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## MODELING AND ANALYSIS OF LOGISTICS SUPPLY AND DISTRIBUTION ROUTES FOR HIGH-TECH PRODUCTS CONSIDERING DIFFERENT MODES OF TRANSPORT

The **subject** of the article is the processes of organizing and optimizing the logistics of supply and distribution of high-tech defense products under wartime conditions, in particular, the development of a network-based logistics structure taking into account reverse flows, risks, and limited resources. The **purpose** of the study is to develop a model of supply and distribution routes that optimizes delivery time and costs while simultaneously reducing the risks of cargo loss and increasing the transport utilization rate. **Tasks** to be solved: to form a generalized combined structure of the logistics chain; to identify and analyze the main parameters of supply and distribution routes across different modes of transport; to develop a computer experiment plan; to conduct simulation modeling of supply and distribution routes; and to develop practical recommendations for implementing logistics projects under wartime conditions. **Research methods** and tools: a systems approach, simulation modeling, graphical and comparative analysis, and the AnyLogic platform. **Results** obtained: A combined structure of the logistics chain for a military drone manufacturing enterprise with multiple route options is schematically presented. A model is proposed that formalizes the logistics chain as a network of nodes and arcs within a transport system and includes a set of input parameters describing vehicles, routes, and order characteristics. The essence of the computer experiment lies in reproducing the properties of infrastructure and logistics projects using a discrete-event simulation model, which makes it possible to analyze critical parameters separately for supply and distribution, as well as to model cases of their interdependence. Particular attention is paid to the separation of routes into supply and distribution, as well as to the use of different modes of transport. **Conclusions**: The obtained results confirm that a decisive factor in logistics decision-making is a balanced ratio between economic costs, risk level, and expected effect. The proposed approach enables a quantitative assessment of management decision options within supply and distribution logistics chains of manufacturing enterprises, thereby increasing the validity of choosing an optimal development strategy.

**Keywords**: logistics; supply chain; risk management; optimization; combined structure; simulation modeling; alternative routes; supply and distribution; manufacturing enterprise; AnyLogic.

### Introduction

Efficient management of logistics flows is a key factor in enhancing the competitiveness of manufacturing enterprises. In the current context of rising demand and constrained transportation infrastructure under martial law, the optimization of delivery routes for raw materials, components, and finished products plays a crucial role.

Modern logistics systems of manufacturing enterprises are characterized by a high level of complexity and a multi-level structure. They encompass a network of raw material and component suppliers, manufacturing plants, warehouses, and end consumers, among which material, informational, and financial flows are organized. The effective functioning of such a system depends on the coordination of all elements of the chain, the optimization of transportation routes.

The study of logistics systems under martial law conditions is further complicated by the fact that the response of the transport and logistics network to changes in management parameters may manifest over months

or even years. Therefore, conducting a full-scale experiment becomes economically and organizationally impractical. This is especially relevant for logistics and infrastructure projects in the field of security and defense, which are characterized by high costs and increased risks.

### Analysis of publications

An analysis of publications on the topic reveals a significant interest in the issue of combined logistics routes. In [1], various types of reverse flows, as well as the factors, barriers, and costs influencing managerial decisions in this field, are systematized. Article [2] examines cooperation between the civilian and military sectors in reverse logistics to support the EU's circular economy, proposing a model for integrating a sustainable supply chain. In [3], an information system for managing the military supply chain based on incident analysis is proposed.

Article [4] investigates the use of military logistics drones for rapid resource delivery in challenging

environments, emphasizing their autonomy and flexibility. Study [5] presents mathematical models and geographic information systems for optimizing logistics routes under wartime conditions.

The authors of [6] analyze strategies for managing supply chains in conflict conditions to enhance business resilience. Paper [7] proposes a concept for integrating forward and reverse logistics within the framework of a circular economy, focusing on overcoming barriers to closing material cycles.

Studies [8] and [9] present algorithms and systems designed to improve the efficiency of military logistics support, automate flow management, and forecast resource needs. In [10], key nodes of reverse logistics networks with remanufacturing are examined, highlighting the role of emerging technologies.

It can be concluded that traditional methods for planning and optimizing logistics processes fail to account for the dynamics and uncertainty inherent in wartime conditions. Moreover, existing approaches typically consider the supply chain as a single entity, without distinguishing between supply routes and distribution routes. This reduces flexibility and prevents the consideration of situations in which supply and distribution have different priorities, risks, or time constraints.

Therefore, for conducting research on supply and distribution logistics, the use of the following methods and technologies is considered effective:

- operations research methods – for the formalization and forecasting of the technical parameters of transport infrastructure in order to design optimal routes [11];
- risk theory – for developing risk maps and performing quantitative and qualitative analyses of potential threats, taking into account uncertain or incomplete data [12];
- computer modeling methods – for reproducing complex scenarios of vehicle movement and the interaction of agents within supply logistics systems through agent-based models [13];
- artificial intelligence technologies, in particular multi-agent systems, for modeling and optimizing the independent or interdependent operation of supply and distribution routes [14].

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### Problem Statement

The purpose of this study is to develop a model of supply and distribution routes that enables the optimization of delivery time and costs while

simultaneously reducing the risk of cargo loss and increasing transport utilization. Particular attention is given to the distinction between supply and distribution routes, as well as to the use of different modes of transportation: trucks, trains, and aircraft.

To achieve this goal, the following objectives must be addressed:

- to formulate a generalized combined structure of the supply chain encompassing both supply and distribution routes;
- to identify and analyze the key parameters of supply and distribution routes across different modes of transport;
- to design a computer experiment plan including several modeling scenarios;
- to perform modeling of supply and distribution paths using an illustrative example, taking into account the following criteria: time, risks, cost, and reliability;
- to develop practical recommendations for the implementation of logistics projects during wartime, considering both separate and joint optimization of supply and distribution processes.

