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USING UNMANNED AERIAL SYSTEMS TO ENSURE ECONOMIC RESILIENCE OF HUMANITARIAN SUPPLY CHAINS IN THE CONTEXT OF THE RUSSIAN FEDERATION'S MILITARY AGGRESSION AGAINST UKRAINE

Background. *The relevance of the study lies in the need to analyze the use of unmanned aerial systems (UAS) in the organization of the humanitarian supply chain to save lives and provide assistance to the affected population in conditions of a humanitarian crisis. The purpose of the study is to substantiate the theoretical foundations of the economic resilience of the humanitarian supply chain as a tool for responding to a humanitarian crisis, as well as to develop conceptual and process models for organizing the delivery of humanitarian cargo using UAS at the "last mile" stage, which is the most costly due to high security risks in combat zones and frontline areas. The paper is devoted to solving the following tasks: to investigate the essence and main characteristics of the economic resilience of the humanitarian supply chain; to identify the possibilities of integrating UAVs into humanitarian supply chains; to substantiate the procedure for making a decision on the choice of UAVs; to detail the technological process of delivering cargo by drones. The authors put forward the following hypothesis: the economic resilience of humanitarian supply chains under martial law in Ukraine can be significantly enhanced by integrating unmanned aerial systems at the "last mile" stage due to development of: a conceptual model of organizing the delivery of humanitarian cargo, which systematizes the parameters of the components of the transport system and reflects their relationships with the decision-making process regarding the organization of the transportation process, which in turn determines the parameters of the logistics chain assessment; an adaptive process model that takes into account specific technological operations for transporting UAV cargo, operational flexibility, and speed of response to critical changes in the conflict zone.*

Methods. *The following methods were used in the study: comparison (to identify differences between humanitarian and commercial supply chains), analysis and synthesis (to reveal the nature and study the components of the humanitarian supply chain), content analysis and bibliometric analysis (when processing scientific literature on the organization of the humanitarian cargo supply), abstract-logical method (to identify key characteristics of the resilience of the supply chain), systems approach (when considering the humanitarian supply chain as a complex system that interacts with the external environment (crisis conditions) and identifying factors that ensure its resilience), generalization (to group factors that influence the integration of UAVs into humanitarian supply chains), morphological analysis (to justify the choice of UAVs). To confirm the hypothesis, a process approach was used, which allowed formalizing the process of delivering humanitarian cargo by UAVs at the "last mile" stage in order to quickly respond to changes and ensure the economic resilience of the supply chain.*

Results. *The study showed the feasibility of integrating UAS into humanitarian supply chains at the "last mile" delivery stage. The humanitarian supply chain is a component of the humanitarian crisis management mechanism and is an integrated system for planning, purchasing, transporting and distributing humanitarian goods for the population affected by military conflicts or disasters. The paper reveals the main characteristics of the humanitarian supply chain as a complex and dynamic system. For the resilience of humanitarian supply chains in conditions of uncertainty, the following three components are important: strategic redundancy, radical flexibility and cluster culture of response. The economic component of the resilience of humanitarian supply chains includes: compliance with the principle of cost-efficiency and ensuring resilience through cost minimization; financial flexibility and the ability to redirect funds from one type of aid to another in the face of changing situations. In the process of assessing economic resilience, the following parameters are assessed: the degree of fulfillment of the request; safety and accuracy of cargo delivery, and delivery speed. The developed models take into account such indicators of economic resilience as: mission success rate, service recovery time, route availability coefficient. From the point of view of socio-economic parameters, it is important to take into account the aid availability index and the cost of a saved life.*

Criteria for evaluating the performance of the mission have been identified, in particular: socio-humanitarian criterion, time minimization criterion, economic cost criterion for performing the delivery task, efficiency and safety of transportation, taking into account the parameters of the control system and the parameters of the external environment. A conceptual model of the organization of humanitarian cargo delivery has been proposed, which systematizes the parameters of the transport system components, and determines the parameters for evaluating the logistics chain.

Conclusions. *The developed adaptive process model for the delivery of humanitarian aid by UAS under martial law, which is based on the delivery organization parameters and technological operations described in the paper, allows for the formalization*

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of the delivery process and its reproducibility, as well as effective risk management. In practice, the use of the proposed model can become an effective tool for designing a safe and economically viable logistics supply chain for humanitarian cargo for the affected population in areas of critical security risk. This experience can be scaled up by other countries.

K e y w o r d s : ***humanitarian cargo, supply chain, economic resilience, unmanned aerial vehicle, unmanned aerial system, efficiency, transportation, technology.***

Background

The issue of using unmanned aerial systems (UASs) for the delivery and supply of humanitarian cargo is especially relevant in the context of the russian federation's military aggression against Ukraine. Military aggression is a critical factor in the destabilization of the socio-economic situation and the emergence of a humanitarian crisis in regions where the front line directly passes and hostilities are underway, as well as in regions close to the front line, occupied and deoccupied (border territories of Chernihiv, Sumy, Kharkiv, Luhansk, Donetsk, Zaporizhzhia, and Kherson regions). According to the "Humanitarian Needs and Response Plan for 2026: humanitarian needs and risks" (Ukraine, 2026a), as of January 2026, there are 8.4 million non-displaced war-affected people in Ukraine in need of assistance (including 1 million residents of the Russian-occupied territories). About 25% of these people are in urgent need of assistance, and 13% are in catastrophic need. These are the most vulnerable groups of the population – children, women and girls, the elderly, and people with disabilities (Ukraine, 2026b).

