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INTRODUCTION

We are happy to invite you to get acquainted with the first issue of the new scientific and practical publication "Intellectualization of Logistics and Supply Chain Management".

We strongly believe that the launch of this magazine indicates the objective need to rethink a wide range of issues related to the development of theory and practice in logistics and supply chain management, awareness of the need to unite the scientific community and logistics practitioners, dissemination of modern knowledge and best practices for innovative development of the logistics services market.

The first issue of the magazine is published at a difficult time. The global coronavirus pandemic and the deep economic crisis have significantly worsened business activity in the world. Currently, global supply chains are collapsing, international trade is declining, and competition between global and regional logistics operators is intensifying. The most common thesis is that the world will never be the same again. Industry experts predict the emergence of new, more flexible and adaptive supply chain management strategies and approaches to logistics business process management. The trend towards collaborations, cooperation and unification of services is emerging, comprehensive proposals for clients are being developed. There is increasing talk about the need to build bimodal supply chains, which involves the development of different decision-making scenarios: the traditional approach - cost-effective efficiency, low risk, high predictability; a new approach "second mode" - rapid recognition of opportunities, adaptability, willingness to solve unexpected problems and look for new opportunities.

Radical transformations of the global and national markets for logistics services require appropriate scientific support. Logistics science has a special role to play in this process. Initiating the emergence of a new journal, we decided to focus on its coverage of problematic aspects of the formation and development of logistics systems at the micro, mezo and macro levels, supply chain management, digitization of logistics, methods and tools for optimizing processes in logistics and supply chains, sociopsychology relations and network interaction of enterprises using cloud technologies, artificial intelligence, e-learning, neural business process management systems, etc.

Therefore, we invite scientists, researchers and business representatives, as well as our colleagues from abroad, to cooperate and present the results of scientific research, to discuss and debate on them, to work together to develop the scientific theory of logistics and promote mutual intellectual enrichment.

We hope that the new scientific publication will become a theoretical guide for young researchers and representatives of other fields.

HRYPHORAK Mariia
Chief Editor



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OPERATIONAL ACTIVITIES OF UKRAINIAN AIRLINES DURING THE WAR: CHALLENGES AND PROACTIVE MANAGEMENT STRATEGIES

Dmytro Bugayko, Olga Shevchenko, Danylo Bugayko. *"Operational activities of Ukrainian airlines during the war: challenges and proactive management strategies".* The beginning of a full-scale war and the closure of Ukrainian airspace became unprecedented challenges for the civil aviation industry of Ukraine. At the same time, Ukrainian airlines found themselves in different conditions. Air carriers that had their fleet partially or completely abroad at the time of the war had more acceptable conditions than airlines whose aircraft remained at Ukrainian airports. A number of powerful companies, such as UIA and Bees Airline, actually ceased to exist, while other airlines, such as Skyline Express, SkyUp Airlines and a number of transport airlines, found adequate answers to today's challenges. It can be noted that it was the proactive approach to strategizing operational activities in conditions of force majeure and uncertainty that became the key to their success. The

implementation of a set of measures to support operational activities during military operations has allowed obtaining positive synergistic effects both for the air carriers themselves and for the national economy. Preservation of the potential of Ukrainian airlines is the key to its further post-war development.

Keywords: airlines, operational activities, military conditions, force majeure, proactive management strategies

Дмитро Бугайко, Ольга Шевченко, Данило Бугайко. «Операційна діяльність українських авіакомпаній під час війни: виклики та проактивні стратегії управління». Початок повномасштабної війни та закриття повітряного простору України стали безпрецедентними викликами для галузі цивільної авіації України. При цьому українські авіакомпанії опинились у різних умовах. Авіаперевізники, які мали на момент початку війни флот частково чи повністю за кордоном, працювали у більш прийнятних умовах, ніж авіакомпанії, літаки яких залишились в аеропортах України. Низка потужних компаній, таких як МАУ та Veas Airline, фактично припинили власне існування, при цьому інші авіакомпанії, такі як Skyline Express, SkyUp Airlines та низка транспортних авіакомпаній, знайшли адекватні відповіді на виклики сьогодення. При цьому можна зазначити що саме проактивний підхід до стратегування операційної діяльності в умовах форс-мажору та невизначеності став запорукою їх успіху. Реалізація комплексу заходів по підтримці операційної діяльності під час військових дій дозволила отримати позитивні синергетичні наслідки як для самих авіаперевізників, так і для національної економіки. Збереження потенціалу українських авіакомпаній є запорукою її подальшого повоєнного розвитку.

Ключові слова: авіакомпанії, операційна діяльність, військові умови, форс-мажор, проактивні стратегії управління.

Introduction. Unfortunately, since February 24, 2022, the airspace of Ukraine has been closed for commercial transportation. Therefore, it is considered appropriate to conduct an analysis of air passenger transportation in the pre-war years. The last pre-war year of 2021 for the aviation industry

of Ukraine was the first year of gradual recovery after a significant decline in production indicators of their activities in 2020, caused by the negative impact of the Covid-19 pandemic.

The results of the operational activities of the civil aviation industry of Ukraine in 2020 and 2021 are presented in Table. 1 [1].

Table 1 - Results of the operational activities of the civil aviation industry of Ukraine in 2020 and 2021

	Units of measurement	Total			including international flights		
		2020p.	2021p.	% 21/20	2020p.	2021p.	% 21/20
Airline operational activities							
Passengers transported	thousand people	4797,5	9348,1	194,9	4287,7	8622,3	201,1
including on regular routes	-,-	1788,1	3322,7	185,8	1284,6	2608,9	203,1
Passenger-kilometers performed	billion passenger-km	10,1	18,7	185,1	9,8	18,4	187,8
including on regular routes	-,-	3,1	5,6	180,6	2,9	5,2	179,3
Cargo and mail transported	thousand tons	88,3	81,8	92,6	88,0	81,8	93,0
including on regular routes	-,-	5,7	8,9	156,1	5,6	8,9	158,9

	Units of measurement	Total			including international flights		
		2020p.	2021p.	% 21/20	2020p.	2021p.	% 21/20
Airline operational activities							
Passengers transported	thousand people	4797,5	9348,1	194,9	4287,7	8622,3	201,1
Tonne-kilometers performed (cargo+mail)		316,2	346,3	109,5	316,1	346,2	109,5
including on regular routes	million tkm	18,4	39,9	216,8	18,4	39,9	216,8
Commercial routes performed	-,-	45,3	74,0	163,4	35,3	59,9	169,7
including on regular routes	thousands	20,4	34,4	168,6	11,8	21,9	185,6

Source: <https://avia.gov.ua/pro-nas/statistika/periodychna-informatsiya> [1].

In 2021, passenger and cargo transportation was carried out by 28 Ukrainian airlines, with a total of 74 thousand commercial flights performed (compared to 45.3 thousand flights in 2020). During 2021, passenger transportation was carried out by 16 Ukrainian airlines, with almost 93 percent of the total volume in the industry provided by four leading airlines: Ukraine International Airlines, SkyUp Airlines, Azur Air Ukraine and Wind Rose. It should also be noted that the fifth position in terms of passenger transportation was taken by Bees Airline, which began operating flights in March of the reporting year [1].

Regular flights to 42 countries of the world were operated by 9 domestic air carriers. The number of passengers who used the services of Ukrainian airlines during 2021 doubled compared to the previous year and reached 2,608.9 thousand people. At the same time, the passenger load factor of international scheduled flights of Ukrainian airlines increased by 6.2 percentage points and amounted to 75.2%. At the same time, 29 foreign airlines from 34 countries of the world operated regular flights to Ukrainian airports. According to the results of 2021, 13 airlines transported 6,013.4 thousand passengers on international flights on an irregular basis, which is twice as much as in the previous year, and also 10.9 percent higher than the "before - Covid" indicator of 2019 [1].

Regular passenger transportation within Ukraine was carried out by six airlines ("Wind Rose", "International Airlines of Ukraine", "Motor-Sich", "Skyup", "Bees Airline" and "Air Ocean Airlines"), which provided air services

to 12 cities of Ukraine. In 2021, 713.8 thousand passengers were transported on regular domestic flights, which is 41.8 percent more than a year earlier. At the same time, the average passenger seat occupancy rate on domestic regular flights of Ukrainian airlines increased by 8.1 percentage points and amounted to 70.7% [1].

So, we can state that in the pre-war period, the civil aviation industry of Ukraine actually fully recovered and had positive growth dynamics. But on February 24, 2022, the situation changed dramatically.

The purpose of the article is to analyze the effectiveness of using a proactive approach to strategizing the operational activities of Ukrainian airlines in conditions of war, force majeure and uncertainty.

The main task is to assess the synergistic effect of the implementation of a set of measures by Ukrainian airlines aimed at supporting operational activities during military operations.

Presentation of the main results.

Challenges for the operational activities of Ukrainian airlines during martial law. Unfortunately, from the first minute, the full-scale war had a devastating impact on the activities of air transport in general, and on the activities of Ukrainian airlines in particular [2]. At the same time, the flagships of Ukrainian aviation found themselves in different conditions. Airlines that had their fleet partially or completely abroad at the time of the war found themselves in more acceptable conditions than airlines whose aircraft remained at Ukrainian airports. On the night of February 24, 2022, UKSATSE closed

the sky over Ukraine for civilian aircraft. Airports were closed, and runways were blocked due to the threat of Russian landings. And unfortunately war is in progress. At least 19 civilian airports in Ukraine were damaged by shelling. Airlines subsequently privately evacuated some of their aircraft to Europe [3].

Ukraine International Airlines (UIA) held a dominant position in the Ukrainian air transportation market before the war. At the beginning of hostilities, its fleet included 25 long-haul and medium-haul aircraft. Most of these aircraft remained hostage to the

situation. After a series of changes in top management, in October 2023, UIA declared bankruptcy, and the company's property was put up for sale. Trademarks with the name and logo of UIA and its aircraft maintenance subsidiary UIA Technik were sold. The Commercial Court of Kyiv has opened proceedings in the bankruptcy case of UIA, which provides for an inventory of all property and a temporary ban on any actions with it, including sales [3].



Figure 1 – Windrose Airlines Boeing 737-800 UR-PSF at Chisinau Airport
Source: <https://www.avianews.com/ukraine/2023/12/25/boeing737-urpsf-kishinev/>

Part of the fleet, which was abroad at the time of the war, was leased or re-registered to other airlines. For example, a Boeing 737-800 with Ukrainian registration and livery operates flights in Chisinau. It is now registered to the Ukrainian air company Windrose, which, in turn, leases the aircraft on a ACMI "wet lease", i.e. leases it together with the crew, to a Moldovan air carrier. In total, the

Windrose fleet has been replenished with three UIA aircraft: an Embraer 190 with registration UR-EMA, a Boeing 737-800 UR-PSF and a Boeing 737-900ER UR-PSI. All of them are actively flying and operate flights for foreign airlines [4]. At the same time, most of Windrose's own fleet remained in Ukraine [5].

As already mentioned above, the top five international air carriers in Ukraine included

Azur Air Ukraine [6]. However, in Russia there is an airline with an almost identical name Azur Air, which is included in the sanctions list in the USA. Under such conditions, the airline's management took a bold step – a

complete rebranding of the air carrier. The new name Skyline Express Airlines appeared in 2023 [7].



Figure 2 – Boeing 777-300ER UR-AZR of the Ukrainian airline Skyline Express
Source: <https://www.avianews.com/ukraine/2025/01/25/skyline-express-boeing777-urazr/> [8].

Skyline Express Airlines business model abroad is based on serving its founder's travel business. Skyline Express currently partners with its affiliated tour operator, Anex Poland, which has Turkish roots. The Ukrainian airline transports passengers from European airports to resorts on behalf of the travel agency on Boeing 757, Boeing 737 and Boeing 777 aircraft.

An interesting story is about the return to service of the largest passenger aircraft used by Ukrainian airlines before the war. At the time of the Russian invasion of Ukraine on February 24, 2022, Boeing 777-300ER UR-AZR was at Boryspil Airport and was unable to depart due to the closure of airspace to civilian aircraft. The owners evacuated the aircraft only on December 19, 2023. For over a

year, the aircraft was stored at Tarbes-Lourdes-Pyrénées Airport in France. This airfield is used as a maintenance base and long-term storage facility for airliners. In December 2024, the aircraft began preparations for commercial flights, and in January 2025, it returned to its previous operator - Skyline Express. Before the launch of the new flight program, the Azur Air Ukraine markings were removed from the aircraft and elements of the Skyline Express corporate identity were applied [7].

Unfortunately, Bees Airline - the pre-war leader in international transportation, could not survive the force majeure conditions. The new Ukrainian airline made its first flight in March 2021. But in 2022, due to the full-scale Russian invasion, Bees Airline was left without

all its aircraft and lost its certificate in Ukraine.
The aircraft had to be driven abroad at the
request of the lessor.



Figure 3 – Boeing 737-800ER UR-UBA of Bees Airline

Source: <https://thepage.ua/ua/news/yaki-ukrayinski-aviakompaniyi-pracyuyut-za-kordonom-v-2024-roci> [7].

At the same time, investors of this Ukrainian start up, who are involved in the tourism business, created a new airline with the same name in Romania. This carrier is currently completing certification [7].

Transport airlines of Ukraine. Ukraine is known throughout the world for its own

transport airlines, which use, among other things, Ukrainian-made aircraft from the Antonov Design Bureau. Among them is the world-famous airline specializing in the transportation of oversized and heavy cargo ANTONOV Airlines [9].



Figure 4. Antonov – 124 – 100 of ANTONOV Airlines

Source: <https://thepage.ua/ua/news/yaki-ukrayinski-aviakompaniyi-pracyuyut-za-kordonom-v-2024-rocii> [9].

Before the war, the total fleet of cargo airlines was about 100 aircraft [7]. They mainly operated outside Ukraine, and today most of them continue their work, as a rule, under ACMI contracts - "Wet" leasing, under charter contracts when performing charter flights (on a regular basis, split charter, chain charter and

one-time charter) when performing missions of the UN and other organizations.

Operational & financial results of Ukrainian airlines during a full-scale war. Table 2, Pic.5 and Pic.6 present results of the operational activities of the civil aviation industry of Ukraine from 2022 to 2024 years.

Table 2 – Results of the operational activities of the civil aviation industry of Ukraine from 2022 to 2024 years.

Transported	Units of measurement	2022	2023	2024
Passengers transported	thousand people	980	422.1	480
Cargo and mail transported	thousand tons	64.1	42.7	31.4

Source: compiled by the authors based on data from [10].

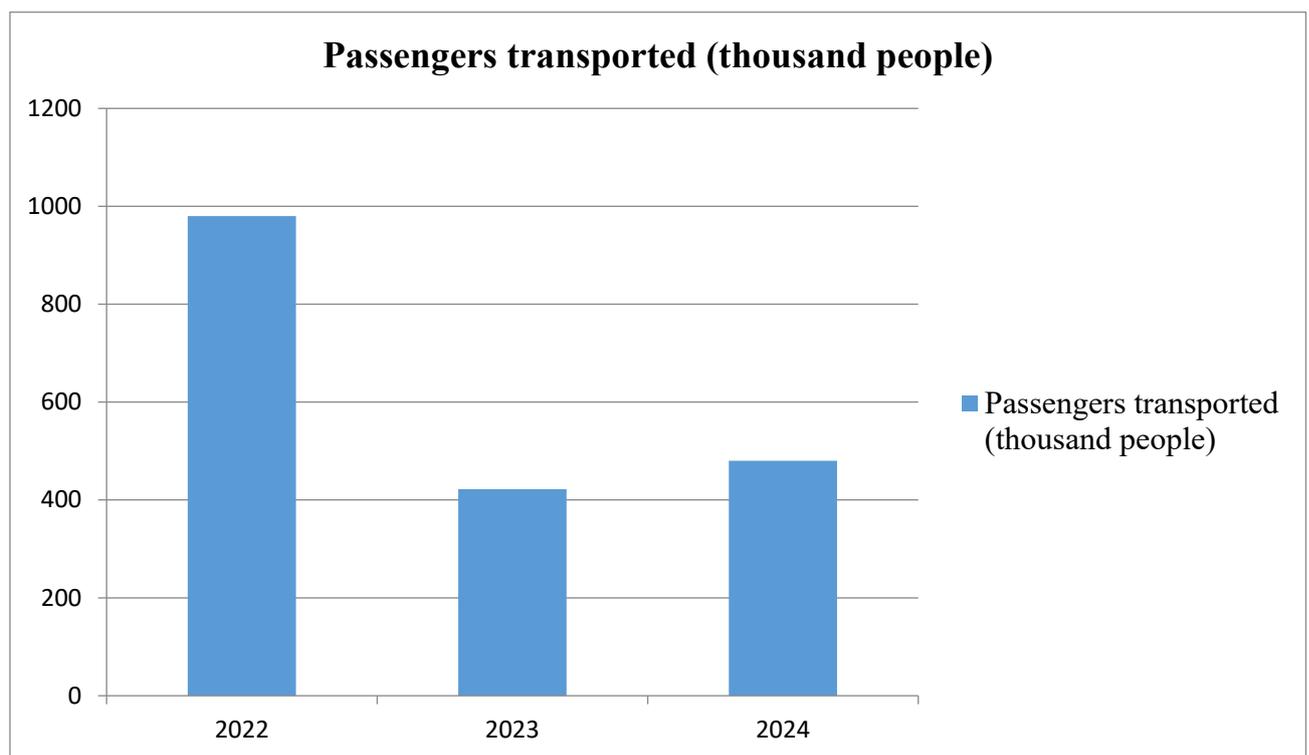


Figure 5 – Results of the passenger transportations of Ukrainian airlines from 2022 to 2024 years
 Source: compiled by the authors based on data from [10].

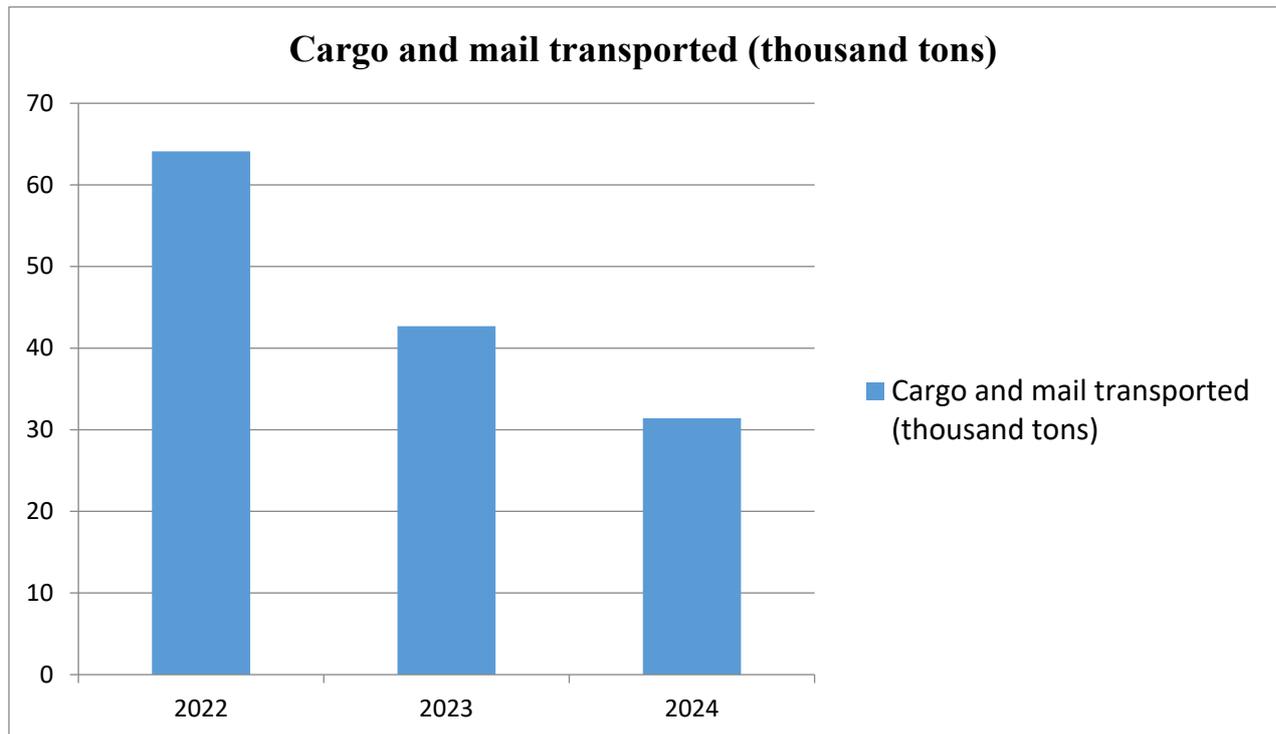


Figure 6 – Results of cargo&mail transportations of Ukrainian airlines from 2022 to 2024 years
 Source: compiled by the authors based on data from [10].

Ukrainian airlines transported 480 thousand passengers and 31.4 thousand tons of cargo in 2024. For comparison: in 2022, 980 thousand passengers and 64.1 thousand tons

of cargo were transported, and in 2023 – 422.1 thousand people and 42.7 thousand tons of cargo [10].

Table 3 - Financial results of Ukrainian airlines from 2022 to 2024 years.

Financial results (millionUAH)	2022	2023	First three quarters 2024
Wind Rose airline	-1600	-750,5	-553
SkyUp airline	-596,7	305,1	137
Skyline Express	-464,7	-25,4	171,2
Constanta	0,3	-20,9	25,1
Ukrainian Helicopters Airlines	94,3	55,1	-73,5
CAVOK Air	-32,5	47,7	21,8
Ukraine Air Alliance	0,5	1,4	1,9
ANTONOV Airlines	654	3000	no statistical data

Source: compiled by the authors based on data from [10].

The largest losses from passenger transportation in 2022 were suffered by the Wind Rose airline – 1.6 billion hryvnias. The company currently operates flights from Moldova and Montenegro. In 2023, the company reduced its loss to 750.5 million hryvnias, and in the first three quarters of 2024 – to 553 million [10].

SkyUp airline in 2022 suffered a loss of 596.7 million hryvnias. In 2023, the company received 305.1 million hryvnias in profit, and in the first three quarters of 2024 - 137 million. In 2024, SkyUp airline reached the pre-war level of air transportation [10].

Skyline Express suffered losses of 464.7 million hryvnias in 2022, the year of the war.

During the war, the company flies from Poland and the Baltic countries to the seaside resorts of Turkey, Egypt and other countries. In 2023, Skyline Express reduced its loss to 25.4 million, and in the three quarters of last year it received 171.2 million in profit [10].

Charter airline Constanta received 0.3 million hryvnias in profit in 2022, and in 2023 - 20.9 million in loss. In the first three quarters of 2024, the company's profit amounted to 25.1 million [10].

Ukrainian Helicopters Airlines ended 2022 and 2023 with a profit of 94.3 million and 55.1 million hryvnias, respectively. According to the results of the three quarters of 2024, the company had a loss of 73.5 million [10].

As for cargo transportation, CAVOK Air was able to turn a profit. It ended 2022 with a loss of 32.5 million hryvnias, and in 2023 and for the incomplete year of 2024 it received 47.7 million and 21.8 million hryvnias in profit [10].

Ukraine Air Alliance had a small profit for all three years of the full-scale war: 2022 – 0.5

million hryvnias, 2023 – 1.4 million, three quarters of 2024 – 1.9 million [10].

ANTONOV Airlines ended 2022 with a profit of 654 million hryvnias, and 2023 - almost 3 billion hryvnias [10].

Thus, the financial results of Ukrainian airlines allow us to assert that a correctly chosen strategy allows airlines to conduct operations and even make a profit even during the closure of their own country's airspace. Let's consider proactive management strategy using the example of SkyUp Airlines - one of the most successful Ukrainian airlines in this difficult period for the industry.

Proactive management strategy of SkyUp Airlines in force majeure conditions

According to the authors, the most successful proactive management strategy in force majeure conditions was demonstrated by the Ukrainian air carrier SkyUp Airlines. From the very beginning of the war, the airline began to actively transform its activities.



Figure 7 – Boeing 737-800ER UR-SDH SkyUp Airlines
Source: <https://skyup.aero/>[11]

SkyUp Airlines' set of measures to support operational activities during war included the following proactive measures:

Evacuation of aircraft. During the war, SkyUp Airlines focused its efforts on evacuating its own aircraft. Before the start of the full-scale invasion, the company was able to evacuate 10 of its 11 aircraft from Ukraine. But the last aircraft had already managed to take off from Boryspil to Chisinau, but after 20 minutes of flight it was ordered to return. On April 4, 2023, the company evacuated its last aircraft from Ukraine. It was at Boryspil Airport [11].

Creation of an airline with European registration. Registration of a subsidiary in the EU with EU certificates, with the transfer of part of the existing aircraft fleet there [11].

Evacuation flights/air corridors. SkyUp Airlines cooperates with organizations that need to transport Ukrainians or other citizens from a particular city or country, and that need air corridors or charter flights [11].

Delivery of humanitarian cargo. SkyUp Airlines cooperates with government institutions, private foundations, companies that seek to organize the delivery of humanitarian cargo to Ukraine, or those who consolidate the volumes of aid for delivery to Poland, Romania, Moldova with further transportation to Ukraine [11].

ACMI contracts - "Wet" leasing. SkyUp Airlines currently accounts for 70% of its business on ACMI contracts, but the company still sees further potential for growth in this area. To expand its operations in different countries on ACMI contracts, SkyUp Airlines received a Maltese operator certificate, as well as FAR129 certificates in the USA and FAOC in Canada. Under ACMI contracts and the charter program for tour operators, SkyUp Airlines performed 10,528 flights in 2023, transported over 1.5 million passengers, and transferred almost UAH 200 million in taxes to the state. In terms of revenue, SkyUp Airlines became the leading airline in Ukraine [7].

Non-aviation activities. SkyUp Airlines such areas of diversification as the provision of expert services, the organization of training

and retraining courses for personnel, the provision of non-aviation services, in order to maximize revenues during the period of forced downtime of a part of the airline's aircraft fleet. The airline develops souvenir products and promotional events for customers, tourist packages using long-term ties in the tourist market of different countries of the world [11].

YIELD Management. SkyUp Airlines constantly conducts market research in order to optimize and establish a competitive price per flight hour according to the "ACMI" system (Aircraft - hourly payment for the aircraft; Crew - hourly payment for the crew; Maintenance - hourly payment for aircraft maintenance; Insurance - hourly payment for mandatory insurance of the aircraft, crew, commercial load such as passengers, cargo&post, third parties on the surface [11].

Resources required implementing a set of measures by SkyUp Airlines to support operational activities during war:

Evacuation of aircraft. Non-revenue operating costs of non-commercial flights.

Creation of an airline with European registration. Costs for registration and certification of the airline.

Delivery of humanitarian cargo and evacuation flights. Costs for assessing the risks of operating flights in unstable regions during the delivery of humanitarian aid and evacuation flights, to calculate potential risks and their consequences.

Non-aviation activities. Costs for retraining and upgrading the certification of experts and instructors. Also costs for contracts for the production of souvenirs and the development of advertising and tourist packages.

YIELD Management. Costs for marketing market research.

Synergistic consequences of the implementation of a set of measures by SkyUp Airlines to support operational activities during war:

Evacuation of aviation equipment. Evacuation of the aircraft fleet from the

combat zone provides the opportunity to carry out operational activities in the future.

Creation of an airline with European registration. Allows to expand the range of potential services to perform regular, international and domestic, passenger and cargo air services, both within and outside the EU.

Evacuation flights / air corridors. Allows to solve important political, social and humanitarian tasks and receive additional income and flight hours for the aircraft fleet.

Delivery of humanitarian cargo. Allows to solve important political, social and humanitarian tasks and receive additional income and flight hours for the aircraft fleet.

ACMI - "Wet" leasing contracts. Wet leasing will allow to fundamentally increasing the flight hours of the aircraft fleet, to work out long-term projects with foreign airlines, to ensure the work of not only the aircraft fleet and technical personnel, but also the airline's flight crew, which is the most vulnerable in conditions of wartime.

Expertise in the aviation and tourism industries. Allows to strengthen the airline's ties with various enterprises in the civil aviation and tourism industries, and most importantly, to receive additional income directly independent of the number of flights.

Non-aviation activities. Allows to provide additional income that does not depend on the regularity of air transportation.

YIELD Management. Competitive pricing of aviation services of leasing and charter operations allows the airline to obtain sufficient resource support to repay the above-mentioned costs of the air carrier and

provide it with the necessary profit for the further development of operational activities.

Conclusions. Summarizing the above analysis, it is possible to conclude that the force majeure conditions of martial law have changed the balance of power in the segments of the Ukrainian aviation market.

A number of powerful companies such as UIA and Bees Airline have actually ceased to exist, while other airlines such as Skyline Express, SkyUp Airlines and a number of transport airlines have found adequate answers to the challenges of today. It can be noted that it is precisely the proactive approach to strategizing operational activities in conditions of force majeure and uncertainty that has become the key to their success [12].

The strategy for adapting to wartime conditions included the following measures: evacuation of aircraft equipment, creation of airlines with European registration, development of evacuation flights/air corridors, delivery of humanitarian cargo, development of ACMI - "Wet" leasing contracts, expansion of non-aviation activities and improvement of YIELD Management.

The implementation of a set of measures to support operational activities during military operations has allowed for positive synergistic effects both for the air carriers themselves and for the national economy. Preservation of the potential of Ukrainian airlines is a guarantee of its further post-war development.

References

1. [https://avia.gov.ua/pro-nas/statistika/periodychna-informatsiya//](https://avia.gov.ua/pro-nas/statistika/periodychna-informatsiya/)
2. Bugayko D.O., Shevchenko O.R., Perederii N.M., Sokolova N.P., Podrieza M.S., Bugayko D.D. Risk management of Ukrainian aviation transport post-war recovery and sustainable development. – Intellectualization of logistics and Supply Chain Management. [Online] -vol.16, -pp.6-22. available at: <https://smart-scm.org/en/journal-16-2022/risk-management-of-ukrainian-aviation-transport-post-war-recovery-and-sustainable-development/>. DOI: <https://doi.org/10.46783/smart-scm/2022-16-1>

3. https://24tv.ua/aviagaluz-ukrayini-pid-chas-viyni-yak-vizhivayut-kompaniyi_n2463408
4. <https://www.avianews.com/ukraine/2023/12/25/boeing737-urpsf-kishinev/>
5. <https://windrose.aero/>
6. <https://skylineexpress.aero/ua>
7. <https://thepage.ua/ua/news/yaki-ukrayinski-aviakompaniyi-pracyuyut-za-kordonom-v-2024-roci>
8. <https://www.avianews.com/ukraine/2025/01/25/skyline-express-boeing777-urazr/>
9. <https://antonov-airlines.aero/>
10. <https://www.slovoidilo.ua/2025/02/20/infografika/biznes/doxody-ta-zbytky-ukrayinskyx-aviakompanij-povnomasshtabnoyi-vijny>
11. <https://skyup.aero/>
12. Kharazishvili, Y., Kwilinski, A., Bugayko, D., Hryhorak, M., Butorina, V., & Yashchyshyna, I. (2022). Strategic scenarios of the post-war recovery of the aviation transport sustainable development: The case of Ukraine. *Virtual Economics*, 5(3), 7-30.

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ENHANCING THE RESILIENCE, ADAPTABILITY, AND ANTIFRAGILITY OF DEFENSE INDUSTRY SUPPLY CHAINS UNDER CONDITIONS OF HIGH TURBULENCE

Mariia Hryhorak, Volodymyr Marchuk, Oleh Harmash. *"Enhancing the resilience, adaptability, and antifragility of defense industry supply chains under conditions of high turbulence".* The article substantiates the theoretical and methodological foundations and develops practical approaches to enhancing the resilience, adaptability, and antifragility of supply chains within Ukraine's defense industry under conditions of high environmental turbulence. The specific nature of defense industry supply chains is defined as complex socio-technical systems operating under the influence of geopolitical risks, restricted access to critical resources and technologies, cyber threats, and strict regulatory requirements. The study systematizes the factors affecting the resilience, adaptability, and viability of defense supply chains and identifies the key threats, barriers, and drivers of their development. The essence of the concepts of resilience, adaptability, and antifragility – which

together constitute the foundation of supply chain viability – is revealed, and the rationale for their integrated application in defense industry management is provided. A system of managerial measures is proposed to foster flexible organizational structures, promote partnership-based interaction among business ecosystem participants, and implement modern digital technologies (IoT, Big Data, AI, blockchain, digital twins) that enhance the ability of supply chains to rapidly respond, recover, and transform during crises. The practical significance of the study lies in formulating scientifically grounded recommendations for Ukraine's defense enterprises to build viable, adaptive, and antifragile supply chains capable of ensuring the continuity of defense production, strengthening national security, and maintaining economic stability amid wartime and global instability.

Keywords: supply chains, defense industry, resilience, adaptability, antifragility, viability, digital technologies, risk management

Марія Григорак, Володимир Марчук, Олег Гармаш. «Підвищення стійкості, адаптивності та антикрихкості ланцюгів постачання підприємств оборонно-промислового комплексу в умовах високої турбулентності». У статті обґрунтовано теоретико-методичні засади та розроблено практичні підходи до підвищення стійкості, адаптивності та антикрихкості ланцюгів постачання підприємств оборонно-промислового комплексу (ОПК) України в умовах високої турбулентності зовнішнього середовища. Визначено специфіку ланцюгів постачання ОПК як складних інтегрованих соціо-технічних систем, що функціонують під впливом геополітичних ризиків, обмежень доступу до ресурсів і технологій, кіберзагроз та жорстких регуляторних вимог. У роботі систематизовано чинники, які впливають на стійкість, адаптивність та життєздатність оборонних ланцюгів постачання, виокремлено ключові загрози, бар'єри та драйвери їх розвитку. Розкрито сутність концепцій стійкості, адаптивності та антикрихкості, що утворюють основу життєздатності систем постачання, та обґрунтовано доцільність їхнього інтегрованого застосування в управлінні ОПК. Запропоновано систему управлінських заходів, спрямованих на формування гнучких організаційних структур, розвиток партнерської взаємодії учасників бізнес-екосистем і впровадження сучасних цифрових технологій (IoT, Big Data, AI, блокчейн, цифрові двійники), які підвищують здатність ланцюгів постачання до швидкого реагування, відновлення та трансформації під час кризових ситуацій. Практичне значення дослідження полягає у формуванні науково обґрунтованих рекомендацій для підприємств ОПК України щодо побудови життєздатних, адаптивних і антикрихких ланцюгів постачання, здатних забезпечити безперервність оборонного виробництва, зміцнення національної безпеки та стійкість економіки в умовах війни та глобальної нестабільності.

Ключові слова: ланцюги постачання, оборонно-промисловий комплекс, стійкість, адаптивність, антикрихкість, життєздатність, цифрові технології, управління ризиками.

Introduction. The contemporary operating environment of enterprises within the defense-industrial complex (DIC) is characterized by an unprecedented level of turbulence driven by both global and regional challenges. The armed aggression against Ukraine, large-scale destruction of industrial and transport infrastructure, disruptions in the supply of critical resources,

intensifying international competition, and stringent sanctions have created a complex environment in which DIC enterprises must ensure the continuity of production and the fulfillment of state defense contracts. Under such conditions, effective supply chain management becomes not only an essential component of economic activity but also a critical factor of national security.

The supply chains of defense-industrial enterprises possess a number of specific characteristics, including a high degree of integration with international suppliers, dependence on imported components, the necessity to comply with strict standards of quality and confidentiality, as well as constraints associated with secrecy regimes and export control regulations. Simultaneously, warfare and geopolitical instability significantly increase the vulnerability of these supply chains, leading to supply disruptions, rising material costs, loss of suppliers, and, in some cases, a complete breakdown of logistical connections.

In this regard, the formation of resilient, adaptive, and antifragile supply chains acquires strategic importance for defense-industrial enterprises. In this context, resilience should be understood as the ability of the supply chain to maintain its functionality under crisis conditions, while adaptiveness refers to its capacity to promptly respond to environmental changes, reconfigure logistical and production processes, engage alternative suppliers, and integrate new technologies.

It should be emphasized that existing scientific approaches to supply chain management are primarily focused on civilian industries and do not fully consider the specific features of the defense-industrial sector, in particular, the increased role of state regulation, the strategic sensitivity of products, and the necessity of accounting for military and political risks. This situation creates a scientific gap that requires comprehensive research and the development of new models and managerial solutions aimed at ensuring the resilience and adaptiveness of defense-industrial supply chains under conditions of high turbulence.

Therefore, the study of methods for enhancing the resilience and adaptability of supply chains within the defense-industrial complex is of exceptional relevance, both for improving the economic efficiency of the

sector and for strengthening the overall defense capability of the state.

Literature Review. The issues of resilience, adaptability, and fragility of supply chains in recent years have attracted increasing attention in global academic literature due to the growing uncertainty and turbulence of the business environment. This is driven both by escalating geopolitical risks and by the rapid development of technologies that are transforming logistics processes.

In foundational research by Ponomarov and Holcomb (2009) [1], supply chain resilience is defined as the system's ability to withstand disruptions, adapt to them, and recover while maintaining its essential functions. The authors emphasize the interconnection between supply chain elements and identify flexibility, redundancy, and adaptability as key components of resilience. These ideas were further developed by Petty et al., who proposed practical tools for assessing an organization's readiness for disruptions [2]. Resilience is an essential attribute of a supply chain for short-term survival and a critical capability for long-term adaptation and prosperity. A particular emphasis is placed on a proactive approach to risk management, which involves identifying potential threats, planning mitigation measures, and preparing recovery scenarios.

The study by Pires Ribeiro and Barbosa-Povoa (2018) [3] broadened the concept of resilience by including the supply chain's ability not only to recover from crises but also to maintain stable operations at acceptable costs and within reasonable timeframes. Melnyk et al. (2010) provided an even broader perspective on the future of supply chains, which must balance efficiency, security, sustainability, resilience, and innovativeness according to customer needs and external challenges.

Further development of supply chain resilience theory is associated with the works of various authors who integrated multiple perspectives. In particular, Dmitry Ivanov substantially expanded the theoretical and

methodological foundations by proposing a comprehensive three-dimensional model for assessing supply chain resilience that encompasses product, process, technological, and social aspects [4]. He also emphasized that resilience should be considered in conjunction with adaptability and the system's transformational capacity – an especially relevant perspective under prolonged crises such as pandemics or armed conflicts [5].

As disruptions and uncertainty have become central themes in supply chain literature [6], researchers [7] have shifted their focus to two dominant strategies – redundancy and flexibility – proposed as means to mitigate the impact of disruptions. They identified four broad conceptual strategies – insurance, acceleration, strategic adaptive capability, and reconfiguration – each uniquely serving to reduce the likelihood and scale of disruptions within supply chains. Other scholars [8–10] have combined different aspects of resilience discussed in the literature using quantitative methods in the design or redesign of supply chains.

At the same time, contemporary literature recognizes that the traditional engineering-based interpretation of resilience is insufficient. Engineering resilience aims at optimality and structural safety and is measured by the speed of returning to equilibrium (recovery time) and resistance to disturbances (survival time). Researchers are increasingly moving toward the concept of socio-ecological resilience, which considers environmental dynamics, uncertainty, and the need for continuous transformation of supply chains [9, 10]. Socio-ecological resilience allows for experimentation and adaptive design since supply chains must evolve over time. This requires managers to foster adaptability and transformability, thereby anticipating and influencing events occurring beyond the immediate supply chain. The same idea is supported by other scholars [11], who argue that maintaining and developing resilience

requires accounting for a wide spectrum of social and environmental changes. Purposeful transformation of the system is necessary for it to continue delivering what holds fundamental value for society.

Summarizing theoretical research on resilience in supply chains based on a systematic review of the literature, it can be concluded that resilience is a multidimensional and interdisciplinary concept. It has evolved from generating reactive strategies to cope with disruptive events toward the development of proactive pre- and post-disruption strategies. Currently, the domain of supply chain resilience encompasses several capabilities: prevention, resistance, response, recovery, and market adaptation. Moreover, resilience includes the ability for cumulative learning and continuous improvement, becoming a strategic capability for enhancing competitiveness – an important reason for its inclusion in modern supply chain management frameworks [12].

Against this background, a new concept – antifragility – has emerged. It interprets disruptions and crises not only as threats but also as opportunities for strengthening, learning, and development of systems. The term antifragility was introduced by Nassim Nicholas Taleb in his 2012 book *Antifragile: Things That Gain from Disorder*. Taleb highlighted that in complex systems there exist not only resilient or fragile structures but also those that do not merely withstand stress and shocks but grow stronger and evolve under their influence. This qualitatively distinguishes antifragility from resilience, which merely denotes the ability to preserve functionality or return to the original state after a disruption [13].

One of the leading researchers integrating the concepts of resilience and antifragility in supply chains is Dmitry Ivanov. In his works, he proposed combining antifragility with resilience theory and developed dynamic models demonstrating how supply chains can reconfigure and strengthen after disruptions. He also

introduced the concept of viability as a logical continuation of antifragility [14, 15].

Considering the complexity, multi-tiered nature, and geographic dispersion of modern supply chains, traditional approaches to assessing their resilience and antifragility – focused solely on internal processes or individual organizations – are no longer adequate. Supply chains increasingly function within broader business ecosystems, where their resilience and capacity for recovery depend not only on internal reserves but also on the nature of interactions among various stakeholders – manufacturers, suppliers, logistics operators, government institutions, research organizations, and the private sector. Therefore, it is appropriate to assess the resilience and antifragility of supply chains through the lens of these interactions – considering the level of partnership, readiness for collaboration, information exchange, technology sharing, and resource coordination [16]. Such an approach allows for a more precise identification of system vulnerabilities while fostering the development of long-term, trust-based relationships among participants, thereby enhancing the ecosystem's ability to adapt, recover swiftly after crises, and transform in response to new challenges.

In the context of the defense-industrial complex (DIC), this issue becomes particularly significant. Supply chains within the DIC are, on the one hand, highly complex, multi-layered, and technologically intensive; on the other hand, they are critically important for ensuring national security, defense resilience, and the state's strategic autonomy. A seminal paper [17] presented the results of a discussion titled "Research Directions in Defense Logistics." Participants of that discussion drew several important conclusions: supply chain management is a critical success factor not only for industrial and commercial enterprises but also for military operations; although there remains a gap between civilian and military research, there exists an opportunity to leverage existing knowledge and expertise to

recognize that competition for defense contracts increasingly occurs not between individual firms but between resilient, adaptive, and interconnected supply chains.

In recent academic publications, it is increasingly emphasized that the successful functioning of defense-industrial enterprises and their ability to fulfill defense orders directly depend on the efficiency, resilience, and flexibility of their supply chains (Ekström [18]; Hilletoft & Skoglund, 2020, 2023 [19–21]). A study of the Swedish defense-industrial complex demonstrated that under military conditions, an optimal approach involves combining the principles of just-in-time, just-in-case, and just-enough. Such a synthesis enables achieving a balance between efficiency and resilience under uncertainty and high disruption risk. Highlighting the importance of responsiveness, recovery, and planning in military supply chains, other authors [22] underscored the need for continuous improvement of logistics strategies and assessment tools to enable military organizations to overcome disruptions effectively and sustain operational efficiency. In the context of global turbulence, the importance of risk management within the defense industry is increasing, particularly given its dependence on foreign supplies [23].

In the studies by Sani et al. (2023) [24–26] and Cabrera et al. (2023) [27], it is substantiated that military supply chains face a set of unique challenges, including:

- excessive dependence on a limited pool of suppliers of critical materials and components;
- high regulatory and technical complexity;
- the need to ensure both informational and physical security at all stages of the supply process;
- constraints on geographical diversification due to strategic and political factors.

It is also worth noting that:

– the application of the concept of antifragility to military supply chains remains at an early stage of theoretical development;

– the integration of digital technologies – such as blockchain, digital twins, and artificial intelligence – aimed at enhancing the resilience and adaptability of defense supply chains requires more in-depth research;

– the interconnection between the resilience of defense-industrial supply chains and sustainable development concepts, which are gaining increasing traction in the EU's defense-industrial sector (notably within Horizon Europe programs), remains insufficiently explored.

At the current stage of the development of theory and practice in defense-industrial supply chain management, there is a noticeable disproportion between quantitative and qualitative approaches to assessing their efficiency, resilience, and antifragility. Most academic studies in this area focus primarily on qualitative analysis, the construction of theoretical models, or conceptual frameworks [28–29], which, although of significant theoretical value, remain distant from the practical needs of supply chain participants. Meanwhile, practical diagnostic tools, quantitative assessment methods, and comparative analyses of resilience, adaptability, and antifragility levels in defense supply chains remain underdeveloped and insufficiently tested in real-world industrial contexts.

Particular attention should be paid to the issue of interaction between defense-industrial enterprises and private sector companies. This dimension is critically important for ensuring the flexibility, innovativeness, and technological competitiveness of defense-industrial supply chains. However, mechanisms of such interaction – legal regulation, information exchange, standardization of requirements, and the development of partnership-based cooperation models – remain inadequately studied, creating additional risks for the efficiency and resilience of defense supply systems.

Summarizing the above, it should be emphasized that the modern military supply network must be capable of promptly adapting to changes in the external environment, requirements, and threats; recovering quickly from disruptions; and maintaining a high level of resilience under uncertainty. To achieve this, it is necessary – already at the design stage of such a network – to clearly define the properties, functional principles, and managerial mechanisms that will enhance its viability, taking into account both internal structural characteristics and external factors of interaction with the private sector.

Purpose of the Article. The purpose of this article is to substantiate the theoretical foundations and propose practical approaches to enhancing the resilience, adaptability, and antifragility of the supply chains of Ukraine's defense-industrial complex (DIC) through the lens of partnership-based interactions among participants of business ecosystems and the integration of modern digital technologies under conditions of global turbulence and military threats.

Research Objectives:

1. To clarify the essence and specific characteristics of defense-industrial supply chains as complex integrated systems.
2. To systematize the challenges, threats, barriers, and drivers of the DIC supply chain development, taking into account the factors of resilience, adaptability, and antifragility.
3. To substantiate the feasibility of applying the concept of business ecosystem interaction for the assessment and enhancement of the viability of DIC supply chains.
4. To determine the role of modern digital technologies in ensuring the resilience, adaptability, and antifragility of supply chains.
5. To formulate practical recommendations for improving the efficiency and viability of Ukraine's DIC supply chains under wartime conditions and global instability.

Research Methodology. The study employs a comprehensive interdisciplinary approach that integrates systems analysis, elements of the theories of resilience, adaptability, and antifragility, the concept of business ecosystems, and modern supply chain management frameworks. The research utilizes content analysis of scientific publications, comparative analysis of existing approaches to assessing resilience, adaptability, and antifragility in supply chains, expert evaluation of current threats and challenges, as well as structural and logical generalization to develop practical recommendations.

Particular attention is devoted to the specific operational features of Ukraine's defense supply chains under armed conflict conditions and to the application of digital technologies aimed at enhancing their viability and sustainability.

Presentation of the main results. Supply chain management represents one of the key components of modern management, ensuring the coordination and integration of all processes related to the movement of materials, information, and financial resources from the supplier to the end consumer. Under conditions of increasing uncertainty and turbulence in the external environment, the concepts of resilience, adaptability, and antifragility of supply chains acquire particular significance – especially within the defense-industrial complex (DIC).

In scientific and applied literature, the term "defense-industrial supply chain" is often used without a precise definition of its specific characteristics and structure, which complicates both theoretical research and the practical development of strategies aimed at enhancing the resilience, adaptability, and antifragility of such systems. Therefore, it is necessary to clarify this concept.