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### Model Description

The logistics supply – distribution chains of a manufacturing enterprise can be divided into two components: the supply routes for material resources and the distribution routes for finished products. Each of these components may include various types of participants in the supply chain and, accordingly, different structural configurations.

In supply logistics, the main participants are:

- suppliers,
- intermediate warehouses (both wholesale and retail),
- intermediaries (carriers or logistics operators).

In distribution logistics, the main participants include:

- intermediaries (both wholesale and retail),
- end consumers.

It should be noted that when considering the production of dual-use goods during wartime, where the end users are military units, the storage of finished products should not be employed in distribution logistics in order to ensure the fastest possible delivery. Moreover, volunteer organizations may act as intermediaries in such cases. Figure 1 schematically illustrates a combined structure of the supply chain for an enterprise engaged in the production of military-purpose drones. It should

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also be emphasized that within such a supply chain, multiple route options exist between the specified elements. For the analysis of logistics networks and the selection of optimal solutions, it is effective to apply simulation modeling, particularly discrete-event models. This method makes it possible to account for the temporal dynamics of processes, random events, and variability in the operating conditions of logistics channels, which cannot be achieved using a classical analytical approach.

The model formalizes the supply chain as a network of nodes and arcs of the transport system represented as a graph  $G = (V, E)$ , where  $V$  – is the set of nodes. These represent individual elements of the logistics network: suppliers of raw materials and components, manufacturing enterprises, warehouses, and end consumers. Each node is characterized by its own storage parameters, throughput capacity, and order processing capabilities;  $E$  is the set of routes between nodes, i.e., the possible transportation paths. Each arc of the graph is described by parameters such as route length, expected travel time, type of transport, throughput capacity, and risk factors.

Thus, the model includes a set of input parameters describing transport vehicles, routes, and order

characteristics. The transport parameters include the type of vehicle  $T = \{road, rail, air\}$ , movement speed  $v$ , carrying capacity  $Q$ , and unit cost per kilometer  $c$ . A route is characterized by the distance between nodes  $d$ , base travel time  $t = d/v$ , and risk coefficient  $r$ , which reflects the probability of delays or additional costs. Order parameters include cargo volume  $W$ , delivery priority  $p$ , and delivery deadline  $D$ .

The input parameters can dynamically change during the simulation, reflecting fluctuations in supply and demand as well as the state of transport infrastructure.

As output parameters, the model provides a comprehensive assessment of the efficiency of logistics solutions using the following indicators: delivery time  $T_{del}$ , which accounts for possible delays along the route; transportation cost  $C_{del}$ , which includes additional expenses associated with risks and the choice of transport mode; and route reliability  $S_{rel}$ , inversely proportional to the risk coefficient. To obtain an integrated evaluation of efficiency, an aggregate criterion is applied, combining normalized indicators of time, cost, and reliability with corresponding weighting coefficients.

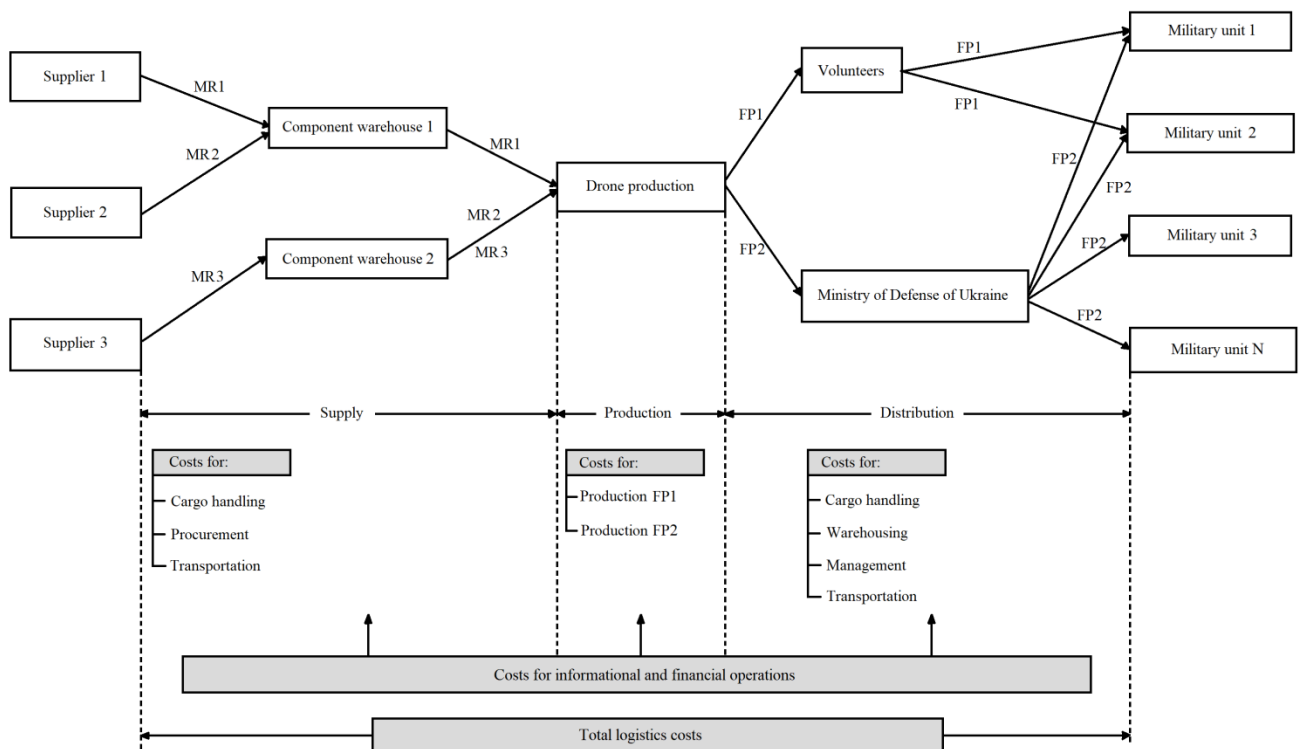


Fig. 1. The supply chain of supply, production, and distribution of unmanned systems