Military aggression has a direct negative impact on the accessibility, security, infrastructural and financial components of supply chains (Bazhenova, & Banna, 2025), as hostilities destroy or damage traditional communication routes (roads, bridges, railways) and key transport hubs (airports, sea and river ports, railway stations), disrupting traditional commercial logistics routes, paralyzing international humanitarian aid imports (Sereda, Nagachevska, & Hryhorova, 2024), or forcing the use of complex and long bypass roads, which increases both delivery times and operational costs. In addition to infrastructure destruction, storage facilities are often destroyed or damaged, leading to loss of cargo and making effective inventory management impossible. Vehicles often become military targets, which leads to the loss of expensive equipment and the cargo itself, increasing the cost of their insurance or the assumption of high financial risks. The situation is complicated by mining and contamination of territories with unexploded ordnance, which makes certain routes and unloading areas completely inaccessible until the completion of demining work and makes it impossible to deliver cargo by land transport. At the same time, military operations create unacceptable risks for drivers, accompanying personnel, and warehouse workers, cause a shortage of personnel, which is exacerbated by the mobilization of part of the employees involved in logistics, the need for high personnel payments for risk and the need to insure vehicles and personnel. Vehicles often become military targets, which leads to the loss of expensive equipment and the cargo itself, increasing the cost of their insurance or the assumption of high financial risks.

In such extremely dangerous conditions, there is a need to organize humanitarian supply chains to provide the necessary assistance to all those in need. The logistics of humanitarian cargo in frontline regions and combat zones is unpredictable and operationally unpredictable due to the constant change of the front line, which leads to changes in routes and requires time and additional material, capital, and human resources. (Osetskyi et al., 2023) Moreover, the use of traditional methods of delivering humanitarian aid is high-risk, which justifies the urgent need to introduce the latest technological solutions into humanitarian supply chains at the "last mile" stage (delivery to the end consumer), one of which is the use of unmanned aerial systems, which reduce transportation costs, ensure speed of delivery and a higher level of safety for personnel (Rejeb et al., 2021; Stierlin, Risch, & Risch, 2024).

This article aims to substantiate the theoretical foundations of the economic resilience of the humanitarian supply chain as a tool for responding to a humanitarian crisis, as well as to develop conceptual and process models for organizing the delivery of humanitarian cargo using UAS at the "last mile" stage, which is the costliest due to high security risks in combat zones and frontline areas.

The implementation of the set goal necessitated the need to solve the following tasks: 1) to investigate the nature and main characteristics of the economic resilience of the humanitarian supply chain; 2) to identify the possibilities of integrating UAVs into humanitarian supply chains; 3) to substantiate the decision-making procedure for choosing UAVs; 4) to detail the technological process of delivering cargo by drones.

The economic resilience of humanitarian supply chains under martial law in Ukraine can be significantly enhanced by integrating unmanned aerial systems at the "last mile" stage due to the development of:

1) a conceptual model of the organization of humanitarian cargo delivery, which systematizes the parameters of the transport system components and reflects their relationships with the decision-making process regarding the organization of the transportation process, which in turn determines the parameters of the humanitarian logistics chain assessment;

2) an adaptive process model that takes into account specific technological operations for transporting cargo by UAV, operational flexibility, and speed of response to critical changes in the conflict zone.

Literature review. The problems of organizing supply chains and ensuring their economic resilience are in the field of research of both domestic and foreign authors. As Yaremenko O. and Matyukh S. note, supply chains represent an area of increased risk (Yaremenko, & Matyukh, 2019). Scientists explain this by the number of participants, their different production capabilities, technological and technical equipment, quality of resources, and transport support. At the same time, the economic resilience of supply chains is affected by logistical and infrastructure risks that arise due to the incoordination of the work of supply chain participants and infrastructure enterprises, as well as due to fluctuations in the markets. Market fluctuations in business activity are manifested in changes in prices and production volumes, which makes adjustments to the work of logistics operators (Panchenko, & Reznikova, 2022). Failure in even one link leads to inefficiency of the entire supply chain.

When we analyze supply chains, we take into account the fact that the influencing factors can be not only local, but also national or international in nature. According to experts, sanctions restrictions and trade wars in 2022-2025 had a particularly acute impact on the economic stability, geography, and security of supply chains (Otsokolich, 2025)

External factors, including natural disasters, climate change, political and military conflicts, man-made disasters, and epidemics, can negatively impact the resilience of supply chains, creating threats and challenges to the security of their operation. Taking threats and risks into account is critical when it comes to humanitarian supply chains.

It should be noted that humanitarian supply chains are built in dangerous (crisis) situations, when a rapid response is required in conditions of destroyed infrastructure and lack of human and material resources (Hryniv, 2023).

Humanitarian supply chains are designed to create positive social, environmental and economic impacts on affected populations (Kunza, & Gold, 2017). Chupryna O., Kolosok E. and Hryhorenko O. emphasize the reliability, safety, speed and timeliness of organizing a humanitarian supply chain to provide affected people with essential goods (Chupryna, Kolosok, & Hryhorenko, 2023).

It also concerns the rationality, efficiency, effectiveness, and reliability of managing available (technical, technological, informational, financial, human resources, etc.) resources within humanitarian supply chains to counter threats and eliminate their consequences (Pokusa, 2024).

At the same time, it is important to develop new solutions in risk management in supply chains to increase the efficiency of resource use throughout the chain, balance profitability and resilience, and ensure the security of all logistics processes (Pogrebnyak et al., 2022).

Methods

The following methods were used in the study: comparison (to identify differences between humanitarian and commercial supply chains), analysis and synthesis (to reveal the nature and study the components of the humanitarian supply chain), content analysis and bibliometric analysis (when processing scientific literature on the organization of the humanitarian cargo supply), abstract-logical method (to identify key characteristics of the resilience of the supply chain), systems approach (when considering the humanitarian supply chain as a complex system that interacts with the external environment (crisis conditions) and identifying factors that ensure its resilience), generalization (to group factors that influence the integration of UAVs into humanitarian supply chains), morphological analysis (to justify the choice of UAVs). To confirm the hypothesis, a process approach was used, which allowed formalizing the process of delivering humanitarian cargo by UAVs at the "last mile" stage in order to quickly respond to changes and ensure the economic resilience of the supply chain.

