real-time supply tracking. International practice shows that a unified logistics information system (e.g., NATO Logistics Functional Services) enables real-time sharing of all supply data, which accelerates decision-making and reduces errors. Considering Azerbaijan's growing role in the region and potential participation in coalition operations, the interoperability of the national logistics system (i.e., its ability to work in alignment with allied systems) becomes a key priority.

Compared with existing international models, the Armed Forces of Azerbaijan also possess certain advantages. The country's small geographic size allows for a relatively compact logistics infrastructure, where short internal lines enable rapid distribution of supplies. At the same time, however, this creates a risk of over-concentration of reserves at a limited number of bases- which may become vulnerable points in the event of enemy attack. As emphasized in NATO doctrine, supply systems should be organized in a dispersed manner, with strategic depots and fuel supply points geographically separated. The targeting of enemy logistic hubs during the Second Karabakh War once again confirmed this lesson. Modern international approaches also underline the necessity of camouflage for logistic elements, deception using decoys (e.g., dummy equipment), and the pre-planning of alternative supply routes. In this regard, it is recommended that Azerbaijan update its existing concepts and doctrines, incorporating the lessons of the 44-day war to implement reforms that will strengthen combat resilience in the logistics domain.

Conclusion

In conclusion, the analysis shows that the scientific improvement of the logistic support model in the Armed Forces of Azerbaijan is of strategic importance for strengthening defense capability. By structuring the supply chain in accordance with modern management principles, optimizing transport-logistics infrastructure, and applying decision-support tools based on mathematical models, military logistics can become more agile, reliable, and efficient. Comparisons with international models reveal useful directions for the development of Azerbaijan's logistics system: improving reserve planning, creating a diversified supply infrastructure, and ensuring real-time information flows. Optimization approaches (MILP models, simulation, game theory, etc.) ground decision-making in scientific methods, contributing both to increased efficiency and to risk reduction in combat conditions.

The findings indicate that specialized software and analytical tools are playing an increasingly important role in the logistics activities of the Armed Forces. Local researchers also emphasize the necessity of developing dedicated decision-support systems that reflect the realities of military logistics and enable flexible and operational planning. Through such systems, planning processes can be automated, supply requirements can be forecast based on big data analysis, and real-time adaptation to changing conditions can be ensured.

As a result, the application of theoretically grounded optimization approaches in logistic support will not only strengthen the combat capabilities of the Azerbaijani Armed Forces but also contribute to efficient resource use and flexible management

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in peacetime. The lessons of recent conflicts clearly show that an army with strong logistics can achieve its strategic objectives with greater confidence - "when troops are left without logistics, even the most perfect plans collapse in no time," as history has repeatedly proven. Therefore, the modernization of the logistic support model in the Armed Forces must remain at the center of defense planning and be continually enriched with scientific innovations.

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МОДЕЛЮВАННЯ ЛОГІСТИЧНОГО ЛАНЦЮГА ПОСТАЧАНЬ У ЗБРОЙНИХ СИЛАХ: ТЕОРЕТИЧНІ ПІДХОДИ ТА МЕТОДИ ОПТИМІЗАЦІЇ

Гусейн-Зада Карім
Бакинський державний університет, Баку, Азербайджан
Талібов Азіз Машалла
д-р. наук, професор
Інститут систем управління, Баку, Азербайджан
Хашимов Елшан Гіяс
д-р. наук, професор
Азербайджанський технічний університет, Баку, Азербайджан
Національний університет оборони, Баку, Азербайджан

Анотація. *У цій статті розглядаються теоретичні основи та методи оптимізації управління логістичним ланцюгом поставок у Збройних силах Азербайджану. Вона підкреслює вирішальну роль логістики в сучасній війні, аналізуючи уроки нещодавніх конфліктів та порівнюючи військові та комерційні ланцюги поставок. У дослідженні підкреслюється важливість транспортних логістичних систем та досліджуються математичні та алгоритмічні підходи, включаючи змішане цілочисельне лінійне програмування (MILP), імітаційні моделі та методи теорії ігор для підвищення ефективності, стійкості та гнучкості. Порівняльний аналіз з міжнародною практикою, зокрема стандартами НАТО та застосуваннями Industry 4.0, виявляє як сильні сторони, так і напрямки для вдосконалення логістичної моделі Азербайджану. Результати дослідження свідчать про те, що інтеграція наукових методів оптимізації та передових технологій у системи логістичного забезпечення може значно посилити бойову готовність, забезпечити стале постачання та покращити використання ресурсів як у воєнний, так і в мирний час.*

Ключові слова: *військова логістика; управління ланцюгами поставок; системи транспортної логістики; методи оптимізації; змішане цілочисельне лінійне програмування (MILP); імітаційні моделі; теорія ігор; стандарти НАТО; Збройні сили Азербайджану; обороноздатність.*