The logic of the model's operation can be described as follows. The model begins by initializing a network with predefined nodes and routes characterized by their parameters. Then, an order flow is generated to represent the demand for raw materials and finished products from consumers. For each order, the system determines feasible routes and available transport modes, calculates the expected delivery time, transportation cost, and probability of successful delivery. During the simulation process, random events such as delays, breakdowns, or other force majeure circumstances are considered, which modify the base parameters. An integrated performance score is calculated for all alternatives, allowing the identification of optimal routes and the formulation of recommendations for logistics flow management.

Among the key application features, the model enables a comprehensive analysis of both supply channels (from suppliers to production enterprises) and distribution channels (from manufacturers to end users), ensuring the evaluation of logistics flow efficiency and reliability. It also allows for extension and customization by incorporating additional criteria such as transportation environmental impact, infrastructure load, and warehouse turnover, thereby improving the flexibility and accuracy of assessments. Under martial law or emergency conditions, the model can be adapted by adjusting risk coefficients for specific routes or restricting their availability, which enables forecasting and managing potential delays and risks. Thus, the proposed discrete-event model provides a systematic approach to logistics

network analysis, accounts for temporal and stochastic factors, and supports scientifically grounded decision-making in optimizing supply and distribution routes.

### Description of the Computer Experiment

For the evaluation of the efficiency and reliability of logistics channels in a manufacturing enterprise, a computer experiment was conducted using a transport network model of Ukraine.

In this study, the enterprise under consideration has a single plant located in Lviv and a network of suppliers and customers distributed across cities throughout the territory of Ukraine. The input parameters of the experiment were formed based on open data on transport infrastructure and transportation statistics, taking into account the specific conditions of operation under martial law. The main focus was placed on two types of logistics flows: supply channels for delivering resources from supplier cities to Lviv, and distribution channels for delivering products from Lviv to frontline and key regional cities.

The input parameters for each route included the type of transport, the distance between nodes, the expected travel time (both without delays and considering risk factors), the cargo capacity, and the qualitative risk characteristics. During the simulation, potential delays caused by technical or security-related restrictions were also taken into account. Tables 1 and 2 present the main parameters of local supply and distribution routes with the production center located in Lviv.

**Table 1.** Main parameters of local supply routes to Lviv (fragment)

| №  | City (Supplier) | Transport | Distance (km) | Time (h) (without delays / considering risks) | Load capacity (approx.)          | Qualitative advantages / risks                                     |
|----|-----------------|-----------|---------------|---|----------------------------------|--|
| 1  | 2               | 3         | 4             | 5   | 6                                | 7  |
| 1  | Lutsk           | Road      | 170.7         | 1.71 / 1.71–4.28                              | ~20 t (truck)                    | Close to Lviv – fast delivery; moderate risk of local traffic jams |
| 2  | Lutsk           | Rail      | 177.6         | 2.28 / 2.28–6.84                              | ~75 t (wagon)                    | Higher throughput; requires coordination at stations               |
| 3  | Lutsk           | Air       | 136.6         | 0.23 / 0.23–0.58                              | ~10–20 t (depending on aircraft) | Very fast for urgent batches; expensive, limited availability      |
| 4  | Rivne           | Road      | 225.4         | 2.25 / 2.25–6.75                              | ~20 t                            | Short regional route; possible local restrictions                  |
| 5  | Rivne           | Rail      | 234.4         | 3.00 / 3.00–12.00                             | ~75 t                            | Suitable for larger batches; risks at junctions                    |
| 6  | Rivne           | Air       | 180.3         | 0.30 / 0.30–0.75                              | ~10–20 t                         | High speed but costly  |
| 7  | Ternopil        | Road      | 146.2         | 1.46 / 1.46–3.65                              | ~20 t                            | Short routes – quick delivery; min delays in peacetime             |
| 8  | Ternopil        | Rail      | 152.1         | 1.95 / 1.95–5.85                              | ~75 t                            | Suitable for medium-sized batches                                  |
| 9  | Ternopil        | Air       | 117.0         | 0.19 / 0.19–0.47                              | ~10–20 t                         | Minimal delivery time; high cost                                   |
| 10 | Vinnitsia       | Road      | 409.1         | 4.09 / 4.09–12.27                             | ~20 t                            | Medium distance; possible delays on highways                       |
| 11 | Vinnitsia       | Rail      | 425.4         | 5.45 / 5.45–21.80                             | ~75 t                            | Good capacity but high risk of node delays                         |