Results

The challenges of the 21st century, such as the COVID-19 pandemic and the russian military aggression against Ukraine, are convincing in the need to develop and implement alternative methods of delivering goods that are safe for people and the environment, and can also be used contactlessly. These are unmanned vehicles, primarily unmanned aerial vehicles (UAV, drones). The use of drones began in 2013 by Chinese companies, but deliveries were limited. Currently, the UAV market is constantly expanding, and companies specializing in drone deliveries such as Wing, Zipline and Matternet are actively working. According to Gartner estimates, the size of the worldwide drone package delivery market will hit $8B by 2027, growing at a noteworthy CAGR of 41.8% (ZhenHub, 2022).

The integration of UAVs into humanitarian supply chains is effective at the "last mile" delivery stage - the final stage of the logistics process, when a cargo of humanitarian aid is delivered from a local warehouse directly to the recipient (Fig. 1).

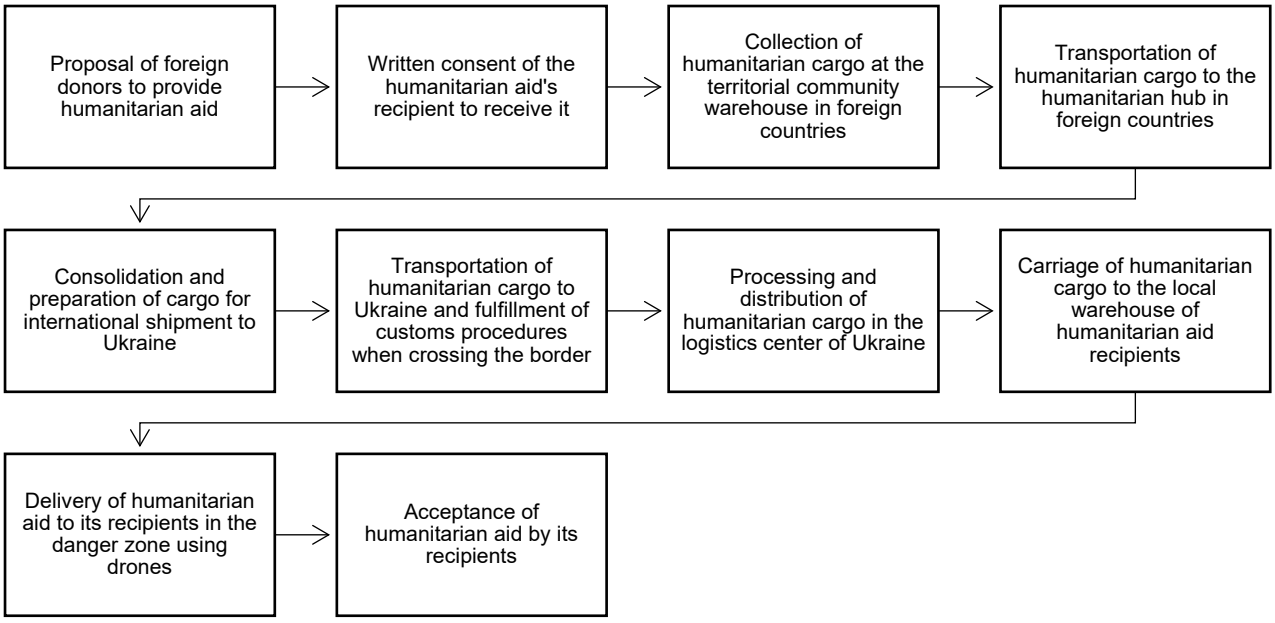


Fig. 1. Integration of UAVs into humanitarian supply chains

Source: compiled by authors.

Humanitarian supply chain is an integrated system of planning, purchasing, transporting and distributing humanitarian goods for the population affected by military conflicts or disasters. In the paper, the humanitarian supply chain is considered as a component of the crisis management mechanism. Humanitarian supply chain management is significantly different from commercial supply chain management. If the main goal of the humanitarian supply chain is to save people's lives and minimize suffering (Myronenko et al., 2021, P. 203-225.), the priority of the commercial supply chain is to maximize profits and minimize costs. In practice, demand for commercial supply chains is planned, while for humanitarian supply chains, demand is unpredictable and sudden (Kovács,

Spens, & Moshtari, 2018). Ensuring the transportation and distribution of humanitarian cargo for the humanitarian supply chain in practice is complicated by the fact that the infrastructure can be destroyed (Apta, 2010, pp. 1–100). While commercial supply chains are time-bound, humanitarian supply chains are often time-constrained, with response times of hours/minutes (Chupryna, Kolosok, & Hryhorenko, 2023). Humanitarian supply chains are financed by state funds or donors.

However, according to Western economists, not only reducing response time, but also reducing costs and saving money is important for humanitarian supply chains, as it allows for more efficient operations and reaching a larger portion of the population with the same budget (Salem et al., 2024; Stumpf, Besiou, & Wakolbinger, 2023).

In the current scientific literature, supply chain resilience is defined as a complex and dynamic system. The resilience of commercial supply chains implies that they possess three qualities, described as the "triple A", as they are: agile (they can respond quickly to any changes in demand or supply); adaptable (they can adapt over time to structural changes and evolving strategies); aligned (they are aligned with the interests of all suppliers in the production network, as well as with a variety of stakeholders, including governments and non-governmental organizations) (Lee, 2004).

The main characteristics of humanitarian supply chains that affect their resilience are:

- social impact, the number of lives saved and the assessment of the level of reduction of suffering;
- the criticality of delivery terms, when time and speed of delivery become very important;
- the specificity of the cargo and the exact correspondence of the aid to the real needs of the final recipient (not just medicine, but specific pharmaceuticals; not just food, but a calorie-balanced diet). This requires the organization of monitoring and the establishment of constant feedback with the affected population to assess the scale of the situation and identify the specific needs of the population;
- accessibility - direct delivery to the point where the need arose;
- logistical integrity and guaranteeing the preservation of the quality of the cargo in extreme conditions, for example, the need to maintain the cold chain of humanitarian vaccine supplies;
- adherence to the principle of cost-efficiency and ensuring resilience through cost minimization and environmental friendliness (reduction of harmful impact on the environment);
- a cluster approach to the organization and involvement of various stakeholders (state authorities and local governments, donors, international organizations, charitable foundations, volunteer organizations, direct participants in the process of delivering humanitarian goods - carriers, logistics operators (forwarders), warehouse complexes), where each participant knows their role, and decisions are made promptly on the ground, taking into account the situation and current needs of the affected population;
- high uncertainty and unpredictability of the emergency occurrence, its scale, consequences and duration;
- high level of danger in implementing humanitarian deliveries, which requires careful identification and risk management.