A defense-industrial supply chain (DIC supply chain) is a complex, integrated system of interconnected organizations, processes, and flows that ensure the development, production, delivery, technical maintenance, and disposal of defense-oriented products, services, and technologies, with the ultimate goal of meeting the needs of national security and defense. Unlike traditional commercial supply chains, DIC supply chains are characterized by a heightened level of strategic importance, stringent requirements for security, confidentiality, technological sophistication, and regulatory oversight.

They possess a unique configuration that includes both state and private sector actors, dual-use elements, and specialized logistical and informational solutions (Fig. 1). Furthermore, such supply chains are inextricably linked with national security and defense systems, which imposes additional requirements for their reliability and their ability to recover rapidly after external or internal disruptive impacts.

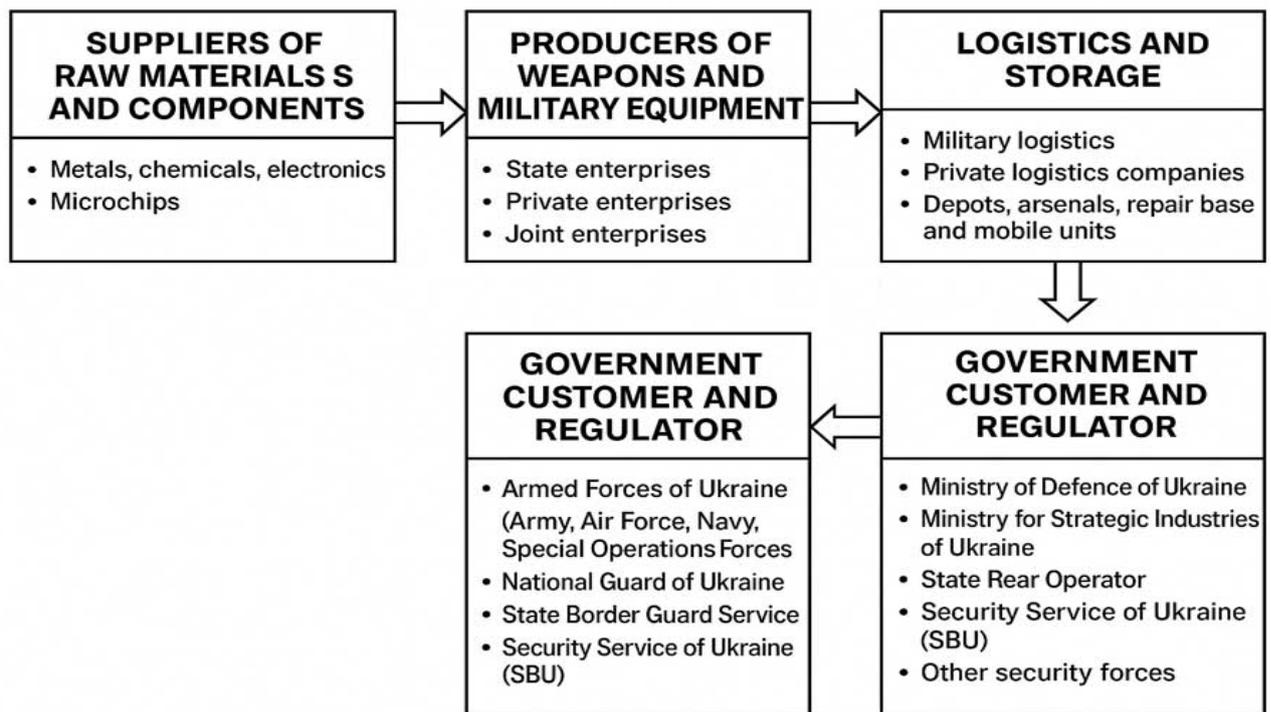


Figure 1 – General configuration of defense-industrial supply chains

Source: Developed by the authors

The configuration of the defense-industrial supply chain (DIC supply chain) comprises five principal blocks. The first block, "Suppliers of raw materials and components," constitutes the foundation of the entire chain. Without high-quality and uninterrupted supplies of materials and components, the production of weapons and military equipment (WME) is impossible. Within this block, various types of linkages operate – horizontal, vertical, and import-based. Horizontal linkages characterize interactions among different domestic suppliers that coordinate volumes and delivery schedules of materials of various purposes. Vertical linkages form between suppliers at different tiers, jointly ensuring the supply of finished assemblies, modules, and components. Import linkages reflect the dependence of certain domestic suppliers on foreign materials or technologies, which creates additional operational risks for the chain.

This block also maintains direct contractual relationships with WME manufacturers for the supply of raw materials, semi-finished products, and components.

Manufacturers provide technical specifications and quality requirements for supplied items. Furthermore, the relationship with the state customer – primarily the Ministry of Defence – plays a decisive role in setting priorities for the development of national suppliers, attracting investment, and establishing certification and standardization requirements for materials.

The "Manufacturers of Weapons and Military Equipment" block comprises plants and enterprises that transform raw materials, semi-finished products, and components into finished WME. This block sustains internal linkages among enterprises within the state conglomerate (e.g., Ukroboronprom), private manufacturers, state and private research and development institutions, design bureaus, and contractors executing specific orders for components, assemblies, or services. External functions include continuous monitoring of the quality and conformity of supplied materials and components to technical requirements; management of logistics and storage of finished products; and

organization of transportation to the customer.

Key external functions of this block also encompass fulfillment of the provisions of the State Defence Order (SDO); reporting on the progress and outcomes of its implementation; participation in tender and competitive procedures; receipt and allocation of funding from the state customer; and obtaining feedback from end users – most notably via the Ministry of Defence of Ukraine – regarding the operational effectiveness of WME under combat conditions. Such feedback is critically important for rapid product modernization, elimination of identified deficiencies, and enhancement of the combat effectiveness of systems.

The "Logistics and Storage" block is responsible for organizing the movement of products from manufacturers to end users and for ensuring appropriate preservation of weapons, equipment, components, and spare parts at all stages of the supply chain. Primary functions of this block include coordination with various modes of transport (road, rail, air) for efficient cargo movement; interaction among different types of warehouses – central, regional, and mobile (field); inventory management; ensuring the security of stored items and compliance with storage conditions; provisioning of spare parts, tools, and equipment for maintenance and repair; transfer of damaged equipment to repair and refurbishment facilities; and the implementation and use of modern logistics information systems for monitoring stock levels, movements, and locations of materiel.

The block's external linkages cover coordination with WME manufacturers for receipt of products into warehouses and organization of their onward transportation; execution of orders from the state customer (Ministry of Defence of Ukraine) regarding movement, allocation, and prioritization of weaponry and equipment deliveries in line with the needs of the Armed Forces of Ukraine; direct delivery of WME, ammunition, and material-technical supplies to military

units, training ranges, and forward positions; route planning and provision of security for transport columns and logistical convoys; and coordination of the security of particularly sensitive or hazardous cargoes with relevant security services and specialized agencies.

The "State Customer and Regulator" block plays a central role in determining what, how much, and at what price must be produced to meet the needs of the security and defence sector. It also shapes the legal, financial, and organizational environment necessary for the effective operation of the DIC. Core functions include close coordination with the General Staff of the Armed Forces for defining volumes, nomenclature, and specifications of required WME on the basis of combat experience, threat analysis, and forecasts; coordination of the formation of the State Defence Order (SDO) and state programs for DIC development; interaction with the Ministry of Defence to optimize procurement procedures with particular emphasis on transparency in the acquisition of non-lethal materiel, logistic support items, and equipment; regulation of issues related to international trafficking of arms, technologies, and licensed export/import; and resolution of complex interagency and strategic tasks for the development of the DIC.

External activities of this block include concluding contracts with WME manufacturers; securing financing and effecting payments for completed work; oversight of SDO execution, technical supervision, and acceptance of finished products; formulation and approval of product and component quality requirements; issuing directives on the allocation and distribution of weapons and military equipment and coordinating logistical operations; receiving requests from military units and analyzing weapon performance in combat to inform future orders, modernization programs, and import substitution initiatives; and engagement with international partners on matters of military-technical assistance, joint production,

cooperation in research and development, and technology transfer.

The "End Users" block – primarily the Armed Forces of Ukraine and other security services – comprises the direct users of WME, whose practical experience is invaluable for product improvement. Principal functions of this block include supplying combat experience, tactical practices, and lessons learned from real-world employment of WME; generating requests for specific types of armament tailored to the tasks of particular units and service branches; coordinating with rear services for receipt of WME, ammunition, spare parts, fuel, and other material-technical provisions; and providing maintenance and light repairs of equipment directly within combat units or at forward positions.

This block also maintains active external interactions, notably: receipt of WME and material-technical resources from warehouses or via direct delivery to positions; provision of feedback via the Ministry of Defence or directly to designers, engineers, and manufacturers regarding field requirements, remarks, and urgent needs; participation in the formulation of modernization requirements based on assessments of effectiveness, reliability, ergonomics, and adaptability to combat conditions; and submission of reports and recommendations to the state customer that form the basis for adjustments to future State Defence Orders and technical specifications (see Fig. 2).

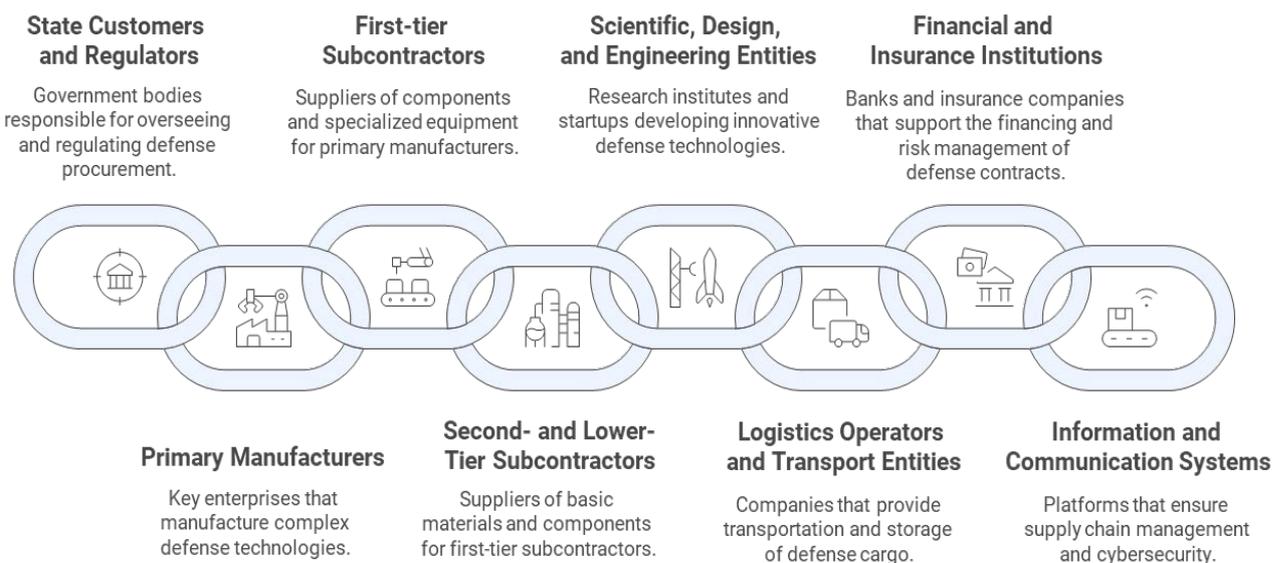


Figure 2 – Structure of the Supply Chain in the Defense-Industrial Complex

Source: Developed by the authors

Thus, feedback from end users is critically important for the closure and overall effectiveness of the entire supply chain within the defense-industrial complex (DIC). Consequently, the defense-industrial ecosystem represents a multilevel system of actors that interact in the processes of creating, supplying, and maintaining military and dual-use technologies. Its functioning is ensured by a network of state, industrial, scientific, logistical, and financial institutions, each performing defined functions in shaping

the nation's defense capabilities and maintaining technological sovereignty, namely:

1. State Customers and Regulators:
 - Ministries of Defense;
 - Security and intelligence agencies;
 - Defense procurement agencies;
 - Certification and standardization authorities;
 - International defense alliances (where cooperation exists).
2. Prime Contractors:

- Key enterprises of the defense industry;
- System integrators;
- Developers of complex technological solutions (aviation, armored vehicles, missile systems, IT systems, etc.).

3. Tier 1 Suppliers:

- Suppliers of components, assemblies, and specialized equipment;
- Dual-use enterprises.

4. Tier 2 and Lower-Tier Suppliers (Tier 2, Tier 3...):

- Manufacturers of basic materials, parts, and components;
- Suppliers of raw materials, rare-earth metals, and electronics.

5. Scientific, Design, and Engineering Institutions:

- State and private research institutes;
- Design bureaus;
- Innovative startups.

6. Logistics Operators and Transport Structures:

- Specialized carriers of defense cargo;
- Warehouses and dual-purpose logistics hubs;
- Multimodal transport companies with appropriate permits.

7. Financial and Insurance Institutions:

- Banks providing financing for defense contracts;
- Insurance companies covering risks associated with supply and production.

8. Information and Communication Systems:

- Digital supply chain management platforms;
- Data protection and cybersecurity systems.

Overall, the configuration of a DIC supply chain is multilevel, high-tech, and often exhibits a networked or hybrid structure, encompassing:

- Vertically integrated structures – leading enterprises that control substantial portions of the chain (e.g., from design to final assembly and testing);

- Cooperative clusters – networks of enterprises concentrated in strategic regions

engaged in joint development and production;

- Global or regional supply chains – involving international suppliers of raw materials, technologies, or components (particularly for high-tech products);

- Closed critical segments – chain segments fully controlled by the state or strategic enterprises to safeguard against external threats;

- Dual-circuit supply chains – separating civilian and military circuits to enhance flexibility and enable rapid capacity mobilization in crises.

Thus, defense-industrial supply chains possess a set of unique characteristics that fundamentally distinguish them from analogous systems in the civilian sector. This specificity arises from the high strategic importance of defense products, the complexity of production processes, and the strict requirements for security, quality, and confidentiality.

First, DIC products are typically technologically sophisticated and unique, requiring the participation of highly specialized suppliers of components and materials. Such suppliers are often monopolistic or form a limited group of contractors, which increases dependency risks and contributes to supply chain fragility.

Second, state regulation plays a dominant role in DIC supply chains, encompassing stringent standards for quality and certification, as well as control over compliance with secrecy and security regimes. This restricts flexibility and the ability to rapidly substitute suppliers, while also complicating integration with international supply chains.

Third, the DIC operates in an environment of high external turbulence – geopolitical conflicts, sanctions, import and export restrictions, and the risks of warfare directly affect resource availability and supply stability. These conditions elevate the requirements for supply chain resilience and adaptability.

Fourth, ensuring continuity of production and adherence to strict timelines for the execution of state defense orders constitutes a critical task. Any disruption in supply can have far-reaching consequences for both enterprises and national security.

Moreover, DIC supply chains are characterized by a high degree of integration among enterprises of different levels – from component developers and manufacturers to final assemblers and military customers. This necessitates effective coordination, information exchange, and mutual trust among participants – factors often complicated by secrecy and regulatory constraints.

Therefore, the distinctive nature of defense-industrial supply chains lies in the combination of high technological complexity, strict regulatory oversight, significant vulnerability to external risks, and the imperative to ensure maximum levels of resilience and adaptability. The management of such supply chains requires specialized approaches that account for both the

strategic importance of defense products and the particularities of the contemporary geopolitical environment.

Effective management of defense-industrial supply chains (DIC supply chains) under contemporary conditions is impossible without the integration of the concepts of resilience, adaptability, and antifragility, which collectively form the foundation of the viability of such supply chains as integrated socio-technical systems.

The viability of a DIC supply chain should be understood as the system's ability to ensure the continuity of its key functions, to respond rapidly to internal and external environmental changes, to effectively counteract disruptive influences, and to leverage crises as opportunities for transformation and structural reinforcement. Table 1 presents the authors' conceptual interpretation of the key characteristics defining resilience, adaptability, fragility, and viability of defense-industrial supply chains.

Table 1. Comparative Analysis of the Key Characteristics of Resilience, Adaptability, Fragility, and Viability in Defense-Industrial Supply Chains

The Concept	The Essence of the Concept	Form of Response to Disruptions	Management Focus	Significance for the Defense Industry
Resilience	Ability to withstand disruptions and recover rapidly	Return to the previous or an acceptable state	Continuity planning, reserves, and recovery strategies	Critical need to maintain uninterrupted functioning during crises
Adaptiveness	Ability to modify structure and processes in accordance with new conditions	Flexible reorganization, process modification, and engagement of new partners	Structural flexibility, link adaptation, and configuration changes	Ability to respond to new challenges (sanctions, changes in suppliers and markets)
Antifragility	Ability to become stronger after disruptions and crises	Utilization of crises as catalysts for growth and development	Promotion of learning, innovation, and structural transformation	Strengthening of competitive advantages and resilience to future shocks
Viability	System's ability to maintain functionality and development in the long term	Balance between efficiency, resilience, adaptability, and innovativeness	Systemic strategic management and integration of approaches	Ensuring long-term national and economic security

Source: Generalized by the authors based on [15-17, 22, 24]

Management of the viability of defense-industrial supply chains is based on a set of interrelated principles that reflect the

integration of approaches to resilience, adaptability, and antifragility. Foremost among these is the principle of security and

criticality priority, which entails the identification of bottlenecks, critical suppliers, and essential resources, as well as ensuring their protection against physical, economic, and cyber threats. Equally important is the principle of structural and informational transparency, which requires the establishment of a network of interactions among supply chain participants based on reliable communication systems that enable real-time monitoring of the condition of key elements of the chain and potential risks.

Given the need to ensure adaptability, a critical aspect is the principle of flexibility and modularity, which implies the creation of capabilities for rapid reconfiguration of production, diversification of supply sources, and logistics routes. This principle is complemented by the principle of decentralization and redundancy, aimed at minimizing dependence on a single supplier

or node, maintaining alternative supply options, and distributing critical capacities geographically.

The concept of antifragility necessitates the implementation of the principle of learning and evolutionary development, which refers to the ability of the supply chain not only to recover from crises but also to accumulate experience, strengthen its internal structure, and enhance management efficiency under the influence of stress factors.

In this context, the principle of integrated risk management acquires strategic importance, implying a systemic approach to the identification, analysis, and neutralization of both anticipated and unforeseen threats across all levels of supply chain functioning (Fig. 3).

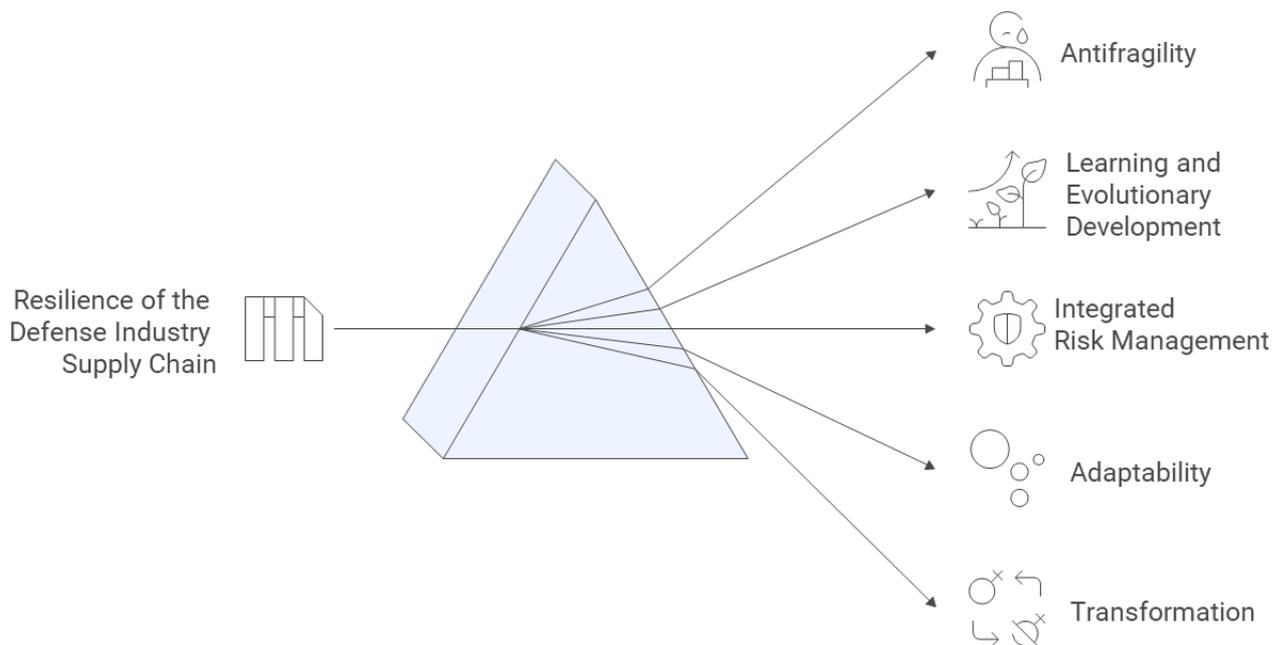


Figure 3 – Structure of the Elements of Resilience in the Defense-Industrial Supply Chain

Source: Developed by the authors

Thus, the viability of a defense-industrial supply chain as an integrated system results from the comprehensive implementation of principles that ensure its resilience to disruptive influences, its adaptability to environmental changes, and its capacity for effective transformation under crisis

conditions. Ensuring such viability is a prerequisite for the sustainable functioning of the defense-industrial complex (DIC), as well as for enhancing national security and the strategic autonomy of the state.

Management of DIC supply chains is characterized by a set of specific challenges

and threats that significantly affect their resilience and fragility. Among the key threats is geopolitical instability, manifested in armed conflicts, sanctions, and political isolation. These factors restrict access to critical resources, thereby reducing overall supply chain resilience and increasing the risk of supply disruptions and functional breakdowns. A particularly serious issue is the high dependence on the import of critical materials and technologies, especially from unstable or unfriendly regions, which introduces additional vulnerabilities and amplifies systemic fragility in the event of interruptions in international deliveries.

Another major threat lies in cyberattacks and other information-related risks, which can compromise the operation of digital supply chain management platforms, leading to reduced process transparency, loss of coordination control, and, consequently, a decline in overall system resilience. Disruptions in global transport and logistics networks caused by crises or emergencies create physical barriers to material flows, further increasing fragility and diminishing the supply chain's ability to respond rapidly to changes.

In addition to external challenges, the development and functioning of DIC supply chains are influenced by a number of internal barriers. A large bureaucratic apparatus and the complexity of state procurement procedures hinder decision-making agility and innovation implementation, thereby

reducing the system's flexibility and adaptability. A shortage of qualified personnel in production, logistics, and innovation limits modernization potential and managerial efficiency, further exacerbating system fragility. Technological obsolescence of equipment and limited access to financing impose additional obstacles to ensuring production continuity and supply chain resilience.

At the same time, there are important drivers of development that contribute to strengthening resilience and reducing fragility in DIC supply chains. Notably, production localization and supplier diversification help decrease dependence on external sources, thereby improving the system's flexibility and reliability. The development of innovative technologies, digitalization of management processes, and enhanced cybersecurity improve transparency, coordination efficiency, and responsiveness to threats.

An equally vital component is integration into international cooperative programs and standardization, which expand technological capabilities and enhance overall resilience through access to shared resources and partner networks. State support—in the form of import substitution policies, incentives for scientific research, and investment in production capacity development—creates the necessary conditions for establishing a viable and adaptive supply system.

Table 2. Challenges, Threats, Barriers, and Development Drivers of Defense-Industrial Supply Chains from the Perspective of Resilience and Fragility

Characteristics	Content	Possible Implications for the Resilience and Fragility of Defense Industry Supply Chains
Challenges and Threats		
Geopolitical Instability	Armed Conflicts, Sanctions, Trade Restrictions, and Political Isolation	Reduced resilience due to limited access to resources; increased fragility caused by supply disruptions and chain breaks
High Technological Complexity and Limited Number of Suppliers	The Production of Defense Industry Products Often Depends on Unique Technological Components Supplied by a Limited Number of or Even Monopolistic Companies.	This creates vulnerability through risk concentration and makes supply chains fragile to technical failures, material shortages, or price fluctuations.

Dependence on Imports	Critical Materials, Technologies, and Components Originating from Unfriendly or Unstable Regions	Increased fragility due to the risk of supply blockades; reduced resilience of the production process
Need for Strict Quality and Safety Control	The requirements for quality, reliability, and safety of products in the defense sector are extremely strict, which limits the possibilities of replacing suppliers and implementing new technologies without lengthy certification and verification procedures.	This creates additional barriers to the rapid adaptation of supply chains.
Increasing Turbulence of the Market Environment	Demand fluctuations, changes in state defense orders, financial constraints, and other factors	Reduced ability of supply chains to adapt quickly
Cyberattacks and Information Threats	Interference with digital platforms, data leaks, and management paralysis	Decreased informational and managerial resilience; increased fragility of management and coordination systems
Environmental and Social Requirements	Modern requirements for sustainability, environmental safety, and social responsibility, which often conflict with other priorities such as speed or cost	Increased fragility of supply chains and the need to adapt to environmental and social requirements
Disruptions in Global Logistics	Interruptions in international routes and shortage of transportation capacities	Increased fragility of physical flows; reduced resilience in the supply of components and resources
Development Barriers		
Bureaucratic Constraints	Complexity and Duration of Public Procurement, Certification, and Licensing Procedures	Reduced flexibility and adaptability; increased fragility due to delays in implementing new solutions
Shortage of Qualified Personnel	Insufficient Number of Specialists in the Fields of Production, Innovation, and Defense Industry Logistics	Decreased operational resilience; increased fragility resulting from human factors and decision-making errors
Technological Obsolescence	High Level of Equipment Wear and Limited Technological Capabilities	Increased production fragility; reduced resilience to technical failures and accidents
Limited Access to Financing	Insufficient Investment in the Modernization and Development of Defense Industry Supply Chains	Reduced resilience of innovative development; increased fragility due to the lack of resources for diversification and protection
Development Drivers		
Localization and Diversification	Development of Domestic Production, Engagement of New Suppliers and Regional Clusters	Increased resilience through reduced external dependence; decreased fragility due to alternative sources of supply
Development of Innovation and Digitalization	Implementation of Advanced Technologies, Digital Management Platforms, and Cybersecurity Measures	Strengthening of management and coordination resilience; reduced fragility through transparency and control
International Cooperation and Standardization	Integration into International Programs, Harmonization of Requirements, and Joint Defense Projects	Enhanced resilience through expanded partnerships; reduced fragility through shared access to technologies and resources
State Support and Incentives	Import Substitution Policies, Tax Incentives, and Support for Research and Development	Strengthening the resilience of domestic production potential; reducing fragility through strategic planning

Source: Generalized by the authors based on [8, 14-16, 21]

Therefore, the successful management of defense-industrial supply chains (DIC supply chains) requires a systemic approach that accounts for the impact of both external challenges and threats, as well as internal

barriers, while simultaneously leveraging development drivers to enhance resilience and reduce fragility within the system. Only through such an integrated approach can the viability of the supply chain be ensured – an

essential foundation for the defense capability and strategic autonomy of the state.

aimed at strengthening the resilience, adaptability, and antifragility of defense-industrial supply chains.

Figure 4 summarizes the authors' proposed set of key management measures

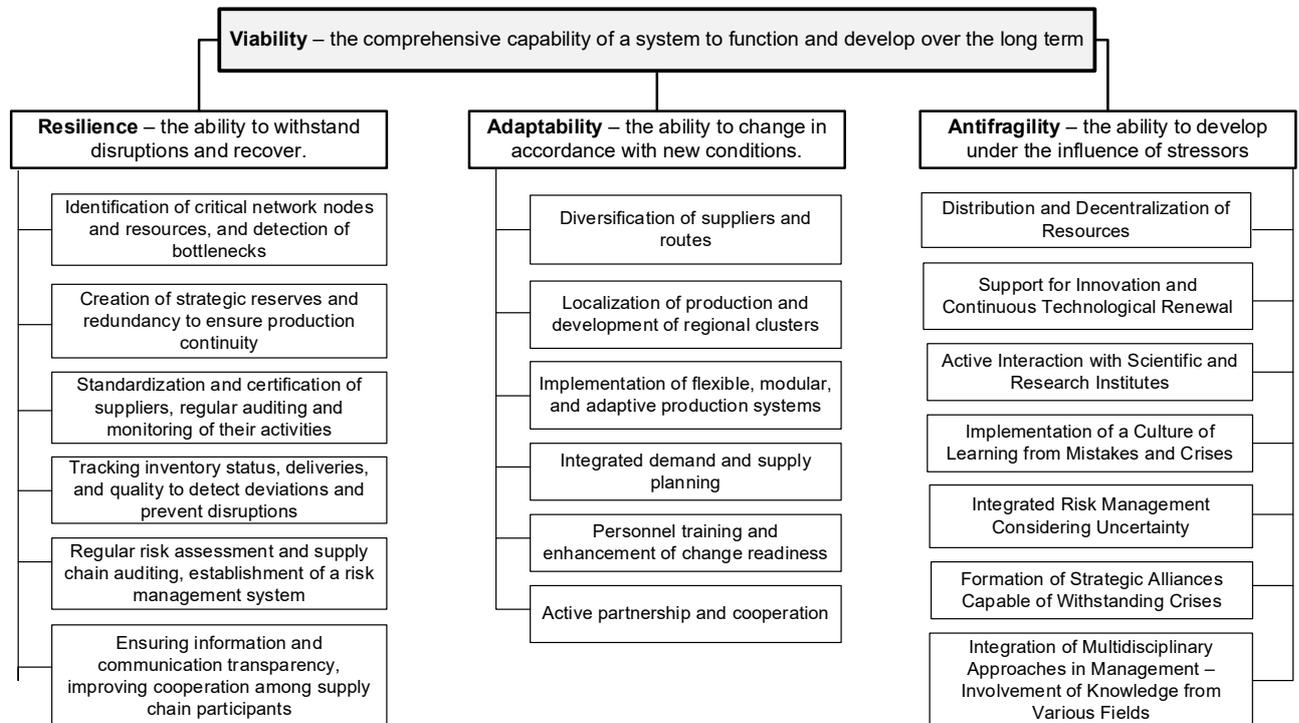


Figure 4 – System of Managerial Measures for Enhancing the Resilience, Adaptability, and Antifragility of Defense-Industrial Supply Chains

Source: Developed by the authors

Thus, ensuring the resilience of defense-industrial supply chains requires the implementation of a comprehensive set of measures that allow them to maintain continuous operation even under adverse conditions. Foremost among these is the identification of critical nodes and resources within the supply chain, enabling a focused allocation of efforts toward the most vulnerable points of the system. The formation of strategic reserves of materials and components ensures the continuity of production in the event of supply disruptions. A well-organized inventory management system helps anticipate demand fluctuations and guarantees the availability of critical materials. This approach enables effective resource management, optimizes production capacities, and maximizes output during peak demand periods. Regular monitoring and

quality control of supplies, together with the standardization of supplier requirements, help prevent the use of substandard products that may cause operational failures. The development of business continuity plans and personnel training allows for rapid and coordinated responses to emergencies.

Equally important is the cybersecurity of information systems supporting supply chain management, as threats in the digital domain can paralyze coordination and control. The optimization of logistics processes, regular risk audits, and ensuring information transparency among participants further enhance system resilience, creating a robust foundation for stable performance. To strengthen the adaptability of supply chains, measures must be implemented to ensure flexibility and rapid system reconfiguration in response to changing conditions. Defense

industry contractors face considerable challenges in ensuring timely deliveries and maintaining high product quality. Diversification of suppliers and logistics routes minimizes the risks associated with disruptions along a single direction or from an individual supplier. Localization of production and the formation of regional clusters reduce dependency on external factors and shorten delivery times.

Flexible production systems, capable of rapidly modifying product assortments or output volumes, enable prompt responses to market needs and operational challenges. The digitalization of management processes – through the use of data analytics and predictive systems – supports effective, real-time decision-making. Conducting scenario-based exercises and decentralizing management authority increase responsiveness to localized problems. Early warning systems and active promotion of innovation facilitate timely adaptation of supply chains to emerging challenges.

Finally, partnership and cooperation among supply chain participants establish a network of mutual support that strengthens adaptive capacity. Cultivating collaboration and building trust within defense-industrial supply chains ensure the stable supply of high-quality products, thereby reinforcing the broader foundation of the national defense industry.

Considering that antifragility is the ability of a supply chain not only to withstand stressors but to become stronger as a result of them, the development of antifragility requires the implementation of a culture of learning from errors and crises, with a systematic analysis of all failures aimed at continuous improvement. Flexible transformation strategies enable rapid reconfiguration of the supply chain in response to unforeseen events. The continuous introduction of innovations and technological upgrades enhances both competitiveness and system endurance. Integrated risk management, which accounts for uncertainty and radical change, allows

preparation for a wide range of potential scenarios. The development of partnership networks, collaboration with scientific institutions, and the establishment of feedback systems ensure a constant exchange of knowledge and resources, thereby strengthening antifragility. Furthermore, the development of human capital focused on innovation and adaptability builds teams capable of operating effectively under uncertainty. Scenario-based training and a multidisciplinary approach to management foster the formation of a holistic, viable, and self-developing supply chain system.

Thus, a comprehensive approach to supply chain management that integrates measures for enhancing resilience, adaptability, and antifragility is crucial for ensuring their viability, especially under conditions of instability and continuous change. Implementing these managerial measures requires a transformation of the technological decision-making base, as traditional approaches are limited in speed, transparency, and coordination of managerial efforts. The absence of integrated systems and unified standards leads to isolated operation of individual departments and contractors, complicating synchronization of actions, generating conflicts, and diminishing overall supply chain efficiency.

First and foremost, it should be emphasized that to increase the resilience, adaptability, and antifragility of defense-industrial supply chains, flexible management structures are essential. Traditional hierarchical models – characterized by excessive bureaucracy and multiple levels of control – impede rapid decision-making and hinder coordination among supply chain participants. Consequently, modern agile organizational structures are shifting away from vertically isolated models toward horizontal systems that minimize bureaucracy and delegate authority directly to those closest to operational processes.

A horizontal organizational structure with broad spans of control and fewer hierarchical

layers dismantles traditional organizational barriers, stimulates cross-functional collaboration, and accelerates decision-making and responsiveness to change. This is particularly critical for defense-industrial supply chains, where timing and precision are of paramount importance. A key element of such a structure is the team-based management model – a network of small, autonomous, cross-functional teams with clearly defined client-oriented accountability. These teams bring together specialists from diverse fields, empowered to make decisions that balance individual initiative with collective coordination. Such an approach fosters innovation and rapid response to emerging challenges and opportunities – an

especially relevant factor within the defense industry context.

Moreover, the mission-oriented focus of these teams enables them to concentrate on meeting the needs of both internal and external clients, fostering shared responsibility for results and reinforcing a collective sense of purpose. This alignment leads to high task efficiency and coordinated action across all supply chain participants. Equally important is the leadership role, which supports transformation and the cultivation of agile thinking, sets the tone for implementing innovative practices, and creates an environment that promotes adaptability and proactivity (Fig. 5).

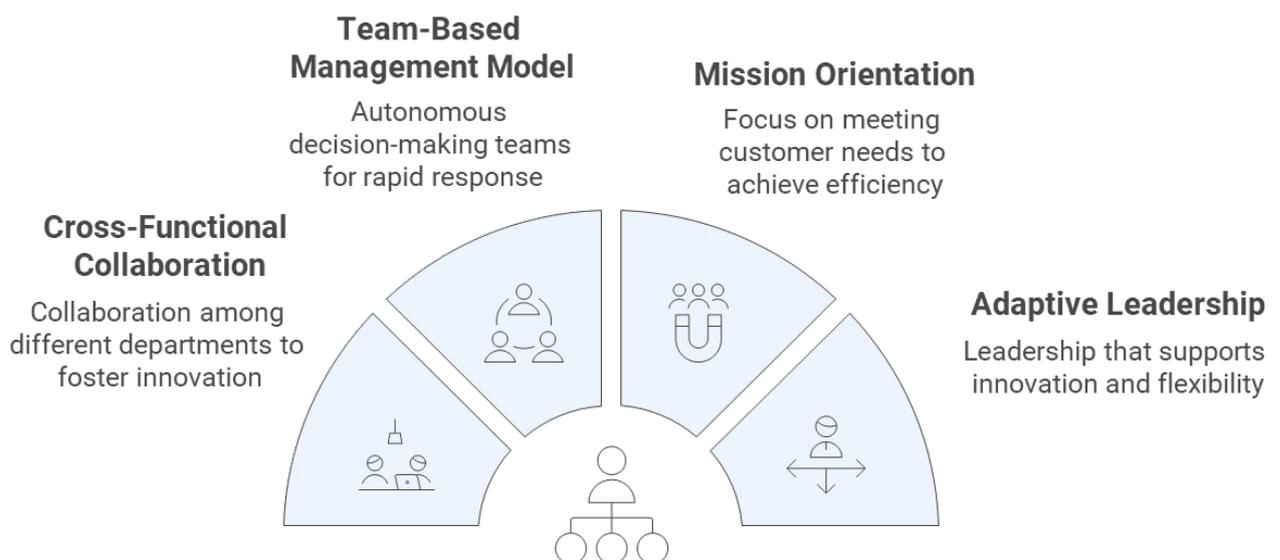


Figure 5 – Structural Support for Innovation

Source: Developed by the authors

Flexible structures with decentralization and a team-based approach require robust technological support to ensure effective coordination, information exchange, and real-time decision-making. Modern digital technologies provide this support by enabling the integration of heterogeneous data, process automation, large-scale information analysis, and risk forecasting. They create a unified information environment that fosters transparency and interaction among supply chain participants,

regardless of their geographical distribution or functional specialization.

Without modern digital solutions, agile organizational models cannot achieve their full efficiency, as it is technology that transforms individual actions into coordinated, rapid, and adaptive processes.

Table 3 illustrates how key digital tools – the Internet of Things (IoT), Big Data, Artificial Intelligence (AI), Blockchain, Cloud Computing, and Digital Management Platforms – contribute to enhancing the

resilience, adaptability, and antifragility of defense-industrial supply chains.

Table 3. The Role of Digital Technologies in Enhancing the Resilience, Adaptability, and Antifragility of Defense-Industrial Supply Chains

Digital Technology	Enhancing Resilience	Enhancing Adaptability	Enhancing Antifragility
Internet of Things (IoT)	<ul style="list-style-type: none"> • Continuous monitoring of equipment and vehicle condition for timely maintenance (predictive maintenance). • Control of temperature, humidity, and storage conditions for critical materials. • Rapid detection and localization of problems to minimize downtime. 	<ul style="list-style-type: none"> • Dynamic adjustment of delivery routes based on real-time traffic and environmental data. • Flexible inventory management in real time. • Support for operational interaction among supply chain participants. 	<ul style="list-style-type: none"> • Sensor data analysis to predict and prevent failures. • Development of recovery scenarios after incidents. • System learning from collected data to enhance resilience.
Big Data	<ul style="list-style-type: none"> • Identification of supply and consumption patterns to prevent shortages. • Risk analysis related to external factors (political instability, climate change). • Monitoring compliance with regulatory requirements. 	<ul style="list-style-type: none"> • Accurate demand forecasting and detection of market trend shifts. • Identification of potential bottlenecks in the supply chain. • Support for adaptive production and procurement planning. 	<ul style="list-style-type: none"> • Analysis of crisis events to develop best practices. • Modeling of scenario developments to improve preparedness. • Detection of vulnerabilities and weak links for further strengthening.
Artificial Intelligence (AI)	<ul style="list-style-type: none"> • Automatic detection of anomalies in processes and prediction of potential disruptions. • Optimization of routes and inventories to reduce risks. • Decision support in complex operational conditions. 	<ul style="list-style-type: none"> • Automation of planning processes considering internal and external changes. • Development of adaptive management strategies based on data analytics. • Identification of new opportunities for supply chain optimization. 	<ul style="list-style-type: none"> • Continuous learning of the system based on environmental changes. • Development and implementation of resilience and transformation strategies. • Decision-making support in crisis situations through simulations.
Blockchain	<ul style="list-style-type: none"> • Guarantee of data transparency and immutability for material origin and transactions. • Reduction of fraud and error risks. • Strengthening of trust among supply chain participants. 	<ul style="list-style-type: none"> • Facilitation of fast and secure transactions between parties. • Greater flexibility in contract and agreement adjustments. • Automation of procedures via smart contracts. 	<ul style="list-style-type: none"> • Decentralized data storage increases resistance to external attacks. • Ensures business continuity even in case of localized disruptions. • Enhances data reliability and security under crisis conditions.
Cloud Computing	<ul style="list-style-type: none"> • Scalable resources for storage and processing of critical data. • Ensuring uninterrupted access to information. • Fast data recovery after system failures. 	<ul style="list-style-type: none"> • Flexible access to information resources from any location. • Support for team mobility and fast data exchange. • Easy integration of new services and applications. 	<ul style="list-style-type: none"> • Data backup and disaster recovery mechanisms. • Automatic resource scaling in response to changing loads. • Strengthening the overall viability of the infrastructure.
Digital Management Platforms	<ul style="list-style-type: none"> • Centralized risk and monitoring management in real time. • Improved process transparency and control. • Integration of different systems for unified supply chain visibility. 	<ul style="list-style-type: none"> • Coordination of actions among different participants via a unified platform. • Support for rapid information exchange and joint decision-making. 	<ul style="list-style-type: none"> • Continuous process improvement based on analytics and feedback. • Support for innovative approaches and development strategies.

		• Flexible planning and adaptation to external changes.	• Ensuring sustainability of transformation processes.
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Source: Generalized by the authors based on [4, 5, 10, 21-24]

Summarizing the data presented in the table, it should be noted that Internet of Things (IoT) technologies enable continuous data collection from equipment, transport, and warehouses, allowing for the prompt detection of potential malfunctions and rapid response, thereby enhancing system resilience. At the same time, IoT facilitates flexible management of routes and inventories, which strengthens adaptability, while also accumulating data for forecasting and process improvement – an essential component of antifragility.

Big Data technologies make it possible to analyze large volumes of information to identify risks, forecast demand, and detect weak links within the supply chain. This enhances resilience through early warning of threats, strengthens adaptability by enabling rapid plan adjustments, and contributes to antifragility through systematic learning from crisis situations.

Artificial Intelligence (AI) automates anomaly detection, optimizes resource allocation, and supports decision-making under complex conditions. As a result, AI contributes to risk reduction and improved efficiency (resilience), rapid reconfiguration of processes (adaptability), and in-depth analysis for post-stress system development (antifragility).

Blockchain technology ensures the transparency and security of transactions, protects against fraud, and increases trust among supply chain participants – key factors for resilience. It also supports rapid and secure coordination of actions (adaptability) and creates a decentralized system resistant to external attacks (antifragility).

Cloud computing guarantees scalability and resource availability, maintaining operational continuity and facilitating rapid recovery after disruptions, thereby enhancing resilience. Flexible access and service

integration strengthen adaptability, while backup mechanisms and automatic scaling sustain the system’s viability and antifragility under crisis conditions.

Digital management platforms integrate heterogeneous data and processes, enabling real-time risk monitoring and effective decision-making (resilience), coordination of actions and rapid adaptation to change (adaptability), and continuous process improvement through innovation support (antifragility).

Thus, the comprehensive implementation of these digital technologies provides the foundation for building viable defense-industrial supply chains capable of functioning effectively and evolving under conditions of persistent challenges and continuous transformation.

Conclusions. Based on the results of the conducted research, the essence of defense-industrial supply chains (DIC supply chains) has been clarified as complex integrated systems operating under conditions of high uncertainty, multiple threats, and severe constraints characteristic of both the global environment and the internal realities of Ukraine during wartime. The study substantiates the relevance of applying the concept of supply chain viability to the DIC, which synthesizes approaches to ensuring their resilience, adaptability, and antifragility.

The research systematized the main challenges, threats, barriers, and drivers influencing the development of such supply chains from the standpoint of their impact on system resilience and fragility. It was established that the key factors shaping viable defense-industrial supply chains include the diversification of suppliers and logistics routes, the development of horizontal interaction among business ecosystem participants, and the extensive use of modern digital technologies.

The necessity of abandoning traditional hierarchical and centralized models of managing DIC supply chains was separately justified in favor of flexible, decentralized organizational structures that combine autonomy, partnership, and an integrated digital environment.

To enhance the resilience, adaptability, and antifragility of Ukraine's defense-industrial supply chains under conditions of global turbulence and armed conflict, a comprehensive approach must be applied, integrating organizational, technological, and managerial measures.

In particular, it is advisable to diversify suppliers and transportation routes, thereby reducing dependence on individual countries and critical logistical nodes. It is equally important to develop horizontal partnerships among defense enterprises, the private sector, research institutions, and international companies to establish a robust and sustainable business ecosystem.

The implementation of modern digital technologies – including the Internet of Things (IoT), Artificial Intelligence (AI), Blockchain, and cloud-based platforms – will enhance transparency, flexibility, and decision-making speed.

A critically important task is the development of local production of

strategically significant components, the strengthening of information security, the implementation of risk monitoring systems, and the regular training of personnel in crisis management principles. The combined effect of these measures will enable Ukraine's defense-industrial supply chains not only to effectively withstand external challenges but also to evolve and improve even under difficult and unstable conditions.

Further research should focus on the quantitative modeling of resilience, adaptability, and antifragility parameters of DIC supply chains, using practical assessment tools tailored to the realities of Ukraine. A promising direction lies in the development of diagnostic methodologies for evaluating the interaction between DIC enterprises and the private sector within business ecosystems, as well as the study of the effectiveness of specific digital technologies (such as Artificial Intelligence, Blockchain, and digital management platforms) in strengthening supply chain viability.

Special attention should also be devoted to the formation of regulatory and organizational frameworks that would enable the implementation of flexible management models for defense supply chains during both wartime and post-war reconstruction periods.