Continuation of the table 1

| 1   | 2             | 3    | 4     | 5                   | 6        | 7  |
|-----|---------------|------|-------|---------------------|----------|--|
| 12  | Vinnitsia     | Air  | 327.3 | 0.55 / 0.55–1.38    | ~10–20 t | Fast but costly and dependent on airports                    |
| 13  | Zhytomyr      | Road | 417.1 | 4.17 / 4.17–12.51   | ~20 t    | Medium distance; risks in the central corridor               |
| 14  | Zhytomyr      | Rail | 433.8 | 5.56 / 5.56–22.24   | ~75 t    | Large shipments possible; complex coordination               |
| 15  | Zhytomyr      | Air  | 333.7 | 0.56 / 0.56–1.40    | ~10–20 t | Fast for small urgent cargo                                  |
| 16  | Kyiv          | Road | 584.4 | 5.84 / 5.84–17.52   | ~20 t    | Major supplier; high traffic intensity; increased road risks |
| 17  | Kyiv          | Rail | 607.8 | 7.79 / 7.79–38.95   | ~75 t    | High capacity, but junctions are vulnerable points           |
| 18  | Kyiv          | Air  | 467.5 | 0.78 / 0.78–1.95    | ~10–20 t | Fast delivery of critical materials                          |
| ... | ...           | ...  | ...   | ...                 | ...      | ...  |
| 25  | Kropyvnytskyi | Road | 770.2 | 7.70 / 7.70–26.95   | ~20 t    | Medium distance; moderate risk                               |
| 26  | Kropyvnytskyi | Rail | 801.0 | 10.27 / 10.27–51.35 | ~75 t    | Effective for large batches                                  |
| 27  | Kropyvnytskyi | Air  | 616.2 | 1.03 / 1.03–2.58    | ~10–20 t | Fast but more expensive                                      |

**Table 2.** Main parameters of distribution routes from Lviv

| Direction           | Transport type | Approx. distance (km) | Travel time (without delays / considering risks) | Load capacity         | Qualitative advantages / risks                                   |
|---------------------|----------------|-----------------------|--|-----------------------|--|
| Lviv → Zaporizhzhia | Road           | ~900                  | 16–20 h / 20–36 h                                | ~20 t                 | Door-to-door delivery possible; high attack risks; long distance |
| Lviv → Zaporizhzhia | Rail           | ~930                  | 18–24 h / 24–72 h                                | ~75 t (×50–70 wagons) | Large-scale deliveries, but dependence on railway junctions      |
| Lviv → Zaporizhzhia | Air            | ~800                  | 1.5–2 h / 3–5 h                                  | ~10–20 t              | Very fast delivery; high risk of air defense engagement          |
| Lviv → Dnipro       | Road           | ~820                  | 14–18 h / 18–30 h                                | ~20 t                 | High mobility; road attack risks                                 |
| Lviv → Dnipro       | Rail           | ~850                  | 16–22 h / 24–60 h                                | ~75 t                 | Large volumes; vulnerable infrastructure nodes                   |
| Lviv → Dnipro       | Air            | ~720                  | 1.5 h / 3–4 h                                    | ~10–20 t              | Fastest option; increased operational risks                      |
| Lviv → Kharkiv      | Road           | ~1000                 | 18–22 h / 24–40 h                                | ~20 t                 | Long route; risk of shelling                                     |
| Lviv → Kharkiv      | Rail           | ~1030                 | 20–26 h / 30–72 h                                | ~75 t                 | Large-scale transport; dependence on junctions                   |
| Lviv → Kharkiv      | Air            | ~950                  | 2 h / 3–5 h                                      | ~10–20 t              | Very fast; vulnerable to attacks                                 |
| Lviv → Poltava      | Road           | ~720                  | 12–16 h / 16–28 h                                | ~20 t                 | Direct delivery; risks in central Ukraine                        |
| Lviv → Poltava      | Rail           | ~740                  | 14–20 h / 24–60 h                                | ~75 t                 | Suitable for bulk cargo; rail junctions under threat             |
| Lviv → Poltava      | Air            | ~650                  | 1.5 h / 3 h                                      | ~10–20 t              | Fastest route; high cost and risk                                |
| Lviv → Sumy         | Road           | ~965                  | 9.5 h / 34 h                                     | ~20 t                 | Long route; elevated risk  |
| Lviv → Sumy         | Rail           | ~1004                 | 13 h / 64.5 h                                    | ~75 t                 | Suitable for large batches if infrastructure remains stable      |
| Lviv → Sumy         | Air            | ~772                  | 1.5 h / 3.5 h                                    | ~10–20 t              | Fast delivery; high cost   |

Figures 2 and 3 graphically illustrate the inverse relationship between delivery time and cost parameters across different types of transport. Thus, even considering only two parameters, the task of selecting a mode of transport is a compromise problem. Therefore, solving the task of forming supply and distribution routes based on five criteria (some of which are fuzzy and some qualitative) by algorithmic means is highly complex and requires the use of simulation modeling.

Table 3 presents the comparative characteristics of the three main types of transport used in the logistics routes for the supply and distribution of products: road, rail, and air transport. To generalize the indicators, average values from the distribution routes from Lviv were used, which makes it possible to obtain a representative picture of the efficiency and limitations of each transport mode.

The main parameters include route length, expected travel time, average speed, maximum load capacity, transportation cost, route throughput, route flexibility, critical points, qualitative advantages and risks, as well as infrastructure availability and reliability.

In the logistic network model, each mode of transport is assigned indicators of risk, reliability, and weight coefficients for the integrated efficiency assessment, reflecting the specifics of transport channel functioning under conditions of increased uncertainty.

For making strategic decisions regarding cargo transportation, it is necessary to take into account possible changes in transportation conditions and to provide, in addition to the main mode of transport, reserve and critical alternatives. Moreover, combined routes based on different modes of transport can be

developed. By summarizing the data presented in Table 3 and identifying the primary decision-making criterion, it is possible to formulate recommendations, which are presented in Table 4. However, it should be noted

that more substantiated decisions can be made by considering the specific characteristics of the territories along the planned route.

