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ENHANCING SUPPLY CHAIN OPERATIONS: A CRITICAL REVIEW OF INTEGRATING ROBOTS AND DRONES IN LOGISTICS

ІНТЕГРАЦІЯ РОБОТІВ І ДРОНІВ У ЛОГІСТИЦІ В КОНТЕКСТІ ВДОСКОНАЛЕННЯ ОПЕРАЦІЙ В ЛАНЦЮГАХ ПОСТАЧАННЯ

Summary. *Implementing innovative solutions to optimise supply chain procedures is becoming increasingly important as the need to improve operations and reduce costs grows. The article explores the potential of integrating robots and drones into logistics operations, particularly in the areas of distribution and delivery, and analyses the prospects for the development of the global logistics robot market. It is emphasised that modern autonomous systems can dynamically adapt to the changing logistics environment, improving resource utilisation through the integration of artificial intelligence and machine learning algorithms; and help create intelligent, interconnected logistics networks through the combination of advanced technologies. It is noted that the integration of advanced technologies in mobile robots and drones allows them to adapt to various tasks, contributing to the flexibility and efficiency of logistics processes. On the other hand, it is emphasised that as the logistics industry adopts automation, it faces the challenge of balancing efficiency gains with potential job displacement, which poses a challenge to the government and business. The authors emphasise that robots play an important role in solving environmental problems, as electric autonomous robots and greener transportation methods reduce carbon emissions in the trade and logistics sectors. In addition, the introduction of robotics can minimise waste and optimise inventory management, contributing to the implementation of environmentally responsible practices in the supply chain.*

The article explores the key challenges faced by businesses and stakeholders in connection with the widespread use of robots at various stages of the value chain. The authors emphasise the importance of adopting new technologies for companies across the supply chain, as well as collaboration between stakeholders to take advantage of the benefits offered by robots and

drones and maintain an innovative ecosystem to address challenges, increase productivity, reduce operating costs and improve customer service.

Key words: *logistics, robotics, automation, supply chain management, warehousing, distribution, Automated Guided Vehicles (AGV), Unmanned Aerial Vehicles (UAV), ESG challenges, robots.*

Анотація. *Впровадження інноваційних рішень для оптимізації процедур ланцюга постачання стає все більш актуальним, оскільки зростає потреба у вдосконаленні операцій та зменшення витрат. У статті досліджується потенціал інтеграції роботів і дронів у логістичні операції, зокрема, у сфері розподілу та доставки, та аналізуються перспективи розвитку глобального ринку логістичних роботів. Підкреслюється, що сучасні автономні системи можуть динамічно адаптуватись до мінливого логістичного середовища, покращуючи використання ресурсів завдяки інтеграції штучного інтелекту і алгоритмів машинного навчання; а також допомагати створювати інтелектуальні, взаємопов'язані логістичні мережі завдяки поєднанню передових технологій. Відмічається, що інтеграція передових технологій у мобільних роботах і дронах дозволяє їм адаптуватися до різноманітних завдань, сприяючи гнучкості та ефективності логістичних процесів. З іншого боку, акцентується, що у міру того, як логістична галузь впроваджує автоматизацію, вона стикається з проблемою балансування між підвищенням ефективності та потенційним витісненням робочих місць, що створює виклик перед владою та бізнесом. Авторами підкреслюється, що роботи відіграють важливу роль у вирішенні екологічних проблем, оскільки електричні автономні роботи та більш екологічні методи транспортування зменшують викиди вуглецю у секторах торгівлі та логістики. Крім того, впровадження робототехніки дозволяє мінімізувати відходи та оптимізувати управління запасами,*

сприяючи впровадженню екологічно відповідальних практик у ланцюгу постачання.

У статті досліджено ключові виклики, що постають перед бізнесом та зацікавленими сторонами у зв'язку з поширенням використання роботів на різних етапах ланцюга доданої вартості. Авторами підкреслюється вагомість впровадження нових технологій для компаній по всьому ланцюгу постачання, а також співпраці між стейкхолдерами для використання переваг, які надають роботи і дрони, і підтримання інноваційної екосистеми для вирішення викликів, підвищення продуктивності, зниження операційних витрат і підвищення рівня клієнтського сервісу.