Comparing humanitarian and commercial supply chains, building resilient commercial supply chains involves three main components: redundancy (maintaining safety stocks and backup suppliers), flexibility (developing dynamic capabilities to quickly adapt and change supply chain organization in the event of disruptions), and a culture of responsiveness (adequate training of personnel and managers, as well as decentralized decision-making to quickly resolve problems as they arise) (OECD, 2025), Moreover, for both humanitarian and commercial supply chains, such components of resilience as the ability to anticipate risks and adapt to (resist) disruptions are important, where disruption is viewed as a catalyst for innovation, allowing us to take a step forward and move to a qualitatively new level with greater capacity and better preparedness, rather than just getting out of the crisis.

Yili Deng emphasizes the vulnerabilities of supply chains and defines their resilience as the ability to respond to emerging disruptions, emphasizing adaptability and flexibility to reduce risks associated with unforeseen events (Deng, 2023).

In the study (Guo et al., 2025), the resilience of supply chains is defined as their ability to mitigate, respond to, and recover from risks that cause mismatches between demand and supply. Therefore, a supply chain is more resilient if the probability of mismatches is lower, the duration is shorter, or the state after recovery is better.

As noted in the paper (Slobodzianyk, & Chornopyska, 2024). Supply chain resilience is determined by the efficiency of information exchange, the speed of decision-making, the development of partnerships between the state and the private sector, the involvement of local operators, the integration of new technologies, as well as flexibility in reviewing partnership relations.

Supply chain resilience is the ability to effectively cope with external and internal challenges, maintaining the continuity of operations and minimizing the negative consequences of possible risks, ensuring the continuity and efficiency of supply in conditions of stress, crisis, unforeseen circumstances, by developing and implementing risk management strategies, diversifying suppliers, creating reserve stocks, and developing business contingency plans (Sushchenko, 2024).

For the resilience of humanitarian supply chains in conditions of uncertainty, the following three components are important:

1) strategic pre-positioning and the use of a network of global and regional hubs. The availability of alternative suppliers is important in terms of avoiding dependence on a single supplier in the event of the closure of one border crossing point or port;

2) radical flexibility and the ability to instantly change the mode of transportation. In some cases, it is advisable to localize and involve local suppliers instead of waiting for long international shipments, which makes the humanitarian supply chain less vulnerable;

3) a cluster culture of response, where each organization and institution has its own role, but decisions on the ground are made quickly, based on real needs and challenges. Building resilience in the humanitarian supply chain through strategic redundancy, localization and cluster coordination allows it to remain effective even when traditional systems fail.

The economic component of commercial supply chain resilience involves ensuring profitability despite disruptions, uncertainties and risks. In the context of humanitarian supply chains, profitability is transformed into the concept of cost-effectiveness and social return on investment. The economic component of humanitarian supply chain resilience includes: compliance with the principle of cost-effectiveness and ensuring resilience through cost minimization; financial flexibility and the ability to redirect

funds from one type of assistance to another in the face of changing situations. In the process of assessing economic resilience, the following parameters are assessed: the degree of fulfillment of the request; safety and accuracy of cargo delivery, and delivery speed.The study took into account such resilience indicators as: mission success rate, time-to-recovery service, route availability score. In conditions of military aggression, a resilient indicator is greater than 70-80%, depending on the criticality of the cargo. From the viewpoint of socio-economic parameters, it is important to consider the aid accessibility index and the cost per life saved.

For example, from the perspective of the traditional approach to minimizing costs, the delivery of humanitarian cargo by UAV is more expensive than one truck round, but during the transportation of humanitarian cargo, the truck can be blown up by a mine, get stuck due to the destruction of infrastructure for hours/days/weeks, so the "cost of waiting" and the risks of cargo loss make drones more economically advantageous in conditions of uncertainty. Not to mention the fact that the timely delivery of such humanitarian cargo as blood by drone can help save a person's life.

The economic resilience of the humanitarian supply chain is determined through preventive measures and an analysis of the "cost of inaction", since investing in preparation (in particular, warehouse infrastructure and personnel) allows for significant savings during emergency response.

There are significant differences between the formation of routes for commercial cargo transportation by unmanned aerial systems and the delivery of humanitarian cargo. Namely, when forming routes for commercial cargo transportation by unmanned aerial systems, it is necessary to take into account the criteria for minimizing delivery time or minimizing economic costs for performing the transportation task, which includes taking into account the costs of paying service personnel (UAV operators), the cost of consumables for drones and fuel, the cost of using ground flight support equipment, depreciation, personnel training costs, costs for construction and maintenance of basing systems, and other (Bondar, 2022).

At the same time, it should be noted that when it comes to humanitarian deliveries to dangerous areas (combat zones and frontline areas), the criteria should also be the effectiveness of transportation (fulfilling the target task of providing those in need with humanitarian assistance) and the safety of transportation (preventing damage and destruction of drones and cargo due to terrorist attacks, which is critically important in the case of organizing cyclical deliveries to the same destinations). In this case, it is necessary to develop alternative routes with different intervals and frequency of shipments, which will reduce the risk of vandalism and ensure a higher level of the logistics chain performance.