References

1. Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. *The International Journal of Logistics Management*, 20(1), 124-143.
2. Pettit, T. J., Fiksel, J., & Croxton, K. L. (2010). Ensuring supply chain resilience: Development and implementation of an assessment tool. *Journal of Business Logistics*, 31(1), 1-21.
3. Pires Ribeiro, J., & Barbosa-Povoa, A. (2018). Supply chain resilience: Definitions and quantitative modelling approaches – A literature review. *Computers & Industrial Engineering*, 115, 109–122. DOI: <https://doi.org/10.1016/j.cie.2017.11.006>
4. Antonio Padovano & Dmitry Ivanov (2025): Towards resilient and viable supply chains: a multidimensional model and empirical analysis, *International Journal of Production Research*, DOI: 10.1080/00207543.2025.2470350
5. Dmitry Ivanov (2024) Two views of supply chain resilience, *International Journal of Production Research*, 62:11, 4031-4045, DOI: 10.1080/00207543.2023.2253328
6. Supply Chain Resilience: Adapting To Global Disruptions and Uncertainty Dr. Arjita Mishra, Nidhi Gupta, Gautam Kumar Jha. *International Journal of Innovative Research in*

Engineering Volume 5, Issue 2 (March-April 2024), PP: 189-196. URL:
<https://www.doi.org/10.59256/ijire.20240502025> ISSN No: 2582-8746

7. Mackay, J., Munoz, A., & Pepper, M. (2020). Conceptualising redundancy and flexibility towards supply chain robustness and resilience. *Journal of Risk Research*, 23(12), 1541–1561. <https://doi.org/10.1080/13669877.2019.1694964>
8. Maharjan, R., & Kato, H. (2022). Resilient supply chain network design: A systematic literature review. *Transport Reviews*, 42(6), 739–761. DOI: <https://doi.org/10.1080/01441647.2022.2080773>
9. Wieland, A., & Durach, C. F. (2021). Two perspectives on supply chain resilience. *Journal of Business Logistics*, 42(3), 315–322. DOI: <https://doi.org/10.1111/jbl.12271>
10. Zavala-Alcívar, A., Verdecho, M. J., & Alfaro-Saiz, J. J. (2023). Supply chain resilience: a conceptual evolution analysis. *Dirección y Organización*, 5-17.
11. Nikookar, E., Stevenson, M., & Varsei, M. (2023). Building an antifragile supply chain: A capability blueprint for resilience and post-disruption growth. *Journal of Supply Chain Management*, 1–19. <https://doi.org/10.1111/jscm.12313>
12. Zavala-Alcívar, A., Verdecho, M. J., & Alfaro-Saiz, J. J. (2023). Supply chain resilience: a conceptual evolution analysis. *Dirección y Organización*, 5-17.
13. Lotfi, R., Mehrjardi, M. S., MohajerAnsari, P., Zolfaqari, F., & Afshar, M. (2023). Antifragile, sustainable, and agile supply chain network design by considering resiliency, robustness, risk, and environmental requirements. *Environmental Science and Pollution Research*, 30(48), 106442-106459.
14. Ivanov D. (2024). Transformation of supply chain resilience research through the COVID-19 pandemic. *International Journal of Production Research*, 62(23), 8217-8238. Ivanov, D. (2025). When is the supply chain resilient? Customer and operational perspectives. *International Journal of Production Research*, 1–16. DOI: <https://doi.org/10.1080/00207543.2025.2454331>
15. Ivanov, D. (2025). No risk, no fun? A bioinspired adaptation-based framework for supply chain resilience in Industry 5.0. *International Journal of Production Research*, 1-21.
16. Ramezani, J., & Camarinha-Matos, L. M. (2020). Approaches for resilience and antifragility in collaborative business ecosystems. *Technological forecasting and social change*, 151, 119846.
17. Zsidisin, G. A., Bresler, A., Hazen, B., Snider, K. F., & Wilkerson, T. H. (2020). Research in defence logistics: Where are we and where are we going? *Journal of Defense Analytics and Logistics*, 4(1), 3–17. <https://doi.org/10.1108/JDAL-07-2019-0012>
18. Ekström, T. (2025). Supply Chain Resilience – An Empirical Exploration of Barriers and Enablers in Military Settings. *Scandinavian Journal of Military Studies*, 8(1), pp. 119–136. DOI: <https://doi.org/10.31374/sjms.350>
19. Melnyk, S., Narasimhan, R., & DeCampos, H. (2014). Supply chain design: Issues, challenges, frameworks and solutions. *International Journal of Production Research*, 52(7), 1887–1896. <https://doi.org/10.1080/00207543.2013.787175>
20. Rebecca Lucas, Thomas Ekström, Paola Fusaro, Elizabeth Hastings Roer, Lucia Retter. Toward Defense Supply Chain Disruption Management. A Research Agenda for Defense Supply Chain Resilience. https://www.rand.org/pubs/research_reports/RRA2504-1.html
21. Roland Hellberg, David Språngare, Olov Candell, Claes Carpenfelt, Kristian Lundberg, Per Samuelsson, Imoh Antai, Per Andersson & Lars Backlund (07 May 2025): Performance constraints in defence industry supply chains: evidence from case studies, *Defence and Peace Economics*, DOI: 10.1080/10242694.2025.2500362
22. Elvemo, L. (2025). Supply Chain Resilience in Military Operations: A Case Study Exploring Command and Control. *Scandinavian Journal of Military Studies*, 8(1), pp. 178–199. DOI: <https://doi.org/10.31374/sjms.356>

23. Korkmaz, G. (2024). Supply chain risks and management strategies in the defense industry. *Journal of Defense Resources Management (JoDRM)*, 15(1), 35-60.
24. Sani, S., Schaefer, D., & Milisavljevic-Syed, J. (2022). Strategies for Achieving Pre-emptive Resilience in Military Supply Chains. *Procedia CIRP*, 107, 1526–1532. DOI: <https://doi.org/10.1016/j.procir.2022.05.186>
25. Sania S., Schaeferb D., Milisavljevic-Syeda J. Strategies for Achieving Pre-emptive Resilience in Military Supply Chains. *Procedia CIRP* 107 (2022) 1526–1532
26. Gürtlich, G., Lampl, S. (2022). Resilience and Military Supply Chain Management. In: Kummer, S., Wakolbinger, T., Novoszel, L., Geske, A.M. (eds) *Supply Chain Resilience*. Springer Series in Supply Chain Management, vol 17. Springer, Cham. DOI: https://doi.org/10.1007/978-3-030-95401-7_29
27. Cabrera, B., Santa, R., Tegethoff, T., Morante, D., & Ferrer, M. (2023). Supply chain resilience in the Colombian defense sector before and during the COVID-19 pandemic: A comparative study. *PLOS ONE*, 18(3), e0282793. <https://doi.org/10.1371/journal.pone.0282793>
28. Antai, I., & Hellberg, R. (2025). Surge complexities in defense industry supply chains: evidence from multiple case studies. *The International Journal of Logistics Management*, 36(7), 242-261.
29. Loska, D., Genchev, S., Rich, N., & Malik, T. (2024). Defense supply chain collaboration: an exploratory study and empirical framework. *Journal of Defense Analytics and Logistics*, 8(1), 2-37.
30. Hubarieva, I. O., Harmash, O. M., Trushkina, N. V., Shkrygun, Yu. O., Patlachuk, T. V. (2024). Digital transformation of enterprise' logistics activities: bibliometric and trend analysis. *Intellectualization of logistics and Supply Chain Management [Online]*, 28, 47-70. <https://doi.org/10.46783/smart-scm/2024-28-5>.
31. Harmash, O., Hubarieva, I., Harmash, T., Trushkina, N. (2024). Relationship between the concepts of "digital transformation" and "industry 5.0": bibliometric analysis. *Intellectualization of logistics and Supply Chain Management [Online]*, 24, 89-106. <https://doi.org/10.46783/smart-scm/2024-24-10>.
32. *Global Risks Report (2024)*. World Economic Forum. URL: <https://www.weforum.org/publications/global-risks-report-2024/>
33. Hryhorak M.Y., Harmash O.M., Popkowski T. Artificial intelligence in supply chain management: opportunities and threats for professional competence. *Intellectualization of logistics and Supply Chain Management. [Online]*, vol.19, pp.24-44, DOI: <https://doi.org/10.46783/smart-scm/2023-19-3>.

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MAIN CHALLENGES ON THE WAY OF IMPLEMENTING «GREEN» TECHNOLOGIES IN THE LOGISTICS SPHERE

Vladyslav Marchenko. *«Main challenges on the way of implementing «green» technologies in the logistics sphere». At present, the escalation of such serious global challenges as environmental pollution, climate change and depletion of natural resources is pushing humanity to find modern technologies, decisions and practices that can minimize the ecological burden on the planet. Sustainable development, as an innovative, balanced concept that counters these problems, could not ignore the logistics sphere, which, despite its invaluable role as a global transport network, unfortunately still has a significant negative impact on the environment. In such conditions, the implementation of «green» technologies in the logistics sphere is not just an important, but a critically needed task. The ecological transformation of logistics has a strategic importance for countries, business representatives and ordinary citizens. The purpose of this article is to study and analyze the main challenges that stand on the way of implementing «green» technologies in the logistics sphere. In this research, the main barriers were identified and explained, starting from economic, technological, regulatory and legislative difficulties and ending with cultural, infrastructural and complex problems. An essential emphasis in the work was made on their relevance in the context of the current Ukrainian realities of wartime, when the «green» modernization of the logistics sphere is greatly complicated. The results of this conducted research can be used by different scientists, developers of «green» policy, managers of logistics companies, business representatives, and simply all other people who are interested in spreading the concept of sustainable development in the logistics sphere.*

Keywords: sustainability, development, technologies, ecology, effectiveness, prospects, transport, logistics, management

Владислав Марченко. *«Головні виклики на шляху впровадження «зелених» технологій у логістичну сферу». В наш час, ескалація таких серйозних глобальних викликів, як забруднення навколишнього середовища, зміна клімату та вичерпання природних ресурсів, плекає людство до знаходження сучасних технологій, рішень та практик, що можуть мінімізувати екологічне навантаження на планету. Сталий розвиток, як інноваційна, збалансована концепція, що протистойть даним проблемам, не могла оминати стороною логістичну сферу, яка крім своєї безцінної ролі світової транспортної мережі, на жаль все ще має значний негативний вплив на навколишнє середовище. В таких умовах імплементація «зелених» технологій в логістичну сферу є не просто важливою, а критично необхідною задачею. Екологічна трансформація логістики має*

стратегічне значення для країн, представників бізнесу та звичайних громадян. Метою цієї статті є вивчення та аналіз головних викликів, які стоять на шляху імплементації «зелених» технологій у логістичній сфері. В цьому дослідженні було визначено та пояснено головні бар'єри, починаючи з економічних, технологічних, нормативно-правових складностей і закінчуючи культурними, інфраструктурними та комплексними проблемами. Важливий акцент в роботі було зроблено на їх актуальності, в контексті нинішніх українських реалій воєнного часу, коли «зелена» модернізація логістичної сфери є суттєво ускладненою. Результати цього проведеного дослідження можуть бути використані різними науковцями, розробниками «зеленої» політики, менеджерами логістичних компаній, представниками бізнесу та просто всіма іншими людьми, які є зацікавленими у поширенні концепції сталого розвитку в логістичній сфері.

Ключові слова: сталість, розвиток, технології, екологія, ефективність, перспективи, транспорт, логістика, менеджмент.

Introduction. At present, humanity faces a wide range of serious global challenges. This undoubtedly includes problems related to climate change, the gradual depletion of various natural resources and environmental pollution. The last questions are being talked about a lot lately, since minimising the negative impact of human activity on the environment is one of the top priority tasks of our time. It is not surprising at all that the search for new approaches to global development has not bypassed the logistics sector. Today, logistics is not just about transport and warehousing operations, but about one of the largest existing sources of environmental pollution. It is enough just to remember its enormous volumes of carbon dioxide emissions and annual packaging waste, and everything immediately becomes clear.

The realisation of the need to reduce its enormous impact on the environment has led humanity to seek new, modern, safe and effective ways for its development. Such a promising option became the idea of integrating the concept of sustainable development into the logistics sphere. The implementation of elements of this concept has had a positive impact on the development of a new, promising direction of «green» logistics. «Green» logistics has focused on the idea of minimizing the ecological impact of logistics on the

environment by balancing social, environmental, and economic aspects.

Nowadays, «green» logistics is a set of effective practices, highly productive approaches, innovative technologies and solutions aimed at reducing the environmental footprint of logistics operations. This direction is a global, strategic vector for the development of the logistics sphere designed for a long-term perspective. It includes the use of a wide array of tools, starting with electric transport and eco-friendly packaging and ending with hydrogen and digital technologies. Many experts agree that «green» logistics can achieve serious success, since not only ordinary society but also modern business is interested in its development. This concept contributes not only to the preservation of ecosystems, but also to increasing the competitiveness of the business itself, improving its reputation and global responsibility.

The logistics sector continues to adapt quickly to all possible changes, globalisation processes and modern trends, but despite this, it must be acknowledged that there are currently a huge number of obstacles that prevent and, in the coming years, will continue to prevent the full-fledged development of this direction. Despite growing environmental awareness and international efforts towards a «green» transition, the development of this direction in most countries, including Ukraine, has

encountered extremely significant difficulties on its way. These problems are very complex and require well-thought-out decisions at both the macro and micro levels. This includes not only the obvious serious initial costs and strategies of logistics companies, but also such global challenges as reforms in the economy, the formation of a modern regulatory framework, and infrastructure development. In the context of the current full-scale hostilities in our country, this question is particularly important, as logistics companies must not only thoroughly plan their economic and resource capabilities, but also carefully consider options for «green» modernization.

Thus, the task of studying the main challenges that stand on the way of implementing «green» technologies in the logistics sphere and searching for possible ways to overcome them is more relevant than ever

The purpose of the article is to study and analyse the main challenges that stand out the way of implementing «green» technologies in the logistics sphere. The article not only explains examples of modern issues, but also puts an emphasis on the current situation in Ukraine.

Presentation of the main results. Today, humanity is fighting a wide variety of serious threats, and inadequate attention to their resolution in our time could lead to a real catastrophe for all our future generations. Currently, the issues related to environmental pollution, the gradual depletion of natural resources and climate change are especially sharp.

In the context of climate changes, increasing carbon dioxide emissions into the atmosphere, growing waste volumes, declining natural resources, and growing number of all possible environmental demands from society, the idea of introducing the concept of sustainable development into the logistics sphere has

become not just a matter of simple importance, but rather a matter of urgent necessity. Sustainable development is critical for our planet and future generations [1].

Even if we take into account only a few of the above-mentioned aspects, it can be confidently stated that the logistics sphere is currently one of the largest sources of environmental pollution, not only in terms of greenhouse gas emissions, but also in terms of the enormous volumes of waste, which is clearly demonstrated in Fig. 1.

The integration of sustainable development aspects into the logistics sphere has allowed humanity to look at it in a completely new way, from a more ecological, «green» point of view. Over many years, society has managed to form a modern vision of logistics as an effective tool that is not only concerned with economic results, but also takes responsibility for preserving the environment.

«Green» logistics aims to minimise the negative impact of logistics on the economy through the massive introduction and use of both «green» technologies and different sustainable practices. Among the most popular examples are energy-efficient warehouses, electric transport, various types of biofuels, wind turbines, solar panels, regenerative energy systems, hydrogen technologies, eco-friendly packaging, modern systems for calculating the most efficient routes, automated resource distribution systems, greenhouse gas emission monitoring systems, and many other options.

For a long time, «green» technologies in logistics were not taken seriously by business representatives, but now there are countless examples of their successful implementation by all kinds of companies. The development and deployment of new green technologies is key to mitigate and adapt to climate change, reduce negative impacts of economic activity on nature and reduce pollution [2].



Figure 1 – Example of huge amounts of packaging waste

Source: <https://thesustainabilist.ae/sustainable-packaging-in-the-uae-e-commerce-industry/>

Despite numerous achievements in this area, it must be acknowledged that successful, truly large-scale cases usually occur in developed states, while in other countries, including Ukraine, the issue of «green» transformation faces significant challenges. These difficulties exist at both the macro and micro levels, and a country's success usually depends on the development of its infrastructure, economic stability, environmental reforms and investments.

Today, there is a greater need than ever in researching the challenges that stand in the way of implementing «green» technologies in the logistics sector. Knowing what to expect helps us adapt and prepare for a more resilient future [3]. A deep understanding of these complexities and the reasons for their emergence can help identify the most effective ways for their potential resolution. That is why this article aims to study and analyse the main challenges that currently stand on the way of implementing «green» technologies in the logistics sphere. At present, they are quite numerous. The «green» transformation of the logistics sphere is a truly complex process, and although the idea of implementing the concept of sustainable development in logistics has

gained support from society and business, the introduction of «green» technologies in logistics companies is still proceeding at a fairly slow pace.

Of course, today, the most obvious challenge is the high initial costs and the need in significant investments. This factor is quite critical for many operators, as reducing the negative impact of logistics activities on the environment is directly linked to the use of modern technical and advanced technological solutions. The need in significant financial investments is a very painful question for small and medium-sized companies, which often simply cannot allow themselves to take such steps. This is not about trivialities, but about large-scale decisions such as purchasing electric transport, charging station equipment, installing energy-efficient lighting, modernising work spaces and warehouses, switching to eco-friendly packaging, starting to use renewable energy sources, and many, many other examples.

In order to achieve success in this area, logistics companies must carefully calculate everything for the long-term perspective, find sources of investment, or at least take advantage of favourable credit offers. In

developed countries, this problem is well understood and attempts are being made to solve it through state funding, sponsorship of ecological programs, grants, «green» crediting and even tax reductions. In developing countries, including Ukraine, despite the existence of certain such initiatives, it should be noted that support for logistics companies in this regard is quite limited. The lack of such assistance is a critical barrier for business on the path to a «green» future, and that is why high initial costs are still considered a significant challenge on the way of implementing «green» technologies in logistics.

Another, but no less large-scale problem is the lack of a detailed regulatory and legislative basis that would regulate the introduction and development of «green» technologies in the logistics sphere. This moment represents the key reason why their implementation in logistics is still at such a low level. The absence of relevant legislation that addresses aspects of «green» logistics deprives business representatives of a clear vision of their direct obligations in terms of complying with modern sustainable norms. This, in its turn, does not give logistics companies confidence in their «green» initiatives, nullifies the very concept of stability and the need to plan such projects, especially large-scale ones. Today, each country has its own approach to this question. Many developed countries already have specific achievements in this direction, but in Ukraine, it still has not received enough attention. At present, there is no comprehensive law in our country that would be responsible for the general, effective regulation of the «green» logistics sphere. In practice, we have separate laws and state strategies, which usually do not indicate specific requirements for logistics operations related to the «green» course, as well as clear, step-by-step time frames for their realization in life. For Ukraine, as a modern developing country, it is important to pay more attention to creating a strong regulatory and legislative framework that will not only turn «green»

logistics into an integral part of our national environmental policy, but will also have clear requirements, obligations, timelines, control methods and enforcement mechanisms.

It is also impossible not to mention such a challenge as the lack of unified, legislatively defined environmental standards for logistics operations, or at least criteria for their assessment. Current legislation lacks a large number of requirements for sustainable supply chains, greenhouse gas emissions accounting in logistics processes, «green» packaging, ecological transport, etc. This leads to a situation where each market player decides for himself what are the frames of acceptable environmental friendliness, which is a completely wrong decision. Currently, logistics companies can only take into account certain aspects of their impact on the environment, ignoring such important factors as the amount of waste, noise pollution, the efficiency of resources use, etc. The result of this is a picture that does not show the real, complex impact of business on the environment. This not only makes this sphere less transparent and honest, but also makes it harder to compare results, and not just between Ukrainian companies, but also with foreign ones. Right now, they cannot prepare accurate, standardised reports that are created according to unified, modern norms and which fully reflect the true picture of their ecological friendliness, which is a very important factor in the question of attracting new investments, obtaining grants, receiving favourable credit offers and even the simple opportunity to participate in various government programmes.

In the absence of unified environmental standards for logistics operations, it is simply impossible to seriously discuss the concepts of «obligation», «control» and «implementation» of sustainable solutions. On this basis, an unpleasant situation arises when companies do not have any relevant guidelines to follow, and regulatory authorities, in their turn, are unable to conduct proper monitoring and enforcement. Such a long-term, irresponsible policy leads to

the result, where companies still do not see much sense in the ecological transition, postpone promising «green» initiatives to the distant future, or banally implement them in a limited form more for PR and marketing purposes than with the aim of conscious reduction of the negative impact of logistics on the environment. A way out of this situation could be the development and popularisation of common international standards that would serve as tools for achieving the set goal. Currently, such modern examples include ISO 14001 environmental certificates, Life Cycle Assessment (LCA) methodologies, GHG Protocol carbon reports, and others. That is why the creation and application of standardised mechanisms for measuring the «green» efficiency of logistics operations is such an important question in our time.

One of the most acute problems today is the lack of government support for logistics companies and a poorly thought-out incentive system for their environmental transition. Governments have a key role to play in supporting green technology dissemination and can influence the flow of technology to their own countries [4]. The introduction of «green» technologies in logistics companies is a very complex task. In developed countries, this issue is regularly brought to the agenda, as people there understand that the state should not stand aside of these processes and silently watch, but rather should perform the role of a reliable regulator, supervisor and responsible investor. In the same European Union countries, the practice of stimulating logistics companies through all possible grants, various subsidies and tax incentives is quite widespread. Talking about our country, it should be noted that such a system is just beginning its formation.

The logistics sphere is often not included in state programmes on sustainable development. This represents a very serious drawback, as today many logistics companies want to conduct «green» modernization but do not do so due to a lack of access to

appropriate long-term financing of their projects or at least favourable credit offers. Ignoring the issue of tax incentives for companies that implement «green» technologies does not add optimism either. Lack of attention to this question from the side of the state leads to the result when companies have no motivation to switch to ecological solutions, as they do not see enough benefits in it. The «green» course looks for them not as an opportunity to gain competitive advantages, but on the contrary, as an additional and very risky burden on business. To overcome the above-mentioned challenge, each country must ensure the formation of an appropriate system of incentives and limitations for logistics companies, which will gradually and quantitatively stimulate the adoption of sustainable solutions in their activities. It is necessary not only to create a complex policy of supporting the development of «green» logistics, but also to include it in the overall strategy of the state's sustainable development.

It is worth mentioning the significant value of the challenge of building modern infrastructure for alternative, «green» solutions. The issue of creating reliable, high-quality and safe infrastructure has always been relevant, and today, at a time of urgent need for the development of «green» logistics, it is regularly discussed around the world, as it represents one of the most critical problems on the path to its widespread use. The fully-fledged functioning of «green» decisions in the logistics sphere directly depends on the availability of modern transport, technical and energy infrastructure. The operation of all electric transport, «green» logistics hubs, hydrogen technologies, automated ecological warehouses and power stations is simply impossible without the creation of appropriate, high-quality infrastructure.

In developed countries, especially in the EU member states, much more attention has been paid to this question in recent years. Ukraine is also well aware of this problem, but

here its solution is proceeding at a rather slow pace. Even without mentioning advanced «green» technologies, but taking into account the banal charging stations for electric transport, it is possible to understand how serious this challenge is for our state. Currently, their number is quite limited, and their distribution across the territory is very unequal. By region, they are usually installed in small quantities and are unable to meet the demand of large logistics operators, which reduces the attractiveness of choosing electric transport for long routes.

On the other hand, despite the complexity of the process of their distribution, the trend in the development of this direction remains positive and is gradually improving with each new year. Large fuel retail chains have a great influence on this issue today, as they practically set the trend for the entire market in terms of installing the relevant electrical infrastructure, which can be seen in Fig. 2.



Figure 2 – OKKO has launched a network of fast electric charging stations

Source: <https://www.okko.ua/okko-masshtabuye-servis-dlya-elektrokariv-na-osnovnih-avtozhlyahah-vpershe-rozgornuto-merezhu-ultra-fast-chargers>

Even more complex is the situation with infrastructure for hydrogen logistics. Many scientists and experts see hydrogen as a promising fuel of the future, which has a wide range of advantages over traditional fuels. Despite our country's enormous potential in this area and the interest of foreign investors, it must be acknowledged that this sector is currently practically unexplored in Ukraine, not only in terms of full-fledged hydrogen filling stations, but also in terms of hydrogen production, distribution and storage systems. It is possible to realise our potential in this area with the help of European Union countries, which are directly interested in the development of this sector and are ready not

only to share their experience and technologies with us, but also to invest significant financial resources in relevant projects. Such a successful example of cooperation is the signing by Ukraine in 2023 of an agreement to join the European Union's Single Market Programme. On this day, a very promising Memorandum of understanding between the European Union and Ukraine on a Strategic Partnership on Biomethane, Hydrogen and other Synthetic Gases was signed at this meeting.

Similarly, regular warehouses are also poorly developed in terms of ecological standards. In fact, in most cases, they are not equipped with solar panels, modern energy-

saving systems or recuperation systems, and zero-emission construction is currently very rare. Success in overcoming this challenge can only be achieved through private investments and government support. If the question of improving logistics infrastructure is not included in the ecological strategy for regional development, any discussion about potential solutions to this problem will remain only theoretical, and will not be implemented in practice.

A unique challenge on the path to implementing «green» technologies is also the need to renew the transport fleet and warehouse facilities of logistics companies. Today, their complex modernisation is a key requirement for the development of «green» logistics. This process is not quick, but rather

step-by-step and long-term. In order to achieve success in this area, a clear ecological policy must be formulated, both at the state and industry programmes level, as well as on a corporate scale. Nowadays, a significant percentage of logistics vehicles are simply outdated and do not meet modern «green» standards. This primarily concerns the issue of their low energy efficiency, high noise levels and harmful emissions. Such companies as Amazon clearly understand this challenge and, having significant resources and financial support, are already working on renewing their logistics fleet of vehicles with more environmentally friendly models, which is perfectly illustrated in Fig. 3.



Figure 3 – Amazon's growing lineup of electric vehicles

Source: <https://www.aboutamazon.com/news/sustainability/amazon-electric-vehicles-vans-trucks-bikes>

The situation is no better when it comes to current warehouse facilities. A large share of them are outdated, poorly equipped, energy inefficient, and unable to perform transportation, sorting, processing, and storage operations in accordance with modern standards. A total replacement of

such a logistics fleet of vehicles or a high-quality modernisation of warehouses requires enormous financial contributions and investments. In most cases, such large-scale initiatives can be brought to life only by the largest market players, such as UPS, DHL or FedEx, which can be seen in Fig. 4.



Figure 4 – FedEx Ship Center in Washington, D.C.

Source: <https://newsroom.fedex.com/newsroom/global-english/communitysolarinstallation>

For small and medium-sized businesses, which are quite limited in terms of economic opportunities and available resources, such large-scale changes are simply an extremely difficult task. The high cost of modern «green» technologies, weak government support, and economic instability leave logistics companies with no choice but to continue using outdated equipment and solutions until the end of their service life, which undoubtedly has a negative impact on the environment. The need for regular maintenance of modern eco-friendly equipment and the search for highly professional personnel to work with «green» technologies does not add optimism either. For this reason, the question of renewing the transport fleet and warehouses still remains so relevant.

An additional challenge to the previously outlined problem is the integration of «green» technologies into the established logistics activities of companies. The process of improving traditional procedures is quite complex. The very fact that logistics companies purchase «green» technologies is not enough to reduce their environmental impact. The final result always depends on the quality of implementation of «green» technologies into the system of established business processes and the effective use of

these technologies in the future. More simple solutions in the sphere of «green» logistics really require replacement of only some separate elements, such as packaging or transport, but more complex «green» modernisation may demand change of the entire operational model of a logistics company. First and foremost, this concerns changes to the system of developed routes, training and preparation of environmentally conscious employees, the use of new software, modernisation of warehouses, and changes to business relationships with customers, partners and even suppliers. In a world of global competition, for many companies, conducting such modernisation represents considerable stress and risk, as this process may be accompanied by a temporary loss of productivity, disruption of logistics processes and a decline in service quality. In our time, this question is quite delicate, since even small declines in efficiency can lead to the loss of clients and a negative impact on the company's image in the market. Based on the above-mentioned moments, it can be emphasised that the complexity of implementing «green» technologies in logistics systems scares even those companies that well understand the importance of a «green» course. This challenge can be resolved through well-

planned, step-by-step introduction of innovations, using flexible methods of adaptation.

An important challenge that is often left unspoken is the poor ecological awareness of logistics companies. This problem cannot be equated with the technical difficulties mentioned above, but it is still worth paying attention to, as it has a key role in the process of «green» logistics development. Currently, the level of environmental awareness among employees of logistics companies around the world is really low. Their unwillingness to accept new, sustainable approaches and lack of eco-thinking leads to inaction, which is a huge barrier on the way to «green» modernisation in logistics. A great number of people still refuse to understand sustainable development as a strategic step into the future that can provide them with enormous number of advantages in the market. They are guided by clear commercial concepts and understand environmental friendliness as an empty bottomless pit, investing in which their time, funds and resources will not bring them adequate feedback. If a person with such a worldview is a manager in a company, this poses a serious threat to the sustainable development of the business, as this individual will simply look for quick ways to make a profit and refuse to consider practical cases where «green» technologies can lead to cost savings through improved routing systems, energy efficiency, waste reduction, etc. This is a negative moment, as logistics companies will in fact focus on operational response to emerging challenges and will not give any priority to «green» projects.

Similarly, this problem is equally challenging in the case of a workforce that is simply inexperienced in this regard. Unfortunately, today, the educational sphere does not pay enough attention to explaining the importance of preserving the environment. This leads to a situation where, without having undergone appropriate training and gained invaluable knowledge in this area, employees may neglect the goals and objectives of sustainable initiatives when

logistics companies begin to implement them. This complex problem can be solved through the gradual improvement of people's environmental awareness. The best way to achieve this is to implement a «green» logistics course in professional education, conduct all possible awareness-raising activities, and create corporate courses for employees. Thus, improving environmental awareness and culture remains a critical task necessary for the development of «green» technologies in logistics.

No less significant difficulty, which today is closely linked to the previous challenge, is weak pressure from clients. This problem is quite complex and practically stems from a combination of several previously explained challenges that stand on the way to the implementation of «green» technologies in the logistics sphere. We live in an era of globalization, and although the level of citizens' environmental awareness continues to grow, it must be acknowledged that this is still happening at a slow pace. In this case, for many people, the priority criteria when choosing products or relevant services are still their price, quality, and speed of delivery, with environmental friendliness coming only after that.

In the context of slowly growing demand for «green» services, logistics companies are in no hurry to enter a completely new area for themselves by implementing environmental initiatives, as they believe that this entails additional costs and risks for them. The lack of noticeable pressure from clients turns the goal of «green» modernization of logistics into a voluntary process. This leads to logistics companies continuing to use familiar technologies and operating models, which in their opinion are simpler, cheaper, and more understandable, even if they have a greater ecological impact on the environment. Not all citizens are aware of the advantages of «green» logistics, and certainly not all are willing to pay for it. This collective behavior does not provide many companies with additional motivation for sustainable development and the introduction of relevant

«green» innovations. To solve this problem, it is necessary to combine the efforts of the state, all possible business associations, and public organizations with the aim of improving citizens' environmental awareness and supporting a culture of ecological responsibility.

The last but not least important challenge that should be mentioned in this article is global instability, geopolitical conflicts, and crises. This factor is especially relevant and painful for our country. Our world is super interconnected, and sometimes even the smallest changes, which at first glance may seem irrelevant, can ultimately cause serious consequences. Today, there is a wide range of instabilities that can affect the development of the entire «green» logistics sector. Disruptions in supply chains, economic crises, fluctuations in demand, wars, and dramatic changes in fuel prices are examples of serious problems, faced with which logistics companies prioritize the survival of their business and its uninterrupted functionality. In such cases, they first and foremost think about the present, high-quality adaptation to difficulties, how to ensure the safety of employees, and how to optimize the route network, while strategic sustainable development remains in the background, as a long-term plan. Even during such crisis periods, it is very important to find a successful balance between countering short-term changes and executing long-term environmental policies, as constant postponement or even complete avoidance of this issue may result in businesses falling behind their competitors and incurring serious losses in the future.

Since 2022, Ukraine has been living in the new reality of full-scale military actions.

Working in conditions of martial law, constant shelling, and when part of the infrastructure is simply destroyed or temporarily non-functional, talks about «green» prospects and projects are in most cases left out of focus and postponed for later. And this is not surprising, since national safety must remain a top priority for the country during such difficult times. Currently, all Ukrainian enterprises and companies, including logistics ones, are concerned with questions of personal survival during this tough crisis period, maintaining their own operational functionality, resolving existing difficulties, and adapting to wartime threats, which is clearly demonstrated in Fig. 5.

At present, war is inextricably linked to the economy. Implementation of various measures to reduce risks requires sufficient costs [5]. The start of active combat actions led to major market shocks, which resulted in rising prices, declining production, inflation, reduced demand, higher fuel prices, and the mobilization of state and community resources for defense. All these reasonable points stand as a wall in the way of implementing «green» technologies and environmental solutions. The «green» transition is usually carried out in stable conditions, when companies not only have the appropriate resources and financial support, but can also clearly predict their future condition for the coming years. This complicates the current situation in this direction in our country. The development of the transport complex under martial law is a very important task for supporting the country's economy [6].

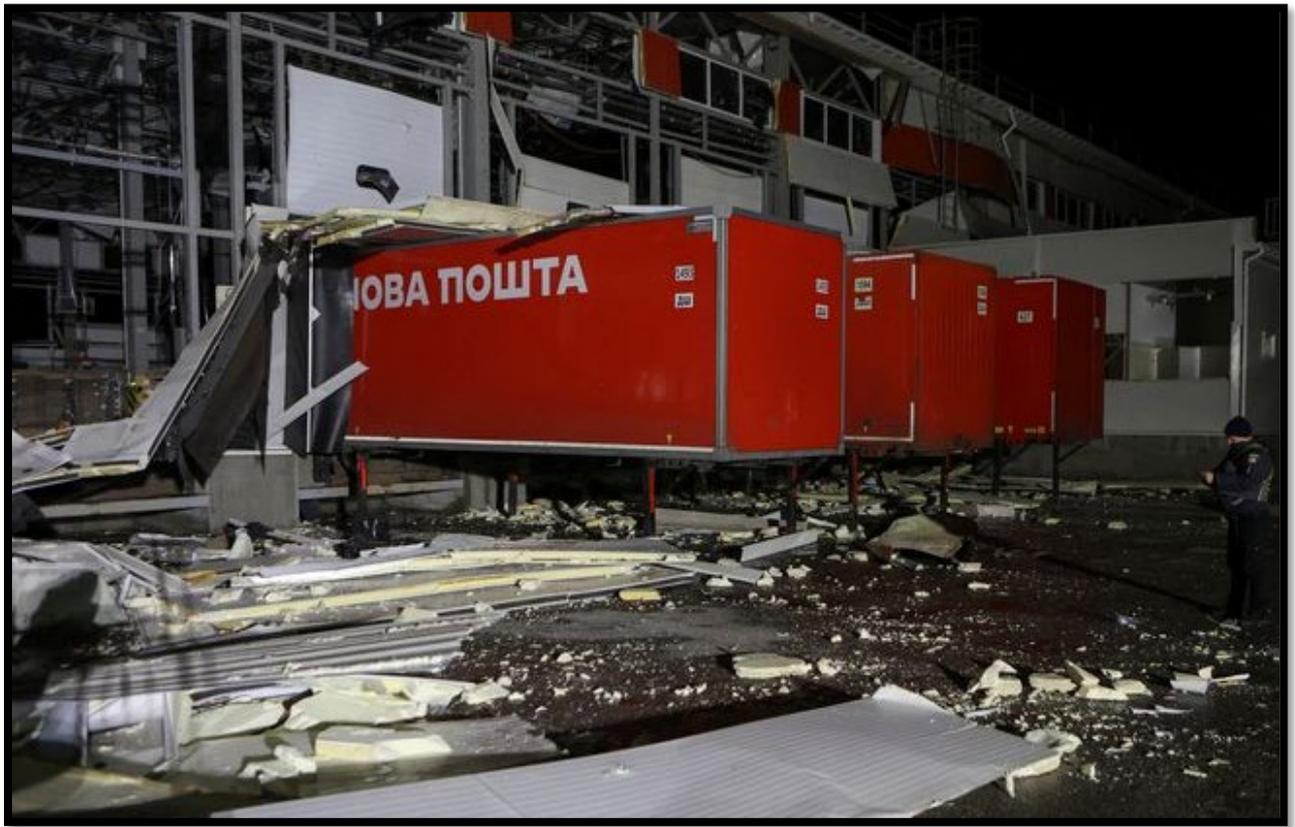


Figure 5 – Russian missile attack on postal centre in Kharkiv

Source: <https://news.sky.com/story/six-killed-in-russian-missile-attack-on-postal-distribution-centre-in-kharkiv-says-ukraine-12989826>

Taking all of the above into account, it can be emphasized that today, more than ever before, it is important to continue studying the challenges that stand on the way of implementing «green» technologies in the logistics sphere, creating modern conditions for the development of «green» logistics, and seeking new possible sources of support for its improvement.

Conclusions. Having conducted an in-depth analysis of the key challenges that stand on the way of implementing «green» technologies in the logistics sphere in this article, it can be highlighted that this process is quite complex in our time. Having studied this question in full, it is important to note that the development of «green» logistics requires not only the renewal of the technical and technological components of companies, but also the introduction of modern reforms and systemic changes in traditional practices of strategic forecasting, state regulation, financing, investment, and the development

of environmental awareness of citizens. Having studied a wide range of difficulties that hinder the implementation of «green» technologies in logistics, it is possible to highlight a list of the main challenges, among which are high initial costs and the need for significant investments, the lack of a detailed regulatory and legislative framework, the lack of unified, legally defined standards for the environmental friendliness of logistics operations, the lack of state support for logistics companies and a poorly thought-out system of incentives for them in terms of ecological transition, the need to build modern infrastructure for alternative, «green» solutions, the complexity of integrating «green» technologies into the established logistics activities of companies, the need to renew the transport fleet and warehouse facilities of logistics companies, poor environmental awareness of logistics companies, weak pressure from clients, as well as global instability, geopolitical

conflicts, and crises. Research has shown that all of the above-mentioned challenges are relevant to our country and are currently greatly complicated by wartime conditions. In order to solve them step by step, it is necessary to achieve active cooperation between the state, business, and society. The development of «green» logistics is undoubtedly a complex but already inevitable process. The survival of humanity and the preservation of our planet depend on the success of this sustainable transformation.

Even in such a difficult situation, we must not forget about «green» logistics and realize its potential, at least in the long term. The gradual resolution of the difficulties mentioned in the article will lead to the formation of a productive, environmentally friendly, energy-efficient, competitive, and safe logistics sphere that meets «green» standards. That is why it is so important to continue to research, analyze, and study this fateful question.

References

1. Consortium for Sustainable Development. The Importance of Sustainable Development for Our Planet and Future Generations. [Electronic resource]. – URL: <https://consortium4sd.org/blog/the-importance-of-sustainable-development-for-our-planet-and-future-generations>
2. OECD. Green technology and innovation. [Electronic resource]. – URL: <https://www.oecd.org/en/topics/green-technology-and-innovation.html>
3. IPCC. Climate change in data. [Electronic resource]. – URL: <https://www.ipcc.ch/report/ar6/wg1/resources/climate-change-in-data>
4. WIPO. Green Technology Diffusion: Insights from Industry. [Electronic resource]. – URL: <https://www.wipo.int/web/wipo-magazine/articles/green-technology-diffusion-insights-from-industry-38710>
5. Dmytro Bugayko, Volodymyr Reznik, New challenges for logistics in the conditions of military operations. Intellectualization of Logistics and Supply Chain Management: The electronic scientifically and practical journal v.21 (2023).
6. Volodymyr Reznik, Dmytro Bugayko, Comparative analysis of the legislation of Ukraine and international norms that regulate the implementation and formation of aviation logistics system. Intellectualization of Logistics and Supply Chain Management: The electronic scientifically and practical journal v.20 (2023).

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HYBRID PROJECT MANAGEMENT METHODOLOGIES IN LOGISTICS

Larysa Shchekhovska. «*Hybrid project management methodologies in logistics*». The article examines the theoretical and practical foundations of applying hybrid project management methodologies in logistics that combine elements of traditional (plan-driven) and agile approaches. The relevance of the study is determined by the need for enterprises to adapt rapidly to dynamic market conditions while maintaining operational stability and regulatory compliance. The paper analyzes recent research focused on customizing hybrid methodologies and assessing their effectiveness in managing complex projects. It identifies key characteristics of logistics projects that influence methodology selection, including physical constraints, regulatory requirements, and dependence on external partners. Three core models of hybrid management are proposed – phase-based, functional, and integrated – each providing a balance between predictability and flexibility. The paper substantiates the rationale for methodological zoning depending on project type: traditional methods for capital investments, Agile for IT and process-oriented initiatives, and hybrid models for complex logistics projects. The study outlines key implementation tools, methodological competency requirements for teams, and typical challenges such as methodological chaos, increased administrative burden, and coordination difficulties. The findings emphasize the potential of hybrid methodologies to enhance logistics project performance through a flexible combination of strategic planning and adaptive management. Future research directions include empirical evaluation of hybrid models in different logistics segments, analysis of organizational culture impacts, and integration of digital technologies (AI, IoT, blockchain) into hybrid management systems.

Keywords: hybrid methodologies, project management, logistics, Agile, traditional approaches, integrated management, adaptability, plan-driven models, project efficiency

Лариса Щеховська. «*Гібридні методології управління проєктами в логістиці*». У статті досліджено теоретичні та практичні засади застосування гібридних методологій управління проєктами в логістиці, що поєднують елементи традиційних (планово-орієнтованих) і гнучких (Agile) підходів. Визначено актуальність проблеми у зв'язку з потребою підприємств швидко адаптуватися до мінливих умов ринку, водночас зберігаючи стабільність операційних процесів і відповідність регуляторним вимогам. Проаналізовано сучасні наукові дослідження, присвячені кастомізації гібридних методологій та їх ефективності в управлінні складними проєктами.

Виявлено основні характеристики логістичних проєктів, що впливають на вибір підходу до управління, зокрема фізичні обмеження, регуляторну обтяженість і залежність від партнерів. Запропоновано три базові моделі гібридного управління – фазову, функціональну та інтегровану, які забезпечують баланс між передбачуваністю і гнучкістю. Обґрунтовано доцільність зонування застосування методологій залежно від типу проєкту: традиційних – для капітальних інвестицій, Agile – для IT- і процесно-орієнтованих задач, гібридних – для комплексних логістичних ініціатив. Розглянуто ключові інструменти впровадження гібридного підходу, вимоги до методологічної компетентності команди, а також типові ризики, пов'язані з методологічним хаосом, адміністративними витратами та недостатньою координацією. Зроблено висновок про потенціал гібридних методологій у підвищенні ефективності логістичних проєктів завдяки гнучкому поєднанню стратегічного планування та адаптивного управління. Визначено напрями подальших досліджень – емпіричну оцінку ефективності різних моделей у різних сегментах логістики, вплив організаційної культури та інтеграцію цифрових технологій у гібридні системи управління.

Ключові слова: гібридні методології, управління проєктами, логістика, Agile, традиційні підходи, інтегроване управління, адаптивність, планово-орієнтовані моделі, ефективність проєктів.

Introduction. Modern logistics is under constant pressure from dynamic changes driven by growing customer expectations, e-commerce development, and the need to improve process efficiency. Among the main challenges faced by enterprises are cost management, optimization of transportation flows, delivery speed, and adaptation to environmental and regulatory requirements. These factors require not only stability and predictability in management, but also flexibility and the ability to respond quickly to changes in the external environment.

The choice of an effective project management methodology is crucial for project success. In the constantly changing landscape of project management, hybrid approaches are gaining increasing popularity. This is primarily due to their unique ability to combine adaptability and predictability by integrating plan-driven project management methods with agile methods. However, to fully benefit from hybrid methodologies, managers face several difficulties in selection, design, and implementation.

Traditional project management methodologies, built on phased planning, provide structure and control, but they often do not match the pace of modern logistics transformations. In contrast, Agile methodologies, which emphasize flexibility,

interaction, and rapid iterations, demonstrate limited effectiveness in large and complex logistics projects, where clear deadlines, budgets, and integration with regulated processes remain key. As a result, a contradiction arises: traditional approaches are too rigid, and Agile is overly dynamic, which complicates their direct application in the logistics context.

Hybrid project management models seek to integrate two opposing worldviews originating from agile and plan-oriented approaches, with conflicting recommendations regarding planning, team structure, management style, and coordination. For example, agile approaches emphasize flexibility and iterative development, while plan-oriented approaches prioritize detailed planning and structured phases. The choice of one type of methodology over another will largely influence the project trajectory.

The growing interest in hybrid methodologies is explained by the desire to integrate the strengths of both management systems. Research shows that project managers are increasingly adapting methodologies to the specifics of the project, combining plan-oriented elements with agile approaches. This allows for both stability and predictability of processes, as well as rapid

response to unforeseen changes, which is especially important for logistics. Thus, the relevance of studying hybrid project management methodologies in logistics is driven by the need to find an optimal balance between stability and flexibility, which becomes a key factor in enterprise competitiveness.

Analysis of recent research and publications. The problem of hybrid project management has been actively studied by the international scientific community in recent years. Fundamental works in this area are represented by systematic literature reviews that demonstrate both theoretical foundations and practical aspects of implementing hybrid methodologies.

The research by Reiff and Schlegel provides a comprehensive systematic literature review on hybrid project management, emphasizing the limited comprehensive understanding of the practical implementation of this approach. Silva, Costa, and Rodrigues in their research focus on customization of hybrid project management methodologies.

Common project management methodologies include plan-oriented methodology (e.g., PMBOK and PRINCE2) and agile methodology (e.g., Scrum and Kanban), both offering a range of effective methods and techniques.

Literature analysis indicates growing attention to hybrid methodologies from both the academic community and practitioners. However, the specifics of applying hybrid approaches specifically in the logistics sector remain insufficiently studied, which necessitates further research in this direction.

Research purpose and objectives. The purpose of the research is to systematize the theoretical and practical aspects of applying hybrid project management methodologies in the logistics sector and to determine optimal models for their implementation, considering the specifics of logistics operations.

To achieve this goal, the following objectives have been defined: to analyze the

specific characteristics of logistics projects that influence the choice of management methodology and to systematize existing hybrid project management models and determine their applicability in the logistics context.

Basic material and results. Logistics projects have a number of characteristic features that significantly influence the choice of approaches to their management. First, physical constraints and hardware-infrastructure factors (warehouse facilities, vehicles, sorting equipment, and loading-unloading operations) define strict frameworks for project implementation: launch deadlines, technical parameters, and safety requirements often do not allow for frequent and extensive iterations without significant financial or operational losses. These features emphasize the need for careful preliminary planning and resource provision, which are strengths of traditional (plan-oriented) methodologies [5].

Second, logistics projects operate within the field of numerous regulatory and legal requirements: sanitary norms, customs rules, environmental restrictions, and safety standards affect the sequence of work and documentation requirements. The need for documented procedures and compliance with regulatory criteria makes classical approaches attractive for parts of the project stages, where deviation from approved procedures may result in legal or financial sanctions.

Third, the degree of dependence on external partners (suppliers, carriers, customs brokers, 3PL operators) creates an additional level of uncertainty and coordination. In such conditions, flexibility in decision-making and rapid communication between participants become critical for successful adaptation to supply chain disruptions or the emergence of new customer requirements. Here the advantages of Agile approaches manifest, particularly short iterations, constant feedback, and the ability to quickly adjust plans [9].

Based on this specificity, the criteria for choosing between traditional and agile approaches should be based on several interrelated indicators: the scale and complexity of logistics processes, the degree of regulatory burden, the level of dependence on external contractors, sensitivity to deadlines and budget, as well as the team's readiness for frequent communications and changes. Thus, for large infrastructure projects with high regulatory sensitivity and low possibility of incremental changes, a structure with pronounced planning and control phases is more appropriate; simultaneously, modular or IT-oriented sub-projects within the same initiative can be effectively implemented using Agile principles [1].

Based on literature analysis and practical experience, three main models of hybrid project management used in logistics can be identified:

Phase-based hybrid involves using traditional methodologies at the planning stage and Agile approaches at the execution stage. This model is especially effective for projects involving the construction of logistics centers or the implementation of complex equipment, where initial planning requires detailed specification, budget approval, and obtaining permits, while execution requires flexibility to adapt to unforeseen circumstances. The advantage of this model is the ability to ensure cost and time predictability at the initial stage while maintaining the ability to respond quickly to changes during implementation [4].

Functional hybrid is characterized by the application of different methodologies for different divisions or project components. For example, the development of information systems (WMS, TMS) can be carried out using Agile methodology with short sprints and constant testing, while physical infrastructure (warehouse construction, conveyor installation) is implemented using the traditional waterfall approach. This model allows optimizing the methodology for the specifics of each component, but requires

careful coordination between different work streams [5].

Integrated hybrid involves combining practices from different methodologies at the process level. For example, a project can use sprints from Agile together with fixed milestones from traditional management. This model provides the greatest flexibility but is also the most complex to implement, as it requires a deep understanding of both methodologies and the ability to organically integrate their elements.

The zoning of methodology application in logistics should be pragmatic and context-specific: traditional approaches are justified for large capital investments, construction, or equipment integration; Agile is appropriate for optimization of operational processes, development of IT tools, and last-mile solutions; hybrid models are most appropriate for complex projects where physical and digital components are combined and a balance between predictability and adaptability is needed. This approach ensures compatibility of procedures, regulatory compliance, and simultaneous preservation of reactivity to changes in market requirements [3].