Ключові слова: *логістика, робототехніка, автоматизація, управління ланцюгами постачання, автоматизовані керовані транспортні засоби (AGV), безпілотні літальні апарати (БПЛА), виклики ESG, роботи.*

Formulation of the problem. Amid globalization and digitalization, when the processes of exchanging goods and services are gaining momentum with every passing day, there is a need for a well-tuned, efficient logistics system. Moreover, labour availability is one of the biggest challenges currently affecting the logistics industry. It is challenging for companies worldwide to find enough high-quality employees to move goods from suppliers to customers efficiently. At the same time, the rapid development and sophistication of modern robotics can best contribute to the development of international logistics activities and overcome all the existing challenges. These considerations make the study of current state, prospects, challenges and further development areas of logistics robots increasingly relevant and important.

Analysis of recent research and publications. Given the relevance of the issue under study, robotics and drones, as well as the various aspects of their implementation in logistics and operations are studied in multiple research publications over the last years. Looking at the literature, often the focus is on the

technical characteristics of AGVs and corresponding systems (such as the vehicles' guidance systems, routing optimization or location on the shop floor). From a practical standpoint, although these studies are relevant, they disregard other equally important aspects, such as organizational (e.g., readiness of the production lines, proper logistic flows, etc.) and safety concerns (for employees in production lines or even logistic operators when working simultaneously with AGV systems) [8]. From the economic perspective, the mainstream research focus is dedicated to the cost reduction and client service boosting potential of automation through implementing robots and/or drones at various stages of the material flow progression. Given the rapid development of e-commerce, much research attention is given to the technology designed to support it. C. Lemardele et al. investigate the potential of unmanned aerial vehicles and ground autonomous delivery devices, concluding that the latter are likely to be more profitable and generate less externalities [11]. Attention is also paid to last-mile delivery with autonomous robots, in particular considering the energy greening prospects [12]. N. Yanpirat et al. focus at ways to boost logistics efficiency indicators by improving drone usage, sustainability, and cost-effectiveness, in particular service time, and pay attention to a crucial literature gap regarding returns, which are common in last mile logistics [18]. Z. Ghelichi et al. examine drone utilisation opportunities for disaster impacted populations and humanitarian logistics [6]. L. Y. Koh et al. address various potential issues of drone and robot adoption in urban areas [10]. Various peculiarities of AGV and UAV are explained in the papers by Karabegović et al. [9], Hrušecká et al. [8], Vassaux [17], and others [1; 3].

Formulation of the aim. In our paper, we aim at explaining robotics and its implementation as an essential process of Industry 4.0 and world economy development, investigating the importance of robotics in logistics, and its benefits, examining Automated Guided Vehicles and drones, comparing and

presenting the performance indicators of autonomous systems, and making some predictions of the evolution of robotics in logistics within ESG inclination.

Presentation of the primary research material. A robot is an automated or computer-controlled integrated system capable of autonomous, target-oriented interaction with the natural environment according to human instructions. Generally speaking, robotics is a complex multidisciplinary science, which is why it combines mechanical engineering, electrical engineering, and computer science but also draws on disciplines such as psychology, biology, neurology, economics, sociology, and mathematics. Furthermore, making a robot perform any of the actions requires considering multi-crossed aspects and study approaches.

The idea of having a machine replicate human actions has existed for a long time. Over 500 years ago, Leonardo da Vinci drew plans for a robotic knight that scholars believed could sit, stand, raise its visor, and move its arms. It was not until 1961 that the first industrial robot was sold to perform practical work, transferring parts from one point to another in a General Motors car factory. Similar to that first robot, the vast majority of industrial robotic arms installed between the 1960s and today were confined to the manufacturing side of the supply chain, mainly in the automotive sector. Only a limited few transitioned to support logistics and distribution [1].