When making decisions on the organization of cargo transportation by traditional modes of transport, the parameters of the transport system, the parameters of the participants in the transport process, the parameters of the cargo and the parameters of the vehicles are taken into account (Kush, & Skrypin, 2016). In our opinion, for unmanned vehicles, it is also necessary to take into account the parameters of the control system and the parameters of the external environment. Figure 2 presents a model of organizing cargo delivery by unmanned aerial systems. It shows how, based on the above parameters, decisions are developed regarding the choice of the type and model of the UAV, transport packaging, cargo securing system to the drone, delivery route, navigation system, drone cargo dropping system, and the issue of selecting appropriate personnel (the UAV operator who controls the device; the technical engineer whose duties include maintenance, repair, and configuration of the devices; a specialist in processing data from drones). In turn, the decisions taken ensure the effectiveness and economic resilience of the humanitarian supply chain, which are assessed by a system of logistical and socio-economic parameters, parameters of operational resilience, flexibility and adaptability of delivery (in particular, financial and time costs for changing the logistical delivery method, the availability of backup systems, like spare drones, alternative communication channels, backup take-off points, etc.).

When organizing cargo delivery in conditions of military aggression, the most difficult task is to choose a UAV that will take into account security risks as much as possible. In our opinion, when choosing a UAV, first of all, it is important to assess the payload of the drone based on the weight of the cargo that will need to be transported. On the other hand, the larger the payload, the larger the size of the drone, and the more noticeable it will be. Here, it is also necessary to take into account the distances that the drone must overcome, and assess possible obstacles and risks.

Second, it is necessary to study the different types of UAVs available. Each type of drone has its own unique capabilities and features, so understanding the differences between them and determining the type and model of UAV that is most suitable for implementing a particular cargo delivery task will be key. Third, in conditions of high uncertainty and danger, it is necessary to consider the safety features of the selected UAV model, including: obstacle avoidance functions, automatic flight paths and automatic landing capabilities. These features will help increase the safety of the cargo and reduce the risk of its damage or loss.

Fourth, the cost of the drone should be taken into account, comparing types and models of drones according to the ratio "drone price - drone functions and capabilities". When assessing the costs of operating a drone, it is necessary to take into account the cost of maintenance and repair, as well as the probability of losing the drone while performing tasks. Fifth, the choice of UAV for delivering humanitarian aid cargo in conditions of military aggression depends on the distance to the epicenter of hostilities and the task being performed, in particular, for emergency delivery to "zero", when the cargo is delivered directly to the trenches; for tactical delivery to positions (5-10 km, the so-called "gray zone"); for logistics support (15-20 km from the front line).

Delivery of goods by drones is a complex technological process, which represents the sequential execution of the following operations (Fig. 3):

1. Receiving an order for the delivery of goods, which indicates the coordinates of the delivery point and the type of humanitarian cargo (food, water, blood, medical supplies), as well as the priority and urgency of the cargo, temperature regime.

2. Packing the ordered goods at the fulfillment warehouse in a special moisture-proof and shock-resistant container so that it can be securely attached to the drone and ensure the safety of the cargo during delivery. In the case of the delivery of goods under temperature conditions, it is necessary to comply with the conditions of the cold chain, ensuring the use of refrigeration equipment. This operation also involves calculating the center of mass to ensure flight stability in windy weather.