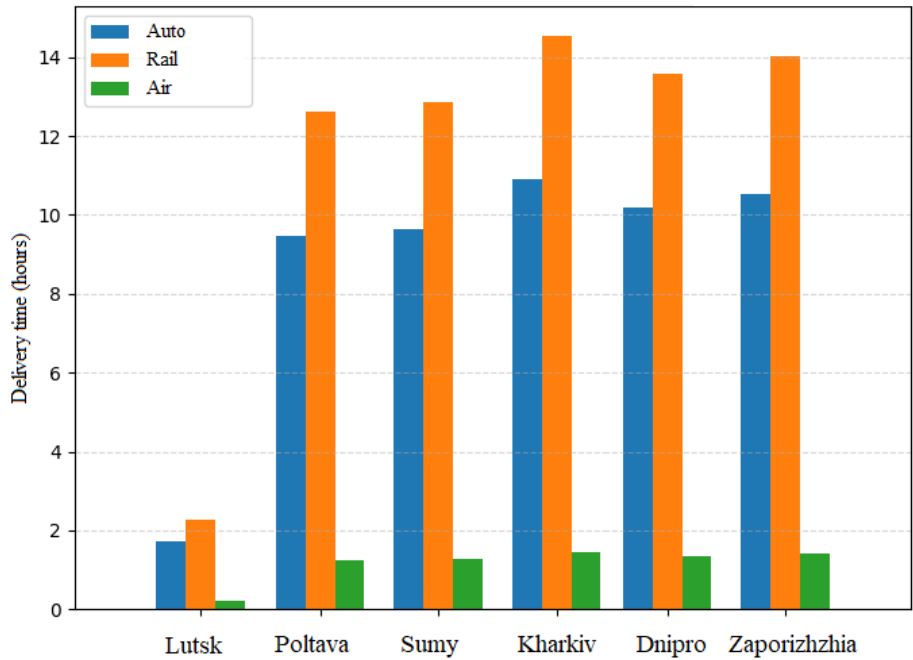


Fig. 2. Delivery time from Lviv by transport type

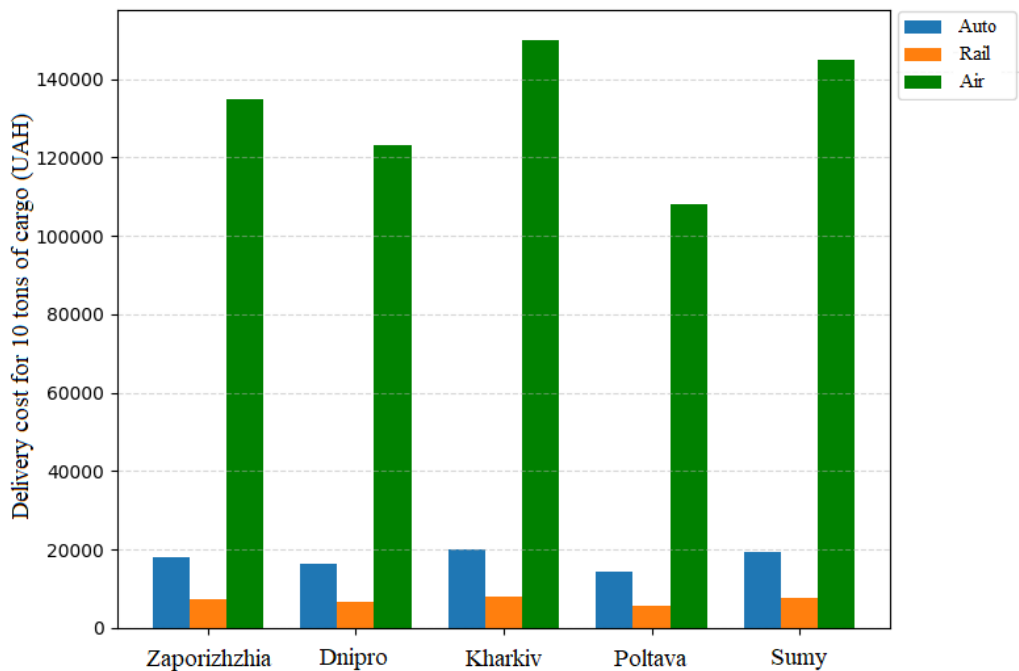


Fig. 3. Delivery cost from Lviv by transport type

**Table 3.** Distribution of transport modes depending on the primary delivery criterion

| Parameter   | Truck   | Train   | Air   |
|---|---|---|---|
| Route length, km  | 820   | 840   | 650   |
| Expected travel time, h<br>(without delays / considering risks) | 8 / 18  | 10 / 35   | 1 / 2   |
| Average speed, km/h   | ~80   | ~60   | ~600  |
| Maximum load capacity, t  | 20  | 75  | 15  |
| Transportation cost per km, UAH                                 | 20  | 8   | 150   |
| Transportation cost per tonne, UAH                              | 820   | 90  | 6500  |
| Route throughput, t/day   | ~400  | ~3,000–5,000  | ~200–300  |
| Route flexibility   | High  | Medium  | Low   |
| Critical route points   | Roadblocks, road repairs, shelling zones              | Railway junctions, track damage, transshipment stations | Airport accessibility, air defense, weather conditions    |
| Qualitative advantages  | Door-to-door delivery, flexibility, local logistics   | High capacity, cost efficiency, stability               | Speed, urgency, contactless delivery                      |
| Main risks  | Shelling, sabotage groups, traffic jams, road repairs | Track damage, infrastructure shelling, delays           | Air defense strikes, weather limitations, accident losses |
| Infrastructure availability                                     | High  | High  | Low   |
| Reliability   | Medium  | High  | Low   |
| Cargo destruction risk, %                                       | 10  | 4   | 35  |

The risk indicator characterizes the probability of delays or additional costs during cargo transportation. Its values were established based on expert evaluations and analysis of Ukraine's transport infrastructure.