It's considered that the main reason for the lack of logistics robots is technological. Earlier, the majority of presented robots were relatively unintelligent and limited in their abilities, repeating the same movement/action repeatedly, which could have made more sense to the logistics system, which is much broader and more complicated than performing one action. In addition, industrial robots were expensive, and not all businesses and factories could allow them because of the high costs. These factors have become a reason for the appearance of the new trend nowadays for creating logistics robots: flexible and available. Therefore, today robotics is an attractive field for funding. A new wave of research and funding is flooding the market, coming from three sources:

government stimulus programs, venture capital investments, and prominent enterprise players such as Google and Amazon [1].

Gearing up to the relevance of the use of robots overall, the global logistics robots market size was approximately USD 5.38 billion in 2020. The global impact of COVID-19 has been unprecedented, with logistics robots witnessing a positive demand shock across all regions amid the pandemic [5], with the global logistics robots' market reaching US$6.17 billion already in 2021, and US$7.11 billion in 2022. It is expected to grow at a CAGR of approximately 16.2% to reach a total market size of US$10.971 billion by 2027, and to US$27.8 billion in 2031 (Fig.1).

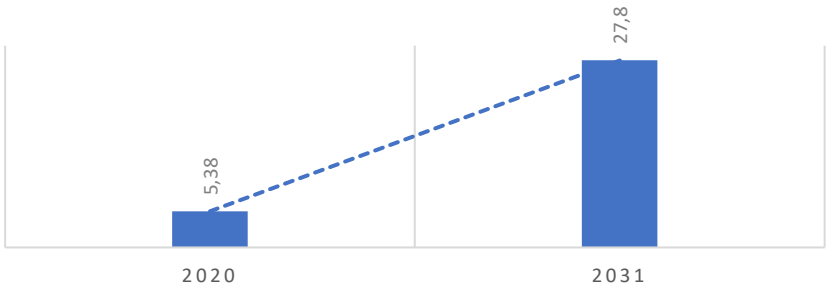

Fig. 1. Predictions on the global logistics robot market, *billion USD*

Source: developed by the authors based on [5; 16]

Talking about the leaders in the market, North America is supposed to have success because of the growth of warehouses and distribution hubs around the region, including significant investments. The same favourable situation is observed in the Asia Pacific; China and South Korea are among the most progressive and confident players.

The bulk of industrial robots in use today are designed to continuously perform the same movements. These motions are all repeated with great accuracy and precision. The most adaptable and suitable robot for logistics processes should be built to conduct its basic actions and functions in a manner comparable to that of a person, combining the components in charge of its physical motions and senses to traverse its surroundings.

From the side of technology, in general, a robot movement system is typically split into two different sections, and it creates the mechanical structure of the industrial robot. The first part is the primary movement system which provides positioning of the centre of gravity of the object in space (positioning system). The second part is presented by the accessory movement system (orientation system), which determines displacement – orientation of the object in the space [14]. Technological advancements make it possible for a robot to be able to coordinate all of its motions, which is expected, and already evidenced to raise the level of manufacturing quality.

Thus, these days' robots are capable of carrying out a variety of tasks, from moving small shelves to warehouse personnel automatically – to following them with mobile carts and picking up straightforward items from racks with mobile robotic arms. Additionally, automated warehouses are typically built to store pallets, boxes, or crates. The operational procedures, including scanning, picking, positioning, and transporting, are handled by robots.

There are various types of logistics robots:

- trailer and container unloading robots (such as the *Parcel Robot* from DHL),
- stationary piece-picking robots (Swisslog's *CarryPick* mobile system),
- mobile piece-picking robots (*TORO* from Magazino),
- co-packing and customization robots (*Baxter* from Rethink Robotics),
- home delivery robots (parcel delivery robots from Starship Technologies).

While robots appeared relatively long ago, the invention and introduction of Unmanned Aerial Vehicles, or simply – drones, came later. However, that didn't diminish their importance. They are still indispensable helpers in many enterprises. The global drone logistics and transportation market was worth $7.5bn in 2020, and according to Emergen Research, that figure will reach $32bn by 2028 [2].

One of the main drivers of market revenue growth was stated as the rising use of drones for quicker delivery of goods, along with the expansion of the e-commerce industry, rising investment in drone research and development, and other technological improvements. Drones were first solely utilized for military applications, but they are now being employed more and more in the global logistics and transportation of goods industries.