Successful implementation of hybrid methodologies in logistics requires both appropriate tools and overcoming specific challenges. Modern digital platforms for project management should support multiple methodologies, provide progress visualization in various formats (Gantt charts, Kanban boards, burndown charts), and integrate with logistics ERP systems. Coordination methods include regular synchronization meetings between teams working with different methodologies, a unified reporting system, and clear definition of interaction interfaces [10, 11].

Managing teams in a hybrid environment presents a particular challenge. Forming cross-functional teams capable of working with different approaches requires not only technical skills but also cultural changes. Employees must be open to experimentation, ready for continuous learning, and able to

work in conditions of uncertainty. Cultural changes include a transition from a command-and-control management model to a collaborative one, from a focus on processes to a focus on results, from individual responsibility to team responsibility [7].

Among typical implementation mistakes are: insufficient preparation of the team and stakeholders, lack of clear justification for choosing a hybrid approach, mechanistic combination of practices without considering context, underestimation of the complexity of coordination between different methodologies, and lack of flexibility in the hybrid approach itself (the paradox of inflexible hybridity). Ways to avoid these mistakes include thorough assessment of organizational readiness for change, pilot implementation on a limited project, investment in team training and development, creation of a methodological coach or coordinator role, and regular review and adaptation of the chosen approach [6].

Conclusions. Research on hybrid project management methodologies in logistics demonstrates their significant potential for resolving the contradiction between the need for stability and the necessity for flexibility. The main advantages of the hybrid approach for logistics projects are the ability to combine the predictability of traditional planning with Agile adaptability, optimization of resource use through the selection of the most appropriate methods for each phase or project component, increased customer satisfaction through focus on their needs and the ability to respond quickly to changes, and improved team dynamics through employee involvement in decision-making processes.

Key success factors for implementing hybrid methodologies are clear understanding of the specifics of the logistics project and justified selection of the hybrid management model, high level of methodological competence of the project manager and team, effective communication and coordination between project participants, support from senior

management and readiness for organizational changes, and availability of appropriate tools and technologies to support the hybrid approach.

For practitioners considering the implementation of hybrid methodologies in logistics projects, the following recommendations can be formulated: start with a thorough analysis of project characteristics and organizational context before choosing a specific model; invest in training the team in the basics of both methodologies (traditional and Agile) before combining them; start with a pilot project to test the chosen approach and train the organization; ensure transparent communication with all stakeholders regarding the features of the hybrid approach; regularly review and adapt the chosen approach based on experience gained; create a community of practitioners to share experience in implementing hybrid methodologies.

However, research limitations should be acknowledged. First, the complexity of hybrid approaches can lead to "methodological chaos" if there is no clear guidance and coordination. Second, increased administrative costs for documentation and communication may negate some of the advantages of increased flexibility. Third, the success of the hybrid approach largely depends on the project manager's qualifications, which limits the scalability of this solution.

Prospects for further research include empirical study of the effectiveness of different hybrid management models in various logistics segments (warehouse logistics, transport logistics, international transportation), research on the impact of organizational culture on the success of hybrid approach implementation, development of tools for automated support in choosing and adapting methodology to a specific project, and study of the integration of new technologies (artificial intelligence, blockchain, IoT) with hybrid logistics project management methodologies. Special

attention should be paid to adapting international experience to the Ukrainian context, considering the specifics of the domestic business environment and the level

of project management maturity in logistics companies.

References

1. A3Logics. (2025). 9 key modern logistics challenges demystified in 2025. A3Logics Blog. URL: <https://www.a3logics.com/blog/modern-logistics-challenges>
2. Azenha M. L., Reis J., Fleury A. (2021). Competences for agile project management in the industry 4.0 environment. *International Journal of Managing Projects in Business*, 14(2), 410-433.
3. Heumann J. (2022). The role of the project manager in hybrid project management. *International Journal of Information Systems and Project Management*, 10(2), 45-68.
4. Joslin R., Müller R. (2015). Relationships between a project management methodology and project success in different project governance contexts. *International Journal of Project Management*, 33(6), 1377-1392.
5. Papadakis E., Tsironis L. (2018). A hybrid project management model for new product development projects. *International Journal of Management and Applied Research*, 5(2), 88-104.
6. Reiff D., Schlegel M. (2022). Hybrid project management – A systematic literature review. *International Journal of Information Systems and Project Management*, 10(3), 45-65.
7. Silva M., Costa R., Rodrigues A. (2024). Customising hybrid project management methodologies. *Production Planning & Control*, 35(9), 765-778.
8. TruckSuvidha. (2025). Essential challenges in transportation and logistics today. TruckSuvidha Blog. URL: <https://blog.trucksuvidha.com/2025/01/essential-challenges-transportation-logistics-today>
9. Vila Grau A., Capuz Rizo S. F. (2022). Hybrid project management: Combining predictive and adaptive tools. *Journal of Modern Project Management*, 9(3), 168-185.
10. Vinekar V., Huntley C. (2010). The role of the hybrid project manager. *PM World Today*, 12(6), 1-12.
11. Zwikael O., Chih Y. Y., Meredith J. R. (2022). Project benefit management: Setting effective target benefits. *International Journal of Project Management*, 36(4), 650-658.

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ANALYTICS IN CONSOLIDATED CARGO TRANSPORTATION

Sergiy Grytsenko, Anastasiia Honcharuk. *«Analytics in consolidated cargo transportation».* The article discusses the role of analytics in the sphere of less-than-container load (LCL) transportation as a key tool for optimizing logistics processes and improving operational efficiency. It examines the specific features and challenges of LCL shipments, including cost distribution, consolidation strategies, and shipment tracking. The article analyzes how data-driven approaches can enhance decision-making in logistics management, particularly in the context of fragmented supply chains and increasing customer demands. It outlines the main objectives of transportation analytics, assesses the impact of digital technologies and data platforms, and presents methodologies for evaluating performance indicators. Key areas of logistics analytics are highlighted, including route optimization, cargo consolidation efficiency, and predictive analysis in shipment scheduling. The necessary tools for implementing analytical solutions in LCL transportation are also presented, with emphasis on business intelligence systems, real-time tracking technologies, and forecasting models.

Keywords: LCL transportation; logistics analytics; cargo consolidation; route optimization; freight efficiency; supply chain visibility; shipment tracking; predictive analytics; transportation costs; digital logistics; delivery scheduling; data-driven decision making

Сергій Гриценко, Анастасія Гончарук. *«Аналітика у сфері збірних контейнерних перевезень».* У статті розглядається роль аналітики у сфері збірних контейнерних перевезень (LCL) як ключового інструменту оптимізації логістичних процесів та підвищення операційної ефективності. Висвітлюються особливості та виклики, притаманні LCL-перевезенням, зокрема розподіл витрат, стратегії консолідації вантажів і відстеження доставок. Проаналізовано, як підходи на основі даних сприяють покращенню прийняття управлінських рішень у сфері логістики,

особливо в умовах фрагментованих ланцюгів постачання та зростаючих вимог клієнтів. Окреслено основні завдання транспортної аналітики, оцінено вплив цифрових технологій і платформ обробки даних, а також представлено методики аналізу ключових показників ефективності. Виокремлено основні напрямки логістичної аналітики, включаючи оптимізацію маршрутів, ефективність консолідації вантажів та прогнозування графіків доставок. Також представлено необхідні інструменти для впровадження аналітичних рішень у сфері LCL-перевезень із акцентом на системи бізнес-аналітики, технології відстеження в реальному часі та прогностичні моделі.

Ключові слова: Збірні перевезення (LCL); логістична аналітика; консолідація вантажів; оптимізація маршрутів; ефективність перевезень; прозорість ланцюга постачання; відстеження вантажів; прогнозна аналітика; вартість транспортування; цифрова логістика; планування доставки; прийняття рішень на основі даних.

Introduction. In the context of economic globalization and the expansion of international trade, the efficiency of logistics processes is increasingly recognized as a key factor in the competitiveness of enterprises. The transportation of goods that do not fill a container completely (hereinafter referred to as LCL) occupies a special place in modern supply chains, contributing to the optimization of costs for small and medium-sized consignments. However, this segment of logistics is characterized by increased complexity, requiring the consolidation of cargo from multiple shippers, complex cost allocation methods, and coordination of the actions of multiple stakeholders involved in the process. The fragmentation of supply chains, combined with increasing customer demands for faster service, transparency, and delivery accuracy, creates significant challenges for logistics operators. The importance of the topic under study is underscored by the fact that traditional methods of managing LCL shipments have become insufficient to ensure the necessary level of efficiency, creating an urgent need to implement innovative tools based on data analysis.

A review of the literature shows that researchers are genuinely interested in optimizing logistics systems. Classic works on supply chain management laid the foundations for modeling transport flows and optimizing routes. In recent decades, the focus of research has shifted toward digital

technologies. Works devoted to the Internet of Things (IoT), artificial intelligence (AI), and big data reveal their potential for real-time cargo monitoring, demand forecasting, and decision-making automation. Areas such as predictive analytics for delivery planning, consolidation optimization using machine learning algorithms, and the use of business intelligence (BI) systems to visualize key performance indicators (KPIs) are being actively explored in the context of general freight transportation.

However, the degree of research on this issue in the LCL transportation segment remains insufficient. Most existing works either consider logistics analytics in general or focus on full container load (hereinafter FCL) transportation, where operational models are more standardized. Issues related to consolidated cargo, in particular dynamic pricing, container filling optimization taking into account the heterogeneity of goods, and last-mile coordination, require more in-depth analysis.

There is a gap between general theoretical models and their practical application to the unique challenges of LCL logistics. This article aims to provide a comprehensive analysis of the role and potential of analytics in groupage freight management, systematize existing approaches, and offer a holistic view of the methodology for implementing analytical solutions to improve operational efficiency in this sector.

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Research objectives and tasks. The purpose of the study is to conduct a comprehensive analysis of the role and tools of analytics as a key factor in improving operational efficiency and optimizing logistics processes in the transportation of small consignments (LCL).

To achieve this goal, the following tasks have been set:

1. Analyze the characteristics and main challenges of organizing LCL transportation, in particular the issues of consolidation, cost allocation, and tracking in fragmented supply chains.

2. Identify the main objectives and areas of application of transport analytics to solve identified problems and strengthen the competitive advantages of logistics operators.

3. Systematize key applications of analytical methods, such as route optimization, improving cargo consolidation efficiency, and predictive analysis in delivery planning.

4. Outline the necessary technologies and tools for implementing analytical solutions, including business intelligence (BI) systems,

real-time monitoring technologies, and forecasting models.

5. Propose approaches for assessing the effectiveness and impact of analytics implementation on key performance indicators (KPIs) in LCL transportation.

Main material and results. Less than container load (LCL) shipping is a key element of modern global logistics, offering significant benefits for businesses, especially small and medium-sized enterprises. The main advantage is cost efficiency. Instead of renting an entire container (FCL), the cost of which is fixed regardless of how full it is, the shipper only pays for the volume or weight of their cargo. This significantly lowers the barrier to entry into international markets. The second important advantage is flexibility in inventory management. Companies can ship smaller batches of goods more frequently, allowing them to maintain optimal inventory levels, avoid tying up working capital in large batches of goods, and respond more quickly to changes in demand. However, flexibility and cost savings come with significant operational challenges that make LCL logistics much more complex than FCL.

The central problem is the complexity of consolidation. It is a real logistical puzzle, where dozens of shipments from different shippers, with different properties and destinations, need to be coordinated in a single container. Any delay on the part of one customer can disrupt shipments for everyone else.

The second problem is the opaque distribution of costs. The total costs of freight, terminal charges, and customs clearance are distributed among all participants, and the methodology for this distribution is not always clear to the customer.

The third critical issue is the lack of comprehensive tracking. Cargo goes through many stages (consolidation warehouse, port, transshipment, deconsolidation warehouse), and each stage is often handled by different contractors. This creates "bottlenecks" in the supply chain, where it becomes almost impossible to obtain accurate information

about the status and location of cargo in real time.

Table 1 lists the main challenges facing logisticians and their assessment according to key parameters. The priority coefficient is calculated as the arithmetic mean of three

indicators (Frequency + Speed + Complexity) / 3, which allows you to identify the most important issues that require priority attention and the implementation of analytical solutions.

Table 1. LCL transportation challenges with priority coefficient calculation

Challenge / Problem	Frequency (1-10)	Speed (1-10) ¹	Complexity (1-10) ²	Priority
Delays during cargo consolidation	9	8	7	8.0
Lack of complete transparency	9	9	9	9.0
Opaque and complex distribution of common costs	8	7	8	7.7
Customs delays due to problems with one of the cargoes	7	9	6	7.3
Difficult communication between chain participants	9	6	7	7.3
Errors in accompanying documentation	8	6	7	7.0
Risk of damage or loss of part of the cargo during transshipment	6	8	6	6.7

Source: author's own work

The analysis of problems presented in Table 1 reveals several interrelated groups of issues that hinder the efficiency of LCL transportation. The most critical problem is information chaos, which combines a lack of end-to-end tracking, communication difficulties, and documentation errors. This creates an atmosphere of complete uncertainty for both the logistics provider and the customer.

The key solution to this problem is the implementation of a unified digital platform that would integrate data from all participants in the supply chain. Using real-time analytics and IoT sensors on cargo, such a system can provide objective data on the location and condition of cargo, becoming a single source of reliable information for all parties and minimizing the risks associated with human error.

Analytics is not just an add-on, but the main driver of such a digital platform. It transforms raw data into a decision-making tool. Here's how analytics solves the problem of information chaos and what tools are used to do so.

Analytics in a unified digital platform works on three key levels to eliminate uncertainty. They are described in Table 2.

The next issue is operational inefficiency, the main cause of which is delays at the consolidation stage. This common problem disrupts schedules and has a cascading effect on the entire supply chain. To solve it, it is necessary to move from reactive to proactive management using predictive analytics and optimization models. Historical data analysis allows machine learning models to predict likely delays and build the necessary time buffers into the schedule. At the same time, special algorithms can calculate the most optimal container loading and cargo grouping schemes in real time, taking into account their parameters and urgency.

Traditionally, logistics has been predominantly reactive. A problem arises—a supplier is late, cargo is delayed at customs, the port is overloaded—and the logistician reacts, hastily searching for a solution. This approach is stressful, inefficient, and often leads to chain delays and increased costs [10].

Proactive, data-driven management is changing this situation. It uses technology to anticipate problems and make adjustments before they affect the supply chain. This is where predictive analytics and optimization

models are crucial. Predictive analytics acts as an early warning system. It analyzes vast amounts of historical and real-time data to predict future outcomes and identify potential risks.

Table 2. Key levels for eliminating uncertainty

Problem	Analytical tool	How it works	Example of a system/platform
TRACKING			
Lack of reliable and comprehensive tracking	Analysis of IoT sensor data	Collection and analysis of telemetry data (location, temperature, impacts) to detect anomalies in real time.	Samsara [1], FourKites [2]
Inaccurate and static estimated time of arrival (ETA) predictions	Modeling of estimated time of arrival (ML)	Algorithms analyze dozens of variables (weather, traffic jams, history) to calculate dynamic and accurate arrival times.	Project44 [3], Descartes MacroPoint™ [4]
COMMUNICATION			
Fragmented data and inefficient communication	Business Intelligence (BI) platforms	Integration of data from all sources into a single information panel, providing a "single source of reliable information" for all parties.	Flexport [6], Microsoft Power BI [5]
Information overload, risk of missing important events	Exception handling	The system automatically tracks deviations from the plan and sends notifications only when real problems arise.	SAP Transportation Management [7]
DOCUMENTATION			
Manual document processing and high risk of human error	Optical character recognition based on artificial intelligence (OCR)	Automatic reading, extraction, and verification of data from documents (bills of lading, invoices) to identify discrepancies.	Shipamax [8], BlueX Trade [9]

Source: author's development based on [1-9]

Key data sources include:

- Historical supplier performance metrics (delivery timeliness).
- Real-time port and terminal congestion levels.
- Weather forecasts for delivery routes.
- Traffic flows and road conditions.
- Seasonal demand fluctuations.

By processing this information, the system can generate valuable insights. For example, instead of simply waiting for a shipment from a supplier, the model can flag it as having an 85% probability of being delayed by two days, based on the supplier's past performance during the holiday season and current port congestion. This warning allows the logistics manager to act proactively. Once predictive analytics

identifies a potential problem, optimization models kick in to recommend the best course of action. These are complex algorithms that can instantly evaluate millions of possible scenarios to find the most effective solution (Figure 1).

In the previous example, with a predicted two-day delay, the optimization model could:

- Reroute the consolidation plan: automatically assess whether other shipments can be rerouted in the same container or whether it is better to delay the container.
- Suggest alternative routes: suggest a different shipping line or a combination of land and air transport to meet the deadline.

– Adjust resource allocation: reschedule truck loading and warehouse slots to avoid downtime.,

Reactive and Proactive Approach to Risk Management

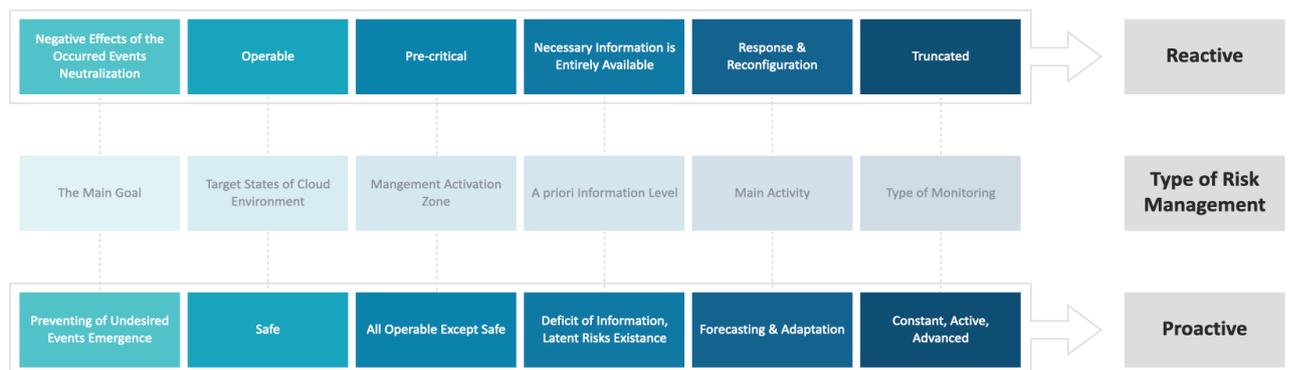


Figure 1 – Comparison of reactive and proactive approaches to management [11]

Previously, logistics operated on a “firefighting” basis. Today, thanks to analytics, it is transforming into an early warning system. This has been made possible by integrating data from previously isolated sources: corporate ERP systems, IoT sensors on containers (which track not only geolocation but also temperature and shocks), API services for real-time traffic monitoring, and even weather forecasts. The analytics platform combines this information to create a single dynamic picture of the entire supply chain.

The first tool is predictive analytics. It uses machine learning (ML) models to analyze historical data and identify hidden patterns. For example, logistics giant DHL uses its Resilience360 platform to analyze more than 50 million data sources to identify political, natural, and infrastructure risks before they affect cargo. This means that the system can predict with high accuracy that there is a 75% probability of a particular container being delayed at the port of Singapore due to seasonal congestion, allowing the logistics provider to take proactive measures [12].

The second tool is optimization algorithms. When the predictive model signals a risk, the optimization system

answers the question: “What to do next?” It instantly calculates thousands of possible courses of action and suggests the best one. This may not be just a change of route, but a comprehensive recommendation: to redirect part of the cargo to another flight, change the loading order at the consolidation warehouse, and automatically notify the customer of the change in arrival time.

By combining these two tools, the logistician no longer simply reacts to delays. They are provided with a predicted problem and a menu of optimal solutions based on data. This transforms their role from crisis manager to strategic planner, ensuring not only the efficiency of the supply chain, but also its resilience to disruptions.

The transition from reactive to proactive management is not just a trend, but a necessity for modern logistics companies. Global supply chains have become extremely complex and vulnerable. According to McKinsey, companies could lose up to 45% of their annual profits over a decade due to sudden disruptions [13]. The traditional model, in which a logistician manually tracks shipments and resolves issues over the phone, is no longer capable of coping with such challenges. This is where transport

analytics becomes a key factor in ensuring resilience and efficiency.

The third group of challenges is related to financial and external risks. Opaque cost allocation undermines customer trust, and customs delays are an uncontrollable external factor that can halt an entire container due to a problem with a single shipment. The solution lies in process automation and proactive data management. Implementing a system that automatically allocates costs based on clear parameters makes pricing transparent [14]. At the same time, analytical tools can automatically check the accuracy of customs documents before shipment, flagging potential risks and allowing errors to be corrected in advance to minimize the likelihood of delays at the border.

These risks, although different in nature, share a common root cause: a lack of data

transparency and an inability to anticipate problems. Analytics addresses this root cause by turning uncertainty into manageable processes.

A). In-depth analysis of financial risks and analytical solutions

Problem: Opaque cost allocation is not just a matter of customer trust. It is a direct path to financial and operational losses. When customers do not understand what they are paying for, lengthy disputes arise, payments are delayed, and the logistics company spends hours manually compiling and justifying each invoice. Moreover, it prevents the customer from calculating a key indicator—the cost of delivery—which complicates their own pricing and financial planning.

The solution that can be proposed using analytics is shown in Table 3.

Table 3. How analytics reduces financial risks in logistics

Analytical application	Main tool/method	Function and operating principle	Practical example and advantages
Dynamic pricing and accurate cost estimation	Dynamic pricing models	Analyzes market conditions in real time: route demand, container capacity, competitor rates, and seasonal data to determine the optimal price that maximizes profit while remaining competitive.	The customer enters shipment details on the online portal and receives an instant accurate price quote. This speeds up the sales process and increases the conversion rate.
Complete cost calculation including delivery costs	Integration with customs tariff and tax databases	Automatically calculates not only the cost of transportation, but also all associated costs: insurance, import/export duties (based on HS code and destination), VAT, and last-mile delivery costs.	The customer receives a full report detailing all components of the final product cost before shipment. This is a high value-added service that helps build trust.
Automated invoice auditing	Invoice reconciliation systems	Automatically compares each item on the contractor's invoice with the original quote and tracking system data to identify discrepancies.	The system instantly flags incorrect cargo weight or unreasonable fuel surcharges from the carrier. This allows the company to dispute invoices and achieve significant cost savings.

Source: author's own work

B). In-depth analysis of external risks and analytical solutions

Problem: Customs delays are a classic example of the domino effect. An error in one shipper's documents leads to a thorough inspection of the entire container. The result

is not just a loss of time. It is demurrage and detention (paid storage of the container at the port), which can cost thousands of dollars, disruption of the customer's production plans due to a lack of components, empty shelves in stores, and damage to reputation. Analytics

turns this "uncontrollable" risk into a predictable one.

The solution that can be proposed using analytics is shown in Table 4.

Table 4. How analytics reduces external (customs) risks

Analytical application	Main tool/method	Function and principle of operation	Practical example and advantages
Automated classification of goods	AI-based HS code classification models	An artificial intelligence model, trained on millions of customs declarations, analyzes the text description of the goods and suggests the most accurate HS code.	The sender describes "men's leather boots," and the system provides the correct code, minimizing the risk of an error that could delay the entire container.
Monitoring changes in legislation	Integration with regulatory intelligence services	The platform tracks changes in trade legislation, sanctions, and tariffs for countries along the delivery route in real time.	The system generates notifications about new product certification requirements in the destination country, allowing documents to be prepared in advance.
Forecasting customs risks	Machine learning models for risk assessment [15]	The system analyzes a set of factors (shipper history, type of goods, country of origin, discrepancies in documents) and assigns a risk rating to each shipment.	High-risk shipments (e.g., 8/10) are automatically flagged for detailed inspection by an expert before shipment, preventing problems at customs.

Source: author's own work

Proposal. The analytical platform for LCL shipments is an integrated cloud-based SaaS (software as a service) platform that functions as a central digital operating system for managing all aspects of consolidated cargo.

Its main goal is to transform a chaotic flow of data from various sources into a single source of reliable information, ensuring transparency, predictability, and control over the entire logistics chain.

The platform consists of several interconnected modules, each of which solves specific business tasks:

- Visibility and Tracking Module: integrates data from IoT sensors on cargo, GPS trackers, and carrier information systems. Using machine learning models, it provides not only the current location but also the accurate estimated time of arrival (Predictive ETA), taking into account weather, traffic jams, and port congestion.

- Proactive Risk Management module: analyzes accompanying documents for errors, checks compliance with customs requirements, and assigns a risk rating to each shipment. This allows you to identify potential

problems (such as incorrect HS codes) before shipment and prevent delays.

- Financial Control and Automation Module: automates the process of allocating costs between different shipments in a container, checks contractor invoices for discrepancies, and generates transparent invoices for customers.

- Business analytics module: visualizes all operational and financial data in the form of interactive dashboards. This allows management to track key performance indicators (KPIs) such as on-time delivery, average transportation costs, and profitability to make informed strategic decisions.

Thus, this platform is not just a tool, but a strategic asset that radically changes the approach to logistics management—from reactive problem solving to proactive, data-driven development.

Assessment of economic efficiency and return on investment using the example of FTP LLC

The implementation of a centralized analytical platform is a strategic investment aimed at improving operational efficiency and expanding the range of services. This

section presents a detailed financial justification for such a project using the example of the logistics company FTP LLC, which allows assessing its feasibility in real business conditions.

FTP LLC is a Ukrainian logistics operator founded in 2011 in Kyiv, specializing in comprehensive international trade services. The company offers a full range of services that go beyond ordinary cargo transportation. FTP LLC specialists provide advice on foreign economic activity, assist with customs clearance, take over the management of the entire logistics chain from the moment of loading the cargo to its final delivery, provide support in concluding contracts and financial transactions, and assist in import processes [16-17].

Over the years, FTP LLC has achieved significant success. In 2014, it received recognition as the "Industry Leader of 2014" in Ukraine. An important milestone in its development was the opening of a branch in Warsaw in 2016, which expanded the company's geographical reach and allowed it to operate effectively even in the difficult conditions associated with the war in Ukraine. In 2020, the company joined the prestigious World Cargo Alliance (WCA), confirming its high standards of service and gaining access to a global network of 12,229 offices in 197 countries. These achievements underscore the reliability and leadership position of FTP LLC in the international logistics services market.

The company is engaged in the following activities [17]:

52.29 Other auxiliary transportation activities;

46.74 Wholesale trade in cast iron products, cast iron products, plumbing and heating equipment and accessories;

47.52 Retail sale of hardware, building materials, and plumbing equipment in specialized stores;

52.10 Warehousing;

52.24 Cargo handling;

70.22 Business and management consulting;

69.10 Legal activities;

49.41 Road freight transport;

50.20 Sea freight transport;

51.21 Air freight transport.

Profile of FTP LLC:

– Staff: ~160 employees in offices in Ukraine and Poland.

– Business model: Asset-light (no own transport), use of partner warehouses in key hubs (China, Poland, EU).

– Services: Comprehensive logistics, financial, banking, and brokerage services, mainly in the import segment from Asia and Europe.

– Finance: Annual net income ~ UAH 30 million (approximately US\$750,000).

– IT infrastructure: A set of disparate systems (BAF, CRM, Power BI, messengers) is used, which creates the problem of "information silos" and complicates comprehensive control.

Investment goal: Implementation of a unified analytical platform for data integration, process automation, and creation of new data-driven services for customers.

Detailed analysis of investment costs for FTP LLC

Investments for FTP LLC are not directed at physical assets, but at creating a unified digital ecosystem, which is a key element of the asset-light model.

The main investment is the SaaS platform. For a company that works with multimodal transportation (sea, air, road, rail) and a large number of contractors, a cloud-based SaaS solution is optimal. It provides flexibility and scalability. The license fee of \$55,000 per year includes visibility, contractor management, and financial analytics modules [18-19].

Ensuring visibility: IoT operating costs. Since FTP LLC does not own any transport, purchasing a fleet of expensive reusable sensors is not feasible. Instead, a budget of \$7,000 per year covers the cost of using disposable trackers or data from partners to monitor the most valuable LCL cargo from Asia.

System integration: Integration. This is the most important one-time expense. It will

cost \$30,000 to seamlessly integrate the new platform with FTP LLC's existing systems – BAF (operational data), CRM (customer data), and financial programs. Without this, the platform will not be able to become a "single source of truth" [18-19].

Staff training: An investment of \$10,000 is aimed at training 40-50 key employees in the operational, financial, and commercial departments so that they can use all the capabilities of the new system for analysis, not just for simple monitoring [18-19].

Detailed analysis of the potential benefits for FTP LLC

The advantages of the project lie not only in cost savings, but also in the creation of new sources of income, which is extremely important for a service company.

Reduced demurrage and detention costs. For FTP LLC, maritime transport from Asia is a key area where the unpredictability of port operations often leads to penalties. Estimated time of arrival (ETA) allows for advance planning of container removal. This reduces costs by at least 50%, which is equivalent to savings of \$15,000 per year.

Optimization of contractor selection. FTP LLC's main expenses are payments for carrier services. The platform allows you to create a rating of contractors based on historical data analysis (timeliness, cost, reliability). Choosing partners based on data, not just price, reduces overall transportation costs by 2-3%, resulting in savings of approximately \$25,000 per year [20].

Increased productivity. Operations managers at FTP LLC spend up to 40% of their time on routine tasks: tracking shipments in different systems, communicating in messengers, and preparing reports. Automating these processes frees up the equivalent of 1.8 employees' productivity, which translates into \$36,000 per year.

Creating new sources of income. The analytics platform allows FTP LLC to monetize data. The company can launch new premium services:

– Pro-Visibility package: providing customers with access to real-time tracking using IoT sensors.

– Risk Management Service: analytical reports on route risks and insurance services.

This can generate up to \$30,000 in new high-margin revenue per year.

Total estimated annual benefit: \$15,000 + \$25,000 + \$36,000 + \$30,000 = \$106,000.

Return on investment (ROI) is a performance metric used to measure the effectiveness or profitability of an investment. It means how much net profit you get for every dollar invested. It is always expressed as a percentage.

Payback period (PP) is the amount of time it takes for an investment to generate enough cash flow to recoup its initial cost. It is expressed in units of time (e.g., months or years).

Net present value (NPV) is an important financial metric that calculates the profitability of an investment, taking into account the time value of money. Simply put, it shows managers how much all future cash flows from a project are worth today. A positive NPV indicates that the project is expected to generate more value than it costs.

All these characteristics were calculated in Table 5, as shown below.

Assumptions for calculation:

Project implementation period: Net present value was calculated for a standard 5-year period.

Discount rate: A discount rate of 12% was used. This rate reflects the minimum return that the company expects from an investment with a similar level of risk.

Cash flows: The calculation uses an initial one-time investment (-\$40,000) and a net annual cash flow (benefits minus current expenses) of +\$44,000 per year.

A positive NPV of \$118,611 over five years strongly indicates that the investment in the analytics platform is financially sound and will create significant value for the company that will far exceed the initial costs.

Table 5. Calculation of the financial impact of the investment plan implementation

Indicator	Formula	Year 1	Year 2	5-year forecast
Total investment amount	Sum of one-time and annual costs	\$102,000	\$62,000	-
Total annual benefit	Sum of direct and indirect savings	\$106,000	\$106,000	-
Net result for the year	Benefits - Investments	\$4,000	\$44,000	-
Return on investment (ROI)	(Net result / Investments) × 100%	3.9%	71%	-
Payback period	Total investments / (Benefits / 12)	-	-	11.5 months
Net present value (NPV)	$\sum((1+r)^t/CFt) - C_0^*$	-	-	\$118,611
*Explanation of NPV formula variables	CFt : Net cash flow for time period t r: Discount rate (required rate of return) t: Time period (e.g., year 1, year 2) C0 : Initial investment cost (at time 0)			

Source: author's own work

KPI assessment

The last part of this work is devoted to the structure of analytics performance evaluation. The true indicator of the success of any technological initiative is its quantitative impact on key business indicators. The implementation of an analytics platform in LCL transportation is not an end in itself, but only a tool for achieving specific business results. At the end of this work, we propose a comprehensive structure for evaluating the effectiveness of the project, which allows us to justify its value to all stakeholders.

This methodology is based on the "before and after" principle, which requires the collection of baseline indicators prior to implementation and their regular monitoring after the platform is launched. The assessment is built around four key areas of impact.

1) Operational efficiency – this group of key performance indicators shows how much more streamlined, faster, and more efficient the company's internal processes have become. The main goal is to measure the reduction of friction in day-to-day operations. Analytics directly contributes to improved planning and automation of routine tasks, which should be reflected in metrics such as on-time delivery (OTD), reduced order processing time, increased container utilization, and accelerated inventory

turnover. The platform's optimization algorithms and predictive capabilities are the main drivers of these improvements.

2) Financial indicators – these indicators directly reflect the impact of the project on the company's final financial result. Here, the final financial condition of the logistics provider is measured. By optimizing routes, minimizing costs, increasing productivity, and ensuring accuracy, analytics should reduce the average cost of processing a cubic meter. This is complemented by a significant reduction in penalty costs, such as downtime and delay penalties. In addition, automation allows the company to process more volume with the same staff, which should lead to increased revenue per employee and improved billing accuracy.

3) Service quality and customer satisfaction – this category assesses how technological changes have improved the customer experience. Successful implementation makes life easier for customers and makes their business more predictable. This can be measured using direct feedback tools such as Net Promoter Score (NPS) or Customer Satisfaction (CSAT). A key indicator of proactive service is a reduction in customer inquiries per shipment, as customers have all the information they need on the self-service portal. Ultimately, the most important indicator is customer

retention, as high quality and transparency of service are key to long-term loyalty.

4) Strategic impact. Strategic supply chain planning is a comprehensive, comprehensive, and integrated planning process to achieve competitive advantages for the chain by increasing added value and improving service parameters. Supply chain

optimization should be viewed from the perspective of a holistic analysis of the value chain and key performance indicators (KPIs), rather than local optimization of production cycle time, inventory levels, etc. [21, pp. 122-126]. The proposed KPIs are described in Table 6.

Table 6. Summary of Key Performance Indicators (KPIs)

Category	KPI	How analytics drives improvement
Operational efficiency	On-time delivery (OTD)	Arrival time forecasting and proactive risk management.
	Order processing time	Automation of documentation and planning.
	Container utilization rate	Load optimization algorithms for maximum space utilization.
Financial results	Cost per cubic meter	Optimization of routes, workforce, and assets; cost reduction.
	Downtime and delay costs	Accurate arrival forecasting and proactive alerts.
	Revenue per employee	Automation allows existing staff to handle a greater volume of work.
	Invoice accuracy	Automated auditing and data verification.
Service quality and customer satisfaction	Customer loyalty index (NPS) / CSAT	Increased transparency, reliability, and proactive communication.
	Number of shipping requests	Customer self-service portals with real-time tracking data.
	Customer retention rate	High-quality service builds long-term loyalty.
Strategic impact	Data-driven decision-making rate	Measures cultural shift toward analytical decision-making.

Source: author's own work

Evaluating analytics effectiveness should not be a one-time event. It should become part of a continuous cycle of "Measurement → Analysis → Optimization." This structure provides a clear roadmap not only for validating the value of the initial investment, but also for transforming the analytics platform into a dynamic tool for finding new avenues for growth. This data-driven approach to management is the foundation for creating a sustainable competitive advantage and establishing leadership in the logistics market.

Conclusions. The study confirms that the targeted use of analytics in consolidated freight transportation is a key factor in the transition from traditional, reactive methods

to a proactive, data-driven business model. Analytics is not just an optimization tool, but a fundamental basis for survival and growth in this complex and competitive segment of logistics. In the course of the work, all the tasks set in the context of the research topic were completed.

First, the features and key challenges inherent in consolidated transportation were analyzed. The study showed that the main problems of the LCL segment are the complexity of physical consolidation of cargo from different shippers, the lack of transparency in the distribution of shared costs between them, and the fragmentation of tracking on multi-stage routes.

Second, the main goals and areas of application of transport analytics for solving these problems were identified. It was found that the main goal of analytics in LCL is to transition to a proactive model capable of managing the high volatility and risks characteristic of consolidated freight supply chains. This allows logistics operators to strengthen their competitive advantages through reliability and transparency.

Thirdly, the paper systematizes key areas of application of analytical methods directly for LCL operations. It shows how modeling the estimated time of arrival for multi-stage consolidated routes, optimization algorithms for maximizing container loading, and intelligent processing of different document packages from multiple senders within a single consolidation can effectively solve specific problems in this market.

Fourth, the technologies and tools required to implement analytics in consolidated transport were outlined. The study showed that the basis is a SaaS cloud platform specialized in managing multi-client LCL shipments. The key tools are machine

learning models for forecasting and business analytics platforms for monitoring KPIs specific to group logistics.

Finally, approaches to evaluating the effectiveness of analytical solutions in the LCL sector were proposed. A KPI system was developed and a detailed ROI calculation model was provided. Calculations based on the example of FTP LLC showed that with an initial investment of \$102,000 and an annual benefit of \$106,000, the project pays for itself in 11.5 months, and the return on investment in the second year reaches 71%. This proves the high economic feasibility of investing in specialized analytical systems for managing consolidated cargo.

Thus, the introduction of analytics into consolidated freight logistics is a sensible and necessary step. It not only solves existing operational problems, but also creates a basis for innovation and transforms information into a strategic asset for gaining a decisive advantage in the competitive market of consolidated transportation.

References

- 1) Samsara. Connected Operations Cloud Report [Electronic resource]. 2025. URL: <https://www.samsara.com/reports/connected-operations> (date of reference: 10.10.2025).
- 2) FourKites. The Future of Real-Time Supply Chain Visibility [Electronic resource] : White Paper. 2025. URL: <https://www.fourkites.com/resources/white-papers/future-of-visibility> (date of reference: 10.10.2025).
- 3) Project44. The State of Supply Chain Visibility [Electronic resource]. 2025. URL: <https://www.project44.com/resources/gated-content/state-of-supply-chain-visibility> (date of reference: 10.10.2025).
- 4) Descartes. MacroPoint™: Real-Time Freight Visibility and Predictive Analytics [Electronic resource] : Solution Brief. 2025. URL: <https://www.descartes.com/resources/documents/solution-brief-macropoint> (date of reference: 10.10.2025).
- 5) Microsoft. Leveraging Power BI for Logistics and Supply Chain Analytics [Electronic resource]. 2025. URL: <https://powerbi.microsoft.com/en-us/solutions/supply-chain-analytics/> (date of reference: 10.10.2025).
- 6) Flexport. The Platform for Global Trade: A Technical Overview [Electronic resource]. 2025. URL: <https://www.flexport.com/platform/overview> (date of reference: 10.10.2025).

- 7) SAP. SAP Transportation Management: Proactive Monitoring and Exception Handling [Electronic resource]. 2025. URL: <https://www.sap.com/products/transportation-management.html> (date of reference: 10.10.2025).
- 8) Shipamax. AI-Powered Document Automation for Logistics [Electronic resource]. 2025. URL: <https://www.shipamax.com/solutions/document-automation> (date of reference: 10.10.2025).
- 9) BlueX Trade. Intelligent Document Processing for Freight Forwarders [Electronic resource]. 2025. URL: <https://www.bluxtrade.com/solutions/document-processing> (date of reference: 10.10.2025).
- 10) Ghoncharuk M. S. Proghnostychny modeljuvannja ta optymizacija ryzykiv u suchasnykh lancjughakh postachannja. Ekonomika ta upravlinnja transportom. 2023. Vyp. 15. S. 34–41.
- 11) Reactive And Proactive Approach To Risk Management Scheme [Electronic resource] // HiSlide. URL: <https://hislide.io/product/reactive-and-proactive-approach-to-risk-management-scheme/> (date of reference: 09.10.2025).
- 12) DHL Resilience360. Annual Risk Report: A Comprehensive Analysis of Global Supply Chain Threats [Electronic resource] // DHL Global Forwarding. 2022. URL: <https://www.dhl.com/global-en/home/insights-and-innovation/thought-leadership/resilience360-reports.html> (date of reference: 01.10.2025).
- 13) Gartner, Inc. The Future of Supply Chains: Predictive Analytics and Corporate Resilience [Electronic resource] : White Paper. 2024. URL: <https://www.gartner.com/en/supply-chain/trends/future-of-supply-chains-2024> (date of reference: 10.10.2025).
- 14) Chumachenko I. V. Intelektualjni systemy dlja proaktyvnogho upravlinnja mytnymy ryzykamy v lohistyzi. Visnyk transportnykh system i tekhnologij. 2023. Vyp. 41. S. 78–85.
- 15) World Customs Organization. Predictive Risk Scoring in Cross-Border Trade: A SAFE Framework Implementation Guide [Electronic resource]. 2024. URL: http://www.wcoomd.org/en/topics/facilitation/instrument-and-tools/frameworks-of-standards/safe_package/predictive-risk-scoring-guide.aspx (date of reference: 10.10.2025).
- 16) TOV «FTP». Oficijnyj vebajtv [Electronic resource]. URL: <https://ftpua.com/> (date of reference: 01.09.2025).
- 17) Opendatabot. TOV «FTP» [Electronic resource]. URL: <https://opendatabot.ua/c/37888626> (date of reference: 01.09.2025).
- 18) 2025 Pricing Guide for Supply Chain Visibility Platforms [Electronic resource] // Logistics Tech Review. 2025. URL: <https://logisticstechreview.com/reports/2025-pricing-guide-visibility-platforms> (date of reference: 10.10.2025).
- 19) Deloitte. The ROI of API Integration in Modern Logistics [Electronic resource]. 2024. URL: <https://www2.deloitte.com/us/en/insights/focus/supply-chain/api-integration-logistics-roi.html> (date of reference: 10.10.2025).
- 20) Leveraging Data to Optimize Carrier Selection and Management. Journal of Supply Chain Management. 2023. Vol. 59, No. 3. P. 112–128. [Electronic resource]. URL: <https://onlinelibrary.wiley.com/journal/1745493x> (date of reference: 10.10.2025).
- 21) Projektuvannja lancjughiv postachannja : navch. posibnyk / S.I. Ghrycenko, V.V. Matvjejev, L.V. Savchenko. NAU, 2023. 256 s. ISBN 978-966-932-195-4.

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DIGITALISATION OF LOGISTICS BUSINESS PROCESSES IN SUPPLY CHAIN MANAGEMENT AGAINST THE BACKGROUND OF GLOBAL TRENDS

Svitlana Smerichevska, Dmytro Tsymbal, Nataliia Tsymbal. *"Digitalisation of logistics business processes in supply chain management against the background of global trends". The article discusses the peculiarities of digitalisation of logistics business processes in supply chain management in the context of global transformations of the digital economy. The purpose of the study is to identify current trends in the digital transformation of logistics systems, analysis the main challenges of its implementation in a dynamic external environment, and substantiate strategic directions for improving the efficiency of digitalisation.*

The study analyses data from leading international indices of digital development (in particular, the Network Readiness Index), and makes a comparative assessment of the level of digitalisation in various sectors of the economy.

The main barriers to the digitalisation of logistics are identified, including the lack of qualified IT personnel, uncertainty about the economic efficiency of investments, cybersecurity threats and infrastructure

constraints. Practical directions for increasing the efficiency of digital transformation of logistics business processes with a view to forming perfect supply chains are proposed, in particular through the development of digital competencies, investment in innovative technologies, strengthening cyber defense and implementation of adaptive management models.

Keywords: digitalisation; digital technologies; logistics; logistics business processes; management; supply chains; digital development indices

Світлана Смерічевська, Дмитро Цимбал, Наталія Цимбал. «Цифровізація логістичних бізнес-процесів в управлінні ланцюгами постачання на тлі глобальних трендів». У статті розглянуто особливості цифровізації логістичних бізнес-процесів в управлінні ланцюгами постачання у контексті глобальних трансформацій цифрової економіки. Метою дослідження є виявлення актуальних тенденцій цифрової трансформації логістичних систем, аналіз основних викликів її впровадження в умовах динамічного зовнішнього середовища та обґрунтування стратегічних напрямів підвищення ефективності цифровізації.

У процесі дослідження проаналізовано дані провідних міжнародних індексів цифрового розвитку (зокрема *Network Readiness Index*), а також здійснено порівняльну оцінку рівня цифровізації в різних секторах економіки.

Виявлено основні бар'єри цифровізації логістики, серед яких — нестача кваліфікованих ІТ-кадрів, невизначеність економічної ефективності інвестицій, загрози кібербезпеці та інфраструктурні обмеження. Запропоновано практичні напрями підвищення ефективності цифрової трансформації логістичних бізнес-процесів з метою формування досконалих ланцюгів постачання, зокрема через розвиток цифрових компетенцій, інвестування в інноваційні технології, посилення кіберзахисту та впровадження адаптивних моделей управління.

Ключові слова: діджиталізація; цифрові технології; логістика; логістичні бізнес-процеси; управління; ланцюги постачання; індекси цифрового розвитку.

Introduction. The war in Ukraine has caused large-scale destruction of infrastructure, power outages, logistical problems, and significant migration. All of these factors have led to a decline in demand for certain goods and services due to a decrease in the purchasing power of the population and a change in consumer priorities. The Russian aggression disrupted traditional logistics routes, making it more difficult to supply raw materials and components and deliver finished products. The increase in prices for energy, raw materials and logistics services significantly increased production costs. Mobilisation, evacuation and migration resulted in a shortage of skilled personnel. The war stimulated the development of import substitution, which led to increased competition in the domestic market.

The twenty-first century is considered to be the century of technical development, built on the basis of fundamentally new industrial technologies, electronic control, computer-integrated production activities and the desire to minimise or replace human labour in production and other activities with artificial intelligence. Borders are increasingly blurred and the structure of production is changing significantly. The desire for comprehensive improvement of technological, auxiliary and information activities is increasingly becoming a key factor in the development of modern production. This means that the structure of production is changing globally on the basis of new communication and computer advances, nanotechnology and other technical solutions. In these conditions, production should be considered as a whole, including

both technological and information processes and functionally integrated production components, including logistics [1].

Logistics, as an integral part of any enterprise, is also undergoing significant transformations under the influence of the digital revolution, as the efficiency of logistics processes and the formation of perfect supply chains directly affect the competitiveness of enterprises and customer satisfaction.

In the 21-st century, logistics has evolved from a purely operational function to a strategic element of business that can determine its sustainability, adaptability and competitiveness. In the era of digital transformation, traditional logistics models are undergoing dramatic changes. Businesses are increasingly adopting digital technologies to ensure efficiency, transparency and effectiveness in their supply chains. However, alongside the new opportunities, challenges are growing in complexity, from digital skills shortages to cyber risks and uncertainty about the return on technology investments.

The digitalisation of logistics business processes goes beyond automation. It is a radical transformation of logistics architecture, business models, management decisions and customer interaction. Today, companies are implementing solutions such as artificial intelligence, blockchain, the Internet of Things (IoT), digital platforms and Big Data analytics. At the same time, the instability of the global environment, the war in Ukraine, disruption of supply chains, and energy challenges create a unique backdrop against which this digital revolution is taking place.

The relevance of this study is driven by several interrelated factors:

firstly, digitalisation is not just a trend, but a prerequisite for the survival and development of business in a globally competitive environment;

secondly, logistics, being one of the most dynamic and resource-dependent sectors, requires rapid adaptation to new digital challenges;

third, Ukraine is undergoing a strategic shift towards the digital economy, which makes logistics a key area of transformation of production and service processes;

fourth, despite the positive dynamics of digital implementation, there is a significant gap between the potential of digital tools and the actual level of their integration into logistics systems, especially at the level of small and medium-sized businesses.

Therefore, the study of current trends and challenges in the digitalisation of logistics business processes is necessary both to form the theoretical foundations of digital logistics and to develop practical recommendations that will help increase the efficiency, adaptability and sustainable development of Ukrainian companies.