**Table 4.** Comparative characteristics of transport modes on the main supply route

| Primary criterion             | Main transport mode | Reserve transport mode | Critical transport mode |
|-------------------------------|---------------------|------------------------|-------------------------|
| Minimization of delivery time | Air                 | Auto                   | Rail                    |
| Minimization of delivery cost | Rail                | Auto                   | Air                     |
| Minimization of delivery risk | Rail                | Auto                   | Air                     |

For road transport, the risk is 0.2, reflecting the average influence of road conditions, checkpoints, and wartime threats. For rail transport, the risk is 0.25, accounting for the concentration at junction stations, possible track damage, and delays at transshipment points. The highest risk is associated with air transport (0.8) due to limited airport accessibility, air defense threats, weather conditions, and high maintenance costs.

To assess risk, factors determined by the hazards of wartime conditions can be used, namely the possibility of attacks on transport infrastructure. The consequences may include damage to railway tracks, highways, or bridges. Such events cannot be predicted in advance; however, based on historical data, it is possible to estimate the overall level of danger in a specific territory by considering the frequency of air raid alerts as well as artillery and missile strikes. Such studies were

conducted in [15], resulting in the determination of territorial hazard indices for both railway and road transport.

**Table 5.** Distribution of cities by hazard indices

| Hazard index | Number of hazardous events       | City            |
|--------------|----------------------------------|-----------------|
| 0.1          | 1                                | Ivano-Frankivsk |
| 0.1          | 2                                | Lutsk           |
| 0.1          | 0                                | Uzhhorod        |
| 0.1          | 0                                | Chernivtsi      |
| 0.5          | 64                               | Vynnytsia       |
| 0.5          | 46                               | Zhytomyr        |
| 0.5          | 47                               | Kropyvnytskyi   |
| 0.5          | 60                               | Lviv            |
| 0.5          | 94                               | Poltava         |
| 0.5          | 18                               | Rivne           |
| 0.5          | 18                               | Ternopil        |
| 0.5          | 48                               | Cherkasy        |
| 0.5          | 69                               | Chernihiv       |
| 0.7          | 971                              | Zaporizhzhia    |
| 0.7          | 290                              | Kyiv            |
| 0.7          | 362                              | Odesa           |
| 0.7          | 105                              | Khmelnyskyi     |
| 0.9          | 9301                             | Dnipro          |
| 0.9          | 1187                             | Mykolaiv        |
| 0.9          | 3623                             | Sumy            |
| 0.9          | 3286                             | Kharkiv         |
| 0.9          | 3769                             | Kherson         |
| 1.0          | Temporarily occupied territories | Donetsk         |
| 1.0          | Temporarily occupied territories | Luhansk         |
| 1.0          | Temporarily occupied territories | Simferopol      |

Reliability reflects the stability and predictability of delivery. Although this indicator is not directly used in the integrated efficiency formula, it serves for qualitative comparison of transport modes. For road

transport, reliability is 0.85, for rail transport – 0.90, and for air transport – 0.50. This correlation aligns with real-world characteristics: road transport is the most flexible, rail transport is the most stable, and air transport is the fastest but least predictable.

The integral assessment of route efficiency (*Score*), taking into account time, cost, and risk indicators, is calculated using an additive aggregation formula:

$$Score = w_1 T_{norm} + w_2 C_{norm} + w_3 R_{norm},$$

where  $T_{norm}, C_{norm}, R_{norm}$  – are the normalized indicators of time, cost, and risk, respectively, and  $w_1, w_2, w_3$  are the corresponding weighting coefficients.

The weight coefficients of the integrated evaluation ( $w_1$  – time,  $w_2$  – cost,  $w_3$  – risk) in this experiment are set as  $w_1 = 0.2, w_2 = 0.2, w_3 = 0.6$ . The significant weight of the risk factor reflects the strategic priority

of transportation safety during wartime, when even short-term disruptions or infrastructure damage can lead to critical consequences. It should be noted that when the weighting coefficients change – for example, when transportation time becomes significantly more important than risk (which may be the case when delivering cargo for immediate needs at the front line) – preference will be given to air transport, such as helicopters or transport unmanned aerial vehicles.

The logistic network model, implemented in the AnyLogic environment, is shown in Figure 4. On the schematic diagram, blue squares represent suppliers, and red squares denote end customers. The model simulates the dynamic movement of road and rail transport, allowing analysis of supply routes, transportation duration, and the collection of statistical data for further efficiency calculations.