As an example, due to the expansion of the organized retail sector, the rising popularity of e-Commerce, particularly in developing economies like India, and the emergence of third-party logistics (3PL) and fourth-party logistics (4PL) service providers, Asia Pacific is predicted to experience the fastest revenue growth in the drone logistics and transportation market over the course of the forecast period. The region's market is expanding as a result of factors like increased disposable income and a wider consumer base [4].

Unmanned aerial vehicles, or UAVs, have a wide range of uses in modern civilization, including transportation and logistics. They can be utilized for consumer purchases, inventory control, and looking for misplaced items in difficult-to-reach places. Additionally, they enable pallet scanning at distribution centres, which enables operations personnel to view inventory and look for misplaced items. Drones also broaden a company's operational range by allowing access to locations that are inaccessible by traditional forms of transportation. They are important for delivering medical and relief supplies to far-off locations in emergencies. In conclusion, the use of drones in logistics results in lower distribution costs, quicker deliveries, and important environmental advantages including lower CO^2 and urban traffic emissions.

Another important issue to mention is Drone Logistics Ecosystem (DLE). The DLE is a free, multidisciplinary "quadruple helix" global network of businesses, academic institutions, public agencies, and investors that aims to promote new developments, partnerships, and standardizations in the drone logistics sector. The Drone Logistics Ecosystem's goal is to gather all relevant

parties under one roof in order to facilitate the commercialization and marketing of the members' products [3].

The development of a new generation of intelligent robots can accelerate progress in whole technological areas, for example, in scanning technology, faster computer technologies, data analysis, accumulators, cloud utilization, and thus greater flexibility, the time for storage or removal of pallets is shortened. So robotization provides new opportunities for the development and growth of the logistics field, and warehousing in particular. As of today, globally, the greatest share of investment in robotics implementation within logistics activities refers to warehousing operations. Each warehouse is unique in terms of its design, storage capacity, and size, as well as the activities carried out there. Whatever its features, the warehouse innovation guarantees higher production efficiency, which boosts profitability among the other benefits of implementing robots and drones in warehouse and distribution logistics (Fig. 2).

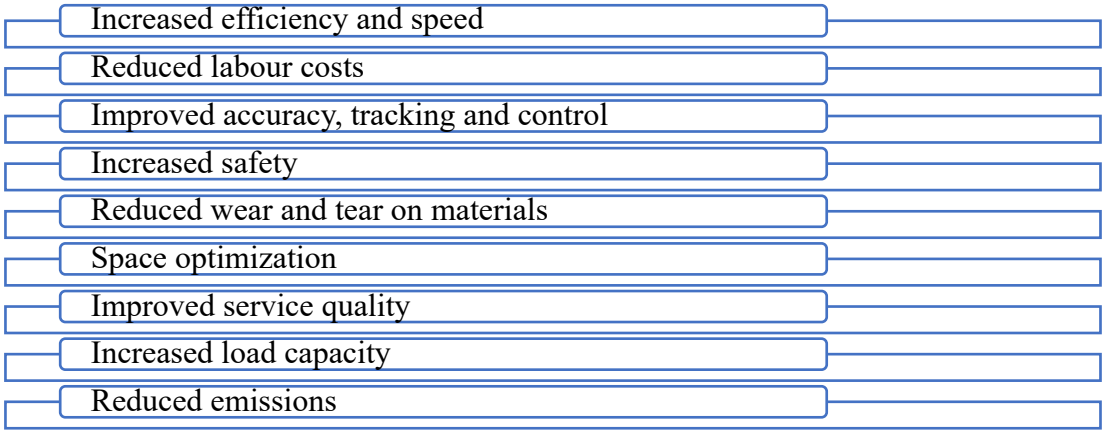

Fig. 2. The benefits of using mobile robots and drones in warehouse and distribution logistics

Source: based on [15]

Moreover, the ideas of "warehouse innovation" and "warehouse automation" are directly related to mobile robots because, from the start, this technology's advancement has been associated with the enhancement of logistical procedures in warehouses and factories. In warehouses and distribution facilities,

mobile robots are already widely used and provide a number of advantages. They can move and work with materials on their own, which increases productivity and profitability. By decreasing labor expenses, eliminating mistakes, and enhancing service quality, logistics automation may boost profitability. AMRs can work in risky conditions without endangering worker safety while handling items with accuracy and care. They are flexible and can adjust to various work and storage needs, which increases productivity and decreases idle time.