Analysis of recent research and publications. In recent years, the digitalisation of logistics has become the subject of active study in both the scientific and applied environment. In numerous works, researchers emphasise that the digital transformation of logistics business processes in supply chain management is a key condition for ensuring the efficiency, flexibility and customer focus of enterprises in the context of global instability.

In particular, in the works of O. Pryhara, L. Yarosh-Dmytrenko [2] and L. Liakhovych [3], the authors analyse strategies for adapting the logistics functions of enterprises in wartime, including digital tools as a key component of crisis management. The publications of M. Hryhorak [4] and E. Krykavskiy [5] highlight the evolution of logistics management in the context of the digital economy. Their approaches focus on the integration of logistics and information flows as a prerequisite for the creation of intelligent logistics systems. In the research of S. Smerichevska [6], E. Cameron [7] and J. Horrell [8] highlight the transformational impact of the latest digital technologies (AI, Big Data, IoT, blockchain) on supply chains and logistics management. The authors draw attention to the changing role of logistics -

from a supporting function to a strategic component of the business model.

The practical aspect of the digital transformation of logistics is revealed in the works of S. Filippova and O. Malin [9], who focus on the impact of digitalisation on the competitiveness and adaptability of enterprises in a turbulent market. The authors analyse the barriers to digitalisation, including limited resources, lack of digital culture and shortage of IT personnel. Publications of international organisations such as the Portulans Institute, World Economic Forum, IMD systematise key indicators of digital readiness, including the Network Readiness Index (NRI), Global Connectivity Index (GCI), Digital Competitiveness Ranking, etc. Analytical reports indicate that a high level of digital maturity in logistics is directly correlated with investment attractiveness, innovation and business flexibility.

At the same time, most existing studies focus either on general aspects of digitalisation or on specific technological solutions without a comprehensive analysis of current trends, barriers and systemic challenges that accompany the digital transformation of logistics processes. It is this gap that determines the relevance of further research in this area.

The aim of the study is to identify current trends in the digitalisation of logistics business processes in supply chain management, analysis the main challenges of its implementation in a turbulent environment, and substantiate ways to improve the efficiency of digital transformation of logistics systems.

The object of research is the logistics business processes of enterprises in the modern global environment.

The subject of the study is modern approaches to the digitalisation of logistics business processes, their impact on the formation of perfect supply chains and ways

to improve the effectiveness of digital transformation in a turbulent environment.

The research methodology is based on the developments of domestic and foreign scientists on the problems of logistics process management. To fulfil the research objectives and achieve the set goal, the following general scientific and special research methods were used: *abstract and logical* - to summarise scientific and methodological approaches to logistics process management; *economic and statistical* - to analyse the impact of modern digital technologies (blockchain, artificial intelligence, IoT, etc.) on the state of market digitalisation; *systematic and comparative* - to determine the main directions for assessing the efficiency of logistics processes.

Main material and results. Recent years have been an unprecedented challenge for Ukrainian business. The combination of a full-scale war and the global COVID-19 pandemic, quarantine restrictions, the transition to remote work, and changing consumer habits have created a unique complex challenge that has forced businesses to adapt to new realities and look for innovative solutions.

However, despite the challenging environment, many Ukrainian businesses have demonstrated incredible resilience and adaptability. Among the strategies that have allowed businesses to survive and grow, the main ones are shown in Table 1.

In the context of globalisation processes that cover the economic, social and cultural spheres, digitalisation is becoming a key driver of innovative economic development. Ukraine is actively joining the global trends of digital transformation. The use of digital technologies for the Ukrainian economy is a promising way of innovative growth, even in difficult conditions caused by crises, including military challenges.

Table 1. Key characteristics of business survival and development strategies

Strategy	Essence	Advantages
Diversification of activities	Expanding the range of products/services, searching for new markets, adopting new technologies	Reducing dependence on one area, increasing revenues, increasing resilience to crises
Digital transformation	Implementation of digital technologies in business processes	Automation, cost optimisation, improved customer experience, increased efficiency
Support for local producers	Cooperation with Ukrainian suppliers	Reducing dependence on imports, supporting the domestic economy, and ensuring stable supply
Development of online sales	Creation of online stores and marketplaces	Expanding sales geography, access to a larger audience, reducing rental costs
Cost optimisation	Reducing rental, marketing and administrative costs	Increase profitability, improve competitiveness
Search for new sources of funding	Attracting investments, using government programmes	Ensuring financial stability, expanding opportunities for development
Cooperation with other companies	Joining forces to solve problems together	Sharing experience, expanding network of contacts, sharing resources
Support for employees	Creating favourable working conditions, providing psychological support	Retaining and attracting talent, increasing employee loyalty, increasing productivity

Source: compiled on the basis of [2, 3, 10].

In the context of globalisation processes that cover the economic, social and cultural spheres, digitalisation is becoming a key driver of innovative economic development. Ukraine is actively joining the global trends of digital transformation. The use of digital technologies for the Ukrainian economy is a promising way of innovative growth, even in difficult conditions caused by crises, including military challenges.

Globalization promotes the active exchange of information, ideas, culture and technology, which forms a single global community. It encompasses economic, political, social and cultural aspects, creating new opportunities for entrepreneurship, market development, and the dissemination of knowledge and technology. At the same time, globalization poses challenges for countries related to competition, inequality and preservation of cultural identity [8].

In recent decades, digital technologies have become a driving force for the development of society and the global economy, causing dramatic changes in socio-economic processes through their digitalization. The areas and degree of digitalization have changed, affecting not

only global and local socio-economic processes, but also digital technologies themselves, moving from digitisation to digitalisation [9].

Today, we often hear the words "digitisation", "digitalisation", "digital state" and "digital transformation" in the media and in everyday life. Although they sound similar, their meanings differ.

At the same time, similar terms such as "digitalization", "digital transformation", as well as "digitization" are often confused, which leads to their incorrect use. It is worth considering two of the closest concepts: "digitization" and "digitalization".

"Digitization" refers to the process of converting analogue information (e.g. paper documents) into a digital, machine-readable format. In the 1990s, the term "digitization" was used to refer to the preparation, conversion and archiving of analogue documents into digital form. In other words, digitization is the transfer of information into digital form. A more technological definition: digital transmission of data encoded into discrete signal pulses [11].

At the same time, digitization is only the first stage of digitalization, which is a much

broader and more complex process. As Professor V. S. Kuibida noted: "Digital technologies require digital information, and digitisation is merely the process of converting information into a digital format. However, for digital transformations, data digitization alone is not enough" [12].

If digitization involves the conversion of data into a digital format, then digitalization is

a radical change in all processes related to the use of this data. It is like moving from manual calculations to using a calculator, or like moving from a library with books to an electronic library where you can search for the information you need instantly - not just by changing the tool, but also the way you work. Table 2 provides a description and examples of these processes.

Table 2. The essence of the concepts of "digitisation" and "digitalisation"

Concept	Description	Example	Differences
Digitisation	Converting analogue information into digital form.	Scanning documents, converting an audio recording into an MP3 file.	Focuses on the form of data
Digitalisation	Global change of processes with the help of digital technologies.	Transitioning a company to a CRM system, creating an online store.	Focuses on processes and business models

Source: compiled on the basis of [9, 11, 12].

The transition from digitisation to digitalisation is the essence of the recent

digital revolution, which takes place in four stages (Table 3).

Table 3. Main stages of the digital revolution

Stage, period	Characteristics	Consequences
1. The first stage: 1990-2000.	Web 1.0: informatisation of websites – filling them with information content. Digitisation.	Creation of an information infrastructure to provide online access to information.
2. The second stage: 2000-2010.	Web 2.0: active involvement of users in the creation and accumulation of data. Digitisation.	Emergence of a new subject of the information process.
3. The third stage: 2010-2020.	Web 3.0: technological network changes to reduce the time of information provision. Digitalisation.	Development of social networks and instant messaging applications. Significant intensification of the use of the human neural network.
4. Fourth stage: from 2020.	Web 4.0: the use of artificial intelligence and neurocommunication to build communication between people, animals and things. Digitalisation.	Building artificial networks (building Neural Networks), Internet of Things.

Source: [9]

The rapid development of digital technologies is dramatically changing our lives. Thanks to digitalisation, we can communicate instantly; quickly access the information we need; receive online services (banking, utility bills, etc.) without leaving home; buy goods; study remotely, choosing a convenient time, level, pace, place without being tied to where we are; create new products and services; solve complex problems, etc.

Taking into account the Generational Theory created by American scientists N.

Howe and W. Strauss in 1991, Generation Z (born in 2003-2023), born in the era of the Internet and smartphones, has unique skills and values and will be the first fully "digital" generation, freely using virtual space and having a virtual mindset. Members of this generation are fluent in virtual space and naturally use digital tools. These features allow them to shape new trends in various areas of life, from entertainment to politics. In the future, Generation Z will become the main driver of the digital economy, which will be

focused on meeting their needs and expectations [13].

Digitalisation is the process of transition from traditional analogue methods to the use of modern digital technologies, systems and tools. It is being implemented in various industries, including business, education, medicine, public administration, and others. Digitalisation allows you to automate processes, optimise costs, improve the quality of services, improve communication and provide access to information.

Digitalisation makes resources more efficient, processes faster, and opportunities for development and innovation broader. It is changing the way organisations and society function, driving the transition to a digital economy and a digital society.

In the context of globalisation, digitalisation of the economy is a tool for transforming economic systems and their infrastructures. Its implementation is aimed at increasing productivity, efficiency and competitiveness. In an interdependent world, digitalisation opens up new ways for businesses and countries to optimise resources, improve production processes, introduce innovations and enter new markets.

The key elements of the digital infrastructure, described by their functions and impact, are presented in Table 4, which demonstrates the interconnection of the main components of digitalisation and their practical application.

Table 4. Elements of digital infrastructure, their description and examples

Element	Description	Examples
Digital technologies	The use of innovative tools such as AI, IoT, blockchain and cloud computing to automate business, analyse data and production processes.	Implementing blockchain for transparent financial transactions; using AI to optimise production.
Digital platforms	Platforms that enable interaction between market participants (buyers, sellers, suppliers) for trade, financial transactions and logistics.	Amazon as a global trading platform; using Uber as an example of a digital service.
E-commerce	Conducting trade operations via the Internet, including buying, selling and business interaction with consumers and partners.	Integration of CRM systems to improve the customer experience; Shopify to manage online stores.
Analytics and big data	Collecting and analysing large volumes of data to identify trends, optimise processes, and conduct strategic planning.	Use AI to analyse consumer habits; Google Analytics to monitor online activity.
Cloud technologies	Data storage and access to resources through cloud computing, which reduces IT infrastructure costs.	Using AWS to deploy IT infrastructure; SaaS solutions such as Microsoft Office 365.
Internet of Things (IoT).	Connecting physical devices to the Internet to automate processes, monitor and improve efficiency.	Smart meters to monitor energy consumption; smart cities with IoT integration.
Cybersecurity	Protecting data and digital infrastructures from threats in cyberspace.	Implementation of two-factor authentication; use of anti-virus software.

Source: generalised based on [14, 15]

Logistics, as one of the most dynamic sectors, is the first to experience both the opportunities and challenges of digitalisation. The rapid development of technologies - from artificial intelligence to the Internet of Things (IoT), from cloud solutions to blockchain - is fundamentally changing approaches to managing logistics business processes,

opening up new horizons of efficiency, flexibility and transparency.

Despite the impact of hostilities, Ukraine is actively seeking to integrate into global digital trends. The use of digital technologies in the logistics sector is seen not only as a response to current challenges, but also as a chance to build more sustainable, adaptive and competitive business models.

This is especially true in the context of disrupted supply chains, changing consumer expectations and rising costs of logistics services.

At the same time, the digitalisation of logistics is not just a technical upgrade of processes, but a comprehensive transformation of management strategies, business architecture and interaction between supply chain participants. There is a gradual shift from traditional logistics to smart logistics, which is based on the integrated use of data, algorithms and digital platforms.

This process of digital evolution is inextricably linked to the overall context of globalisation. Global networks create new opportunities for the exchange of information, technology and innovation, as well as challenges related to cybersecurity, regulatory uncertainty and technological inequality. In this context, it is important to adapt logistics systems to new market requirements, which involves not only digitisation but also a deep digital transformation of logistics business processes in supply chains.

In the current environment of globalisation and technological breakthroughs, supply chains are undergoing

a large-scale transformation under the influence of digital technologies. The digitalisation of logistics business processes is becoming a key factor in improving the efficiency of supply chain management, optimising costs, increasing transparency and speeding up customer service. The successful implementation of digital solutions in the logistics activities of enterprises is closely linked to the overall level of development of the digital infrastructure and IT sector in the country, which, in turn, is reflected in global digital indices.

The assessment of the level of digital readiness of different countries is based on a number of reputable international rankings and indices that help determine the potential for digital transformation of logistics systems. These indices include: Network Readiness Index (NRI), Global Connectivity Index (GCI), 3I-Index (3I-Index), Digital Competitiveness Index (WDCR), Global Cybersecurity Index (GCSI), National Cybersecurity Index (NCSI), Global Innovation Index (GII) and Global Knowledge Index (GKI). They allow not only to compare the level of digital maturity between countries, but also to form a strategic vision for the development of digital logistics infrastructures (Table 5).

Table 5. International indicators for assessing the level of digitalisation

Indicators	Organisations conducting the assessment
Network Readiness Index (NRI)	World Economic Forum, INSEAD
Global Connectivity Index (GCI)	Huawei
The Inclusive Internet Index (3I-index)	Analytical division of the British magazine "The Economist"
IMD World Digital Competitiveness Ranking (WDCR)	IMD Research Centre in Switzerland
Global Cybersecurity Index (GCSI)	ITU Global Cybersecurity Agenda (GCA)
National Cyber Security Index (NCSI)	Academy of e-Governance Tallinn, Estonia
Global Innovation Index (GII)	INSEAD International Business School, Cornell University and the World Intellectual Property Organisation (WIPO)
Global Knowledge Index (GKI)	United Nations Development Programme (UNDP) and Mohammed bin Rashid Al Maktoum Knowledge Foundation (MBRF)

Source: compiled on the basis of [15].

Thus, the study of these indices in the context of the digitalisation of logistics business processes allows identifying key

global trends, assessing challenges and opportunities, and substantiating ways to improve the efficiency of digital

transformation of logistics systems and supply chains in the turbulent environment of the modern market.

With a strong IT sector, talented professionals and open access to global markets, Ukraine has a unique opportunity to become a leader in digital transformation in the region.

Digitalisation of all sectors of the economy opens up new opportunities for Ukraine, including:

- expanding citizens' access to convenient and high-quality electronic services;

- simplification of business processes, which contributes to the development of entrepreneurship;

- increasing the country's attractiveness to investors;

- creating effective mechanisms of interaction between government agencies, citizens and business;

- improving the productivity and competitiveness of enterprises;

- stimulating innovation and the introduction of modern technologies in various sectors of the economy.

Active digitalisation also contributes to Ukraine's integration into the global digital economy, creating new opportunities for economic growth and strengthening its position in the international arena.

Let's take a closer look at the Network Readiness Index (NRI), which is a powerful tool for assessing a country's digital development and readiness to use information and communication technologies (ICTs) for economic growth and social development around the world. The NRI Index is developed and published by the Portulans Institute, a non-profit organisation. This organisation specialises in research on innovation, competitiveness and technology. Until 2019, this index was developed and published as part of the World Economic Forum's Global Information Technology Report in cooperation with the INSEAD Institute. In 2019, the rights to publish the index were transferred to the Portulans Institute. The Portulans Institute uses modern

methodologies, including data from international organisations such as the World Bank and the International Telecommunication Union (ITU), as well as its own research. The reports they publish analyse the level of readiness of countries for the digital economy and offer recommendations for further development.

Ukraine holds an average position in the NRI ranking. Although our country demonstrates significant potential in the ICT sector due to its developed IT industry and talented professionals, there are still many areas that need to be improved.

In recent years, Ukraine has shown positive dynamics in NRI indicators due to reform efforts, digitalisation of public services (e.g. Diia platform, Electronic Citizen's Office, eBaby programme) and support for the IT sector. This creates conditions for improving our country's position in the ranking in the future.

The dynamics of Ukraine's position in the NRI index for the period 2002-2024 is shown in Figure 1.

Analysing the above data, it can be noted that in the period 2002-2010, Ukraine occupied positions in the range of 62-75 places, which indicates a relatively stable level of readiness for digital technologies in this period. We can observe a significant deterioration in 2014. The decline to 81st place may be due to economic and political challenges in the country, in particular the crisis that affected investments in the digital sphere. The country's position has been gradually improving since 2015. This may be the result of reforms in digitalisation, support for the IT sector, and the development of e-government. A significant breakthrough can be seen in 2021-2024, when Ukraine rose from 64th place (2020) to 43rd place (2023-2024). This demonstrates significant achievements in the implementation of digital technologies, such as the development of the Diia platform, as well as improved infrastructure and the growing role of the IT industry. For further growth, there is a need to focus on expanding access to digital infrastructure in the regions,

investing in innovation, and improving the level of digital education of the population.

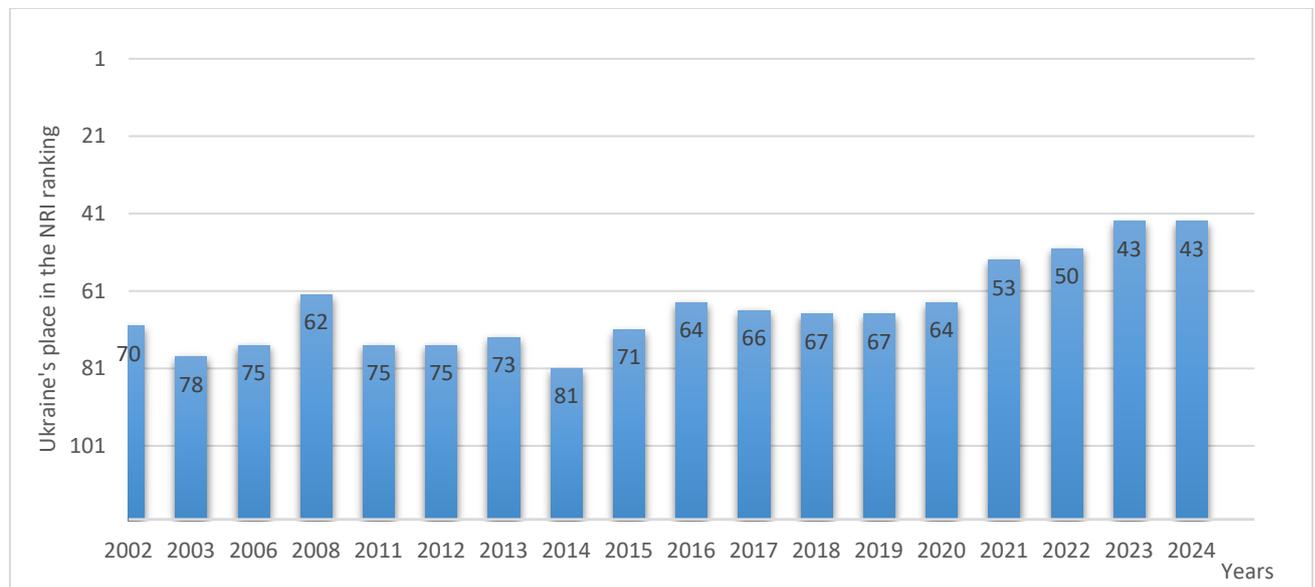


Figure 1 – Dynamics of Ukraine's position in the NRI index for the period 2002-2024.

Source: based on [16 - 26].

Digitalisation is firmly established in the long-term strategies of Ukrainian companies: 99% of respondents mentioned it as part of their strategic vision, and 96% actively monitor the effectiveness of the digital technologies they have already implemented. The most important results of digitalisation for business are the indicators of reducing operating costs (76%) and attracting/retaining customers (68%) [27].

The use of advanced technologies, such as artificial intelligence and machine learning, reveals interesting patterns of staff engagement in digitalisation: companies that use these technologies are less likely to have high staff engagement (4%), but are also more likely to have specialised technical teams (69%). In contrast, companies that do not use such technologies still have high employee engagement (35%), but the lack of specialised teams can pose challenges. The data shows that companies that rely on sophisticated

technical solutions focus on forming highly specialised expert groups to ensure that digital transformation is implemented at the strategic level.

Among the priority areas of digitalisation, Ukrainian companies highlight improving operational efficiency (76%) and increasing sales with an expanding customer base (63%). At the same time, the creation of integrated systems with partners and alliances remains on the periphery of attention (7%). Small and medium-sized manufacturing companies in particular focus on improving business models and turning risks into opportunities (75% and 67%, respectively), while large service companies additionally rely on developing their own innovative products (61%) [30].

The focus of future implementations is on artificial intelligence (94%) and cloud services for software integration and collaboration (71% each) (Fig. 2).

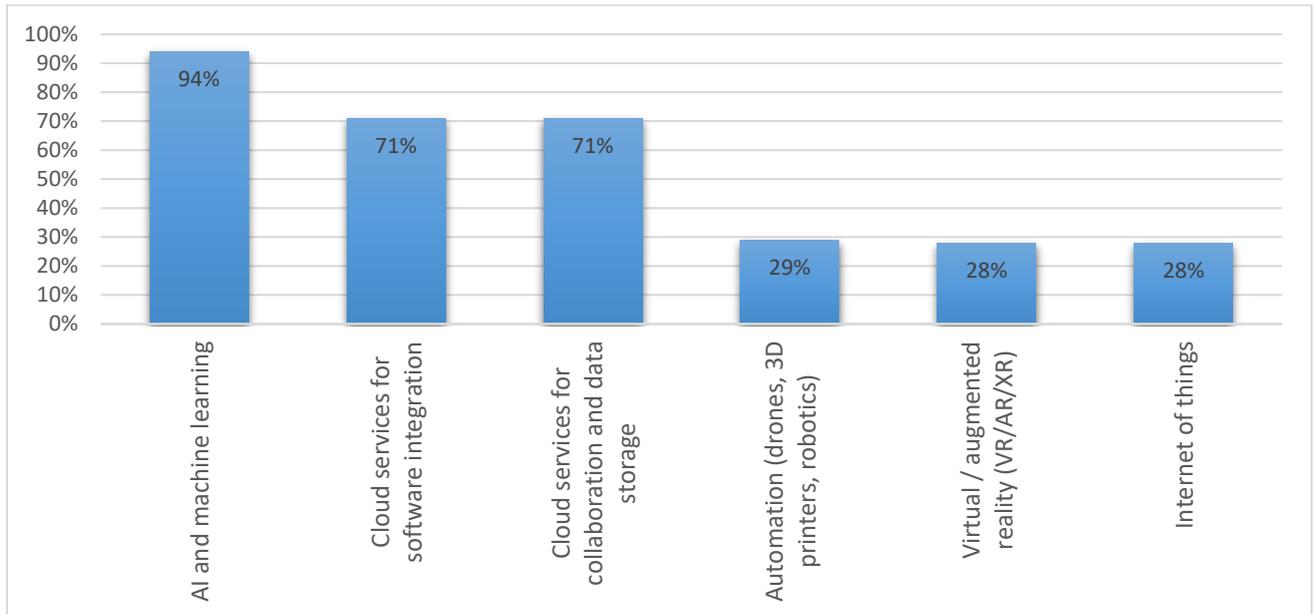


Figure 2 – Plans of the surveyed companies to implement IT technologies over the next two years

Source: based on [27].

Almost all of the surveyed companies (91% of manufacturing and 97% of service companies) plan to introduce AI and machine learning technologies. In addition, every third company surveyed plans to introduce more specialised technologies such as robotics, 3D printers, AR/VR/XR, and IoT.

According to KPMG research [27], the priority areas for further digitalisation of logistics business processes are improving operational efficiency (74%), increasing sales and expanding the customer base (63%), and others, as shown in Figure 3.

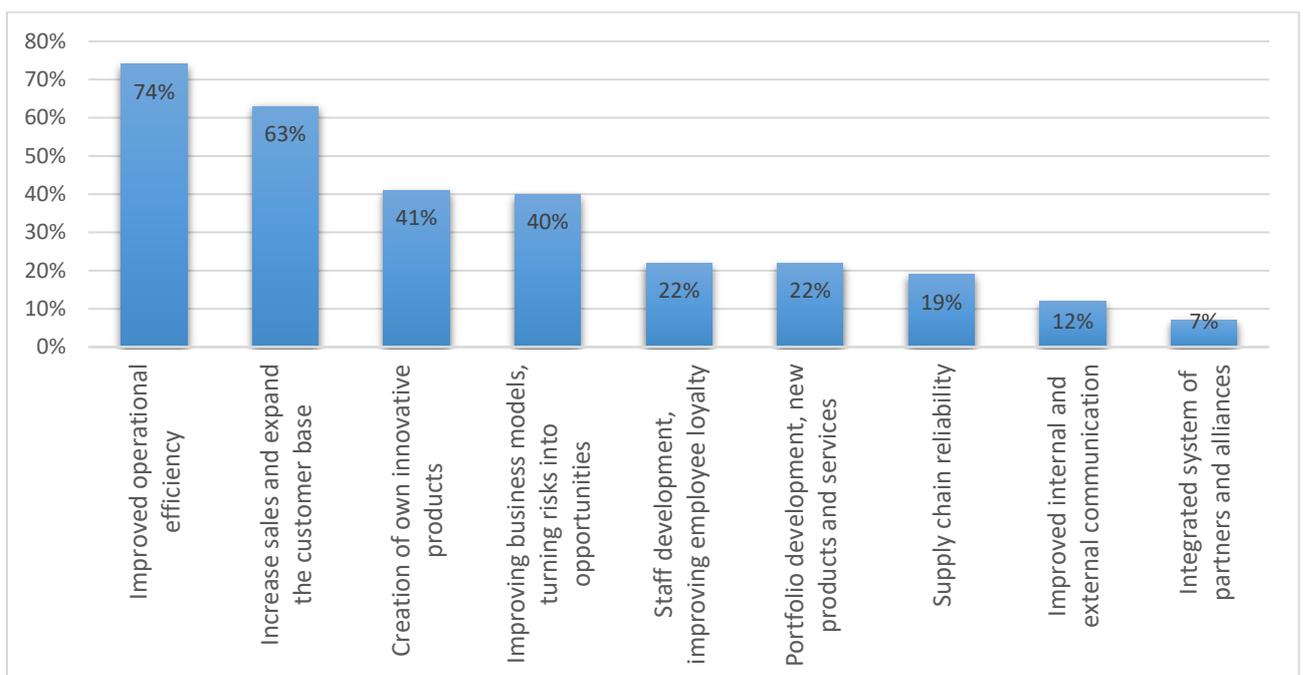


Figure 3 – Priority areas for further digitalisation

Source: based on [27].

However, the path to digital business transformation is hampered by many challenges. In particular, the lack of qualified IT specialists (49%) and uncertainty about the return on investment (46%) are the biggest obstacles to this process. Another significant challenge is the reluctance to disrupt the usual model of work (34%), i.e. resistance of

employees and managers to innovations and the allocation of all resources to support the current business (34%), as there is not enough time or money for development. Another key challenge is the threat of cybersecurity (32%), namely the fear of hacker attacks or data leakage after digitalisation (Figure 4).

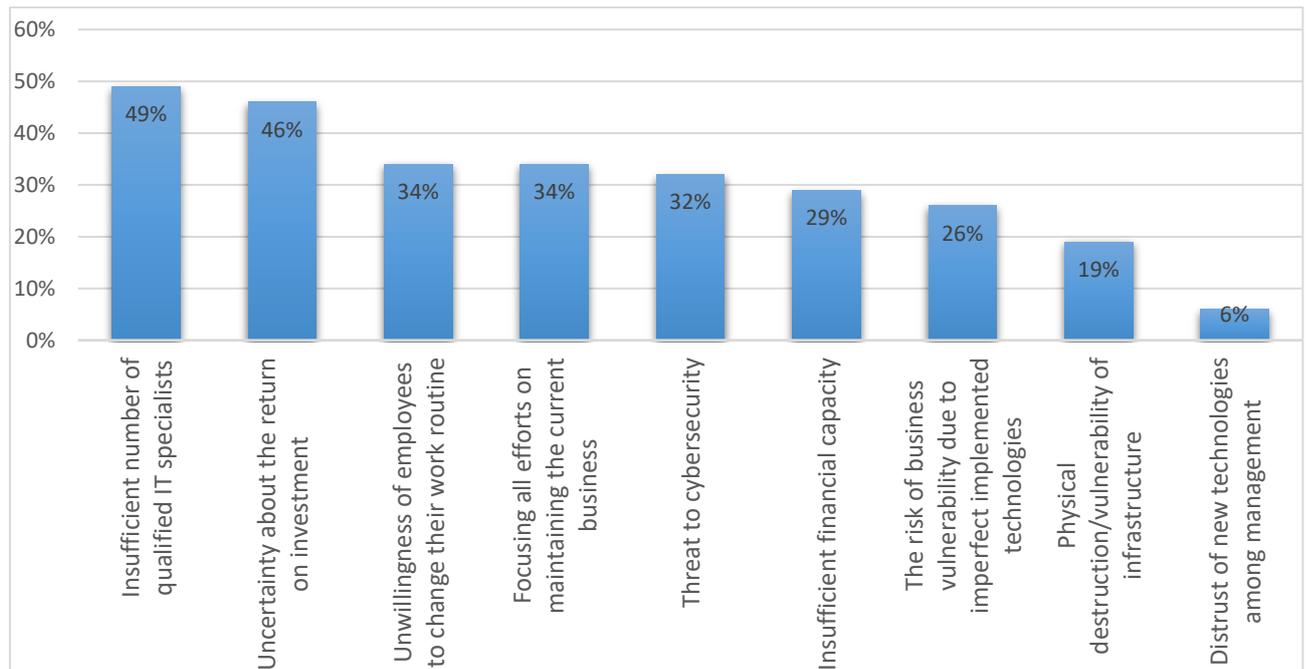


Figure 4 – Challenges that slow down digital transformation the most

Source: based on [27].

Despite all the challenges, companies continue to integrate digital technologies into their supply chain management business processes. The leader in digitalisation among business processes is core operations in both manufacturing and service businesses (46%). This is the highest share of digitalisation in both sectors, which indicates the priority of automation and digital solutions in core business processes. The level of digitalisation is also high in the IT sector: manufacturing - 38%, services - 44%, and sales management: 41% in both sectors. These areas in both sectors also demonstrate active digital transformation. The average level of digitalisation in finance and marketing: finance 35% in both sectors; marketing:

manufacturing 28%, services 40%. Marketing in service businesses is more digitised, likely due to greater contact with online customers. The lowest adoption of digital technologies can be observed in human resources management: manufacturing - 29%, services - 34%; supply chain management: manufacturing - 32%, services - 26%. These areas remain less digitised, which indicates the complexity or slowdown of transformation in human resources and logistics.

Figure 5 shows a diagram that demonstrates which business processes have been digitised over the past 2 years, broken down by manufacturing and service businesses.

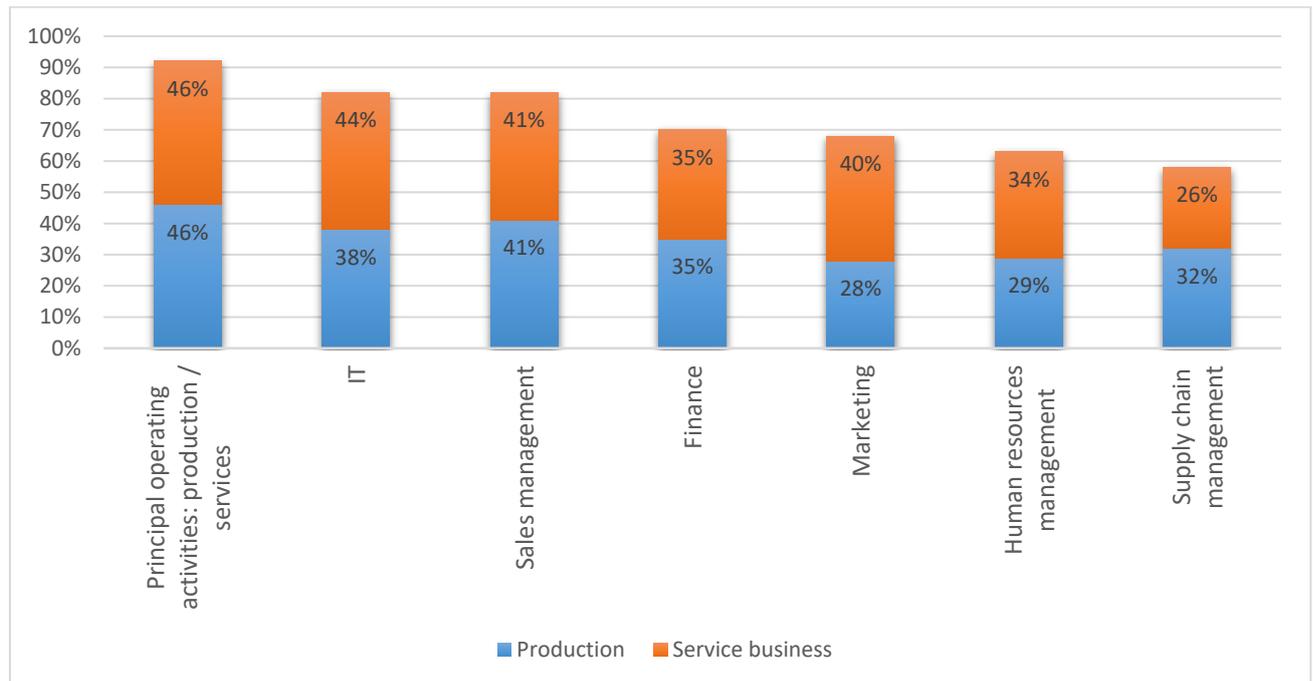


Figure 5 – Business processes in which digital technologies were introduced in 2023-2024
Source: based on [27].

Both manufacturing and service sectors are most actively implementing digital technologies in their core business. Service companies invest more in digitalising marketing, while manufacturing companies invest more in supply chain management. Human resources and logistics remain the "weak links" in digital transformation.

Let's take a closer look at the digitalisation index, which reflects the level of digital development of economic sectors and allows us to assess how actively digital technologies are used to improve the efficiency, innovation and competitiveness of supply chains.

The highest digitalisation index is observed in the service business. In particular, IT and telecommunications - 65%, and trade - 61%. These industries are leaders in the implementation of digital solutions, which is to be expected: they have a high level of digitalisation, process automation, and active contact with the end consumer through digital channels.

A high and stable level of digitalisation in both sectors can be seen in construction, oil and gas, transport and logistics, finance and insurance, and food and tobacco production - 56-59%.

These industries demonstrate the active implementation of digital solutions in both manufacturing and service companies. For example, digital logistics or automated financial planning have already become standard in many organisations.

Industries with a lower level of digitalisation are concentrated in manufacturing. In particular, mining and metallurgy - 50 per cent, agriculture - 50 per cent, energy - 48 per cent, and pharmaceuticals - 47 per cent. Manufacturing industries with significant tangible assets, often with complex infrastructure, are the slowest to adopt digital technologies. This is due to the high cost of modernisation, conservative management or the difficulty of adapting new solutions.

The average digitalisation index by economic sector is shown in Figure 6.

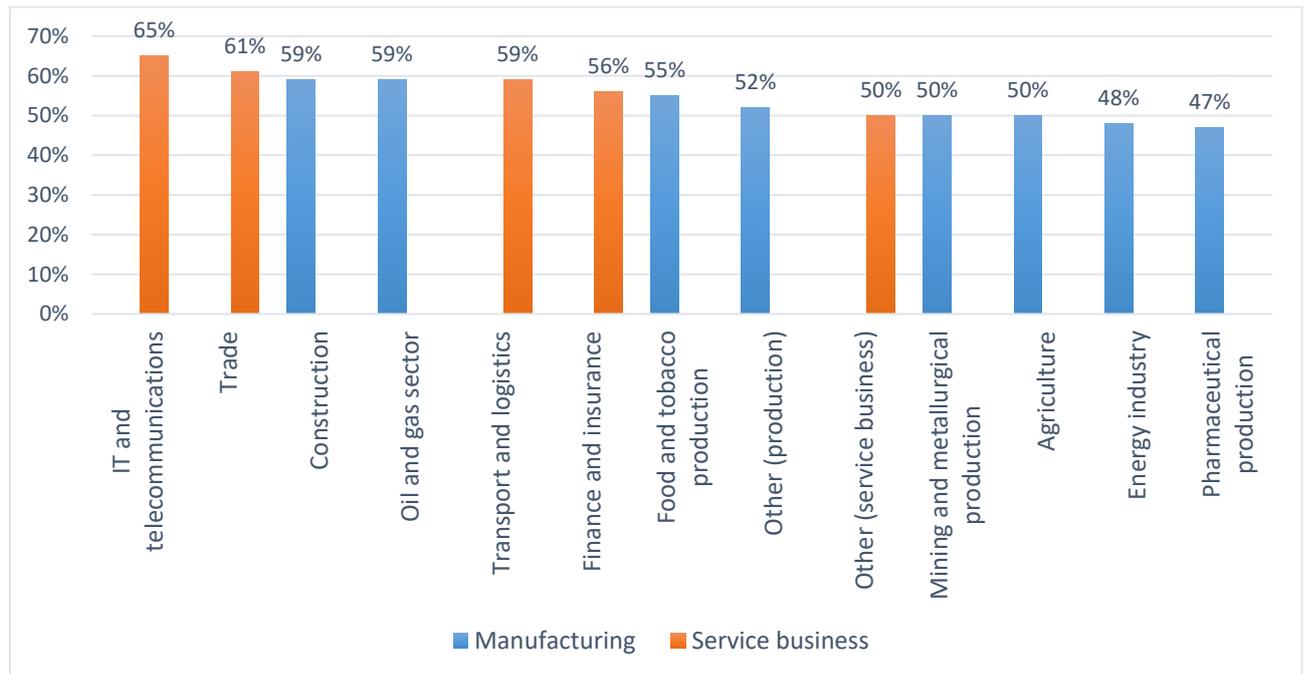


Figure 6 – Average digitalisation index by industry

Source: based on [27].

Service industries are leading the way in digitalisation, in particular those operating in communications, trade, and finance. Manufacturing companies demonstrate a somewhat slower pace of digital transformation, especially in the energy, pharmaceuticals, and agriculture sectors. Many traditional industries still have significant potential for digital development, which could become a key competitive advantage in the future.

The digitalisation of logistics business processes in supply chain management is a crucial factor in increasing the competitiveness of enterprises in today's globalised and turbulent environment. It provides flexibility, transparency, and efficiency in resource management and facilitates the integration of logistics into digital supply chains.

Conclusions. The results of the study indicate an uneven level of digitalisation in different sectors of the economy. The highest rates are observed in IT, telecommunications, trade, transport, and finance. Meanwhile, in manufacturing industries, such as energy, agriculture, and pharmaceuticals, digital transformation is slower to take place due to

limited resources, process complexity, and institutional barriers.

A comparative analysis shows that service businesses demonstrate a higher level of digital adoption than manufacturing businesses. This is due to the need to respond quickly to changing consumer demands, the high level of digital communication with customers, and the rapid adaptation of business models to digital realities.

The main barriers to the digitalisation of logistics processes include a shortage of skilled IT personnel, lack of guarantees of return on investment, cybersecurity threats, resistance to organisational change, and insufficient development of digital infrastructure. These factors significantly constrain the speed and scale of digital transformation.

Index-based assessments of digital development (such as the Network Readiness Index, Global Connectivity Index, IMD Digital Competitiveness Ranking, Global Innovation Index, etc.) are an important analytical tool for comparative analysis and strategy development for the digitalisation of logistics systems on a global scale.

To ensure an effective digital transformation of logistics business processes, it is advisable to focus on the development of digital competencies of personnel, attracting investments in

innovative technologies, creating a secure digital infrastructure, as well as implementing adaptive management models that take into account the challenges of the digital economy.

References

1. Study of the level of digitalization of logistics activities in small and medium-sized enterprises in the North-East Region. Retrieved March 21, 2025, from <https://www.academia.edu/107269562/>
2. Prygara, O., & Yarosh-Dmytrenko, L. (2023). Stratehii adaptatsii biznesu v turbulentnomu rynkovomu seredovyschi pid chas viiny v Ukraini [Business adaptation strategies in a turbulent market environment during the war in Ukraine]. *Visnyk Kyivskoho natsionalnoho universytetu imeni Tarasa Shevchenka. Ekonomika*, 2(223), 108–114. <https://doi.org/10.17721/1728-2667.2023/223-2/14>
3. Liakhovych, L. (2022). Stratehichna povedinka kompanii v umovakh viiny ta povoiennoho vidnovlennia [Strategic behavior of companies in conditions of war and post-war recovery]. *Ekonomichnyi prostir*, (180), 139–143. <https://doi.org/10.32782/2224-6282/180-22>
4. Hryhorak, M. Yu. (2017). Intelektualizatsiia rynku lohistychnykh posluh: kontseptsii, metodolohiia, kompetentnist [Intellectualization of the logistics services market: concept, methodology, competence]. Kyiv: Sik Hrupa Ukraina.
5. Krykavskiy, Ye. V. (2004). Lohistyka. Osnovy teorii [Logistics. Fundamentals of theory]. Lviv: Vydavnytstvo Natsionalnoho universytetu "Lvivska politekhnika".
6. Smerichevska, S. V., Prodanova, V. V., & Yakushev, O. V. (2024). Digitization of logistics and supply chain management. *Intellectualization of Logistics and Supply Chain Management*, (26), 113–123. <https://doi.org/10.46783/smart-scm/2024-26-9>
7. Cameron, E., & Green, M. (2015). *Making sense of change management: A complete guide to the models, tools and techniques of organizational change* (4th ed.). London: Kogan Page Publishers.
8. Hazen, D., Horrell, J., & Merrill-Oldham, J. (1998). Selecting research collections for digitization. *Proceedings of the Council on Library and Information Resources*. Retrieved from <https://www.clir.org/pubs/reports/hazen/pub74/>
9. Fylyppova, S. V., & Malin, O. L. (2020). Sutnist ta vyklyky tsyfrovizatsii ekonomiky dlia derzhavno-pryvatnoho partnerstva [The essence and challenges of digitalization of the economy for public-private partnership]. *Ekonomichnyi zhurnal Odeskoho politekhnichnoho universytetu*, 3(13), 55–63. <https://economics.opu.ua/ejopu/2020/No3/55.pdf>
10. Tendentsii ta perspektyvy rozvytku ekonomiky Ukrainy v umovakh suchasnykh vyklykiv [Trends and prospects for the development of Ukraine's economy under modern challenges]. (2024). *Proceedings of the 16th All-Ukrainian Scientific and Practical Conference*, April 18–19, 2024, Cherkasy. Cherkasy: ChDBK.
11. Mikhrovska, M. S. (2021). Tsyfrova terminolohiia v publichnomu upravlinni: vid otsyfrovuvannia do tsyfrovoho uriaduvannia [Digital terminology in public administration: from

digitization to digital governance]. *Yurydychnyi naukovyi elektronnyi zhurnal*, (6), 142–144.
http://www.lsej.org.ua/6_2021/40.pdf

12. Kuibida, V. S., Karpenko, O. V., & Namestnik, V. V. (2018). Tsyfrove vriaduvannia v Ukraini: bazovi definitsii poniatiino-katehorialnoho aparatu [Digital governance in Ukraine: basic definitions of conceptual and categorical apparatus]. *Visnyk Natsionalnoi akademii derzhavnoho upravlinnia pry Prezydentovi Ukrainy*, (1), 5–10.

13. Bodaratskyi, B. A., & Obikhod, S. V. (2023). Didzhitalizatsiia ekonomiky Ukrainy v umovakh hlobalizatsii [Digitalization of Ukraine's economy in the context of globalization]. *Proceedings of the All-Ukrainian Scientific and Practical Online Conference of Higher Education Applicants and Young Scientists*, May 15–19, 2023, Zhytomyr. Zhytomyr: Zhytomyrska Politekhnikha, 308–309.

14. Matsyshyna, O., & Smerichevska, S. V. (2022). Intehrovanyi pidkhid do stratehichnoho upravlinnia lantsiuhamy postachannia v umovakh tsyfrovoi ekonomiky [An integrated approach to strategic supply chain management in the digital economy]. *Business, Innovation Management: Problems and Prospects*, *Proceedings of the 3rd International Scientific and Practical Conference*, December 8, 2022, Kyiv: KPI im. Ihoria Sikorskoho, 78–79.
<http://confmanagement.kpi.ua/proc/article/view/271608>

15. Khaustova, V. Ye., Reshetnyak, O. I., Khaustov, M. M., & Zinchenko, V. A. (2022). Analiz rozvytku IKT-sfery v Ukraini za mizhnarodnymy indeksamy ta reitynhamy [Analysis of ICT sector development in Ukraine according to international indices and ratings]. *BiznesInform*, (5), 40–56.

16. NRI: Country Profile. Ukraine. Retrieved February 15, 2025, from <https://networkreadinessindex.org/country/ukraine/>

17. The Global Information Technology Report 2002–2003. (2003). New York, Oxford: Oxford University Press. Retrieved March 12, 2025, from <http://citeseerx.ist.psu.edu/viewdoc/download?>

18. The Global Information Technology Report 2003–2004. (2004). New York, Oxford: Oxford University Press. Retrieved March 12, 2025, from https://www.infodev.org/infodev-files/resource/InfodevDocuments_15.pdf

19. The Global Information Technology Report 2005–2006. Retrieved March 12, 2025, from <https://afyonluoglu.org/PublicWebFiles/>

20. The Global Information Technology Report 2016: Innovating in the Digital Economy. (2016). Geneva: World Economic Forum and INSEAD. Retrieved February 7, 2025, from <https://www3.weforum.org/docs/GITR2016/>

21. The Network Readiness Index 2019: Towards a Future-Ready Society. (2019). Washington, D. C.: Portulans Institute. Retrieved July 28, 2025, from <https://download.networkreadinessindex.org/reports/data/2019/nri-2019.pdf>

22. Network Readiness Index 2020: Digital Transformation at a Glance. (2021). Retrieved February 7, 2025, from <https://knoema.com/infographics/ljsicg/network-readiness-index>

23. Network Readiness Index 2021: Benchmarking the Future of the Network Economy. Retrieved February 18, 2025, from <https://networkreadinessindex.org>

24. Network Readiness Index 2022: Stepping into the New Digital Era. Retrieved February 18, 2025, from <https://portulansinstitute.org/wp-content/uploads/>

25. Network Readiness Index 2023: Trust in a Network Society: A Crisis of the Digital Age?. Retrieved March 13, 2025, from <https://portulansinstitute.org/wp-content/uploads/>

26. Network Readiness Index 2024: Building a Digital Tomorrow: Public-Private Partnerships for Digital Readiness. Retrieved March 13, 2025, from <https://portulansinstitute.org/wp-content/>

27. Chempiony didzhitalizatsii 2024 [Champions of Digitalization 2024]. Retrieved March 28, 2025, from <https://kpmg.com/ua/uk/home/insights/>

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INTEGRATION OF ARTIFICIAL INTELLIGENCE AND ELECTRONIC DOCUMENT MANAGEMENT IN LOGISTICS: COMPARATIVE ANALYSIS OF UKRAINE, EUROPE, AND THE USA

Oksana Pozniak, Natalia Kharakhash, Irina Suvorova. «*Integration of Artificial Intelligence and Electronic Document Management in Logistics: Comparative Analysis of Ukraine, Europe, and the USA*». The article examines the role and effectiveness of integrating artificial intelligence and electronic document management in logistics, with an emphasis on its strategic function of ensuring speed, reliability, and global connectivity in multimodal supply chains. The integration of artificial intelligence (AI) into electronic document management (EDM) systems represents a key stage in the digital transformation of logistics. Over the past five years, the logistics sector in Europe and the United States has shifted from traditional digital archiving toward intelligent automation and predictive data management. The study aims to examine the interaction between AI technologies and EDM solutions in logistics and to compare the technological, regulatory, and organizational approaches of Ukraine, the European Union, and the United States. The research applies a comparative and

analytical methodology based on official EU and OECD reports, KPMG and ACCA industry analyses, and Ukrainian digitalization frameworks. The results demonstrate that in Europe, the integration of AI and EDM is strongly influenced by the EU Artificial Intelligence Act (Regulation 2024/1689), which establishes a risk-based approach to AI governance. In the United States, innovation is driven by private investment and sectoral standards, while Ukraine is still at an early stage of AI adoption, facing infrastructure and regulatory challenges. The findings confirm that AI enhances the efficiency, traceability, and compliance of logistics document flows, automates reporting and verification, and supports strategic decision-making. The article identifies the main barriers to implementation — technical barriers, regulatory barriers, and personnel and organizational barriers that lead to technological fragmentation, data interoperability issues, and skills shortages. Special attention is paid to comparing regulatory barriers to implementing AI-generated documents in Europe, the USA, and Ukraine, which provides an opportunity to adapt legislation not only to national requirements, but also to take into account the experience of best legislative practices. Proposes a conceptual model for harmonizing AI-based document management systems in logistics, forms an intelligent ecosystem of logistics data, in which electronic document flow acts not only as a tool for information exchange, but also as an active analytical resource for managing logistics processes. The results contribute to understanding how AI-driven EDM can improve transparency, sustainability, and competitiveness in global logistics chains.