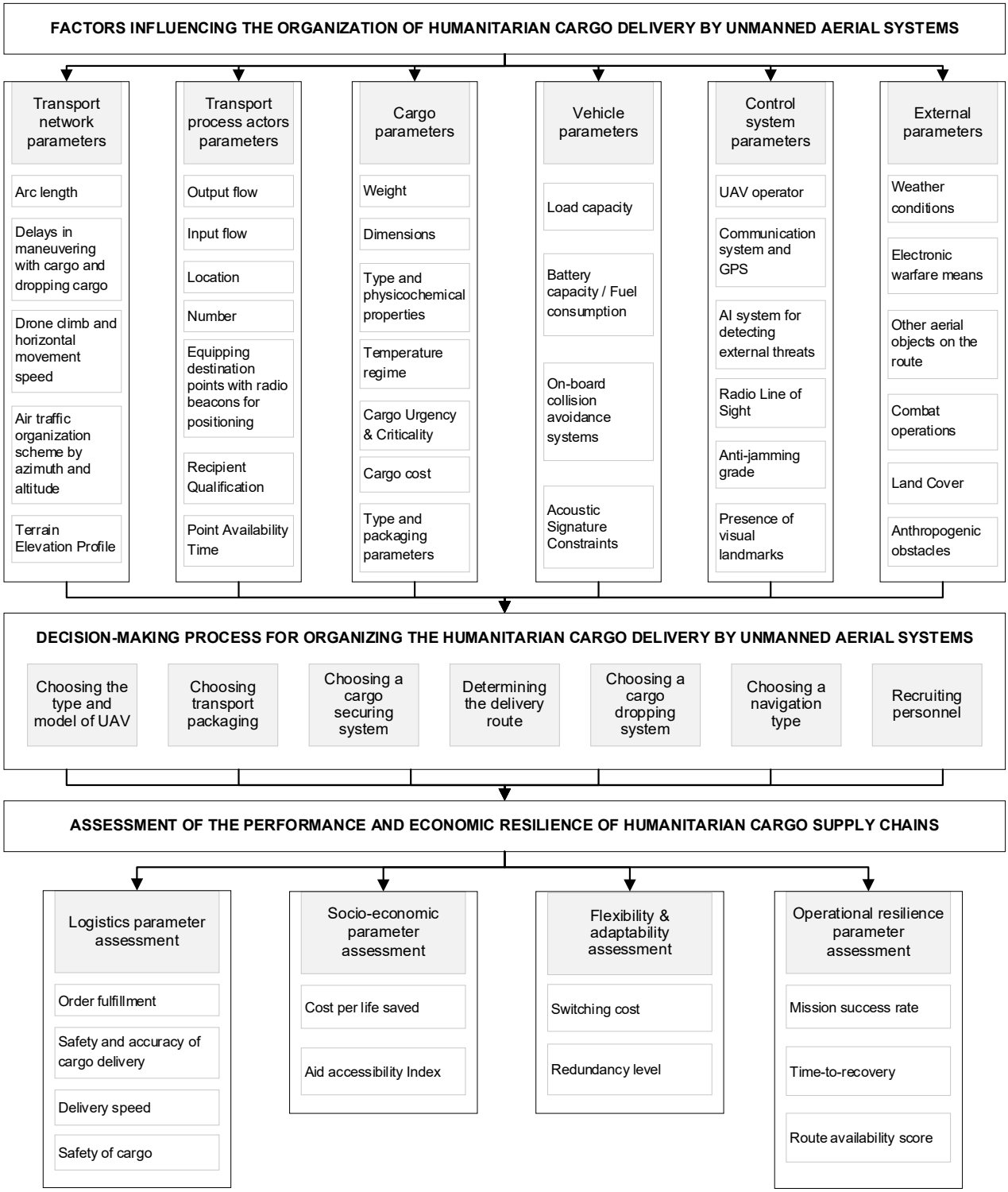


Fig. 2. Model for organizing the humanitarian cargo delivery by unmanned aerial systems to war zones
Source: developed by authors.

3. Attaching (fastening) the packaged goods to the drone using special systems (rigid fastening or mechanical grips, electromagnets, standard containers for placing cargo, a winch with a motorized reel, suspension on a cable). In this case, it is necessary to check the reliability of the locks in conditions of vibration and overloads when maneuvering the drone with the cargo, and also take into account the aerodynamic resistance of the container.

4. Pre-flight inspection, including checking the battery charge (fuel), communication, and testing the mechanism for unhooking the load from the drone.

5. Drone takeoff, which includes starting the engines, vertical movement and reaching cruising altitude.

6. Transporting cargo by drone to its destination using GPS navigation to plot the route and built-in cameras and sonar (LiDAR, ultrasonic sensors) to avoid obstacles during

the flight. The operator monitors telemetry (charge, speed, wind) in real time.

7. Arrival of the drone with the cargo at the destination. Here, it is important to assess, first of all, the wind gusts near the ground, the absence of people and animals directly in the area of potential cargo dropping.

8. Identification of the exact destination by scanning a QR code, with which customers mark a safe place (customers can use a specially marked mat) for landing the cargo.

9. Dropping cargo by drone to a location specified by customers. In conditions of high risk, preference is given to dropping cargo from a low altitude, without landing the drone. This minimizes the time spent in a vulnerable state.

10. Returning the drone to the warehouse. When performing this operation, it should be taken into account that the drone without cargo becomes lighter, which changes its sailing ability and reaction to the wind. Accordingly, the return route can be adjusted to a higher echelon to save battery power (fuel), if it is safe from the point of view of air defense and electronic warfare. The route should also be changed in case of detection of shelling.

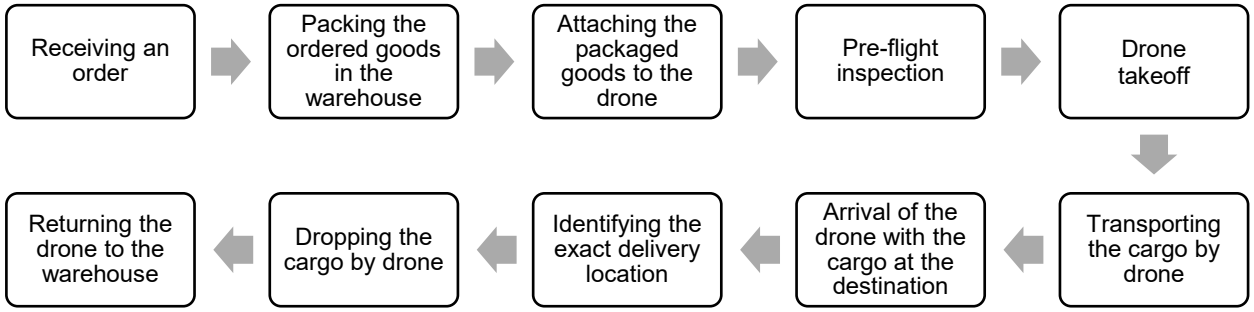


Fig. 3. Drone cargo delivery technology
Source: developed by authors.

It should be noted that dropping cargo by drone is one of the rather complex operations. Currently, various dropping systems are used:

1) mechanical, which are used when dropping cargo weighing up to 5 kg. These include devices with latches controlled by a servo motor, latches with a magnetic lock, and parachute systems;

2) electronic, like servo drives and magnets integrated with navigation, as well as systems controlled via radio signal or Bluetooth;

3) pneumatic and hydraulic systems, which are used for heavy cargo and provide for the possibility of both simultaneous dropping of the entire cargo and phased, when the cargo is dropped in different places when transporting along delivery routes (Drone cargo drop systems, 2024).

The choice of cargo dropping system is influenced by the type and weight of cargo, weather conditions and altitude. In particular, parachute systems are used when dropping cargo from high altitudes (100+ m), as well as fragile cargo.

In order to transform the delivery of humanitarian cargo by drones into a controlled system, a process model has been developed. The process model for the delivery of humanitarian aid cargo by unmanned aerial systems to combat zones, presented in Fig. 4, is based on the above-mentioned parameters of the delivery organization and technological operations.

The process model presented in Fig. 4 is a fundamental tool for effective management of the humanitarian supply chain at the stage of delivery of the "last mile" by unmanned aerial vehicles to war zones and ensuring its economic resilience in conditions of military aggression, since:

- it describes in detail a clear sequence of all possible operations related to the transportation of goods by unmanned aerial vehicles in critical emergencies, starting from the moment of receipt of the order to the moment of delivery of the goods to the end consumer;
- it reflects the risks that may arise at each technological stage of delivery of goods to high-risk areas, and also contains alternative solutions to minimize risks and ensure flexibility and adaptability of delivery;
- it allows you to identify "bottlenecks" in delivery and take preventive measures to eliminate them, ensuring reliability and speed of delivery;
- it standardizes and ensures the reproducibility of the entire process of using UAVs for cargo delivery, which in conditions of great danger allows both experienced UAV operators and beginners to complete the task. This is important for ensuring the effectiveness and continuity of delivery;
- it reflects the area of responsibility of all participants;
- it accelerates the training time of UAV operators in real conditions of military threats.