By accelerating procedures, lowering mistake rates, and shortening delivery times, mobile robots also enhance the quality of service. They are capable of carrying large weights safely and may be fitted with sensors and tracking systems to provide real-time data. By decreasing downtime and maximizing resources, logistics automation with mobile robots may increase total warehouse efficiency. Mobile robots offer a cleaner, greener alternative to fossil-fueled transport and material handling vehicles. more client happiness, quicker delivery times, more manufacturing capacity, fewer mistakes, and better service quality are the outcomes of this [13; 15].

It is also worth paying attention to the fact that the AGVs are a two-sided technology with promising prospective, but also with and concomitant risks. Automated guided vehicles and corresponding systems have been around for some time. In fact, the automation of transportation systems in the production, trade, and service sectors is currently considered a critical point when addressing internal logistics optimization. This has led over the years to an increasing interest in such material handling systems in manufacturing and assembly companies. Still, the implementation of these systems is not straightforward, and companies typically face several challenges [8].

Starting with basic characteristics, the weight that AGV can transport ranges from a light load of several kg up to 100.000 kg of load. The application of these systems increases the efficiency in the working environment and reduces the costs of labour, energy, and system maintenance. Basic advantages of

introducing AGV vehicles into the automation of transport operations in the manufacturing itself are the following: reduced labour costs and other operating costs, one AGV vehicle that works in three shifts can save three wages of workers who operate a forklift, increased reliability and productivity – AGV vehicle can work without problems in three shifts without breaks and days off, a reduction of goods damage – AGV has a controlled movement of the vehicle with an accuracy of ± 10 mm, increased safety – since the material handling processes do not require human activity and the vehicle always behaves according to pre-programmed instructions, the minimum the possibility of employee's accidents and injuries, flexibility – unlike fixed (stationary) solutions for material handling, the path by which the AGV moves can be reprogrammed very easily [9].

The application of autonomous service robots for logistics involves the transport, handling, packaging, sorting, and delivery of products. Normally, these robots are installed in industrial plants where they are used to move the working elements, boxes, pallets, or tools from machines to machines, shipping areas, or storage.

With the growth of e-commerce, logistics services today require innovative approaches. AGVs address the challenges that arise within a distribution chain. Primarily, they boost productivity, efficiency, and quality by enabling operators to handle higher product volumes while maintaining dependability. Compared to humans working alone, this method is more than 30% faster and has lower mistake rates. As a result, businesses are continuously able to complete their orders more rapidly while also providing improved safety for both people and commodities. Further, AGVs improve working conditions through mechanical aid, which considerably lowers workplace accidents and musculoskeletal disorders (MSDs). The overall goal of robotics (collaborative robotics) is to relieve human workers' physical discomfort while allowing them to continue performing their duties. In addition, due to improved organization and space efficiency, they also help warehouses save space. At a time when every square

meter conserved equates to a financial benefit over several years, this delivers a significant real estate cost advantage.

There are certain technical constraints and challenges of the sector. Manufacturers must address the technological issues before they can satisfy the needs of their clients, particularly in logistics. To maximize the profitability of warehouses, AGVs must provide long-term dependability and robustness so they may operate without requiring maintenance for at least two years. Keep in mind that any downtimes cause a domino effect that might cause significant financial losses. AGVs must be tiny in order for their owners to utilize smaller warehouses and save operational expenses. AGVs must have high power density yet being smaller and able to carry huge loads. Miniaturization is a crucial problem since it saves space and improves the efficiency and reliability of driving systems [17]. Additionally, the automated cars rely heavily on digital information about the jobs they perform and the settings they operate in, which is typically limited to small businesses and is notoriously difficult to safeguard. Wireless AGV systems must always be aware of their location and be able to calculate the best route to the endpoint in order to move through the limitless open area [17].