Keywords: artificial intelligence; electronic document management; logistics; digital transformation; data management; AI regulation; logistics supply chains

Оксана Позняк, Наталія Харахаш, Ірина Суворова. «Інтеграція штучного інтелекту та електронного документообігу в логістиці: порівняльний аналіз України, Європи та США». У статті розглядається роль та ефективність інтеграції штучного інтелекту та електронного документообігу в логістиці, з акцентом на його стратегічну функцію забезпечення швидкості, надійності та глобальної зв'язності в умовах мультимодальних ланцюгів постачання. Інтеграція технологій штучного інтелекту (ШІ) в електронні системи документообігу (ЕДМ) становить ключовий етап цифрової трансформації логістичної галузі. Протягом останніх п'яти років у Європі та США спостерігається перехід від традиційного електронного архівування до інтелектуальної автоматизації та предиктивного управління даними. Метою дослідження є визначення закономірностей взаємодії між технологіями ШІ та системами ЕДМ у логістиці, а також порівняння технологічних, регуляторних і організаційних підходів України, Європейського Союзу та Сполучених Штатів Америки. Методологічною основою дослідження є порівняльний і аналітичний підхід, що базується на офіційних звітах ЄС і ОЕСР, аналітиці компанії KPMG та ACCA, а також нормативних документах України у сфері цифровізації. Результати показують, що в ЄС інтеграція ШІ та ЕДМ відбувається в контексті впровадження Регламенту ЄС 2024/1689 «Акт про штучний інтелект», який устанавлює ризик-орієнтовану модель регулювання. У США розвиток відбувається під впливом приватних інвестицій та галузевих стандартів, тоді як Україна перебуває на початковій стадії імплементації таких рішень, стикаючись із технологічними та інфраструктурними бар'єрами. Доведено, що використання ШІ підвищує ефективність, прозорість і відповідність логістичних інформаційних (документних) потоків, автоматизує звітність і перевірку, сприяє ухваленню стратегічних рішень. У статті визначено основні перешкоди для впровадження — технічні бар'єри, регуляторні бар'єри, а також кадрові та організаційні бар'єри, що призводять до технологічної фрагментації, проблем сумісності даних та дефіциту кваліфікованих кадрів. Запропоновано концептуальну модель гармонізації систем ЕДМ на базі ШІ у логістичних процесах. Отримані результати сприяють формуванню розуміння ролі ШІ у підвищенні стійкості, прозорості та конкурентоспроможності глобальних логістичних ланцюгів.

Ключові слова: штучний інтелект; електронний документообіг; логістика; цифрова трансформація; управління даними; регулювання ШІ; логістичні ланцюги постачання

Introduction. Document management systems have come a long way from traditional paper-based to modern electronic platforms designed to optimize business processes and increase the efficiency of information management.

The COVID-19 pandemic in 2020 became a turning point for the global economy and a catalyst for accelerated digitalization. The logistics business, which largely depended on paper document management, faced paralysis of key functions: signing contracts, exchanging primary documentation, accounting and tax accounting were under threat. Under these conditions, electronic document management (EDM) turned from a promising area into a vital element of corporate infrastructure.

In the period 2020–2025, the EDM market demonstrated stable growth in all regions, but the nature of its development was different:

- Ukraine - decentralized model based on private operators ("Вчасно", EDIN, M.E.Doc).
- Europe - Centralized model through eIDAS regulation and the Peppol network.
- USA – Corporate Leadership of Global Providers (DocuSign, Adobe, Microsoft, OpenText).

For ACCA members and professionals, these topics are critically important: they define not only current practice, but also the requirements for competencies that are valued and recognized internationally.

Today, the next stage comes to the fore - the integration of artificial intelligence (AI) in various industries, as well as in logistics, which radically changes the very nature of document management, moving from simple digitization to the creation of an intelligent digital ecosystem.

Analysis of the latest research and publications. In recent years, the integration of artificial intelligence (AI) with electronic

document management (EDM) systems has emerged as a core component of digital transformation across various sectors, including logistics. According to the Association of Chartered Certified Accountants [1], technological innovation and automation are reshaping information management processes, moving from basic electronic archiving toward intelligent data-driven ecosystems. The ACCA Smart Alliance Report [2] emphasizes that the convergence of human professional expertise and machine intelligence enables more adaptive and sustainable management models, particularly in data-intensive industries.

Helen Brand [3] argues that the trustworthiness and transparency of AI systems are fundamental prerequisites for their widespread adoption in operational environments. Her research highlights the importance of AI assessments in strengthening confidence in digital ecosystems. Complementing this, Brand and Van Onselen [4] explore the ethical dimension of AI implementation, linking responsible adoption with the ESG (Environmental, Social, and Governance) framework, which is of particular relevance to sustainable logistics and global supply chain operations.

From an applied business perspective, KPMG [8] demonstrates that the integration of AI in financial and operational management has led to significant efficiency improvements, primarily through automation of document flows, risk assessment, and predictive analytics. These findings can be directly extended to logistics, where similar document-heavy workflows—such as shipment documentation, customs forms, and supplier records—require intelligent processing and compliance assurance.

The technological foundations of AI-enhanced EDM systems are described in the study by SmartPoint DMS [12], which outlines the transformation from traditional EDM to

intelligent document processing (IDP) platforms integrating optical character recognition (OCR), natural language processing (NLP), and large language models (LLMs). Similarly, The Insight Partners [13] analyze the European electronic signature software market, noting that the European Union demonstrates leadership in ethical AI adoption and regulatory harmonization, particularly under the EU Artificial Intelligence Act (Regulation (EU) 2024/1689). By contrast, the United States emphasizes technological scalability and innovation-driven competition, resulting in distinct trajectories of AI development between the two regions.

At the national level, Onuchak [11] investigates the role of digital workflow automation in Ukrainian enterprises, emphasizing that automation of routine documentation tasks significantly enhances operational efficiency. However, the author points out challenges related to interoperability, data security, and the limited integration of AI tools in logistics and supply chain documentation.

Despite the substantial body of literature examining AI adoption in business and administrative processes, there remains a notable research gap in understanding the integration of AI-driven EDM systems within logistics operations, particularly through an international comparative lens.

Existing research primarily addresses:

- technological and organizational aspects of EDM transformation (SmartPoint DMS, 2025; KPMG, 2024);
- ethical and governance frameworks for AI adoption (Brand & Van Onselen, 2021; Helen Brand, 2024);
- regional market and policy analysis in Europe and the USA (The Insight Partners, 2025).

However, these studies do not sufficiently explore the mechanisms by which AI-enabled EDM transforms logistics workflows, documentation accuracy, and decision-making processes, the regulatory and infrastructural differences between Ukraine,

the European Union, and the United States in supporting AI-based logistics documentation and the interoperability and data governance challenges that impede AI adoption in supply chain document management.

Thus, the unresolved problem lies in the lack of a holistic comparative framework that evaluates the integration of AI and EDM in logistics across different regulatory environments. Addressing this gap can contribute to the development of a unified model for digital transformation and intelligent automation in global supply chains.

Objectives statement. The primary objective of this study is to analyze the integration of artificial intelligence (AI) into electronic document management (EDM) systems within the logistics sector, and to conduct a comparative assessment of implementation strategies, technological maturity, and regulatory frameworks in Ukraine, Europe, and the United States.

Basic material and results. Recent years have been an unprecedented Electronic document management (EDM) is a comprehensive system that ensures the creation, transfer, signing, storage and processing of documents in digital format. The main goal of EDM implementation is to optimize business processes, reduce time and financial costs, and reduce the risks associated with errors and the human factor.

In modern business, EDM covers a wide range of documents: from financial and accounting forms to HR documentation and corporate solutions. The transition to electronic formats allows organizations to significantly speed up the exchange of information, ensure the legal force of documents and increase the transparency of processes. Table 1 shows the main categories of documents that are converted into electronic format, as well as the mechanisms used for signing in Ukraine, Europe and the United States

Table 1. Types of document and signature in EDM

No.	Category of documents	UKRAINE	EUROPE	USA
1.	Financial	Invoices Payments Reports	Invoices Payments Reports	Invoices Payments Reports Contracts
2.	Legal of contracts	Supply Contracts Leases Service Contracts	Contracts	Contracts Agreements
3.	Staffing	Employment Contracts Timesheets Applications	Employment Contracts HR Documentation	Employment Contracts HR Documentation
4.	Tax	Tax Returns	Tax Returns	Tax Returns
5.	Logistics	Invoices Shipping Documents Delivery Documents	Invoices Delivery Documents	Invoices Shipping Documents Delivery Documents
6.	Corporate Management	Board Minutes	Board Minutes Management Reports Resolutions	Board Minutes Management Reports Resolutions

Source: compiled by the authors

Thus, EDM not only optimizes internal processes, but also becomes a strategic factor in increasing competitiveness, which is especially important in the context of global digitalization and the integration of AI in data management.

Electronic document management (EDM) offers significant economic benefits (see Figure 1) by reducing costs through lower paper and storage expenses, increasing productivity with faster access and automated workflows, and mitigating financial risks via improved security and compliance. It also contributes to higher profitability by allowing employees to focus on higher-value tasks and by improving operational efficiency through streamlined processes.

Accordingly, automation of document flow in business has become a trend in recent years. Companies in various business sectors use digital tools to work with documents faster and spend less time on routine. For

example, electronic document flow services automate the entire life cycle of an electronic document - from creation to archiving. Let's consider the main trends in the implementation of a certain technology in the context of different regions. In Ukraine, there is no single state provider of services for business, so the EDM market is formed at the expense of private operators.

In Ukraine, the following operators are accredited for the exchange of electronic documents that work with QES (Qualified Electronic Signature) and integration with the Tax system:

- M.E.Doc;
- Вчасно;
- Paperless;
- EDIN (e-TTN);
- Сота (iFin, Liga: REPORT);
- Dubidoc.

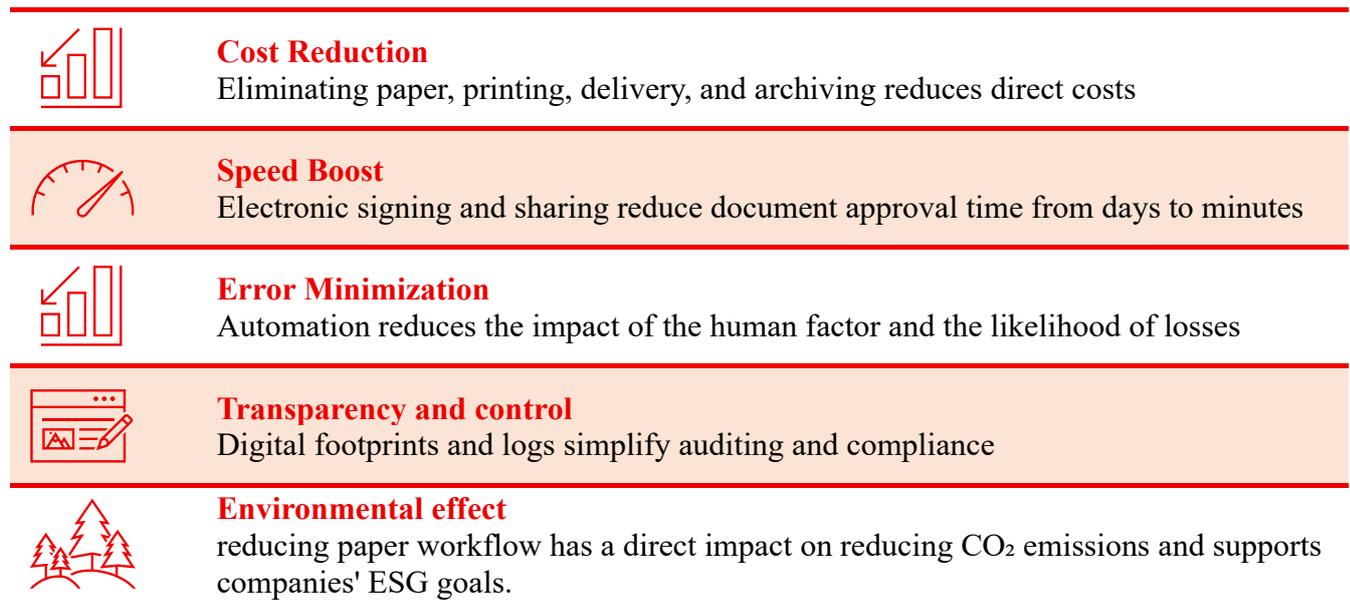


Figure 1 – Comprehensive economic benefits of EDM to business

Source: compiled by the authors

Figure 2 presents the platforms that are leaders in usage on the Ukrainian market.

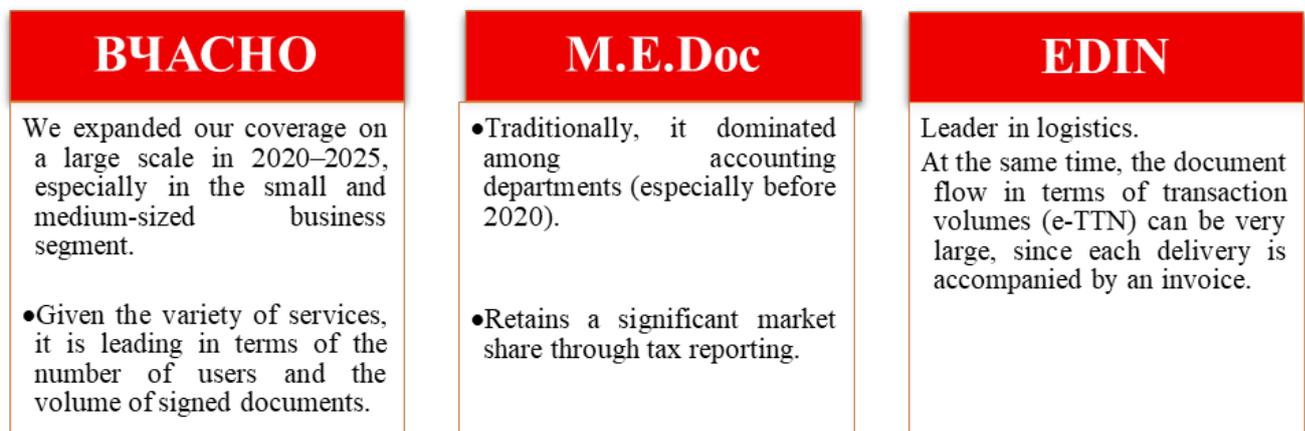


Figure 2 – The leaders in EDM industry in Ukraine

Source: compiled by the authors

Each of these platforms provides solutions for creating, exchanging, signing and storing legally significant electronic documents using a qualified electronic signature (QES), in accordance with the requirements of Ukrainian legislation.

For the state, there is the state platform Diya. The platform works mainly for citizens and partly for government agencies. This platform, although widespread among

citizens, is only partially integrated into the business environment.

Thus, the EDM market in Ukraine is developing rapidly, but remains fragmented, decentralized and applied inconsistently on a selective basis. Each company (EDIN, M.E.Doc) develops its own AI modules, there is no single standard. The war and remote work have increased the demand for sustainable digital solutions.

AI is mainly applied as a supporting tool and is not yet widely adopted due to regulatory restrictions on the use of qualified electronic signatures (QES).

In the EU, the situation is closer to centralized.

In contrast to decentralized or predominantly market-based models, the European framework for the implementation of EDI relies on institutional standards and regulatory support that ensure a high degree of legal reliability and cross-border interoperability.

The key regulatory document defining the framework for working with electronic documents in the EU is the eIDAS (Electronic Identification, Authentication and Trust Services) regulation. It establishes the legal status of electronic signatures and classifies them into levels of trust - from basic (SES) to qualified (QES), which are equated to a handwritten signature in court.

An additional element of the infrastructure is the Peppol (Pan-European Public Procurement Online) network, which provides a standardized exchange of electronic invoices and contracts between organizations from different EU countries. This is critical for companies operating in multiple jurisdictions and interacting with public procurement or corporate partners at a pan-European level.

The industry leaders in Europe are the following platforms:

- Adobe,
- DocuSign,
- OneSpan,
- Thales.

The European Commission's strategic documents (including Digital Decade 2030 and the European Data Strategy) envisage further consolidation of digital systems, the

creation of pan-European data spaces, and the strengthening of the role of AI in document management. The focus is on creating a single digital environment where the exchange of electronic data and documents will take place transparently, safely and legally reliable.

In the United States of America, electronic document management (EDM) has evolved as part of the market's digital transformation, rather than as a result of centralized regulation. Unlike the EU or individual countries with an active role of the state, the American model is based on the initiative of the private sector and the adaptability of business to technological trends. This has made the United States a global leader in the commercialization of EDM and the introduction of artificial intelligence (AI)-based systems.

The development of EDM in the United States is closely related to technology corporations that provide cloud-based, scalable, and integrable document management solutions.

The industry leaders in the USA are the following platforms, the main functionality of which is shown in Figure 3.

- DocuSign,
- Adobe,
- OpenTex,
- Microsoft,
- IBM,
- Oracle

The U.S. forms the backbone of the global DMS market, including SaaS export solutions and the development of industry standards.

Unlike eIDAS in the EU, the U.S. does not have a single federal law governing electronic signatures and document management.



Figure 3 – The leaders in EDM industry in USA

Source: compiled by the authors

The main regulatory acts governing the activities of these platforms are:

- E-SIGN Act (2000) - recognizes the legal force of electronic signatures.
- UETA (Uniform Electronic Transactions Act) - Applied at the state level.

This system provides companies with flexibility in choosing platforms, formats, and procedures, but requires businesses to be attentive to internal security policies and compliance with industry regulators (For example, IRS, SEC, HIPAA and others.).

The American EDM model is a commercially oriented ecosystem based on innovation, scalability, and user convenience. The U.S. is showing how the free market can quickly adapt to the demands of the digital age, while actively shaping global standards.

Unlike EDM, Artificial Intelligence (AI) is a technology that combines machine learning, automatic image and speech recognition, and data analysis. AI models are able to analyze large amounts of information in a very short time, draw conclusions, make decisions, and interact with the environment.

This opens up wide opportunities for the use of AI in various software solutions aimed at optimizing key business processes, improving efficiency, and increasing overall profitability. One of the most effective areas of

application of AI is document processing, especially when it comes to routine tasks typical of traditional document management. Sorting, classifying, extracting data, and transferring information to the accounting system are all tasks that require a lot of time and labor, and are prone to errors and duplication when done manually.

AI has different impacts on the development of industries; the role of AI in the development of EDM in specific countries in the period 2023–2025 is shown in Figure 4.

A key advantage of AI-powered document analysis is its ability to significantly reduce manual operations, improve data processing accuracy, and ensure consistent performance. With fully automated metadata extraction, these systems help speed up document registration and approval processes while ensuring full compliance with business rules, internal policies, and regulatory standards.

Implementing an AI-powered document management system is not just a step towards digital transformation, it's a strategic investment in the resilience, agility, and competitiveness of your business in the face of ever-increasing amounts of information and data processing requirements.

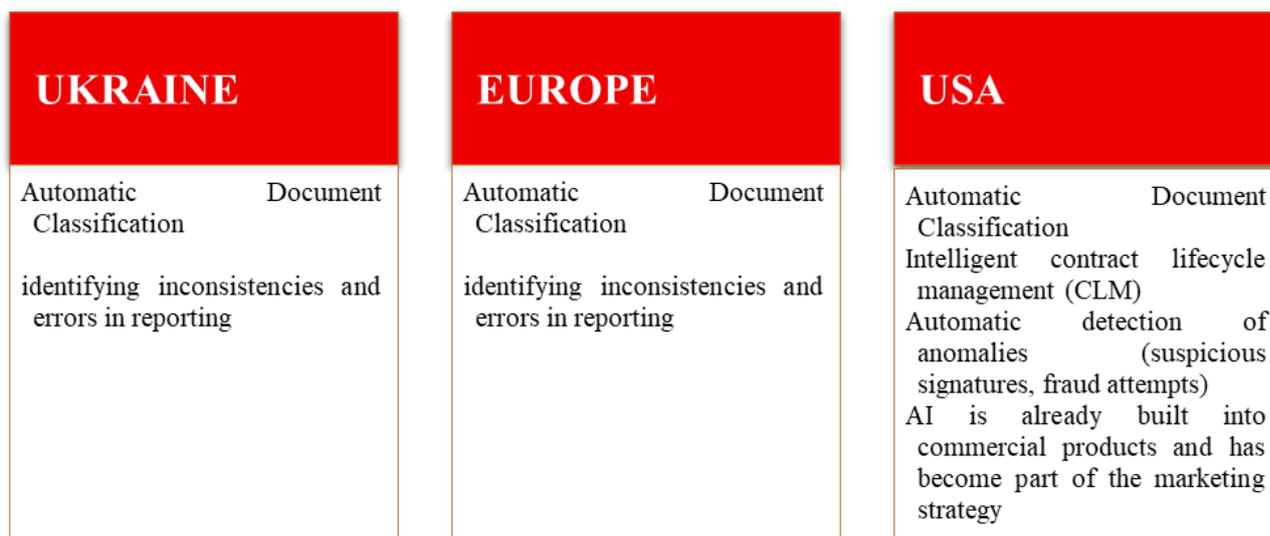


Figure 4 – The role of AI in development of EDM (2023–2025)

Source: compiled by the authors

Electronic document management and the introduction of artificial intelligence are becoming the most important factors in the transformation of business and the financial profession. However, the productivity of their application largely depends on the extent to which specialists have the same standards and rules of work.

Technology has the potential to revolutionize financial management practices, but its value is only realized if professionals have the knowledge and competencies to apply it effectively.

Professional training is becoming a key tool for adaptation. ACCA forms in accountants not only technical skills in working with EDM and AI, but also an ethical understanding of responsibility for the use of technology.

The future of the profession depends on the willingness of specialists to cooperate with artificial intelligence. The machine provides speed and scale; professionals ensure quality and trust.

Artificial intelligence (AI) has enormous potential to transform the way we work. However, as AI evolves, it presents both great opportunities and major challenges for accounting and finance professionals. For companies, it is critical that financial

professionals have the same training and understanding of the use of AI and digital technologies. Standardization of knowledge and practices reduces the risk of errors, ensures transparency and strengthens trust between counterparties.

Uniform qualifications allow accountants to "speak the same language", which makes it easier to implement AI tools and make them as productive as possible.

For auditors, the importance of training at ACCA lies in the ability to correctly assess the correctness of the use of AI in accounting and document management processes. Ethical principles and uniform standards are the basis for responsible AI implementation. Without them, trust in digital systems and analysis will be undermined. Thus, auditors need not only to be proficient in digital analysis tools, but also to be able to check whether the use of AI meets professional and ethical standards. EDM frees you from routine and transfers the role of an accountant to analytics and strategic consulting.

The USA is a leader in the development and implementation of AI in various industries, which is confirmed by the data in Figure 5.

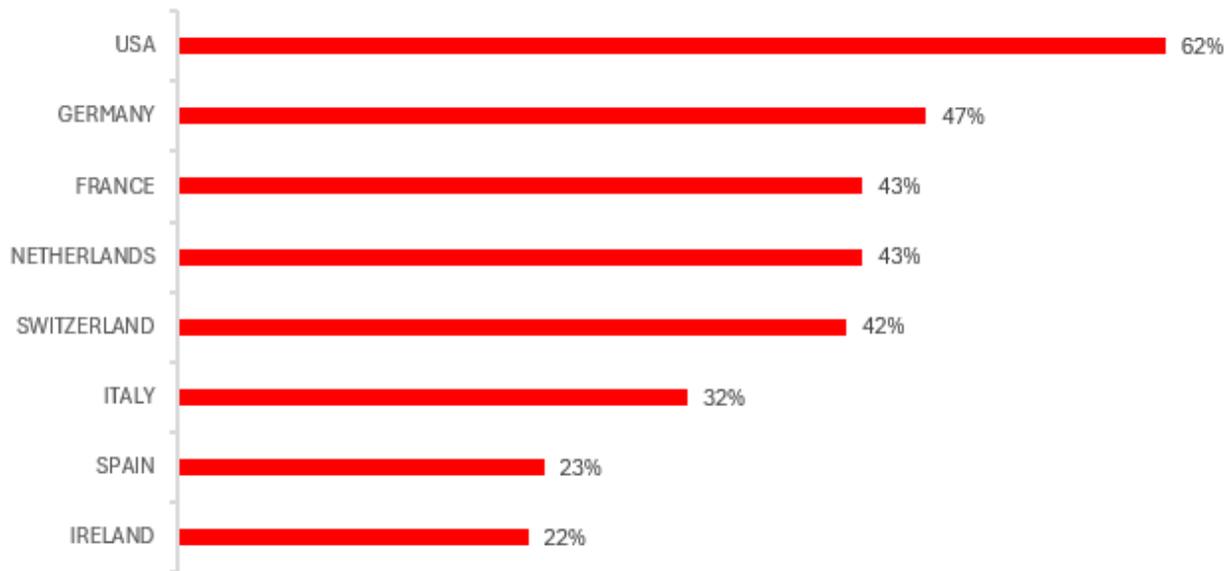


Figure 5 – US vs. other countries: moderate or large degree of usage.

Source: [1]

So, the development of artificial intelligence (AI) opens up new opportunities for the logistics industry, but its implementation is associated with a number of challenges, from cybersecurity to a shortage of qualified personnel. Many companies note that the limited skills of employees in working with AI are becoming one of the main obstacles.

The rapid development of Artificial Intelligence (AI) and Machine Learning (ML) has significantly transformed logistics and supply chain management, especially for sustainability and environmental efficiency [5].

The integration of Artificial Intelligence (AI) technologies into Electronic Document Management (EDM) systems is becoming one of the most significant trends in the digital transformation of logistics in 2020–2025. Document management, previously perceived as a supporting function, is now becoming the main source of data and management information that can affect the efficiency of the entire supply chain.

AI document management systems have radically changed the logic of logistics [9]:

- automated and predictive document processing processes;
- decisions are made based on real-time data;
- end-to-end transparency and cost reduction;
- sustainable growth and digital trust.

DHL [6] frames logistics competitiveness increasingly in terms of how fast organizations can interpret, reconcile and act on supply chain data, rather than purely how fast they can move physical goods. The integration of AI and EDM turns logistics networks into intelligent ecosystems, where each document becomes a source of value and management knowledge.

Current literature and industry reports [7] agree that the core of the transformation is formed by five technological areas of AI, each of which directly affects electronic document management.

1. *Advanced Analytics*. AI can help us analyze and interpret data using sophisticated tools and algorithms to gain actionable insights and predictions beyond the capabilities of traditional business intelligence. The data empowers businesses to plan more strategically, increase

operational resilience, and gain a competitive edge.

It's not just about reporting, but about mathematical models that analyze transactional documents (purchase orders, invoices, bills of lading), identify patterns and generate forecasts. Such models help plan capacity, procurement, and logistics resources, reducing supply volatility and making the network more resilient. Studies note that AI-powered predictive analytics improve demand forecasting, inventory management, and resource allocation, increasing supply chain competitiveness by reducing uncertainty.

2. *Generative AI (Gen AI)*. Generative models automatically generate text (delivery status reports, summaries of contract terms, explanations of delays), visual materials, and even audio instructions. Industry reports indicate that it is AI generating models that are becoming critically important for the automatic "translation" of complex logistics documents into a management solution that is understandable to management and the client.

AI today can autonomously generate new content – images, text, audio, or videos – based on patterns learned from existing data. Technology is on an explosive upward trajectory, growing by 50% in 2023, and is projected to compound this growth annually through 2030. We expect GenAI to have a huge near-term impact on logistics.

3. *Computer Vision*. Computer vision tools use cameras to capture photos or videos and AI algorithms to analyze the extracted data. Basic systems are trained to simply differentiate objects, while advanced systems can track objects across viewpoints and learn on their own. Recent breakthroughs even achieve prediction through pattern recognition, with a wealth of enticing use cases, especially in warehouse environments.

Computer vision links physical operations (warehouse, ramp, distribution center) to documents. Cameras record the condition of loading units, barcodes, seals, fill out electronic acts of acceptance/transfer and

automatically confirm compliance with the declared quantity.

4. *Audio AI*. Audio AI is about analyzing, synthesizing, and understanding audio signals. It allows machines to perceive, process, and interpret sound in a manner similar to human auditory systems. Audio AI encompasses techniques such as speech recognition, sound classification, and environmental noise detection to enhance human-computer interaction and support predictive maintenance, fatigue detection, process optimization, and more.

Voice interfaces and analysis of audio streams allow operators to dictate real-time data on delivery, cargo condition, damage, and deviations. The AI system transcribes the speech, structures it as an incident report document, and immediately embeds it into a digital archive [10].

5. *AI ethics*. As AI rapidly scales up, ethical considerations have become an important near-term trend that examines the implications of AI to ensure its responsible development and deployment. Legislative and regulatory responses are one aspect of this. The security of data and algorithms, bias, and transparency are others. The logistics industry will likely face heightened regulatory scrutiny in the coming years [6].

AI scaling inevitably leads to issues of algorithm transparency, bias, and control over the use of personal and commercially sensitive data. In the EU, these issues are already institutionalized through Regulation (EU) 2024/1689 (the EU Artificial Intelligence Act) and the GDPR; research papers from 2024-2025 emphasize that the credibility of AI and the legal acceptability of automatically generated documents are becoming as important as processing speed. This defines the requirements for auditing AI models and for the reproducibility of document-based solutions [7].

In Ukraine, the potential of AI systems in logistics is especially high, because since 2020, several processes have been going on at the same time: military and humanitarian logistics, restructuring of import/export

chains, and accelerated digitalization of business documents through state initiatives of electronic trust and Qualified Electronic Signature (QES) Law No 2155-VIII "On Electronic Trust Services".

The state policy of the digital state ("Дія") and the development of the electronic trust services market have created a regulatory and technical framework for the transition to end-to-end electronic document management.

The most promising areas for Ukrainian logistics operators are:

- automatic generation of applications for the search and approval of documents between branches and the central accounting department (centralized electronic archive);

- a legally significant electronic document with a QES instead of a paper acceptance certificate, recognized within the corporate supply chain and, over time, outside it;

- reconciliation of electronic documents with ERP using AI, which reduces the burden on accounting;

- integration of predictive analytics (forecast of delays, stock shortages, bottlenecks in transportation) into operational supply management, and not only into financial statements.

Despite the active development of artificial intelligence (AI) and electronic document management (EDM) technologies, their widespread introduction into logistics processes is largely constrained by the existing regulatory environment and structural constraints. The legislative regimes of Ukraine, the European Union and the United States of America form different levels of maturity and legal certainty, which directly affects the integration of AI systems into the electronic exchange of documents between participants in supply chains.

These barriers are conventionally divided into three groups, as presented in Figure 6.

Technical barriers are manifested in the definition of the following obstacles, namely:

1. *Lack of unified standards for electronic document interchange.* All three jurisdictions have the principle of recognizing electronic

documents as legally significant, but there is no single international standard for the exchange of logistics documents using AI.

In Ukraine, according to the Law "On Electronic Documents and Electronic Document Management" [14] No 851-IV (2003), an electronic document is recognized as equivalent to a paper one if there is an electronic signature. However, there are no uniform interoperability protocols with EU or US systems, which makes automated cross-border data exchange difficult.

In the EU, Regulation (EU) No 910/2014 (*eIDAS*) establishes requirements for qualified electronic signatures and trust services. However, this act does not contain specific provisions for AI logistics platforms and their interaction with automatically generated documents, which leaves a legal gap in the legal validity of AI-generated documents.

In the United States, the *Electronic Signatures in Global and National Commerce Act* (2000) recognizes the legal validity of electronic signatures and documents but does not regulate the algorithmic creation or processing of such documents using AI.

2. *Incompatibility of information systems and data quality.* The laws of all three regions enshrine the obligation to ensure the integrity and authenticity of electronic documents, but do not establish technical standards for their processing by AI systems. In the EU, this is reflected in the AI Act 2024/1689, which explicitly states the requirement of "appropriate quality and representativeness of data". However, there are no industry guidelines for logistics, which creates technical uncertainty, as these requirements are often defined by corporate regulations rather than state regulation. This makes it difficult to integrate with international AI platforms that require common metadata schemas, APIs, and trust protocols.

3. *Information security and infrastructure resilience.* In the EU, there is Directive (EU) 2022/2555 (NIS 2 Directive), which obliges companies in the transport and logistics sector to comply with cybersecurity measures. In the United States, a similar

requirement arises from the *Cybersecurity and Infrastructure Security Act* (2018).

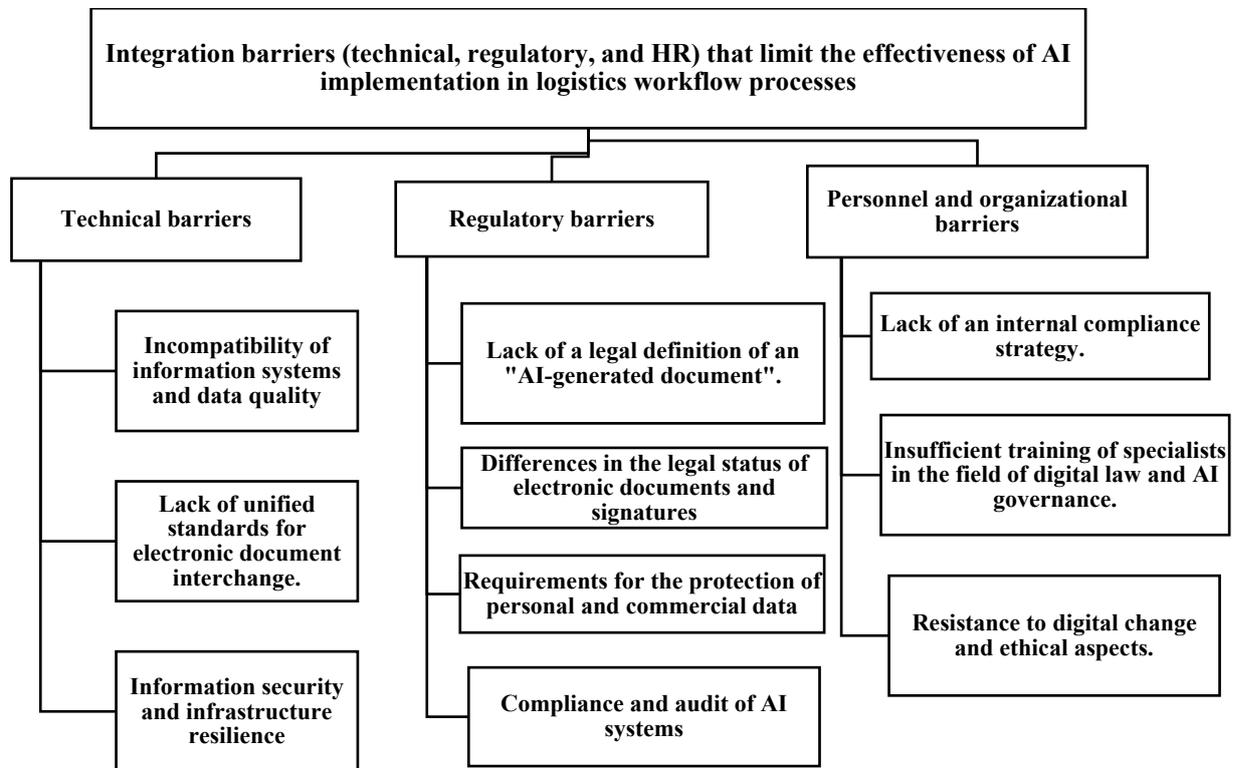


Figure 6 – Integration barriers (technical, regulatory, and HR) that limit the effectiveness of AI implementation in logistics workflow processes

Source: compiled by the authors

In Ukraine, there is no separate act regulating cybersecurity in logistics, which creates a gap in the integration of AI modules into critical document management processes.

Thus, technical barriers largely stem not from a lack of technology, but from the lack of globally interoperable standards for AI processing of electronic documents and data quality requirements in logistics.

Regulatory barriers are represented by the following problematic aspects:

1. *Differences in the legal status of electronic documents and signatures.* In Ukraine, the Law "On Electronic Trust Services" [15] No 2155-VIII (of 5 October 2017) is in force, which provides for state accreditation of trust service providers. However, its effect is limited by national jurisdiction: an electronic signature issued in Ukraine is not recognized as valid in the EU or

the United States, which creates barriers to international document flow in logistics [15].

In the EU, the mutual recognition mechanism is provided for by *eIDAS*, but it applies only to the member states of the Union. In the United States, the regulation of electronic signatures and documents (E-SIGN Act and Uniform Electronic Transactions Act (UETA) varies by state, which gives rise to heterogeneity of rules for cross-border supply chains.

2. *Lack of a legal definition of an "AI-generated document".* In the EU, for the first time, an attempt was made to legislate this issue in the *AI Act (2024/1689)*, which introduces categories of systems according to the level of risk and the responsibilities of AI operators for transparency and explainability of algorithms. However, the regulation does not give a clear answer whether a document created or processed by an AI system has

independent legal force without human confirmation.

There is no such definition in the legislation of the United States and Ukraine, which creates legal uncertainty for the use of automatic classification and electronic signing of documents without direct human involvement.

3. *Requirements for the protection of personal and commercial data.* The EU has *GDPR (2016/679)*, which restricts the automated processing of personal data if it leads to legal consequences. This directly affects the use of AI algorithms in logistics document management, where information about customers, cargoes, and financial transactions is recorded.

In the United States, data protection is regulated at the level of individual acts, such as *the California Consumer Privacy Act (CCPA)*, and does not have a single federal regulation.

In Ukraine, similar principles are enshrined in the *Law on the Protection of Personal Data (2023)*, but without detailed procedures for AI systems, which limits trust in the electronic processing of confidential logistics documents.

4. *Compliance and audit of AI systems.* In the EU, companies are required to demonstrate that AI systems comply with the principles of transparency and security, and operators of "high-risk" systems are subject to certification and external audits. This is provided by *AI Act 2024/1689* and *Directive (EU) 2022/2555*.

In Ukraine and the United States, similar requirements are still at the stage of formation: there are no procedures for mandatory certification of AI solutions in the field of document management.

These differences create barriers for companies operating in international logistics networks, which are forced to adapt solutions to different legal regimes.

Personnel and organizational barriers include the following issues:

1. *Insufficient training of specialists in the field of digital law and AI governance.* The legislation of Ukraine, the EU and the USA

does not have mandatory requirements for professional certification of specialists implementing AI document management systems. However, regulations require ensuring an "appropriate level of competence" of responsible persons:

– in the EU, this is enshrined in the *AI Act (Article 18 – "Human Oversight and Competence")*,

– In the U.S., AI governance is largely driven by soft-law instruments such as *NIST's AI Risk Management Framework (2023)*, rather than by a binding federal AI statute, which means that compliance obligations are often contractual and sector-specific rather than universally mandated,

– in Ukraine – in the methodological recommendations of the *Ministry of Digital Transformation on the use of electronic trust services [14]*.

In practice, this means that the legal responsibility for the correct use of AI rests with the organization, but its employees often do not have the necessary qualifications.

2. *Lack of an internal compliance strategy.* The laws of Ukraine and the United States do not require the mandatory implementation of an AI risk management policy, unlike the EU, where such an approach is provided for by *the AI Act*. Therefore, Ukrainian and American companies often do not have internal audit procedures for AI-generated electronic documents, and the roles of those responsible for data quality control are not defined.

3. *Resistance to digital change and ethical aspects.* Although regulations do not directly regulate the cultural aspects of AI implementation, *the OECD Recommendation on Artificial Intelligence (2021)* and *the AI Act (EU)* emphasize the need to ensure human control and prevent discrimination in algorithmic processes. In logistics, this is expressed in the need to combine document automation with the preservation of control by specialists.

The conceptual model of harmonization of electronic document management (EDM) systems based on artificial intelligence in logistics processes, shown in *Figure 7*, can

potentially reduce the negative impact of the identified barriers.

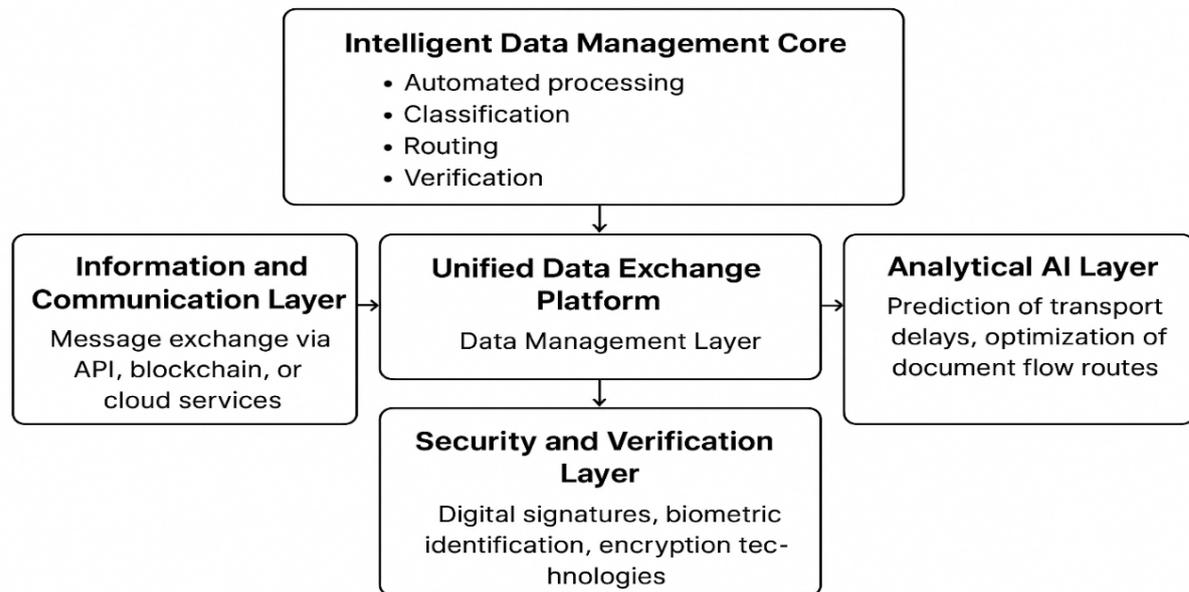


Figure 7 – Conceptual model for harmonizing AI-based Electronic Document Management (EDM) systems in logistics processes

Source: compiled by the authors

The conceptual model for harmonization of electronic document management (EDM) systems based on artificial intelligence in logistics processes involves the creation of a single integration space for the interaction of all participants in the logistics chain - suppliers, carriers, warehouses, distributors and consumers - through a unified data exchange platform.

The basis of the model is an intelligent data management core, which performs the functions of automated processing, classification, routing and verification of electronic documents using machine learning and natural language processing (NLP) algorithms. This ensures compatibility and harmonization of data formats between different corporate systems (ERP, WMS, TMS, etc.) and national or international EDM standards (e.g. EDIFACT, UBL, XML, eCMR).

The model includes the following structural components:

Information and communication layer – provides message exchange between the systems of the logistics chain participants via API, blockchain or cloud services.

Analytical AI layer – uses artificial intelligence algorithms to predict transport delays, optimize document flow routes and detect anomalies or duplications in documents.

Data management layer – provides integration, normalization and synchronization of information in real time between all system nodes.

Security and verification layer – implements digital signatures, biometric identification and encryption technologies to guarantee document integrity.

User interface – provides intuitive document management, analytics and communication between parties through personalized dashboards.

The functional logic of the model is based on the principles of harmonization: compatibility, transparency, standardization and adaptability. The use of AI provides dynamic coordination of heterogeneous document formats, automatic detection of discrepancies and generation of recommendations for their elimination. This increases the level of digital integration of

logistics processes, reduces document flow time, minimizes the human factor and ensures strategic transparency of the supply chain.

Thus, the conceptual model of harmonization of EDM systems based on AI forms an intelligent ecosystem of logistics data, in which electronic document flow acts not only as a tool for information exchange, but also as an active analytical resource for managing logistics processes.

Conclusions. Between 2020 and 2025, EDM has evolved from an "anti-crisis measure" into a core element of strategic business infrastructure.

The integration of AI represents next level of maturity, transforming EDM from a time-saving tool into an intelligent ecosystem.

Over the past five years, electronic document management has become a key driver of efficiency across regions:

- Ukraine has shown the ability to adapt quickly even in wartime conditions.
- Europe provides a model of harmonization through regulatory standards.
- The United States is a leader in the commercialization of EDM and AI adoption.

Looking ahead, the next stage will be the rise of smart ecosystems, where AI becomes a key element of document management, auditing, and sustainability reporting.

The integration of AI into electronic logistics document management systems takes place in conditions of legal heterogeneity.

Ukraine has a developed regulatory framework for electronic documents and signatures, but there are no regulations for AI technologies yet. The European Union has the most comprehensive regulatory system: eIDAS provides a trustworthy infrastructure, the GDPR protects data, and the AI Act introduces the responsibility of AI operators. In the United States, the approach is more flexible and decentralized: with the recognition of electronic documents, AI regulation is based on voluntary standards.

Thus, the effectiveness of the implementation of AI in logistics document management depends on the harmonization of technical standards, the coordination of the legal status of AI-processed documents and the training of qualified specialists who are able to ensure the compliance of systems with national and international requirements.