Discussion and conclusions

As can be concluded from the study, the use of unmanned aerial systems for the delivery of humanitarian cargo is an effective solution, especially in conditions of military aggression, in dangerous (crisis) situations, when a rapid response is required in conditions of destroyed infrastructure and lack of human, material and technical resources to save people's lives, support and have a positive social, environmental and economic impact on the affected population. The integration of UAVs into humanitarian supply chains is especially effective at the stage of "last mile" delivery – the final stage of the logistics process, when humanitarian cargo is delivered to the direct recipient.

The developed conceptual model of organizing the delivery of humanitarian cargo by unmanned aerial systems to combat zones allows taking into account the main factors of influence of both the external environment and internal factors that affect the choice of the type of UAV and determine the delivery technology. Based on the analysis of the influence factors, the decision-making process is carried out on the organization of the delivery of humanitarian cargo by UAVs. The criteria defined in the model allow assessing the cost-efficiency and resilience of the humanitarian cargo supply chain based on mission performance.

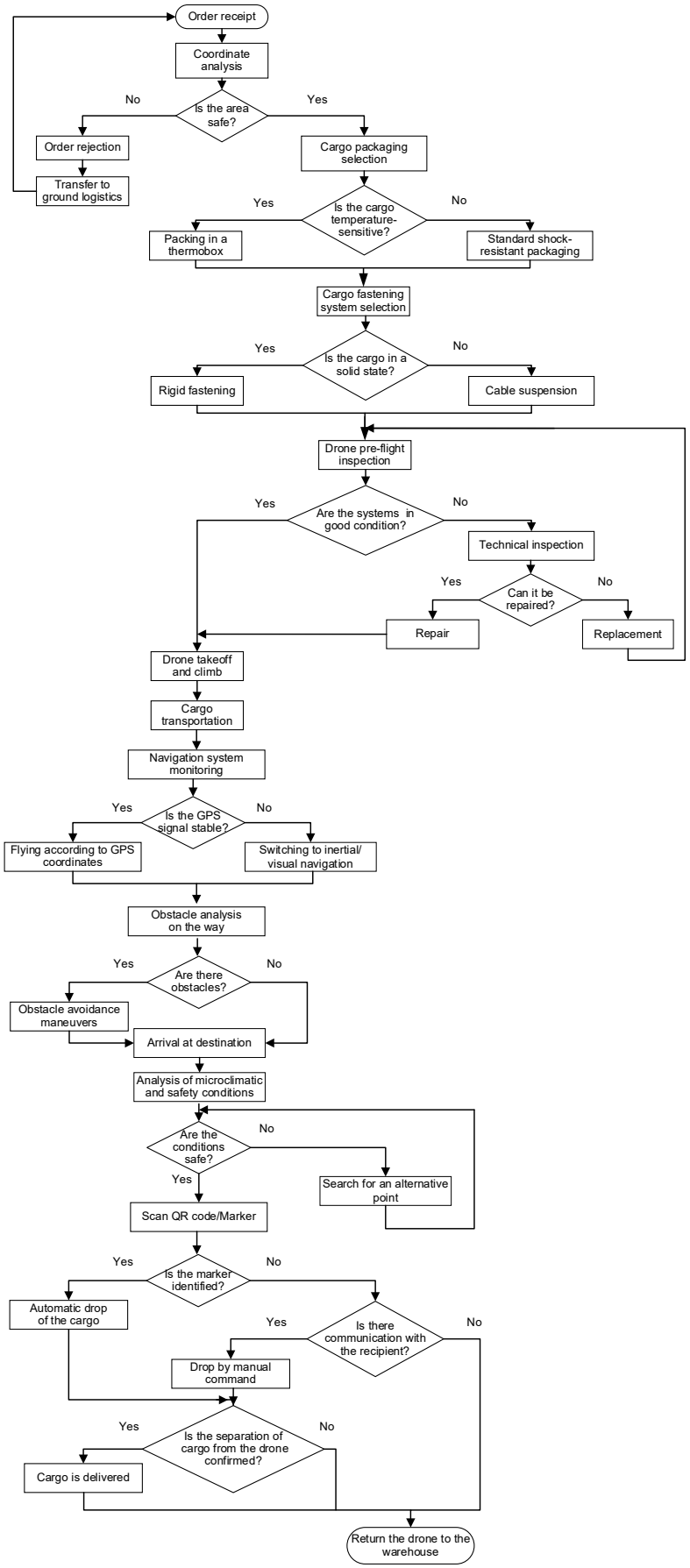


Fig. 4. Process model for delivering humanitarian cargo by unmanned aerial systems to war zones
Source: developed by authors.

The detailing of the technology for delivering humanitarian cargo by drones allowed us to identify "bottlenecks" and risks that may arise in the process of fulfilling the target task, which is important for prompt response and elimination of dangers during the mission. The experience of using UAVs to deliver humanitarian cargo in Ukraine can be further used in other combat zones or dangerous (crisis) situations for the timely provision of the affected population and saving people's lives.

The developed algorithmic model of the process of delivering humanitarian aid by unmanned aerial systems in conditions of military aggression, based on the parameters of the delivery organization and technological operations described in the paper, allows us to standardize the delivery process in the future, develop appropriate procedures for controlling this process at all stages and avoid human errors that may be critical in conditions of military aggression or disaster. Visualization of the process allows us to quickly identify "bottlenecks" where the greatest delays or risks may occur in order to take corrective measures to avoid or reduce the negative impact.

In practice, the use of the proposed model can become an effective tool for designing a safe and cost-effective logistics supply chain for humanitarian cargo for the affected population. This experience can be scaled up by other countries. The prospects for further development are to assess the economic and social efficiency of integrating UAVs into the supply chain for delivering humanitarian cargo compared to traditional transport and technological schemes.