Logistics solutions using robots have advanced rapidly since major internet companies began using them as the forefront of their expansion strategies. Robotization distinguishes itself from mechanization or automation by offering a flexible and adaptable solution that can be easily incorporated into existing infrastructures alongside human operators. With the significant cost reductions and increasing maturity of these solutions, we are now nearing a tipping point where robots will become more prevalent in warehouses.

The introduction of robots into logistics has been a game-changer for companies looking to expand their operations. The benefits of robotization are clear: it's a flexible and adaptable solution that can work alongside human operators. However, there are concerns about the impact that robotization will have on the job market. Experts predict that hundreds of thousands of unskilled

jobs will disappear over the next decade, with up to 1.5 million jobs at risk in the Eurozone. While the economic benefits of robotization are clear, the impact on the labour market is still uncertain, and it's unclear how these lost jobs will be replaced.

Given the urgency of climate action and ESG transformations, in line with considering the advantages which come with implementation of different technological perks, there appears the responsibility for addressing ESG – environmental, social and governance challenges. Therefore, it is worth paying attention to the use of robots which are designed to promote ESG practices in retail. There is some evidence the robots providing ways to tackle the ESG issue facing the retail sector [7].

One of such ways is sustainable transportation. Electric autonomous robots can considerably lower businesses' carbon footprints by streamlining logistics for transportation and lowering fuel use and emissions. Customers can unlock goods via an app, and Co-op and Starship Technologies have successfully deployed autonomous robot delivery in the UK. These robots employ AI and sensors to move on pavements at the speed of a pedestrian while being powered by zero-carbon electricity. During the Covid-19 epidemic, Alibaba also used autonomous robots. Its delivery robot, Xiaomanlv, delivered over 10 million packages between September 2020 and March 2022. These robots, which are propelled by equipment from the DAMO Academy's Autonomous Driving Lab at Alibaba, are capable of carrying about 50 parcels and covering 100 kilometers each load. This sustainable and efficient delivery method reduces the need for large, polluting delivery trucks, enabling retailers to operate more sustainably and efficiently.

The other thing to point out is concerning reducing waste by using robots. Retailers are making use of robotics to improve sustainability. One example is Nike's Bot Initiated Longevity Lab (BILL) for footwear, which cleans and fixes shoes with modifications to increase their lifespan. This technology is said to

lessen the negative impact on the environment, and is a component of Nike's "Move to Zero" program.

By automating procedures like material sorting and recycling, minimizing packaging, and keeping track of food loss in supermarkets, robots can also assist minimize waste. This reduces overstocking and avoidable waste by assisting with inventory management and precise stock tracking. Robotics not only lower carbon footprints but also improve operations and boost brand recognition by displaying a commitment to sustainability.

Conclusion. The field of logistics is experiencing a transformative phase with the rapid integration of robotics and automation. The introduction of robots in various aspects of logistics operations has led to improved efficiency, reduced costs, and enhanced sustainability. The shift towards robotics is evident not only in manufacturing but also in the transportation and distribution sectors. With the global logistics robots market witnessing substantial growth and the rising adoption of drones in logistics and transportation, the future of the industry looks promising.

The benefits of implementing robots in warehouse and distribution logistics are manifold, including increased productivity for the supply chains, reduced errors, improved safety, and flexibility in handling various tasks. Moreover, advancements in technology and the development of intelligent robots are further propelling the growth of this field. Mobile robots and drones are playing a crucial role in making logistics processes faster, more reliable, and environmentally friendly.

While robotization offers numerous advantages, it also raises concerns about its potential impact on the job market. As the logistics industry embraces automation, addressing the social and labour implications becomes crucial. However, by focusing on upskilling the workforce and leveraging robots to enhance operational efficiency, the logistics sector can transform this challenge into an opportunity for growth and competitiveness.

As the world grapples with climate change and environmental challenges, the application of robots in logistics is offering sustainable solutions. Electric autonomous robots and sustainable transportation methods are reducing carbon footprints and improving the overall sustainability of the retail and logistics sectors. Moreover, robots are proving to be instrumental in reducing waste, optimizing inventory management, and promoting responsible practices in the supply chain. In light of these developments, it is clear that robotics is playing a pivotal role in shaping the future of logistics and supply chain management.

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