References

1. ACCA. (2023). Technology, innovation and the future of accounting. URL: <https://www.accaglobal.com/us/en/professional-insights/technology/digital-horizons.html>
2. ACCA. (2024). Smart Alliance Report: Accounting Expertise Meets Machine Intelligence. URL: <https://www.accaglobal.com/us/en/professional-insights/technology/digital-horizons.html>
3. Brand, H. (2024). AI Assessments: Enhancing Confidence in the Use of AI. London: ACCA. URL: <https://www.accaglobal.com/gb/en/professional-insights/technology/ai-assessments.html>
4. Brand, H., & Van Onselen, A. (2021). Ethics for Sustainable AI Adoption: Connecting AI and ESG. ACCA. UR: https://www.accaglobal.com/content/dam/ACCA_Global/professional-insights/nv-ai-ethics/PI-AI-ETHICS.pdf
5. Cornell University (2025). Designing and Deploying AI Models for Sustainable Logistics Optimization: A Case Study on Eco-Efficient Supply Chains in the USA. URL: <https://arxiv.org/abs/2503.14556>
6. DHL Delivered (2025). AI in logistics: 5 trends you need to know about. URL: <https://www.dhl.com/global-en/delivered/innovation/ai-trends-in-logistics.html>

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7. Giovanna Culot, Matteo Podrecca (2025). AI in supply chain management: A systematic literature review of empirical studies and research directions. URL: <https://www.sciencedirect.com/science/article/pii/S0166361524000605>
 8. KPMG. (2024). AI in Finance: US Report. URL: <https://kpmg.com/us/en/articles/2024/ai-in-finance-us-report.html>
 9. McKinsey&Company (2025). Digital logistics: Into the express lane? URL: <https://www.mckinsey.com/capabilities/operations/our-insights/digital-logistics-into-the-express-lane>
 10. Oluwaseun Badmus, Shahab Anas Rajput, John Babatope Arogundade, Mosope Williams, 2024. AI-driven business analytics and decision making. World Journal of Advanced Research and Reviews, Issue. URL: <https://wjarr.com/sites/default/files/WJARR-2024-3093.pdf>.
 11. Onuchak, V. (2024). Document Workflow Automation in the Enterprise: How Digital Services Solve Routine Tasks. URL: <https://vchasno.ua/en/avtomatyzatsiia-dokumentoobihu/>
 12. SmartPoint DMS. (2025). Applications and Prospects of AI Technologies in Electronic Document Management. URL: <https://dms.smart-it.com/en/blog-post/ai-document-management/>
 13. The Insight Partners. (2025). Europe Electronic Signature Software Market Size, Trends & Forecast (2025–2031). URL: <https://www.theinsightpartners.com/reports/electronic-signature-software-market>
 14. Verkhovna Rada of Ukraine (2025). «On electronic documents and electronic document management». URL: <https://zakon.rada.gov.ua/laws/show/en/851-15/ed20220105#Text>
 15. Verkhovna Rada of Ukraine (2025). «On Electronic Trust Services». URL: <https://zakon.rada.gov.ua/laws/show/2155-19/ed20171005#Text>

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AIR CARGO TRANSPORTATION AS AN ELEMENT OF THE RESTORATION OF THE AVIATION SECTOR IN UKRAINE AGAINST THE BACKGROUND OF MILITARY OPERATIONS

Maryna Boldyrieva, Dmytro Shevchuk. *«Air cargo transportation as an element of the restoration of the aviation sector in Ukraine against the background of military operations».* The article examines the negative impact of military operations in Ukraine on the functioning of the aviation sector as a transport infrastructure object. There were identified the risks that exist today in connection with military actions in the country. There was substantiated the relevance of the restoration of full or partial operation of the aviation sector in Ukraine, which is one of the current urgent problems and requires a quick and optimal solution. There were proposed the stages of logistics operations for an airport carrying out only cargo transportations. There were established the prospects for optimal adjustment of airport operations for cargo transportation in wartime conditions in Ukraine.

Keywords: airport, transport infrastructure, cargo transportation, logistics, military conflict

Марина Болдирєва, Дмитро Шевчук. *«Авіаційні вантажні перевезення як елемент відновлення авіаційного сектору України в умовах воєнних дій».* У статті розглянуто негативний вплив військових дій в Україні на функціонування авіаційного сектору як об'єкта транспортної інфраструктури. Визначено існуючі на сьогоднішній день ризики, що мають місце у зв'язку із воєнними діями в країні. Обґрунтовано актуальність щодо відновлення повноцінної або часткової роботи авіаційного сектору в Україні, що є однією із нагальних проблем сьогодення і

потребує швидкого та оптимального вирішення. Запропоновано етапи логістичних операцій для аеропорта, який працює тільки з вантажними перевезеннями. Встановлено перспективи оптимального налагодження роботи аеропортів для здійснення вантажних перевезень в умовах військових дій в Україні.

Ключові слова: аеропорт, транспортна інфраструктура, вантажні перевезення, логістика, військовий конфлікт

Introduction. According to the 2025 Global Peace Index (GPI) report by the Institute for Economics and Peace (IEP), there has been a continuing decline in global peacefulness, with 59 active state-level conflicts and over 180 regional armed conflicts [1]. In addition to the enormous human suffering, armed conflicts have a negative impact on the economy through the destruction of infrastructure, the displacement and dislocation of trade, and uncertainty about the future. This, in turn, negatively affects the transport and logistics infrastructure of the state. Aviation infrastructure is particularly vulnerable: airports, cargo hubs, and air corridors are becoming targets for damage and restrictions. Under these conditions, airport logistics are forced to adapt to new realities: infrastructure destruction, airspace closures, route changes, and a high degree of uncertainty.

The protracted military operations in Ukraine have halted the work of the aviation sector in the country. Today, the question of resuming the work of some airports despite the continuation of military operations is acute.

Airports are not just infrastructure facilities, but key elements of economic, humanitarian and security strategy. Their timely reconstruction and development can ensure a country's dynamic return to normal life, increase its competitiveness in the international arena and guarantee national security.

This can be accomplished according to several different models, one of which is to envisage a partial recovery of cargo transportations first, and then, under

favorable conditions, a partial recovery of passenger transportations.

Analysis of recent research and publications. The Russian military aggression has caused significant damage to the territory of Ukraine. According to the report, which presents the results of the assessment of the losses suffered by the Ukrainian economy as a result of Russia's military aggression for the period from February 2022 to November 2024, the amount of direct damage to real estate, other infrastructure, vehicles and inventories amounted to almost \$170 billion [2].

The largest share of the total direct damage was caused to residential buildings (\$60.0 billion) and transport infrastructure (\$38.5 billion). Infrastructure facilities became one of the key areas that suffered the most attacks from the aggressor. In particular, in the first weeks of the war, Russian troops carried out massive shelling of aviation infrastructure, primarily airfields not only of military, but also of civilian and military-civilian (dual) purpose [2].

Today, despite the continued military aggression by the Russian Federation, a necessary prerequisite for the opening of any airport in Ukraine will be the decisions of the State Aviation Service of Ukraine – to open part or all of the airspace. And this will depend on the results of a thorough analysis of real risks.

In this case the military component will be essential – air defense forces and means, as well as the formation of a fundamentally new security architecture, which, through the creation of a Joint Control and Coordination Center between the military and civilians, will allow risks to be managed and minimized to an acceptable level.

The experience of actions in the world under similar circumstances has been currently studied and tried to be applied in Ukraine, actively involving international experts [3].

The purpose and objectives of the article. In current conditions, there is an urgent need to resume the aviation industry as soon as possible. However, given the existing risks, it is first necessary to establish the operation of airports exclusively for cargo transportation, which, in turn, requires a clear organization of logistics.

After all, logistics during military actions requires flexibility, rapid adaptation to new conditions, and coordination with armed forces.

In the study „Examining Airport Agility at Air Cargo Hub Airports“ there was shown that the agility of a cargo hub airport depends on digital transformation, flight services, information exchange, and infrastructure availability. In a military context, these factors become even more significant, as infrastructure is under threat, routes are disrupted, and rapid logistics restructuring is required [4].

Basic material and results. Since February 24, 2022, the safe operation of civil aviation ports for the transportation of passengers and cargo has become impossible. The aviation sector in Ukraine is currently going through a difficult stage of its existence. However, despite all the existing challenges, the industry continues to function.

It is known that airports are compound complexes with infrastructure and rolling stock that require constant maintenance and keeping in proper working condition. The necessity of it is evident, since it is essential to maintain the qualifications of workers and still carry out transportations in the future; it is required to take care of the infrastructure constantly, to implement a set of measures to maintain the operational and technical suitability of the airport.

Also, one of the main reasons for the continued operation of airports is a security

reason – to prevent extraordinary accidents and events of a technogenic nature that may occur during shelling. This especially applies to airports with the status of critically important facilities: the state airport „Boryspil“ and the Lviv airport named after Danylo Halytsky [5]. Their preservation is a priority issue in terms of security. Thus, the entire period since the beginning of the war, the airport’s operational activity has been taking place without being noticeable from the outside [6].

Currently, the import and export of goods from remote countries of the continent, as well as from the USA, is carried out by multimodal transportation using aviation and road transport [7; 8].

In modern conditions, logistics chains are forced to change routes and look for alternatives, which increases costs and reduces efficiency. Cargo operations are transferred through neighboring countries, ground transportation is used after air hubs abroad.

A previous analysis of cases of civilian aircraft being shot down over conflict zones in the past shows that there is no practice of mandatory complete closure of airspace.

Today, flights can also be carried out from airports classified as the highest risk. For example, flights to Iraq are operated by airlines from Middle Eastern countries; a few local carriers operate flights to airports in Yemen and Libya [9].

During wartime, the importance of aviation logistics increases: cargo flights, humanitarian aid, and military supplies require fast and reliable movement. Therefore, given the above, there is confidence that airports may yet transition to cargo operations during wartime in Ukraine. It is worth noting that during military operations, the optimization of airport operations for cargo transportation has its own specifics – priorities shift from commercial efficiency to stability, security, and flexibility of logistics chains.

There are proposed stages of logistics operations for an airport carrying out only cargo transportation (Table 1).

Table 1. Logistics operations stages for an airport handling only cargo

Stage	Definition	Resources and infrastructure	Responsibility
1. Cargo acceptance	Cargo arrives at the airport via trucks, trains or airplanes.	Unloading zones, transport corridors, air defense for infrastructure protection.	Logistics services, security services.
2. Cargo sorting	Cargo is divided into humanitarian, military and commercial categories.	Sorting lines, automated WMS (Warehouse Management systems).	Warehouse staff, WMS operators.
3. Cargo storage	Temporary placement of goods in warehouses or mobile containers.	Reinforced warehouses, cold storage rooms for perishable goods.	Warehouse managers, security.
4. Customs clearance	Inspection and registration of cargo, simplification of procedures for humanitarian aid.	Separate customs zones, inspection equipment.	Customs services.
5. Loading cargo for delivery	Preparation of cargo for transportation (cars, trains, planes).	Loading zones, lifts, conveyors.	Loading operators.
6. Cargo distribution	Delivery of goods to final destinations.	Truck routes, railway junctions, air corridors.	Logistics coordinators
7. Monitoring and reporting	Cargo tracking using GPS and RFID, analysis of operational efficiency.	Information systems, IoT (Internet of Things) devices for tracking.	Analysts, monitoring operators.

Source: compiled by the authors

Logistics in such work will be aimed at receiving, storing and sending humanitarian, military and critical cargo, organizing reserve

warehouses and delivery routes, and quickly reconfiguring processes to change supply directions.

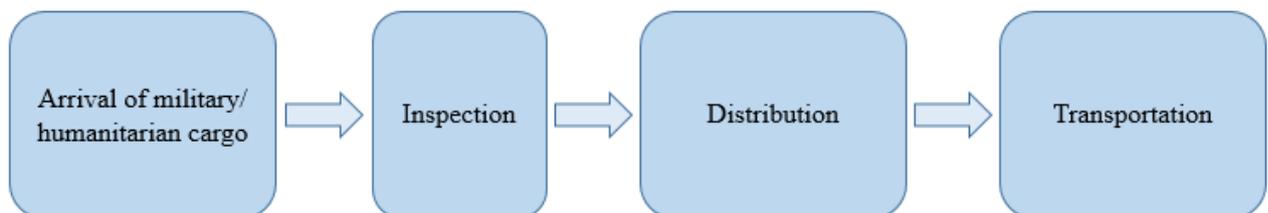


Figure 1 – Scheme of the cargo receiving and handling process

Source: compiled by the authors

The process of receiving and processing cargo (Fig. 1.) ensures the efficient delivery of military and humanitarian cargo and includes the following stages:

- arrival of cargo (at this stage, the vehicle with the cargo arrives at the unloading area, where the goods are registered and documents are checked);

- control and inspection (the process of checking the cargo takes place, which involves scanners, service dogs, x-rays and ist division into military and humanitarian supplies);

- distribution by storage zones (accordingly, military cargo is sent to special

hangars, and humanitarian aid, in other turn, is distributed among warehouses);

- preparation for shipment (including the formation of batches of goods, packaging and labeling, as well as loading into transport – air or road) [7].

It is obvious that in peacetime operational or financial risks are crucial, but in wartime they become systemic, interconnected and directly affect the safety of personnel, the stability of infrastructure and the efficiency of logistics processes [10].

A comprehensive understanding of these threats is a key condition for developing an effective risk management system that will ensure the continuity of logistics processes, which have always been accompanied by a number of diverse risks, and with the outbreak of the war, their number, probability of occurrence, and severity of consequences have increased many times over.

In the table below (Table 2) there are presented the main types of risks arising from the operation of airports caused by war.

Table 2. Classification of the main risks that arise during the operation of airports in wartime

Risk category	Description	Possible consequences
Security risks	Shelling, sabotage, missile strikes	Destruction of infrastructure, human casualties
Logistical risks	Airspace closure, route disruptions	Supply disruption, cargo losses
Technological risks	IT systems failure, cyberattacks	Management violations, information leaks
Financial risks	High costs for repairs, security and insurance	Unprofitability, need for governmental support
Operational risks	Shortage of fuel, personnel, equipment	Capacity reduction
Social risks	Evacuation, stress, decreased motivation	High employee turnover

Source: compiled by the authors

It can be seen that it poses a significant threat to the stable operation of airports. However, it should be noted that over three years of full-scale Russian invasion, most enterprises have been able to withstand numerous challenges and continue their activities; and given the above, such a development is possible for the aviation sector.

Conclusions. Safe airport operations during wartime require a combination of military control, modern technology, flexible routes, and airspace protection. The experience of other countries can be adapted

in Ukraine to organize closed but controlled air traffic.

Currently, it is not spoken about restoring the volume of Ukrainian air traffic that existed before the Russian invasion. However there is a possibility of transferring airports to cargo operations – one way to preserve the functionality of the air hub and maintain the country's logistics. And this, in turn, will make it possible to modernize the infrastructure and prepare for post-war recovery with an improved logistics base.

References

1. „The Great Fragmentation“ Driving Conflict: World Peace Plummet (2025, June 18). Vision of Humanity. <https://www.visionofhumanity.org/the-great-fragmentation-driving-conflict-world-peace-plummet/>
2. Andrijenko D. et al. (2024). Report on damages to infrastructure from the destruction caused by Russia's military aggression against Ukraine as of November 2024. Kyiv School of

economics. https://kse.ua/wp-content/uploads/2025/02/KSE_Damages_Report-November-2024-UA.pdf.

3. Airport Boryspil (2025, February 14). Ukrinform. <https://www.ukrinform.ua/tag-aeroport-borispil>
4. Hong, Seock-Jin & Kim, Woongyi & Hiatt, Brian (2025). Examining airport agility at air cargo hub airports. *Journal of Air Transport Management*, Elsevier, vol. 122.
5. Government portal. <https://www.kmu.gov.ua/>
6. Zakon Ukrainy „Pro krytychnu infrastrukturu“ vid 16.11.2021, 1882-IX / Vidomosti Verkhovnoi Rady 2023.
7. Puente-Mejia B., Lange A. (2025). Characterizing global air cargo: A study profiling air cargo operations worldwide. *Journal of Transport Geography*, Vol. 127.
8. Aviaperevezennia vantazhiv u voiennyi chas (n.d.). Avialohistyka. <https://aclogistic.ua/aviaperevezennya-vantazhiv/>
9. Korba G. (2022). Yak ukrainski aviakompanii zarobliaiut i zanepadaiut pid chas viiny. *BBC News Ukraine*. <https://www.bbc.com/ukrainian/features-63403865>.
10. International Air Transport Association (IATA) (2022). Risk Management Framework for Aviation. IATA.

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MATHEMATICAL MODEL OF DECISION MAKING DURING SEARCH AND RESCUE OPERATIONS AT SEA

Andrii Liamzin, Serhii Hodovaniuk, Iryna Borets, Viktoriia Klymenko. «*Mathematical Model of Decision Making during Search and Rescue Operations at Sea*». The article considers the issue of increasing the efficiency of search and rescue operations management at sea by applying the provisions of the queuing theory. A mathematical model of decision support in the system of coordination of rescue units is proposed, which takes into account the stochastic nature of the receipt of applications and the limited bandwidth of service channels. Examples of calculations of the system functioning efficiency indicators are given, which confirm the feasibility of using intelligent decision support technologies (IQ technologies) to increase the

efficiency of the response of search and rescue services. The practical significance of the use of mathematical modeling for reducing the time of information processing, making management decisions and transmitting commands to executors in difficult sea conditions is substantiated.

Keywords: maritime transport, search and rescue operations, queuing theory, efficiency, decision-making, IQ technologies

Андрій Лямзін, Сергій Годованюк, Ірина Борець, Вікторія Клименко. *«Математична модель прийняття рішень під час пошуково-рятувальних операцій на морі». У статті розглянуто питання підвищення ефективності управління пошуково-рятувальними операціями (ПРМ) на морі шляхом застосування положень теорії масового обслуговування. Запропоновано математичну модель підтримки прийняття рішень у системі координації дій рятувальних підрозділів, яка враховує стохастичний характер надходження заявок і обмежену пропускну спроможність каналів обслуговування. Наведено приклади розрахунків показників ефективності функціонування системи, що підтверджують доцільність використання інтелектуальних технологій підтримки прийняття рішень (IQ-технологій) для підвищення оперативності реагування служб ПРМ. Обґрунтовано практичну значущість застосування математичного моделювання для скорочення часу оброблення інформації, ухвалення управлінських рішень і передачі команд виконавцям у складних морських умовах.*

Ключові слова: морський транспорт, пошуково-рятувальні операції, теорія масового обслуговування, ефективність, прийняття рішень, IQ-технології

Introduction. Over the past decades, the issues of ensuring the safety and efficiency of maritime transport have become increasingly relevant due to the intensification of global cargo flows, the expansion of transport and logistics corridors and the increasing complexity of international transport networks. The maritime sector remains one of the most dynamic elements of the global economy, accounting for more than 80% of international trade. At the same time, with the development of maritime transport, the number of emergencies at sea is increasing, requiring timely and clearly coordinated search and rescue activities.

The efficiency of maritime search and rescue operations is determined not only by the technical readiness of forces and means, but primarily by the quality of management decision-making and coordination of actions within the system. In practice, delays in processing distress signals, forming response priorities and distributing rescue resources often lead to critical time losses, which directly affects the results of rescue missions

[1, 2]. That is why the optimization of management processes in the maritime search and rescue system is an important direction for increasing the efficiency of maritime logistics and ensuring shipping safety.

In modern scientific discourse, search and rescue operations management is considered as a component of logistics systems in which information, material and human flows are coordinated within a single management loop. This approach corresponds to the principles of adaptive logistics, which considers transport and emergency and rescue networks as dynamic systems with limited capacity and stochastic nature of functioning [3, 4]. From this perspective, the process of receiving and processing rescue requests can be described using the theory of queuing, which allows us to quantitatively assess the efficiency of the system and identify bottlenecks in the use of resources.

Relevance of research is due to the need to reduce the time for organizing and conducting rescue operations, which directly

depends on the efficiency of collecting, processing and analyzing information, the speed of decision-making and transmitting commands to executors. The use of mathematical tools in this context creates a methodological basis for increasing the speed of management decisions, determining the optimal number of service channels and predicting the behavior of the system at different load levels [5–7].

In parallel, there is a steady trend in the maritime industry towards digitalization and the introduction of intelligent management technologies that provide real-time decision support based on data analytics and predictive algorithms [8, 9]. The integration of IQ technologies into the search and rescue operations management system contributes to increasing the adaptability of management processes, minimizing response delays and strengthening the resilience of maritime transport systems to crisis situations.

Therefore, the scientific problem addressed in the article is to develop and substantiate a mathematical model of decision-making in the maritime search and rescue system, built on the principles of the queuing theory and adaptive logistics. The proposed approach combines theoretical principles and practical mechanisms for managing dynamic information flows and can be used to increase the efficiency of maritime coordination and rescue centers within the integrated system of maritime transport and shipping safety.

Literature review. The formation of the maritime transport safety management system as an integrated interdisciplinary field is closely related to the development of logistics, management theory and operations research. Over time, maritime logistics has evolved from a narrowly functional understanding focused only on transportation and shipping planning to a strategic, systemic subject that encompasses efficiency, safety and environmental responsibility. This transformation is due to the growing complexity of global transport and logistics systems, the digitalization of

operational processes and the need for effective management of emergencies at sea [1, 2].

The theoretical basis for modeling emergency situations and rescue processes at sea is the queuing theory, which has been actively used in transport research since the middle of the 20th century. The classic works of A. Erlang, D. Kendall and J. Little created a mathematical apparatus for analyzing random flows and service processes [3]. In the maritime industry, these principles were adapted for modeling the movement of sea vessels, port processes, and later for organizing search and rescue operations [4, 5].

Early research in the field of search and rescue management was mainly organizational, aimed at standardizing procedures and creating an international regulatory framework, in particular the International Aeronautical and Maritime Search and Rescue Manual (IAMSAR Manual), developed by ICAO and IMO [6]. These documents defined the structure of coordination centers, the procedure for information exchange, the division of responsibilities and the decision-making hierarchy. However, subsequent scientific research focused on the stochastic nature of distress signal flows and the need to use adaptive mathematical models to improve the efficiency of the management system [7].

At the end of the 20th and beginning of the 21st centuries, a number of Ukrainian scientists (Kondratyuk, 2020; Godovanyuk, 2020; Simonov, 2021) proposed applying logistics principles to the management of search and rescue processes at sea. They considered the maritime rescue system as a component of a transport and logistics network, within which the coordination of information and human flows determines the overall efficiency of the system [8–10]. In this context, the queuing model is used to describe the flow of applications, determine the probability of service, queue length, and average response time.

Modern research proves that modeling search and rescue operations requires a combination of deterministic and probabilistic approaches. Thus, according to the conclusions of Bakharev and Khokhlov (2020), the random nature of the occurrence of emergency events at sea allows the use of Poisson distributions and the exponential law to model the flow of applications and the duration of their service [11]. This makes it possible to determine critical points of system overload and its behavior under extreme conditions, for example, during storms or mass rescue operations.

At the same time, the development of intelligent maritime logistics has led to the introduction of digital and analytical technologies into the process of managing rescue operations. The use of simulation modeling, machine learning, and real-time decision support systems allows predicting vessel movement routes, detecting anomalies, and automating the coordination of rescue units [12, 13]. Studies by Pagonis and Balbo (2022), Shiryayev and Bogdanov (2021) confirm that the combination of mathematical modeling and artificial intelligence-based analytics increases the efficiency of marine emergency management [14, 15].

From the perspective of logistics theory, search and rescue management corresponds to the concept of adaptive logistics, according to which the system should respond flexibly to changes in the external and internal environment. As Trushkina and Dzvigol (2021) point out, modern logistics systems are based on the principles of flexibility, digital integration and resilience, which are the main factors of the efficiency of complex transport networks [16]. Accordingly, the integration of search and rescue systems into the broader digital ecosystem of maritime logistics reflects the global trend towards Logistics 4.0, which is characterized by automation, interconnectedness and predictive analytics [17, 18].

In addition, the concept of sustainable and resilient logistics has become

widespread, within which the management of rescue processes should ensure a balance between the speed of response, the rational use of resources and the minimization of environmental impact [19, 20]. International organizations, in particular IMO and UNCTAD, emphasize that digital transformation, the implementation of intelligent systems, and taking into account the human factor are key conditions for creating resilient maritime infrastructures capable of effectively responding to emergencies [21, 22].

Thus, the literature review shows that the maritime search and rescue management system is gradually moving from static procedural models to adaptive, data-driven systems that integrate logistics principles, mathematical modeling, and intelligent technologies. This evolution is shaping a new interdisciplinary paradigm, within which maritime transport safety management is viewed as a field that combines logistics, mathematics, computer science, and control theory to achieve optimal levels of responsiveness, coordination, and resilience of maritime transport systems.

Purpose of research is to improve the efficiency of search and rescue operations management at sea by creating a mathematical model of decision-making based on the principles of the queuing theory. This approach allows to quantitatively assess the dynamics of information flows, determine the load on the control system and justify ways to reduce response time in the process of rescue operations.

To achieve the purpose, the following **objectives** were solved in the research:

- modern approaches to managing search and rescue operations at sea were analyzed;
- the possibilities of applying the queuing theory to model the processes of receiving and processing requests were considered;
- the diagram of managing search and rescue operations' logistical process was developed;

– examples of calculations of the main indicators of the system's efficiency were performed;

– conclusions regarding to the need of implementing the intelligent decision-making support technologies (IQ technologies) in the field of maritime rescue were formulated.

Research methodology is based on the use of theoretical-analytical and mathematical approaches. The main tool is the apparatus of the theory of queuing, which allows us to model the process of receiving applications, assess the system load and determine the probability of service failure. To describe practical situations, elements of simulation modeling and comparative analysis were used, which made it possible to assess the efficiency of the search and rescue service under different load conditions.

The research is analytical in nature and is based on the generalization of scientific publications, official documents of the International Maritime Organization (IMO) and the results of our own calculations. The conclusions obtained can be used to improve the organizational structure of maritime search and rescue services and increase the efficiency of their work.

Basic material and results. One of the key areas of improving the efficiency of maritime transport management and ensuring shipping safety is reducing the time

for organizing and conducting search and rescue operations. This involves optimizing the duration of the management cycle - from collecting and processing information to making decisions and transmitting coordination commands to performers.

According to the logistical approach, such optimization is considered as a process of increasing the efficiency of managing information flows, resources and actions within a single maritime transport system.

The application of methods of the queuing theory allows formalizing the patterns of receipt, sequence and processing of requests in the dynamic environment of maritime transport [1, 30].

Let's consider the process of processing requests for search and rescue operations within the maritime transport logistics system using the provisions of the queuing theory (Fig. 1).

The system for organizing search and rescue operations at sea can be considered as an element of managing logistical flows in the maritime transport system, which combines information, material and human resources in order to ensure the continuity of the process of responding to emergency events. Such a system operates on the principles of adaptive management, where management decisions are made taking into account the real state of the load and the priority of tasks.

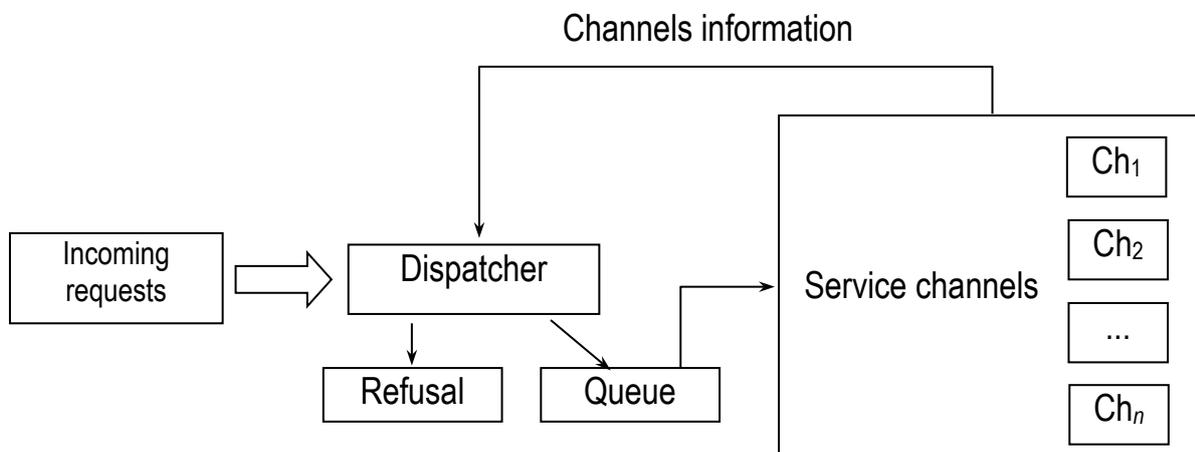


Figure 1 – Processing rescue requests using the principles of the queuing theory

Source: developed by authors

Its structure includes a number of interconnected stages typical for logistics processes in maritime transportation:

information and analytical unit collects and initially processes requests from vessels that find themselves in difficult navigation conditions;

coordination and dispatch center (human or automated system) ensures registration of requests, determines the procedure for their execution, routes information flows to executive units (State Maritime Rescue Coordination Center, Maritime Rescue Subcenter) and can form a queue in case of system overload;

queue-storage unit functions as a regulator of logistical flows, ensuring optimization of priorities and resource use;

service node forms the structure of response channels according to the type and scale of the event;

service channels reflect the operating states of the system ("free", "busy", "inoperative") and determine the real throughput capacity of the rescue network;

service refusal is the result of exceeding the system's capacity or individual channels failing, requiring management intervention to reallocate resources.

In the event of emergencies at sea, one of the key efficiency indicators of the maritime search and rescue system is the timeliness and quality of response to information flows about disaster events. An appropriate response requires not only the technical readiness of units, but also a high level of coordination, information interaction and management consistency between all links of the logistics system.

Effective management includes: prompt reception of messages, rapid search coordination, rational allocation of resources and ensuring continuity of the management cycle - from the receipt of a signal to the completion of the rescue operation. Fulfilling these conditions allows to significantly reduce time, increase the stability of functioning and efficiency of the maritime rescue system.

Requests for rescue operations are received by the system at random moments of time, which determines the stochastic nature of the management process. Similarly, the duration of processing each request depends on the complexity of the situation, geographical conditions, type of vessel and other factors, therefore it has a random nature. In terms of the queuing theory, the receipt of each request to the system is considered as *the event*, and the set of such events forms *the input flow*. In turn, the execution of requests and the completion of operations constitute *the output flow*, which reflects the throughput of the system and the level of its organizational coherence.

The mathematical apparatus of the queuing theory allows us to quantitatively assess the efficiency of the logistical management of the search and rescue process depending on the characteristics of the request flows, the selected discipline of their service and the level of resource utilization [1; 2].

The indicators obtained in the modeling process make it possible to assess the behavior of the system not only in the conditions of a single event, but also in the medium-run period, which is especially important for resource planning and load forecasting in the field of maritime transportation.

In the research, the incoming flow of information messages (requests) about emergency situations at sea is considered as the simplest flow of events. This approach is appropriate, since it is the simplest flows that most often describe the nature of the arrival of distress signals in real conditions of maritime transport operation.

In a search and rescue management system, this means that the moment of receipt of each request is random and does not depend on previous events, which allows the use of the Poisson model to estimate the intensity of the flow.

The simplest flow of requests has the following properties:

- randomness and independence of events: the receipt of the next request does not depend on the time of receipt of the previous one;
- stationarity of the flow: the intensity of the receipt of request (λ) remains constant during the analyzed period;
- constant average intensity: the average number of requests received per unit of time does not change within the selected observation interval;
- ordinariness: at any given time, only one request is received in the system; the probability of simultaneous receipt of two or more requests is insignificant;
- mass nature of the process: during large-scale events (storm, accident, mass accumulation of vessels), the number of requests can increase significantly, but the general pattern of the flow remains close to the Poisson model.

The request of the simplest flow model in the logistic analysis of maritime search and rescue systems allows to quantitatively describe the load on the control system, to estimate the probability of overloading of service channels, and to optimize the distribution of resources in space and time. This approach provides the basis for building adaptive algorithms for responding to and predicting situations in the field of maritime transport safety.

As noted in [2], in most practical cases, the efficiency of the functioning of maritime search and rescue systems can be adequately assessed by replacing complex non-stationary request flows with simpler ones, provided that they have the same intensity density. This is explained by the fact that the sum of a large number of ordinary and stationary flows with different aftereffect parameters forms the resulting flow, which in its characteristics approaches the simplest. Such an effect is analogous to the action of the central limit theorem, according to which the total influence of individual random processes tends to normalize.

However, in real conditions of operation of marine control systems, the flow of

requests rarely remains stationary. The non-stationarity of information flows is most clearly manifested during the occurrence of mass or sudden events – when the intensity of incoming signals increases sharply. This is typical for periods of increased navigation activity, in particular in the summer, when the number of small tonnage vessels, yachts and passenger routes increases. Under such conditions, the probability of accidents increases, in particular, loss of control of vessels during storms, damage to the hull, or the need to provide emergency medical care to the crew, which forms peak loads on the maritime search and rescue system [2].

To ensure the stable operation of the system in such conditions, indicators of the success of the actions of the Search and Rescue Service at Sea are used, which allow assessing its efficiency from two interrelated positions – operational reliability and logistical productivity. The main indicators include:

- maximum system throughput (the number of requests that can be processed per unit of time during extreme situations);
- average waiting time for request service (minimization of downtime in the queue);
- service channel load factor (degree of use of system resources);
- economic efficiency of the service operation – maximizing the result from the use of available resources in a given time interval.

Comparative analysis of different configurations of the Maritime Search and Rescue Service allows to determine the optimal parameters of its functioning, to find a rational balance between the speed of response, reliability and resource costs, as well as to formulate recommendations for improving the structure of the service. Thus, the integration of mathematical models of mass service into management solutions allows to increase the efficiency of maritime logistics security systems and reduce time losses during rescue operations.

To practically confirm the efficiency of the request of the queuing theory provisions, we

will consider a number of elementary operations of managing the flow of requests aimed at reducing the time for processing information, making decisions and delivering commands to the executors. The implementation of these processes is significantly influenced by random factors, such as weather conditions, the number of simultaneous emergency events or the technical condition of rescue vehicles.

Let the Maritime Search and Rescue Service receive approximately two requests at random every 10 hours. Determine the probability $p_i(t)$ flow of receiving an average of four requests in 30 hours.

The probability flow of applications received in a time period t is calculated using the formula:

$$p_i(t) = \frac{(\lambda t)^i}{i!} e^{-\lambda t}, \quad i = 0, 1, 2, \dots \quad (1)$$

The following notations are introduced in formula (1):

λ – intensity of requests: $\lambda = \frac{2}{10} \text{ hour} = 0.2 (\text{hour})^{-1}$;

t – time during which request were received: $t = 30 \text{ hour}$;

i – number of requests (messages): $i = 4$.

Then:

$$p_4(t) = \frac{(0.2 \cdot 30)^4}{4!} e^{-0.2 \cdot 30} = \frac{6^4}{24} e^{-6} = \frac{1296}{24} 0.025 \approx 0.134.$$

i.e. the probability flow of four requests for service within 30 hours is $p_4(t) \approx 0.134$.

In the second example, let's consider a situation where the Maritime Search and Rescue Service receives an average of about 1.2 requests per hour during extreme conditions, during mass search and rescue operations. The average duration of one call is 10 service minutes.

It is necessary to determine the main characteristics of the queue system and evaluate the efficiency of its operation.

Input data:

– incoming flow of requests – the simplest with intensity $\lambda = 1.2 (\text{hour})^{-1}$,

– the intensity of the flow of service requests has

$$\mu = 10(\text{min})^{-1} = 0.17 (\text{hour})^{-1},$$

– service channel load factor: $\rho = \frac{\lambda}{\mu} = \frac{1.2}{0.17} = 7.06$.

Probability of service of the request $p_{serv} = p_0 = \frac{1}{1+\rho} = \frac{1}{1+7.06} = 0.12$.

Probability of service refusal $p_{ref} = p_1 = \frac{\rho}{1+\rho} = \frac{7.06}{1+7.06} = 0.88$.

Thus, the system serves only 12% of calls, which is unsatisfactory.

Absolute system throughput $A = \lambda \cdot p_{serv} = 1.2 \cdot 0.12 = 0.144 (\text{hour})^{-1}$, that is, on average, requests are served per hour.

The results obtained indicate that the traditional model of information flow management in the search and rescue service does not meet modern requirements for speed of response and adaptability. To increase the efficiency of the system, it is advisable to implement intelligent logistics

technologies (IQ technologies), which provide:

– automated processing of incoming signals in real time;

– analytical forecasting of the load on service channels;

- optimization of the order and priority of requests;
- integration of information flows with marine vessel monitoring systems (AIS, SAR, VTS).

Thus, the use of mathematical modeling in combination with intelligent logistics technologies allows you to create an adaptive management system for maritime search and rescue operations, which ensures reduced response time, increased reliability of solutions, and efficient use of resources within the transport and logistics infrastructure of the maritime sector.

Conclusions. As a result of the research, it was substantiated that the application of the queuing theory is an effective scientific and methodological basis for optimizing the management of search and rescue operations at sea. The developed mathematical model allows us to quantitatively assess the efficiency of the system, taking into account the random nature of the receipt of requests, the limited throughput of service channels and the stochastic features of maritime emergencies.

It is shown that the simplest flow model, which is based on the Poisson distribution, adequately describes the statistical nature of the receipt of rescue requests in maritime logistics systems. This approach allows us to assess the level of system loading, the probability of service requests, the average waiting time and the risk of channel overload, which are key indicators of the operational efficiency of rescue coordination centers.

The results of analytical calculations show that in conditions of high intensity of incoming signals, the current search and rescue system is able to service only about 12% of incoming calls, which indicates a low level of throughput and the need to modernize the information and management infrastructure. This necessitates the introduction of intelligent decision-making support technologies (IQ technologies).

Such technologies provide automated data processing in real time, analytical forecasting of the load on service channels,

dynamic prioritization of requests and integration with vessel traffic monitoring systems (AIS, SAR, VTS). Their implementation increases the adaptability of management processes and improves coordination between units within maritime logistics systems.

The scientific novelty of the research lies in integrating the principles of logistics, cybernetics and management sciences, forming a comprehensive model of adaptive decision-making in the maritime transport safety system. The research contributes to the development of interdisciplinary methods that combine mathematical modeling, information flow management and risk analysis within a single management paradigm.

The practical significance of the results obtained lies in the possibility of their use to increase the efficiency of maritime coordination and rescue centers, the creation of digital emergency management systems, as well as the modernization of training programs for maritime specialists in the fields of logistics and security management. The proposed model can serve as the basis for the development of intelligent search and rescue operations management systems that can optimize resource allocation and minimize response time in conditions of uncertainty.

Prospects for further research include empirical verification of the proposed model in real-world conditions of maritime rescue services, as well as the development of hybrid algorithms that combine mathematical modeling, artificial intelligence, and predictive analytics. Such research will contribute to the creation of modern decision support systems that integrate technological, organizational, and human factors, increasing the resilience and efficiency of the maritime transport sector as a whole.

References

1. Kondratiuk, O. M. (2020). Metodolohiya modelyuvannya protsesiv upravlinnya bezpekoju na morskomu transporti. Dys. ... d-ra tekhn. nauk. Odesa: ONMU.
2. Hodovanyuk, S. P. (2019). Models and methods of management of search and rescue operations at sea under uncertainty. Dys. ... Cand. Tech. Sci. Kyiv: National Aviation University.
3. IMO (2022). International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual. Vol. I–III. London: International Maritime Organization.
4. ICAO & IMO (2023). Global SAR Plan: Maritime and Aeronautical Cooperation. Montreal – London.
5. Simonov, V. I., ta in. (2021). Lohistychny upravlinnya na transporti. Kyiv: NAU.
6. Tyurina, N. M., Hoy, I. M. (2021). Lohistyka: navchalnyy posibnyk. Kyiv: Tsentr uchbovoyi literatury.
7. Zharska, I. O. (2019). Logistics: Educational Manual. Odesa: ONEU.
8. Marchenko, V. M., & Shutuyuk, V. V. (2022). Logistics. Kyiv: NUKhT.
9. Lambert, D. M., & Stock, J. R. (1993). Strategic Logistics Management. Homewood, IL: Irwin.
10. Bowersox, D. J., Closs, D. J., & Helferich, O. K. (1991). Logistical Management. 3rd ed. New York: McMillan.
11. Christopher, M. (2016). Logistics and Supply Chain Management. Pearson UK.
12. Mentzer, J. T., Min, S., & Bobbitt, L. M. (2004). Toward a Unified Theory of Logistics. *International Journal of Physical Distribution & Logistics Management*, 34(8), 606–627.
13. Ballou, R. H. (2007). The Evolution and Future of Logistics and Supply Chain Management. *European Business Review*, 19(4), 332–348.
14. Dzwigol, H., Trushkina, N., & Kwilinski, A. (2021). Green Logistics as a Sustainable Development Concept of Logistics Systems in a Circular Economy. *IBIMA Proceedings*, 37, 2021.
15. Hofmann, E., & Rüsck, M. (2017). Industry 4.0 and the Current Status and Future Prospects on Logistics. *Computers in Industry*, 89, 23–34.
16. Junge, A. L., Verhoeven, P., & Mansfeld, M. (2019). Pathway of Digital Transformation in Logistics: Best Practice Concepts and Future Developments. TU Berlin.
17. Trushkina, N., Dzwigol, H., & Serhieieva, O. (2020). Development of the Logistics 4.0 Concept in the Digital Economy. *Economic Bulletin of Donbas*, 4(62), 85–96.
18. Hou, H., Chaudhry, S., Chen, Y., & Hu, M. (2017). Physical Distribution, Logistics, Supply Chain Management, and the Material Flow Theory. *Information Technology and Management*, 18, 107–117.
19. McKinnon, A., Browne, M., Whiteing, A., & Piecyk, M. (2015). *Green Logistics: Improving the Environmental Sustainability of Logistics*. Kogan Page Publishers.
20. Bakharev, V., & Khokhlov, V. (2020). Application of Queueing Theory to the Management of Search and Rescue Operations at Sea. *Marine Science and Technology Bulletin*, 9(3), 145–156.

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21. Pagonis, D., & Balbo, S. (2022). Decision Support Models for Maritime Emergency Management. *Journal of Navigation*, 75(4), 891–909.
 22. Shirayayev, A., & Bogdanov, I. (2021). Simulation Modeling of Maritime SAR System Performance. *Transport Problems*, 16(4), 27–39.
 23. Van Fenema, P. C., & Van Kampen, T. (2020). Foundational Concepts of Military Logistics. *Handbook of Military Sciences*, 1–25.
 24. Aćimović, S., & Mijušković, V. (2021). Military Logistics vs. Business Logistics. *Economic Analysis*, 54(1), 118–138.
 25. Klumpp, M., & Ruiner, C. (2022). Artificial Intelligence, Robotics, and Logistics Employment. *Journal of Business Logistics*, 43(3), 297–301.
 26. Delfmann, W., Günthner, W., & Klaus, W. (2010). Towards a Science of Logistics: Cornerstones of a Framework. *Logistics Research*, 2(2), 57–63.
 27. Fisher-Holloway, B., & Mokhele, M. (2022). The Deployment of Theory in Logistics Research. *Journal of Transport and Supply Chain Management*, 16, a716.
 28. Rodrigue, J. P., & Notteboom, T. (2020). *The Geography of Transport Systems*. 5th ed. New York: Routledge.
 29. UNCTAD (2023). *Review of Maritime Transport 2023*. Geneva: United Nations.
 30. IMO (2024). *Safety of Life at Sea (SOLAS) Convention – 50 Years of Global Impact*. London: IMO Publications.

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INSTITUTIONAL BASIS OF AIR TRANSPORT ORGANIZATION: CURRENT STATE AND DEVELOPMENT PROSPECTS

Olena Harazha, Dmytro Shevchuk. *«Institutional basis of air transport organization: current state and development prospects».* The article analyzes the institutional foundations of the organization of air transportation in the context of the current state and prospects for further development.

High-speed delivery of goods by aircraft provides advantages over other popular types of transportation by land and water vehicles. The development of the air transport industry becomes the main factor in strengthening the competitiveness of the transport complex of the national economy. The latest modern information and communication tools of technological processes of processing, analysis and provision of information provide wider opportunities for improving the quality of delivery of goods from the seller to the buyer. At the same time, the issues of institutional support for international transportation, which involve the location of departure and destination points on the territory of two different states or one country with an intermediate stop on the territory of another state, while national transportation is carried out within the borders of one country by licensed business entities on a paid basis, require in-depth study. own or leased aircraft. After all, achieving efficiency from the organizational activity of air transportation is possible thanks to the functioning of the institutional base, the development of which is becoming an extremely urgent problem today.

The purpose of our work is to study the institutional foundations of the organization of international and national air transport of passengers and cargo in the context of sustainable development of the national economy of an individual state and globalization processes at the world level. The primary task of our research

is to identify the challenges and prospects of institutional support for air carriers to improve the quality of passenger service and international cargo delivery.

The disclosure of the purpose and the solution of the set tasks was carried out on the basis of comparative legal and operational methodological approaches with a set of methods of abstraction, concretization, formalization and analogy, induction and deduction. The statutes of international aviation organizations, normative legal acts and rules, scientific developments of domestic and foreign scientists served as reference material.

Based on the results of the study, three directions for the formation of the institutional foundations of the organization of air transportation of goods at the international level were identified: development and guarantee of the fulfillment of contractual conditions by air carriers when transporting goods by several modes of transport; compliance with international quality standards for the provision of transport services by air carriers in the context of fast and safe delivery of goods from the seller to the buyer; increasing the efficiency of the transport activity of air carriers due to the optimization of cargo transportation routes taking into account external and internal factors influencing the existing institutional environment. The prospects for the development of institutional support for air transportation through the implementation of the best global experience in the organization of air transportation are characterized; active participation in international aviation organizations regarding the development of institutional norms and rules for air transportation of cargo and passengers; strengthening of international economic cooperation, balancing the interests of business entities of different countries, for which the rules of concluding international contracts and conducting commercial transactions are important elements.

The key provisions of the institutional foundations of the organization of air transportation are international aviation organizations and regulatory provisions regarding improving the quality of service and flight safety, institutional support for the development of multimodal transportation and the creation of large transnational transport hubs with the latest information and technological equipment.

Keywords: institute, contract, international cooperation, transport, air carrier, cargo, rules, standards

Олена Гаража, Дмитро Шевчук. «Інституціональні засади організації авіаційних перевезень: поточний стан та перспективи розвитку». У статті аналізуються інституціональні засади організації авіаційних перевезень в контексті сучасного стану та перспектив подальшого розвитку.

Швидкісна доставка вантажів повітряними суднами надає переваги серед інших популярних видів транспортування наземними та водними транспортними засобами. Розвиток авіатранспортної галузі стає головним чинником посилення конкурентоспроможності транспортного комплексу національної економіки. Найновітніші сучасні інформаційно-комунікаційні інструменти технологічних процесів обробки, аналізу та надання інформації надають ширші можливості для поліпшення якості доставки вантажів від продавця до покупця. Водночас, поглибленого вивчення потребують питання інституціонального забезпечення міжнародних перевезень, які передбачають розміщення пунктів відправлення та призначення на території двох різних держав або однієї країни із проміжною зупинкою на території іншої держави, а національні перевезення здійснюються в межах однієї країни ліцензованими суб'єктами господарювання на платній основі власним повітряним судном або у лізингу. Зрештою, досягнення ефективності від організаційної діяльності авіаційних перевезень можливе завдяки функціонуванню інституціональної бази, розвиток якої стає надзвичайно актуальною проблемою сьогодення.

Метою нашої роботи є вивчення інституціональних засад організації авіаційних перевезень пасажирів та вантажів міжнародного та національного рівня в контексті сталого розвитку національної економіки окремої держави та глобалізаційних процесів світового рівня. Похідне

завдання нашого дослідження – виявити виклики та перспективи інституціонального забезпечення авіаперевізників для підвищення якості обслуговування пасажирів та доставки вантажів міжнародного рівня.

Розкриття мети та вирішення поставлених завдань проведено на основі порівняльно-правового та діяльнісного методологічних підходів із сукупністю методів абстрагування, конкретизації, формалізації та аналогії, індукції та дедукції. Довідковим матеріалом слугували статuti міжнародних авіаційних організацій, нормативно-правові акти та правила, наукові розробки вітчизняних і закордонних вчених.