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ВИКОРИСТАННЯ БАС ДЛЯ ЗАБЕЗПЕЧЕННЯ ЕКОНОМІЧНОЇ СТІЙКОСТІ ГУМАНІТАРНИХ ЛАНЦЮГІВ ПОСТАЧАННЯ В УМОВАХ ВІЙСЬКОВОЇ АГРЕСІЇ РОСІЇ ПРОТИ УКРАЇНИ

В с т у п . ***Актуальність дослідження полягає в необхідності аналізу застосування безпілотних авіаційних систем (БАС) в організації гуманітарного ланцюга постачання для збереження життя та надання допомоги постраждалому населенню в умовах гуманітарної кризи. Робота присвячена розв'язанню таких завдань: дослідити сутність та основні характеристики економічної стійкості гуманітарного ланцюга постачання; виявити можливості інтеграції БПЛА у гуманітарні ланцюги постачання; обґрунтувати процедуру прийняття рішення щодо вибору БПЛА; деталізувати технологічний процес доставки вантажів дронами. Автори висувають таку гіпотезу: економічна стійкість гуманітарних ланцюгів постачання в умовах воєнного стану в Україні може бути суттєво посилена за рахунок інтеграції безпілотних авіаційних систем на етапі "останньої милі" за умови розроблення: концептуальної моделі організації доставки гуманітарних вантажів, яка систематизує параметри складових транспортної системи та відображає їхні взаємозв'язки з процесом прийняття рішення щодо організації перевізного процесу, що зокрема і визначає параметри оцінювання логістичного ланцюга; адаптивної процесної моделі, яка враховує специфічні технологічні операції із транспортування вантажів БПЛА, операційну гнучкість і швидкість реагування на критичні зміни в зоні конфлікту.***

Мета статті полягає в обґрунтуванні теоретичних засад щодо економічної стійкості гуманітарного ланцюга постачання як інструмента реагування на гуманітарну кризу, а також розроблення концептуальної та процесної моделей організації доставки гуманітарних вантажів за допомогою БАС на етапі "останньої милі", який є найбільш високовартісним через високі безпекові ризики у зонах бойових дій і на прифронтових територіях.

М е т о д и . ***У дослідженні використано такі методи: порівняння (для виявленні відмінностей між гуманітарним і комерційним ланцюгами постачання), аналізу і синтезу (для розкриття сутності та вивчення складових гуманітарного ланцюга постачання), контент-аналізу та бібліометричного аналізу (при опрацюванні наукової літератури з організації постачання гуманітарних вантажів), абстрактно-логічний метод (для виявлення ключових характеристик стійкості ланцюга постачання), системний підхід (за розгляду гуманітарного ланцюга постачання як складної системи, що взаємодіє із зовнішнім середовищем (кризовими умовами), і визначає фактори, які забезпечують його стійкість), узагальнення (для групування чинників, що впливають на інтеграцію БАС у гуманітарні ланцюги постачання), морфологічний аналіз (для обґрунтування вибору БПЛА). Для підтвердження гіпотези застосовано процесний підхід, що дозволило формалізувати процес доставки гуманітарних вантажів БПЛА на етапі "останньої милі" з метою швидкого реагування на зміни та забезпечення економічної стійкості ланцюга постачання.***

Р е з у л ь т а т и . ***Дослідження показало доцільність інтеграції БАС у гуманітарні ланцюги постачання на етапі доставки "останньої милі". Гуманітарний ланцюг постачання є складовою механізму управління гуманітарними кризами і являє собою інтегровану систему планування, закупівлі, транспортування та розподілу гуманітарних вантажів для населення, що постраждало від воєнних конфліктів або катастроф. В роботі розкрито основні характеристики гуманітарного ланцюга постачання як складної та динамічної системи. Для стійкості гуманітарних ланцюгів постачання в умовах невизначеності, важливі такі три складові: стратегічне резервування, радикальна гнучкість і кластерна культура реагування. Економічна складова стійкості гуманітарних ланцюгів постачання включає: дотримання принципу ефективності витрат і забезпечення стійкості через мінімізацію витрат; фінансову гнучкість і можливість перенаправляти кошти з одного виду допомоги на інший за зміни ситуації. У процесі оцінювання економічної стійкості оцінюють такі параметри: ступінь виконання заявки; схоронність і точність доставки вантажу, швидкість доставки, безпечність. В розроблених моделях враховано такі показники економічної стійкості: показник успішності місій, час відновлення сервісу, коефіцієнт доступності маршрутів. З погляду соціально-економічних параметрів важливо врахувати індекс доступності допомоги та вартість врятованого життя.***

Виявлено критерії оцінювання виконання місії, зокрема: соціально-гуманітарний критерій, критерій мінімізації часу, критерій економічних витрат на виконання завдання з доставки, результативність і безпечність перевезення з урахуванням параметрів керуючої системи та параметрів зовнішнього середовища. Запропоновано концептуальну модель організації доставки гуманітарних вантажів, яка систематизує параметри складових транспортної системи, визначає параметри оцінювання логістичного ланцюга.

В и с н о в к и . ***Розроблена адаптивна процесна модель доставки гуманітарної допомоги БАС у воєнний час, яка базується на описаних в роботі параметрах організації доставки та технологічних операціях, дає змогу формалізувати процес доставки та його відтворюваність, а також ефективно управляти ризиками. На практиці використання запропонованої моделі може стати ефективним інструментом проєктування безпечного й економічно обґрунтованого логістичного ланцюга постачання гуманітарного вантажу для постраждалого населення в зони критичного безпекового ризику. Цей досвід може бути масштабовано іншими країнами.***

К л ю ч о в і с л о в а : гуманітарні вантажі, ланцюг поставок, економічна стійкість, безпілотний літальний апарат, безпілотна авіаційна система, ефективність, транспортування, технологія.

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