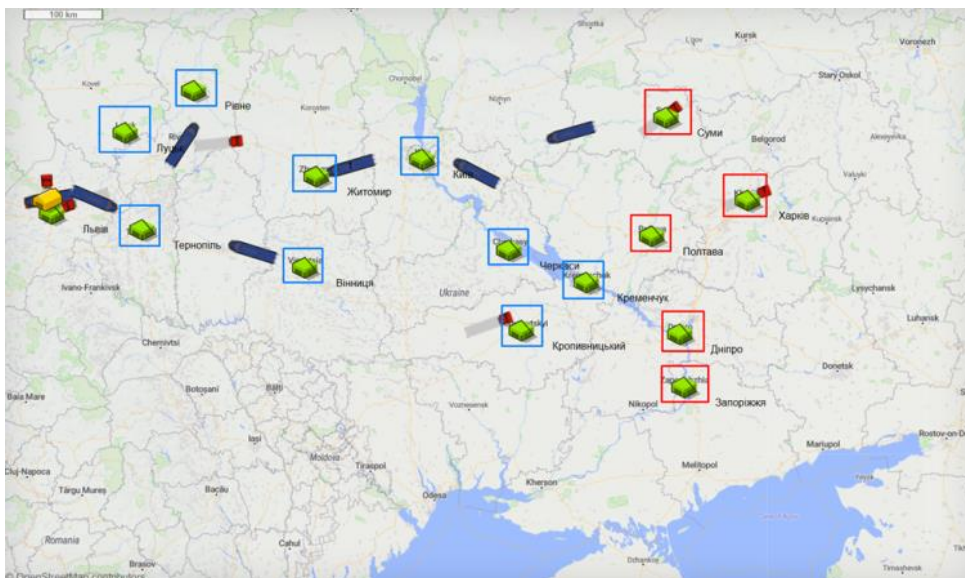


Fig. 4. Scheme of the supply and distribution logistics network implemented in the AnyLogic environment

For the experiment, a discrete-event model of the logistics system was developed, covering supply and distribution routes between major industrial and regional centers. Three baseline scenarios were formulated:

- Scenario 1 – Dependent supply and distribution using in-house transport. Characterized by stable operation of road transport over short and medium distances. The main advantage is route flexibility and the possibility of direct delivery; however, sensitivity to wartime risks and road congestion increases. The average reliability is 0.85.

- Scenario 2 – Dependent supply and distribution with cost, time, and risk optimization. This scenario

implements an algorithmic selection of the most efficient transport type according to an integral indicator (*Score*) calculated using established weighting coefficients. The model minimizes the risks of delays and cost overruns, prioritizing railway transport for large shipments and road transport for short routes. The average reliability is 0.87, indicating a balanced system.

- Scenario 3 – Independent supply and distribution. The channels operate autonomously, involving external logistics operators. The average reliability is 0.90; however, the system has lower flexibility and higher costs.

For each scenario, a series of computational experiments was conducted, resulting in the

determination of integral efficiency indicators for the routes. The evaluation, in addition to the three main criteria, also included an additional reliability parameter. The obtained results are presented in graphical form (Figures 5–7), which illustrate the advantages and limitations of each scenario.

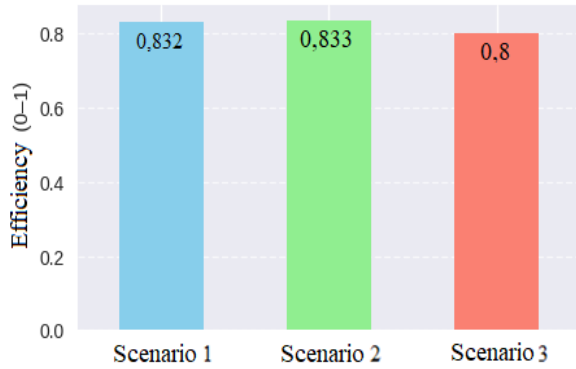


Fig. 5. Integral efficiency of the experimental scenarios

The analysis of the results showed that the integral efficiency (Fig. 5), which accounts for costs, risks, and delivery time, is nearly identical in Scenarios 1 and 2 ( $\approx 0.83$ ), whereas independent supply (Scenario 3) demonstrates lower efficiency (0.8) due to a higher risk of flow concentration (risk coefficient  $\approx 0.32$ ).

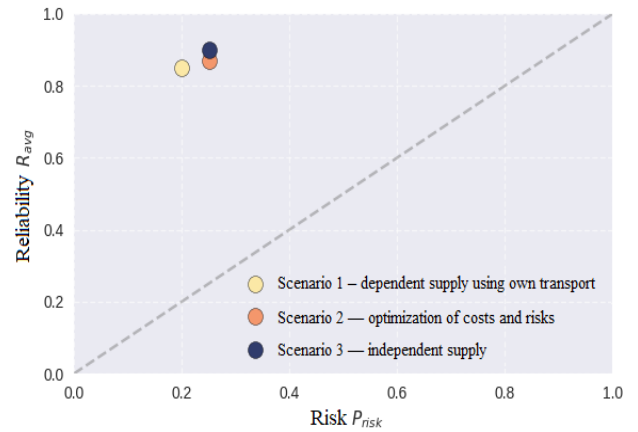


Fig. 6. Ratio of reliability to risk across scenarios

Figure 6 illustrates the relationship between transport system reliability and risk, where reliability is interpreted as an availability-oriented measure of successful delivery, while risk reflects aggregated probabilities of disruptive events under wartime conditions based on historical data and expert assessments. This relationship supports strategic decision-making by justifying rail transport as a stable primary channel, road transport as a flexible backup, and air transport for critical time-sensitive deliveries despite higher risk.