За результатами дослідження виділено три основні напрями формування інституціональних засад організації авіаційних перевезень вантажів міжнародного рівня: розробка та гарантування виконання договірних умов авіаперевізниками при транспортуванні вантажів декількома видами транспорту; дотримання міжнародних стандартів якості надання транспортних послуг авіаперевізниками в контексті швидкої та безпечної доставки товару від продавця до покупця; підвищення ефективності транспортної діяльності авіаперевізників за рахунок оптимізації маршрутів перевезень вантажів з урахуванням зовнішніх та внутрішніх факторів впливу існуючого інституціонального середовища. Охарактеризовано перспективи розвитку інституціонального забезпечення авіаційних перевезень шляхом впровадження найкращого світового досвіду організації авіаційних перевезень; активна участь у складі світових авіаційних організацій з приводу розробки інституціональних норм та правил авіаційних перевезень вантажів та пасажирів; зміцнення міжнародного економічного співробітництва, врівноважуючи інтереси суб'єктів господарювання різних країн, для яких важливими елементами стають правила укладання міжнародних контрактів та проведення комерційних операцій.

Ключовими положеннями інституціональних засад організації авіаційних перевезень стають міжнародні авіаційні організації та нормативно-правові положення стосовно підвищення якості обслуговування та безпеки польотів, інституціональне забезпечення розвитку мультимодальних перевезень та створення великих транснаціональних транспортних вузлів з новітнім інформаційно-технологічним обладнанням.

Ключові слова: морський транспорт, пошуково-рятувальні операції, теорія масового обслуговування, ефективність, прийняття рішень, IQ-технології

Introduction. Aviation is a modern fast and comfortable mode of transport that transports passengers and cargo to any country in the world and has significant competitive advantages over rail and road transport systems. Therefore, the development of civil aviation and the organization of transportation become priority issues at the national level of many countries of the world. In turn, air transportation and use of air space becomes the object of regulation of national and international law. Scientific and technical achievements and the use of state-of-the-art information and communication tools in the latest technological processes of processing, analysis, data accumulation and their

connections have become the driving force for dynamic changes in national legislation in general and in its individual branches, in particular. Therefore, international transportation involves placement of destinations on the territory of two different states or one country with a stopover on the territory of another state on the basis of a contract, and national transportation is carried out within the borders of one country by licensed business entities on a paid basis with their own aircraft or under leasing. After all, achieving efficiency from the organizational activity of air transportation is possible thanks to the functioning of the institutional base, the development of which

is becoming an extremely urgent problem today.

Analysis of recent research and publications. The institutional foundations of the organization of air transportation are the subject of research in numerous works of international and domestic scientists. O. M. Kyrylenko, O. B. Naumov, V. O. Novak, K. M. Razumova [1], D. Bugayko, Yu. Ierkovska [2], B. Kenneth, G. McDougall [3] reviewed regulatory changes affecting different parts of the air transport supply chain, different ownership models and ways of providing traffic management and navigation services, the formation of integrated air transport associations, the concept of national aviation risk management, as well as a number of institutional measures: harmonization of national regulation of air transport with the requirements of global and regional levels, development of mechanisms for commercial protection of domestic air transport enterprises, implementation of strategic scenarios for the sustainable development of air transport. J. Thums, L. Künzel, M. Klumpp, M. Bardmann, C. Ruiner [4] investigated air cargo logistics as a component of the latest technologies and international cooperation, the main developments in the cooperation of people and digital systems, the safety of human-technology interaction, and the measurement of productivity due to digitization in airports and the air transport sector. A. Reynolds-Feighan [5] revealed the influence of institutions on the development of international aviation, the spatial distribution of traffic (connections between firm behavior, industry structure and organization, as well as the spatial manifestation of transport production solutions at the national, regional and local levels), the full cost of accessibility due to the "efficiency-availability" compromise, institutions for working with multimodal transport and promoting international combined transportation. B. Kenneth [6] examined the activities of the Ryanair "organization" in relation to other airline "organizations" within the existing set of legal

"institutions" created by the European Union, as well as mergers and new forms of airlines. K. Yokoyama [7] analyzed air transport through the change of institutions and customs of trade operations, as well as the transformation of transactional institutions. A. Odoni [8] studied changes in the international and national regulatory environment of the aviation industry, as well as the influence of governmental and non-governmental organizations (agencies and associations) at the international and national level on regulatory, supervisory or advocacy roles in critical issues (security, economy, defense and defense) of air transport. E. Schneider de Almeida, H. Bettini [9] studied the internationalization of airlines regarding the institutional environment, hybrid forms of organization and management, access of airlines to international markets through bilateral or multilateral agreements between nations. A. Kuhait, S. Mohammed, M. Jasim [10] studied airports from the point of view of multi-functional institutions that perform different activities and provide different services. They proved that the performance-based analysis method provides useful information for the public management of the airport, which allows it to make decisions to increase productivity and improve the implementation of various activities of the airport, which positively affects the quality of services provided to citizens. However, the institutional foundations of the organization of air transportation require a deeper study, based on the significant scientific achievements of scientists from many countries around the world, which confirms the relevance of the chosen topic.

The purpose of the article is to study the institutional foundations of the organization of international and national air transportation of passengers and cargo in the context of sustainable development of the national economy of an individual state and globalization processes at the world level. The derivative task of our research is to identify the challenges and prospects of institutional support of air carriers to improve the quality

of passenger service and international cargo delivery.

Presentation of the main research material. Modern institutional transformation processes are determined by constant changes in the institutional environment under the influence of many internal and external factors. The rapid development of modern technologies creates grounds for the formation of a decisive role of the state as a regulator of social relations, a guarantor and a controller of compliance with established norms and rules. In particular, the effective functioning of modern society requires the creation of a competitive development of the aviation industry. Therefore, the organization of air transportation is influenced by institutional norms and rules, which are established thanks to the state regulation of the aviation industry for the implementation of its tasks, goals and functions in a harmonious combination with the private interests of individual citizens. At the same time, the institutional regulation of air transport involves the formation by law-making international and national organizations and institutions of a system of creating favorable socio-economic relations to guarantee the continuous development of the chain of high-quality deliveries within the air transport system, taking into account multimodal principles with the highest social significance highlighted [11]. Therefore, the state acts as a guarantor of the existence and organization of air transportation to ensure the needs of the economy and the population in obtaining transport services for the economic development of regions and increasing the level of providing citizens with high-quality and safe aviation services. According to the Law of Ukraine "On Transport", air transport includes air transport enterprises that carry out the transportation of passengers, cargo, baggage, mail, aerial photography, agricultural works, as well as airports, airfields, aero clubs, vehicles, air traffic control systems, educational institutions, civil aviation repair plants and other enterprises, institutions and

organizations, regardless of the forms of ownership, that ensure the operation of air transport [12]. The aviation rules of Ukraine "Rules of air transportation of cargo" apply to all subjects of aviation activity and determine the conditions of air transportation of cargo and are mandatory for all subjects of aviation activity [13]. The main document that regulates the procedures and rules for customs security of cargo transportation is the Kyoto Convention [14], which is the Law of Ukraine No. 227-V "On Ukraine's Accession to the Protocol on Amendments to the International Convention on Simplification and Harmonization of Customs Procedures" [15]. The Kyoto Convention envisages cooperation between the state and business on partnership terms to establish rational relations between the interests of the state and the private sector of the economy. In accordance with the Special Annex, all stages of cargo registration are established, from the moment of their arrival at the customs territory, temporary storage, transit, to the moment of creation of economic customs regimes for the purpose of processing, temporary importation, free zones. Prevention of offenses in foreign economic activity has transnational features. Therefore, the effective interaction of customs organizations of different countries will counteract the distribution of narcotics, terrorist acts, weapons, evasion of customs payments and other economic offenses. At the same time, modern information technologies will facilitate similar cooperation between the customs services of Ukraine and foreign countries. Based on the Kyoto Convention, each state has the right to independently justify and adopt a set of norms and rules that correspond to its economic environment and the level of development of the transport system.

International economic cooperation affects the development of the economy of the state and the world, affecting the interests of business entities of various countries, for which the rules of concluding international contracts and commercial transactions are

important elements. In accordance with the Law of Ukraine "On Foreign Economic Activity" dated April 16, 1991, a foreign economic agreement (contract) is a materially executed agreement between two or more subjects of foreign economic activity and their foreign counterparties, aimed at establishing, changing or terminating their mutual rights and obligations in foreign economic activity [16]. Therefore, two features of the conclusion of the contract are distinguished: firstly, one of the subjects is a foreign entrepreneur, secondly, the fulfillment of special conditions must be observed. The written form of the contract usually prevails. At the same time, international commerce contains various contracts in which the content and structure are formed under the influence of the type of foreign economic transaction. Thus, insurance contracts, transportation, loans, licensing, franchising, exchange and leasing agreements, foreign trade contracts of sale, contract, etc. are distinguished.

Institutional regulation of the conclusion of international agreements is carried out by the International Chamber of Commerce through the development and distribution of collections of "International rules for the interpretation of trade terms" - Incoterms, which contain a single set of international rules and trade terms at the international level. Therefore, Incoterms allows you to avoid differences in the interpretation of legal provisions of transport concepts of different countries. In the process of concluding agreements on the transportation of goods, the following must be determined: the name of the port of loading (unloading) of goods, transshipment point, cargo transfer; substantiation of the terms of the charter or bill of lading; providing information about the arrival of the vessel at the port of loading (unloading); inspection of the vessel in accordance with the provisions of its readiness for the ability to carry out cargo transportation. Therefore, the use of Incoterms rules is regulated by Clause 4 of Article 265 of the Economic Code of Ukraine

[17], Article 14 of the Law of Ukraine "On the Application of Special Measures Regarding Imports to Ukraine" [18], Article 8 of the Law of Ukraine "On Transport and Forwarding Activities" [19], Clause 2.19 of Article 2 of the Law of Ukraine "On State Support of the Agriculture of Ukraine" [20], Article 9 of the Law of Ukraine "On Protection of National Product Producers from Dumping Imports" [21].

The organization of the delivery of goods from the place of shipment to the place of destination is regulated by Incoterms in the context of three key transport provisions:

1. Determination of the share of transport costs between the seller and the buyer for the delivery of the goods. Therefore, in the process of concluding the contract, the analysis and grouping of the buyer's and seller's expenses is carried out with the precise determination of the moment of their liability at the route point in time and space.

2. Correlation of responsibility for the risks of cargo delivery between the seller and the buyer. At the same time, the moment of transfer of risks of loss, damage and accidental death of the cargo from the seller to the buyer during its transportation from the place of shipment to the place of destination is discussed and agreed upon.

3. Determination of the date of delivery of goods to the buyer. Therefore, the event of receipt of the goods by the buyer is substantiated by the moment of actual transfer to the possession of the buyer from the seller of the goods or to the disposal of his representative (transport organization). At the same time, compliance with the seller's compliance or non-compliance with the terms of delivery of the goods to the buyer is analyzed.

Obviously, the economic efficiency of foreign economic activity is directly related to the correctness of the choice of means of transport, the route and the basic conditions for the delivery of goods from the seller to the buyer. Therefore, there are two types of duties of the seller (minimum and maximum). According to the first type, where the

minimum actions of the seller include the preparation of the goods for shipment: put the goods in packaging, prepare the container with the packaged goods, mark the product units. At the same time, the buyer must take responsibility for transporting the goods from the place of production to the place of consumption. According to the second type, where the seller is responsible for the maximum actions on the transportation of goods, the basic terms of delivery with or without payment of customs duty are determined.

The basic concepts of the organization of cargo transportation by air transport are regulated by the Air Code of Ukraine [11]. Therefore, cargo is property that is transported by aircraft, but excludes mail, supplies on board the aircraft and accompanying baggage. Cargoes are divided into several categories, among which dangerous ones are highlighted, that is, those that are a threat to health, property, safety and the environment. The procedure for the transportation of dangerous substances and products is regulated by the Aviation Rules [13] and the Air Code of Ukraine [11], which state that the air carrier must operate on the basis of a license, and personnel must be trained in the handling of dangerous goods. At the same time, increasing the competitiveness of cargo air carriers strengthens the information technology component, which helps to develop the transportation route in advance, develop a business plan and optimize it, and save time and paper media. The most modern methods of institutional management are implemented by the International Air Transport Association (IATA). Therefore, IATA, based on EDI standards, developed and implemented the EFreight (electronic freight) technology. The positive aspects of this technology are the reduction of time spent on processing information, the reduction of the cost of work in monetary terms, and the optimization of transportation routes. Obviously, the main advantage is that the state and the air carrier exchange information

exclusively in electronic form. Logistics management of air transportation regulates the integrated cargo flow, not separately allocated cargo transportation. In the process of transportation of various types of cargo, a unified approach to financial-economic, information-service characteristics in space and time is applied not only to the aviation network of carriers, but also to railway, automobile, sea and river companies, as well as redistribution and sales agents and distributors goods. Therefore, regulation of the cargo flow of the airline involves: determination of key points of the transportation route, speed and time of transportation, calculation of income from additional areas of service. The institutional framework for the regulation of cargo air transportation includes regulations from the International Air Transport Association (IATA), the International Organization for Standardization (ISO); International Civil Aviation Organization (ICAO), European Union Aviation Safety Agency (EASA), Federal Aviation Administration (FAA), which are organized by the European Aviation Safety Agency and the US Federal Civil Aviation Administration; by the ISAGO industry standard IATA Safety Audit for Ground Operations.

On the one hand, modern air carriers ensure the quality and transparency of cargo and passenger transportation services, and on the other hand, try to identify and level the challenges of external and internal factors of the institutional environment in order to meet the needs and expectations of both individual customers and large stakeholders in a timely manner. The institutional basis of the organization of air transportation is based on the quality management system of entities whose sphere of activity is related to the maintenance of air transport, execution of work processes, measurement and comparison of real parameters with normative ones. Therefore, the effectiveness of the business of aviation enterprises becomes the main criterion for achieving the development strategy of both an individual

enterprise and the industry as a whole. At the same time, when organizing the transportation of goods, they must be divided into critical and secondary ones. Institutional management of air carriers provides for compliance with the requirements and regulations of international standards and recommendations.

At the current stage of society's development, the state's aviation industry is going through crisis phenomena: a pandemic and martial law. The coronavirus pandemic affected not only the aviation industries of individual countries, but also the entire world. Large global airlines made losses, but were able to refocus in time. Small regional aviation companies were completely ruined. After the end of the pandemic in 2023, the demand for air transportation increased so much that it exceeded the supply. This prompted a rapid increase in the industry's profitability. In Ukraine, the aviation industry went from one crisis state (pandemic) to another (military). During the first, the aviation industry functioned poorly, and during the second, it completely closed. Since the beginning of the political-military conflict, aviation infrastructure has been the object of massive shelling. Active attacks were carried out on civilian, military, and civil-military airfields. European partners anticipated the possibility of a military invasion. Therefore, since mid-February 2022, insurance organizations around the world have refused or suspended insurance of Ukrainian aircraft. As a result, flights of international air carriers to our country were canceled. At the same time, the state came to the defense of aviation companies, providing additional financial guarantees to support the aviation market.

Flights in airspace were suspended due to the full-scale invasion. The main missile strike fell on airfields in order to eliminate air defense. The total number of airfields was 35, of which 19 suffered significant damage. 12 civilian airfields were destroyed. Similar destructive damage was suffered by dual-purpose aviation facilities, that is, civil-military, in the amount of 17 airfields. Some

airfields were subjected to repeated missile attacks. Therefore, damaged airfields should be examined in detail to identify their technical condition and draw up an estimate for their restoration. The preliminary expert assessment of damaged airfields is 2.04 billion dollars. To this should be added losses from non-operating air lines for the transportation of passengers and cargo. During the political crisis, financial revenues from passenger traffic ceased. The expert assessment of losses from non-operating air transportation of passengers and cargo is 5.3 billion dollars [22].

The primary tasks of restoring the aviation industry consist of several important stages. First, calculating losses and creating financial funds for restoration work. Second, carrying out work on the reconstruction and reconstruction of regional airports that would meet modern technological requirements and ICAO standards. Third, with the development of the aviation industry, it is necessary to build additional airports according to world standards. Fourth, launching ICAO audits regarding the guarantee of aircraft safety on flights and civil aviation airports to ensure the safety of passengers, airport workers, aircraft in the sky and at airfields, certification of aircraft and pilots, investigation of accidents and incidents. Fifth, the formation of highly qualified personnel to ensure world standards of quality of passenger service and cargo delivery.

The world economy is developing under the influence of globalization processes in the transport complex and receives a significant contribution from the aviation industry, which provides a wide range of services to changing customer requirements. Therefore, there is a diversification of typical business models, which has increased the level of passenger service and cargo transportation to enter the international market. Thus, new market directions have appeared by reducing the cost of transportation: low-cost, which covers short, medium and long distances of transcontinental flights; economy class, which provides more comfort for little money;

premium class, which is called the model of smart consumption and provides comfort to the passenger; cargo transportation, which has grown on the basis of the development of world trade in the Asia-Pacific region. The main reasons for the growth of air transportation have been an increase in household incomes, the well-being of the population and the profitability of the manufacturing sector of the economy. Therefore, there is an economic readiness to expand air transportation, which is hindered by political disputes between countries and the lack of common infrastructure.

Modern trends in the impact of aviation enterprises on the environment and public health have become the basis for research in recent decades. At the global level, leading associations of airlines, airports, and aviation enterprises are developing the main directions of environmental policy aimed at reducing negative environmental impacts and carbon emissions, increasing environmental efficiency, environmental sustainability of aviation companies, compensation systems for environmental protection measures, and improving environmental performance. The introduction of innovative solutions in the aviation industry involves: the use of biofuels, energy-efficient engines, carbon offsets through financing reforestation funds, and wildlife protection.

In connection with the development of air transportation, the need for highly qualified personnel who have high-tech knowledge of the latest technologies and high-precision equipment used on aircraft, their maintenance, passenger service at airports, at aircraft construction plants, etc. is expanding. The main potential of the aviation industry is made up of highly qualified pilots, the need for which is growing every year. Therefore, the main factors in increasing the demand for aviation industry specialists are: increasing the volume of aircraft maintenance and service, rejuvenation of human resources, increasing the technological equipment of

aircraft, which require a new generation of pilots.

The rapid development of world aviation and the growing demand for passenger air transportation require maximum safety of passengers and their luggage during air travel. Therefore, modern airports simultaneously solve the problem of increasing the efficiency of processing traveler data and compliance with global security standards. For this purpose, biometrics has been introduced in the aviation industry, which helps to observe and determine body measurements and calculations. Obviously, airport security is able to track passenger data very quickly and accurately, thereby reducing waiting times and avoiding queues. The most common types of biometric measurements are: fingerprints, retinal scans, facial recognition. In general, the latest developments help to conduct human health monitoring, which involves automatically determining and measuring temperature, rapid testing for viral infections with the formation of a single database that can be used by different countries to identify the movement of viruses.

The introduction of artificial intelligence to facilitate the work of pilots by creating an intelligent cockpit, which helps ground operators have data on the status of various key indicators of the aircraft and make decisions in real time. Thus, direct communication between the cockpit and ground operators allows: to prevent disruptions to the flight plan based on the analysis of a set of factors and determining flight delays or cancellations, identifying the necessary aircraft maintenance upon landing, the need for refueling; mitigating the consequences of flight cancellations, which involves creating an adjusted plan. At the same time, the formation of the infrastructure for connecting to the cockpit requires significant investments, which in the future should have an economic payback through the level of passenger satisfaction and effective management of resource potential.

Thereby, reducing the costs of the aviation industry and carbon emissions.

The majority of overhead costs in air transportation are maintenance costs, which include a system of comprehensive inspections of aircraft, their maintenance, repair, replacement, installation of components, upgrades and modernization. Direct costs include labor resources and logistics, which are also included in aircraft maintenance. Indirect costs include losses on unplanned maintenance due to delays or cancellations of aircraft flights. Therefore, the modern direction is "smart" maintenance, which allows you to systematize the workplaces of aviation engineers and technicians, who quickly and accurately diagnose technical problems and reduce the time to eliminate them. To implement smart maintenance, the following are used: drones for external inspection of aircraft; "digital twin" technology, which online monitors the external condition of the aircraft and creates its virtual copy at the time of flight in the air with all the shortcomings that need to be eliminated on the ground. In the modern aviation environment, flight safety takes first place. Therefore, advanced technologies are aimed at improving safety standards in the aviation industry. One of the main methods is aircraft testing and continuous improvement of aviation rules and standards. The aviation construction industry uses the latest materials. Therefore, composites are used instead of aluminum and aluminum alloys.

Thus, the strength, safety and operational performance of the aircraft are ensured. At the same time, an improved testing system for newer materials will allow the aerospace testing market to develop. Modern aviation associations require compliance with global standards and regulations based on compliance with regulations and are confirmed by certificates and licenses. Specially authorized management bodies in the aviation industry collect and analyze safety data to identify risks and make forecasts in order to prevent accidents. The product of the combined efforts of scientific aerospace research and operating airlines is the improvement of the testing process and updating of safety standards. It is obvious that a new direction for the aviation industry is a partnership that ensures the prevention of aviation incidents. The aviation environment in Ukraine is focused on restoring infrastructure and transforming airlines into a global market for passenger aviation services and aircraft maintenance to increase capacity.

Current trends in the aviation industry show a recovery after the pandemic and a gradual increase in air passenger and cargo transportation in Europe. As data for the period 2019-2023 show, air cargo transportation in the European Union decreased by up to 96%, and passenger transportation by up to 94% (Table 1).

Table 1. Transport of passengers, cargo and mail in the European Union for the period 2019-2023

Indicators	Years					2023/ 2019, %
	2019	2020	2021	2022	2023	
Air transport of goods by country, tonne	13 739 927,90	12 426 326,60	15 045 040	13 862 510,10	13 141 089,10	96
Air transport of passengers by country, passenger	1 035 119 832	276 758 108	373 809 763	815 689 131	973 032 747	94

Source: [24]

Air transportation is an integral element of the transport system of the global

economic infrastructure, which allows for the rapid and efficient movement of cargo, mail

and passengers to any point in the world. Unfortunately, international armed conflicts become obstacles to the development of the aviation industry, especially civil aviation, negatively affecting flight safety, the economic sustainability of air routes and the functioning of airports. Armed conflicts directly affect air traffic in various regions of the world. As a result, many airlines reduce routes and increase fuel and operating costs. At the same time, the closure of airspace due to military operations is important for ensuring the safety of civil aviation flights. Knowing their locations, alternative routes for commercial flights are developed. However, it negatively affects the cost of air

transportation and the loss of many customers due to high ticket prices and longer flight times. Armed conflicts provoke the threat of terrorist acts and require increased security measures both on the ground and in the air. At the same time, crews must adhere to special safety protocols when crossing dangerous areas. Air transport insurance is associated with increased insurance premiums due to increased risks in the context of hostilities. Therefore, increased insurance costs force insurance companies to refuse due to large financial losses (Fig. 1).

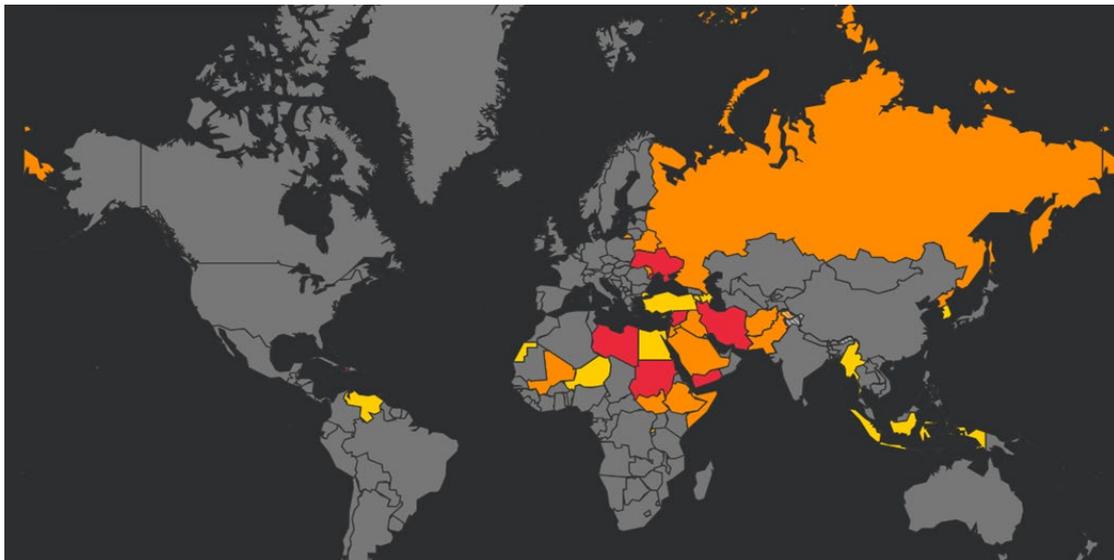


Figure 1 – World map of armed conflicts
Source: [25]

However, armed conflicts affect the aviation industry in the long term even after they end. Because the restoration of destroyed infrastructure does not happen in one day, additional funds are needed to restore airlines, restore the airline brand after a negative reputation, restore passenger confidence in flights in areas that have been under fire, additional costs for advertising and dissemination of truthful information about flight safety in the media. Therefore, a very important element of resolving this issue is international cooperation, the legal basis of which is written in the Chicago Convention,

which contains the main rules governing civil aviation cooperation at the international level.

Conclusions. Regulation of the economic activity of various agents takes place on the basis of institutional mechanisms that balance the interaction between institutions and institutes in the aviation institutional environment. Thus, institutions establish the rules of the game in society and govern repetitive interactions. At the same time, modern legal support for the organization of air transportation of passengers and cargo is based on the national

legislative base and international legal acts. Among cargo transportation, the most common combination is a combination of air and road transport. Therefore, multimodal transportation is aimed at the maximum reduction of cost and delivery time based on the implementation of the most optimal route. The key factors of multimodal transportation include the type of cargo, the final destination of cargo delivery and the terms of transportation to the buyer. The state becomes the guarantor and controller of the adopted norms and rules. The institutional basis of air transport consists of air transport enterprises and organizations. At the same time, the Kyoto Convention provides for cooperation between the state and business on partnership terms with the aim of combining the interests of the state and business regarding the stages of customs clearance of goods in foreign economic

activities with transnational features. The interests of economic entities of different countries regarding the transportation of goods are taken into account in the foreign economic agreement. An important institution in the field of concluding international agreements is the International Chamber of Commerce, which develops a single set of international rules and trade terms (Incoterms). The promising directions of the institutional foundations of the organization of air transportation are the development of a single international normative and legal framework for regulation and the implementation of best practices in the transparency and quality of organizations of air transportation of passengers and cargo at the national level, strengthening of European integration and international cooperation.

References

1. Kyrylenko, O., Naumov, O., Novak, V., Razumova, K. (2022). Institutional foundations of development of the air transport sector and supporting infrastructure. *International scientific journal «Air transport»*, №1(16), 5-15. <https://doi.org/61510/3>
2. Bugayko, D., Ierkovska Yu. (2021). Institutional measures of air transport safety strategic management at the level of state regulation. *Intellectualization of logistics and Supply Chain Management*, 9, 6-19. <https://doi.org/10.46783/smart-scm/2021-9-1>
3. Button, K., McDougall, G. (2006). Institutional and structure changes in air navigation service-providing organizations. *Journal of Air Transport Management*, 12(5), 236-252. <https://doi.org/10.1016/j.jairtraman.2006.07.001>.
4. Thums, J., Künzel, L., Klumpp, M., Bardmann, M., Ruiner, C. (2023). Future air transportation and digital work at airports – Review and developments. *Transportation Research Interdisciplinary Perspectives*, 19, 100808. <https://doi.org/10.1016/j.trip.2023.100808>
5. Reynolds-Feighan, A. *Institutional issues in transatlantic aviation. Barriers to Sustainable Transport. Institutions, regulation and sustainability*, Spon Press, London, p.143-157.
6. Kenneth, B. (2011). Does institutional economics add to our understanding of transportation? Air transport policy as an example. *International Journal of Transport Economics*, 38(2), 123–45. <http://www.jstor.org/stable/42747915>.
7. Yokoyama, K. (2004). Study of Formation and Change of the Institutions and Customs in the Trade Transaction System. *Ritsumeikan Asia Pacific University*, 1-16. https://en.apu.ac.jp/rcaps/uploads/fckeditor/publications/journal/RJAPS_V21_Yokoyama.pdf
8. Odoni A. (2009). The International Institutional and Regulatory Environment. *The Global Airline Industry*, 19– 46 <https://www.studocu.com/ph/document/lyceum-of-the-philippines->

university/international-tourism-management/the-global-airline-industry-the-international-institutional-and-regulatory-environment/18448174

9. Eric, F., Schneider, A., Humberto, F., Bettini, A. (2019). Exploring relations between new institutional economics and international business: addressing the air transport industry. Leibniz Information Centre for Economics, 1-17. https://www.zbw.eu/econis-archiv/bitstream/11159/402486/1/EBP076152987_0.pdf

10. Kuhait, A., Jasim, M. (2020). Analysis of Activity Productivity in Government Air Transport Organizations: Basra International Airport, Case Study--Palarch's Journal of Archaeology of Egypt/Egyptology, 17(5), 1504-1517. <https://doi.org/10.1142/S0219877020400155>

11. Air Code. (2011). Code of Ukraine № 3393-VI. URL: <https://zakon.rada.gov.ua/laws/show/3393-17> (Last accessed: 24.06.2024).

12. On transport. (1994). Law of Ukraine № 232/94-VR. <https://zakon.rada.gov.ua/laws/show/232/94> (Last accessed: 24.06.2024).

13. Rules of air transportation of goods. (2021). Aviation rules of Ukraine, №1795. URL: <https://zakon.rada.gov.ua/laws/show/z0029-22> (Last accessed: 24.06.2024).

14. Kyoto Convention of the World Customs Organization. (1973). World Customs Organization. URL: <https://zakon.rada.gov.ua/laws/show/995> (Last accessed: 24.06.2024).

15. On the accession of Ukraine to the Protocol on Amendments to the International Convention on Simplification and Harmonization of Customs Procedures. (2006). Law of Ukraine №227-V. <https://zakon.rada.gov.ua/laws/show/227-16> (Last accessed: 24.06.2024).

16. On foreign economic activity. (2024). Law of Ukraine №959-XII. URL: <https://zakon.rada.gov.ua/laws/show/959-12> (Last accessed: 24.06.2024).

17. Economic Code of Ukraine. (2003). Law of Ukraine №436-IV. URL: <https://zakon.rada.gov.ua/laws/show/436-15> (Last accessed: 24.06.2024).

18. On the application of special measures regarding imports into Ukraine. (1998). Law of Ukraine №332-XIV. URL: <https://zakon.rada.gov.ua/laws/show/332-14#Text> (Last accessed: 24.06.2024).

19. On transport and forwarding activities. (2004). Law of Ukraine. №1955-IV. <https://zakon.rada.gov.ua/laws/show/1955-15> (Last accessed: 24.06.2024).

20. On state support of agriculture of Ukraine (2004). Law of Ukraine. №1877-IV. URL: <https://zakon.rada.gov.ua/laws/show/1877-15> (Last accessed: 24.06.2024).

21. On the protection of the national producer from dumping imports. (1998). Law of Ukraine № 330-XIV. URL: <https://zakon.rada.gov.ua/laws/show/330-14> (Last accessed: 24.06.2024).

22. Draft Ukraine Recovery Plan (2022). National Council for the Recovery of Ukraine from the Consequences of War. 86 p. URL: <https://www.kmu.gov.ua/storage/app/sites/1/recoveryrada/ua/audit-of-war-damage.pdf> (Last accessed: 24.06.2024).

23. Air transport of goods by country (yearly data) (2024). Eurostat. URL: https://ec.europa.eu/eurostat/databrowser/view/ttr00011/default/table?lang=en&category=t_a via (Last accessed: 24.06.2024).

24. Conflict Zone & Risk Database (2024). SafeAirspace. URL: <https://safeairspace.net/> (Last accessed: 24.06.2024).

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THE DEVELOPMENT AND SIGNIFICANCE OF INDUSTRIAL SYMBIOSIS IN UKRAINE

Volodymyr Davydenko, Olga Karpun. *«The development and significance of industrial symbiosis in Ukraine».* The article comprehensively investigates the stages of development and current trends of industrial symbiosis in Ukraine, analyzing its role in shaping the foundations of the circular economy and the post-war economic recovery. It highlights the main advantages of symbiosis for Ukrainian industrial enterprises, ranging from the reduction of production costs and the creation of new sources of income to the improvement of environmental safety in manufacturing and increased competitiveness in international markets. Particular attention is paid to the interaction between business, communities, local authorities, and the experience of implementing eco-industrial parks in different regions of the country. The main barriers – technological, infrastructural, legislative, and motivational – that constrain the development of industrial symbiosis are outlined, and the prospects for further scaling this model are substantiated, taking into account the specifics of the national economy and contemporary global trends in sustainable development. The article contains practical recommendations for improving the development of infrastructure and mechanisms for stimulating cooperation within symbiotic networks.

Keywords: industrial symbiosis, resource efficiency, environmental friendliness, circular economy

Володимир Давиденко, Ольга Карпунь. *«Становлення та значення промислового симбіозу в Україні».* У статті комплексно досліджено етапи становлення та сучасні тенденції

промислового симбіозу в Україні, з аналізом його ролі у формуванні засад циркулярної економіки та післявоєнного відновлення економіки держави. Висвітлено основні переваги симбіозу для українських промислових підприємств - від зниження виробничих витрат і утворення нових джерел доходу до підвищення екологічної безпеки виробництва та конкурентоспроможності на міжнародних ринках. Особливу увагу приділено взаємодії бізнесу, громад, органів місцевого самоврядування, а також досвіду впровадження еко-індустріальних парків у різних регіонах країни. Окреслено основні бар'єри – технологічні, інфраструктурні, законодавчі та мотиваційні – що стримують розвиток промислового симбіозу, а також обґрунтовано перспективи подальшого масштабування цієї моделі з урахуванням специфіки національної економіки й сучасних глобальних трендів сталого розвитку. Стаття містить практичні рекомендації щодо удосконалення розвитку інфраструктури та механізмів стимулювання співпраці в межах симбіотичних мереж.

Ключові слова: промисловий симбіоз, ресурсоефективність, екологічність, циркулярна економіка

Introduction. Industrial symbiosis is one of the essential tools for implementing a circular economy, which replaces the traditional linear "take-make-dispose" model with a closed-loop system. In this system, the waste of one enterprise becomes a valuable raw material for another. This approach is crucial for the transition to sustainable development, combining economic efficiency with environmental responsibility.

Industrial symbiosis is an integral part of industrial ecology, based on the principle of cooperation between industries that traditionally operate separately. The core idea is the exchange of materials, energy, water resources, and by-products between enterprises. This concept follows the laws of natural ecosystems, where the waste of one organism serves as a source of resources for another, forming closed cycles with minimal losses.

Industrial symbiosis is defined as integration between different enterprises, in which they share resources, energy flows, or residual products. Such cooperation contributes to the creation of industrial ecosystems with closed loops of material and energy flows. As a result, the efficiency of production processes increases, the negative environmental impacts decrease, and new economic ties develop.

The implementation of industrial symbiosis systems helps reduce enterprises'

costs for energy and material resources through rational resource exchange and waste reuse, which directly enhances their competitiveness. This approach leads to a significant reduction in industrial waste and pollution, supporting the circular economy, and promotes sustainable development solutions. The emergence of new business models and cluster cooperation opens up access to additional sources of income and innovative partnerships, as well as creating additional jobs.

Analysis of recent studies and publications. Ukrainian and foreign scientists are researching the topic of industrial symbiosis, developing both theoretical foundations and practical cases of applying this approach for the transition to a circular economy and sustainable development.

The problems of integration between different enterprises, in the process of which they jointly use resources, are considered in foreign and domestic works by scientists, including V. Dykan [1], M. Melnikova [2], T. Domenech, R. Bleischwitz, Marian Chertow, T. Domenech, R. Bleischwitz, A. Doranova, D. Panayotopoulos, L. Roman [3].

The studies conducted prioritize the environmental impact of industrial symbiosis with its associated benefits, including the conservation of local resources and the social consequences associated with improving living conditions.

Identification of previously unresolved parts of the overall problem. Ukrainian industry requires renewal, resource optimization, and the implementation of ecological standards during infrastructure reconstruction.

The growing shortage of primary resources and energy carriers, as well as environmental challenges, necessitates seeking models for the effective utilization of all types of flows. Therefore, industrial symbiosis is strategically important for the sustainability of the country's economy.

For regions with strong industrial traditions, long-term synergistic exchange allows for the development of local clusters and the attraction of foreign investment, stimulating recovery and sustainable development.

The development of eco-industrial parks and integration into European circular economy chains strengthens Ukraine's position in the global market and prepares industries for future environmental requirements.

Formulation of the article's objectives. The purpose of the study is to analyze and develop proposals for the introduction of industrial symbiosis within the context of sustainable development.

Presentation of the main research material. Industrial symbiosis is a model of collaborative economy where enterprises exchange resources, waste, and services to increase efficiency and reduce environmental impact. A key feature is the exchange of by-products flows, where one company's waste, by-products, energy (such as heat), water, or chemicals are utilized by others as raw materials, thus avoiding disposal and reducing the need for primary resources. This model is based on a collaborative network involving several companies, often from different industries, at the regional or cluster level, coordinated through platforms or organizations such as regional hubs. This coordination includes the exchange of information, technology, and infrastructure. Economic efficiency is realized through the

reduction of costs associated with raw materials, energy, and disposal, which increases profitability and creates new sources of income, for example, through the sale of waste as raw materials. Environmental sustainability is achieved by reducing waste, CO₂ emissions, and pollution, promoting a circular economy where resources are reused, and helping to achieve the UN's Sustainable Development Goals (SDGs).

Innovativeness and flexibility stimulate the development of new technologies for purification or processing of waste, as well as new business models, allowing the network to adapt to market changes. Social and regional integration supports local communities through job creation, infrastructure development, and increased regional competitiveness, which requires trust, contracts, and regulatory support. Finally, scalability allows for starting with a small number of businesses and expanding to industrial parks or national networks, making industrial symbiosis a powerful tool for transitioning to a green economy.

Industrial symbiosis is viewed as an integrated model of interaction between enterprises aimed at increasing resource utilization efficiency through the smooth exchange of material, energy, and water flows and the shared use of infrastructure. One of the basic characteristics of industrial symbiosis is the geographical proximity of participants, which contributes to the optimization of logistics costs and ensures the convenience of resource exchange; at the same time, this feature is not mandatory, but it enables the formation of more sustainable interaction networks.

Open communication and trusting relationships between the parties are critical factors for the success of symbiotic relationships, as only effective cooperation can lead to sustainable mutual benefits. The participation of companies from different sectors of the economy helps broaden the spectrum of potential exchanges, forming cross-sectoral interaction, which, in turn, leads to the widespread implementation of

innovative solutions. Innovativeness is manifested, in particular, in the development of new approaches to by-product processing and the creation of technologies for their secondary use.

All decisions regarding the organization of industrial symbiosis must meet the criteria of economic feasibility for each participant, as financial effectiveness is precisely what ensures the motivation of enterprises to participate in exchange processes and integrate into symbiotic networks.

The implementation of circular economy principles within the framework of industrial symbiosis occurs through the transformation of waste into resources, which minimizes the consumption of primary materials. Exchange mechanisms include [4,5]:

- material exchange, in which by-products (slag, ash, gypsum, biomass, etc.) become raw materials for other production processes,
- energy exchange (transfer of excess heat, steam, or electricity between enterprises),
- water exchange (use of treated wastewater for technological or cooling purposes),
- shared use of infrastructure (collective use of treatment systems, pipelines, and equipment).

Thus, industrial symbiosis creates a powerful tool for implementing sustainable production models, integrating environmental and economic goals, generating added value by optimizing resource flows, and strengthening the competitiveness of enterprises within the circular economy.

The main tool is the creation of eco-industrial parks – specially organized areas where enterprises collaborate to solve environmental and resource challenges. These parks include infrastructure that facilitates resource sharing, centralized treatment systems, and digital platforms designed to identify opportunities for cooperation.

The economic benefits of industrial symbiosis are significant and multifaceted, which makes it highly attractive to business. First of all, it reduces costs by decreasing the volume of primary raw materials purchased and lowering waste disposal costs. In addition, by-products previously perceived as waste can become new sources of income – they are sold or used to create new products, forming new business models and market opportunities.

The use of industrial symbiosis leads to increased resource efficiency: the utilization of energy, water, and materials is optimized, which translates into higher productivity and enterprise competitiveness while simultaneously reducing the negative environmental impact.

Industrial symbiosis is a crucial component of the modern economic development model, allowing enterprises to achieve significant economic, environmental, and social benefits within the circular economy. The primary stimulus for businesses is cost reduction – using by-products as secondary raw materials reduces resource procurement expenditures and waste disposal costs. By-products, previously seen as liabilities, are transformed into sources of income: they can be sold or utilized for the development of new products, opening up new opportunities for companies in the market.

Optimizing the use of energy, water, and materials increases overall resource efficiency, which translates into increased productivity, reduced environmental impact, and improved competitiveness. Additionally, establishing symbiotic relationships reduces dependence on unstable external markets and raw material price volatility, which is critical for businesses in times of geopolitical instability and resource scarcity [6].

The environmental benefits of industrial symbiosis are reflected in a significant reduction in greenhouse gas emissions, thanks to reduced demand for new materials and more efficient energy use.

Reusing materials reduces the extraction of primary raw materials, which helps to conserve natural resources, especially scarce and non-renewable ones. Waste is transformed into resources, which significantly reduces the amount of materials sent to landfills or incinerated – materials remain in economic circulation for as long as possible. The exchange of water and energy resources ensures rational use and reduces overall consumption in industrial regions [7].

The social and innovative effects of implementing industrial symbiosis are equally important. The exchange of resources between enterprises from different industries creates favorable conditions for cross-sector cooperation, stimulates cross-fertilization of ideas, accelerates the development of new products, and leads to unexpected technological solutions. The development of circular industry sectors, such as recycling, remanufacturing, and waste management, contributes to the creation of new jobs and the improvement of professional skills, diversifying the economy and strengthening social capital. Successful industrial symbiosis initiatives attract investment, stimulate employment, promote the formation of circular economy clusters, and create a favorable environment for businesses focused on sustainable development. Active participation of companies in resource efficiency and waste reduction programs improves their corporate image, increases customer loyalty, and facilitates access to environmentally oriented financing.

Thus, industrial symbiosis integrates economic, environmental, and social aspects, creating added value and ensuring the sustainable development of businesses and regions.

Despite its numerous advantages, industrial symbiosis faces significant challenges that limit its widespread implementation. One of the most significant obstacles remains the lack of trust between partners – companies are often reluctant to share production information and waste data due to confidentiality concerns.

Insufficient technological and infrastructural readiness also plays a significant role: the lack of specialized equipment, transport, and processing systems complicates the implementation of symbiotic networks. The lack of financial incentives and regulatory support from the state reduces the motivation of enterprises to participate in symbiosis, and fluctuations in the quality and volume of by-products create additional risks for investors and disrupt the stability of supply chains. The increase in transaction costs associated with coordination, partner search, and exchange system setup requires improvements in waste pricing models, strengthening the role of industry associations, and taking into account the territorial location of enterprises.

Industrial symbiosis is of strategic importance for the circular economy, as it is not only a tool for reducing waste, but also the foundation for the systemic transformation of industrial ecosystems. The implementation of the key principles of the circular economy – maximizing resource value, eliminating waste, and regenerating natural systems – allows for the formation of more sustainable and adaptive economic models. Symbiotic networks, eco-industrial parks, and cross-sector clusters expand the possibilities for scaling circular solutions, providing a multiplier effect and systemic impact at the regional and national levels. The experience of successful cases, such as the Kalundborg symbiosis in Denmark or various international initiatives, acts as a catalyst for the global expansion of industrial symbiosis practices [8].

For Ukraine, industrial symbiosis is particularly important in the context of post-war recovery, European integration, and changing economic priorities. Saving primary resources is one of the most important advantages in the post-war period, when there is an urgent need to increase resource efficiency and optimize infrastructure reconstruction. The implementation of a circular economy creates conditions for transformation of the national economy into

a more sustainable and environmentally friendly one, contributes to the conservation of valuable resources, the development of new employment sectors, and the increase in competitiveness for both individual enterprises and the country as a whole. The transition to circular economy models is an important step for Ukraine on its path to European integration and sustainable post-war growth. The recycling of industrial waste into building materials, the combination of symbiotic solutions with smart specialization of urban projects and urban planning allow for the most effective utilization of the symbiosis potential for saving primary resources during reconstruction.

Conclusions. In summary, industrial symbiosis is a central element of the circular economy, transforming production waste into valuable resources, stimulating innovation, creating new economic opportunities, and providing significant environmental and social benefits. It is not only a method of resource optimization, but also a systematic approach to building a more sustainable, competitive, and environmentally responsible industry, which is crucial important for the global transition to sustainable development.

Industrial symbiosis is gradually becoming one of the leading trends in the development of the modern economy, introducing innovative approaches to resource utilization, stimulating cooperation between enterprises, reducing waste, and simultaneously opening up new economic prospects. The practices of advanced countries and the application of symbiotic models demonstrate that this strategy

provides significant economic benefits, including reduced costs, increased competitiveness, optimization of material, energy and water consumption, and the creation of additional sources of income. At the same time, industrial symbiosis plays an important role in environmental protection by contributing to the reduction of emissions, waste, and the conservation of natural resources, which is fully aligns with the principles of the circular economy.

For Ukraine, the implementation of industrial symbiosis is extremely relevant in the context of post-war reconstruction, economic modernization, and integration into the European economic space. The creation of sustainable symbiotic networks between enterprises from different industries will not only save scarce natural resources and reduce environmental impact, but also generate additional competitive advantages for Ukrainian producers in European and global markets. To unlock this potential, it is necessary first and foremost to strengthen trust between business partners, develop infrastructure, ensure state support for innovation, and improve the regulatory framework in accordance with the needs of the circular economy.

The large-scale implementation of industrial symbiosis in Ukraine can become a powerful catalyst for the systematic modernization of the national economy. The transition from the traditional linear model to a resource-efficient and sustainable development strategy will facilitate the country's integration into contemporary global trends and meet the requirements of sustainable development.

References

1. Dykan V.L. (2023) Visnyk ekonomiky transportu i promyslovosti. URL: <http://lib.kart.edu.ua/bitstream/123456789/16816/1/Dykan.pdf>

2. Melnykova M.V. (2022) Promyslovyi symbioz v umovakh povoiennoho vidnovlennia ekonomiky mista. *Ekonomika ta suspilstvo*, №44. 2022. URL: <https://economyandsociety.in.ua/index.php/journal/article/download/1884>.
3. State-of-the-art report on Industrial Symbiosis (EU review). URL: https://www.liaise-action.eu/wp-content/uploads/2024/11/D1.1-State-of-the-art-report-on-Industrial-Symbiosis-topic-and-its-different-subareas_v1.pdf
4. Industrial symbiosis: turning waste into value in industrial networks. August 14 2025. URL: <https://asuene.com/us/blog/industrial-symbiosis-turning-waste-into-value-in-industrial-networks>.
5. Paché, G. (2024). Kalundborg Industrial Symbiosis: Circular Strategy in the Light of Mutualism. *Journal of Strategic Innovation and Sustainability*, 19(3). URL: <https://articlegateway.com/index.php/JSIS/article/view/7330>.
6. Sustainability Directory. What Are Symbiosis Economic Benefits? URL: <https://pollution.sustainability-directory.com/question/what-are-symbiosis-economic-benefits>.
7. Ernest A. Lowe. Creating by-product resource exchanges: Strategies for eco-industrial parks. URL: <https://www.sciencedirect.com/science/article/abs/pii/S0959652697000176>.
8. Global change through Industrial Symbiosis: Kalundborg Symbiosis as an inspiration for innovation and development. URL: <https://www.symbiosis.dk/en/2024/12/16/global-change-through-industrial-symbiosis>.

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