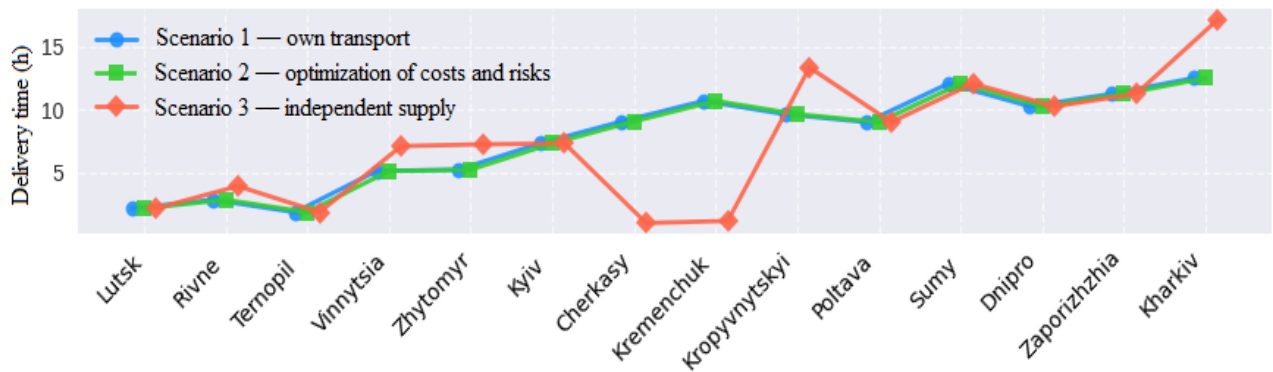


Fig. 7. Delivery time across cities in different scenarios

The best performance was achieved by rail transport in the optimization scenario, combining economic feasibility and stability. Road transport remained effective for short routes within the western and central regions.

Air transport, despite its minimal delivery time, proved economically inefficient and the least reliable (efficiency coefficient  $\approx 0.3$ ). The stability analysis based on the reliability-to-risk ratio further confirms the trade-off between efficiency and robustness across the

considered scenarios. The upper part of the chart (high reliability) represents the area of high or satisfactory stability, where the system operates efficiently with low risk. The lower part (low reliability) corresponds to the area of low stability, where risks increase significantly. Thus, the results of computer modeling confirm the feasibility of a hybrid logistics strategy, in which road transport ensures responsiveness on short routes, while rail transport provides stability and scalability over long distances.

## Conclusions

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Within the scope of the conducted study, the following results were obtained:

- a generalized combined structure of the logistics chain with supply and distribution routes was formed for an enterprise engaged in the production of military-purpose drones;
- the key parameters of supply and distribution routes for different modes of transport – such as delivery time, cost, risk, and reliability – were identified and analyzed; an integral indicator of route efficiency was proposed;
- a computer experiment plan was developed, including three simulation scenarios that take into account the interdependence of supply and distribution processes;
- a discrete-event model of supply and distribution routes was developed, enabling the analysis of alternative logistics scenarios with the determination of optimal delivery time and costs while simultaneously reducing the risk of cargo loss;
- supply and distribution routes were simulated using an illustrative case study within the territory of Ukraine, considering the criteria of distance, time, risk, cost, and reliability;
- recommendations were developed to support strategic decision-making in the implementation of logistics projects under wartime conditions.

The obtained results confirm that increased costs do not always correlate with improved

performance indicators, as the decisive factor is a balanced ratio between economic expenses, risk level, and expected outcomes. The proposed approach enables quantitative evaluation of management decision alternatives within the supply and distribution chains of manufacturing enterprises, thereby enhancing the justification for selecting an optimal development strategy.

## Conflict of interest

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The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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## Data availability

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The manuscript has no associated data.

## Use of artificial intelligence

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The authors confirm that they did not use artificial intelligence methods while creating the presented work.

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## МОДЕЛЮВАННЯ Й АНАЛІЗ ЛОГІСТИЧНИХ МАРШРУТІВ ПОСТАЧАННЯ ТА ЗБУТУ ВИСОКОТЕХНОЛОГІЧНОЇ ПРОДУКЦІЇ З ОГЛЯДУ НА РІЗНІ ВИДИ ТРАНСПОРТУ

**Предметом дослідження** в статті є процеси організації та оптимізації логістики постачання й збуту високотехнологічної оборонної продукції в умовах воєнного часу, зокрема розроблення мережевої логістичної структури з огляду на зворотні потоки, ризики й обмежені ресурси. **Мета дослідження** – розроблення моделі маршрутів постачання та розподілу, яка оптимізує час і витрати доставки, одночасно знижуючи ризики втрати вантажів і підвищуючи коефіцієнт використання транспорту. **Завдання:** сформулювати узагальнену комбіновану структуру логістичного ланцюга; визначити й проаналізувати основні параметри маршрутів постачання та збуту за різними видами транспорту; розробити план комп'ютерного експерименту; змодельовати шляхи постачання й збуту; запропонувати практичні рекомендації для реалізації логістичних проєктів у воєнний час. **Методи й засоби дослідження:** системний підхід, імітаційне моделювання, графічно-порівняльний аналіз, платформа AnyLogic. **Досягнуті результати.** Схематично подано комбіновану структуру логістичного ланцюга для підприємства з виробництва дронів військового призначення з множиною варіантів шляхів. Запропоновано модель, що формалізує логістичний ланцюг як мережу вузлів і дуг транспортної системи та містить набір вхідних параметрів, що описують транспортні засоби, маршрути й характеристики замовлень. Сутність комп'ютерного експерименту полягає у відтворенні властивостей інфраструктурних і логістичних проєктів за допомогою дискретно-подієвої імітаційної моделі, що дає змогу аналізувати критичні параметри окремо для постачання та розподілу, а також моделювати випадки їх взаємозалежності. Особливу увагу приділено розділенню маршрутів на постачання й розподіл, а також використанню різних видів транспорту. **Висновки.** Досягнуті результати підтверджують, що вирішальним чинником логістичних рішень є збалансоване співвідношення між економічними витратами, рівнем ризику й очікуваним ефектом. Запропонований підхід сприяє кількісному оцінюванню варіантів управлінських рішень у логістичних ланцюгах постачання й збуту виробничих підприємств, що підвищує обґрунтованість вибору оптимальної стратегії розвитку.

**Ключові слова:** логістика; ланцюг постачання; управління ризиками; оптимізація; комбінована структура; моделювання; альтернативні маршрути; постачання та збут; виробниче підприємство; AnyLogic.

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