

Unmanned Aerial Vehicles in Transport – A Vision of the Future or a Real Trend in Logistics Development?

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Abstract

The use of unmanned aerial vehicles in logistics is shaped by the simultaneous advancement of technology, evolving legal regulations, and operational requirements. Modern UAV designs, such as the Amazon MK30 and Matternet M2, demonstrate the potential for transport applications, including advanced perception systems, autonomous navigation, and increased resilience to selected weather conditions. At the same time, the implementation of these technologies faces clear limitations resulting from restrictions on beyond-visual-line-of-sight flights, complex certification procedures, and the lack of unified international standards. Technological barriers also remain significant, including limited payload capacity, flight time, and the characteristics of currently used energy sources, as well as the need for operator oversight in situations requiring intervention. An additional challenge is the underdeveloped infrastructure necessary to integrate drones into supply chains, including networks of landing sites, charging systems, and UTM traffic-management platforms. Despite these limitations, unmanned systems are becoming an increasingly important component of modern logistics services, contributing to shorter delivery times, reduced operational costs, and greater flexibility in transport organisation.

Keywords: unmanned aerial vehicles, last-mile logistics, automation, innovations in Logistics.

INTRODUCTION

The development of unmanned aerial vehicle (UAVs) technology, commonly referred to as drones is one of the most dynamically evolving areas of contemporary innovation in transport and logistics. At the beginning of the 21st century, their use was primarily focused on military purposes, but recent years have seen a significant increase in interest in their use in the civilian, commercial, and industrial sectors.

In logistics, drones are no longer perceived solely as a symbol of technological progress; they are increasingly being treated as a practical tool supporting the operation of complex supply chains in the TSL (transport-shipping-logistics) sector. The use of drones in transport is part of the broader trend of automation, digitisation, and greening of logistics processes. Autonomous aerial systems enable significant increases in operational efficiency, shorter delivery times, reduced costs, and reduced the negative impact of transport operations on the environment.

Effective integration of drones with transport systems requires not only the improvement of technology, but also the creation of an appropriate legal and infrastructural framework and organisational. A report by McKinsey & Company indicates that the global market for commercial drone applications could reach a value exceeding USD 40 billion by 2030, which highlights the growing importance of this industry in the global economy (Cornell A, Mahan S, Riedel R, 2023). In parallel, the European Aviation Safety Agency (EASA) and the European Commission are working on harmonising regulations on the safety and traffic management of unmanned aircraft, with the aim of fully implementing them into the European Union airspace.

The purpose of the present research is to show the importance and role of drones in modern transport systems and whether their development is only a vision of the future or a real trend shaping the directions of development of modern logistics. Based on the above aim of the work, the **research problem** takes the following form: "Are drones in transport a real direction of logistics development, contributing to increased operational efficiency, or are they still a technological vision of the future burdened with significant legal and organisational limitations?" Based on the specific aim of the work and the specified research problem, it was found that the following **research hypothesis** can be defined: Unmanned aerial vehicles are playing an increasingly significant role in the development of modern logistics systems, constituting a real trend in the automation and optimisation of transport processes. The following literature, scientific articles, and websites were used to write this article. The following research methods, techniques and tools were used to create the subsequent chapters:

- analysis of the subject literature,
- research on normative documents,
- deduction and induction,
- comparative analysis.

2. UNMANNED AIRCRAFT IN LOGISTICS – ORIGINS AND DEVELOPMENT

The concept of an unmanned aerial vehicle (UAV) refers to a category of aircraft without a crew or passengers on board. These types of structures can function both as fully automated flying systems, commonly referred to as drones, and as remotely piloted vehicles (RPV), controlled by an operator from the ground. As J. Karpowicz and K. Kozłowski point out, an unmanned aerial vehicle should be understood as "an apparatus (aerodyne or aerostat) equipped with propulsion that does not have a crew on board." This definition emphasises the technical nature of the UAV as a device with flight characteristics, capable of performing transport, observation, or measurement tasks without the physical presence of a human in the cockpit. Unmanned aerial vehicles are designed to perform stable and controlled flights, maintaining a specified speed and altitude for extended periods. Their design enables precise operations in various environmental conditions, making them a versatile tool in many areas of modern aviation. Moreover, these devices are characterised by high operational efficiency – they can achieve a much greater range and longer flight time than comparable manned systems, while maintaining lower operating costs and risk to human life (Dobek P. & Dobek J. 2022, p. 17). The development of unmanned aerial vehicle technology is one of the key stages in the evolution of modern transport systems. Although drones are primarily associated with modern civilian solutions, their history dates back to ancient times, when pioneers of science constructed the first prototypes of UAVs (Adamski M. & Rajchel J., 2013, pp. 16-17). The first unmanned aerial vehicles known in the 21st century were developed during World War II – at that time, they were primitive, remotely controlled aircraft used for artillery training and reconnaissance. The dynamic development of unmanned aerial vehicle technology was a result of numerous innovations in aviation, the increasing miniaturisation of electronic systems, and the growing demand for such solutions after the end of World War II. The post-war period spurred intensive research and development into the use of unmanned systems for reconnaissance and military purposes, which initiated a "technology race" between the major powers. In the first decades, the United States and the Soviet Union led the way in this field, investing significantly in the development of remotely controlled aerial platforms. Later, Israel joined the group of leaders and, thanks to intensive research and combat experience, became one of the pioneers of modern UAV systems (Polkowski P., 2016, p. 239). With the rapid development of electronics, GPS systems, and component miniaturisation, the use of lightweight composite materials, inertial sensors, and modern control systems

enabled the design of devices capable of stable, autonomous flight. During this period, work also began on adapting drones for civilian purposes.

The development of unmanned aerial vehicles in the logistics context is directly linked to progress in several key technological areas. The first is the automation of control and navigation, based on advanced artificial intelligence algorithms and high-precision GPS systems. Drones are able to navigate routes autonomously, taking into account terrain obstacles and weather conditions. The second area is miniaturisation and energy optimisation, thanks to which modern UAVs can operate longer and over greater distances and with higher energy efficiency. The third element, crucial from a logistics perspective, is the development of communication and data integration systems, enabling the connection of drones with transport management systems (TMS) and warehouse management systems (WMS). Unmanned aerial vehicles used in logistics are characterised by a high degree of autonomy and safety. They are equipped with optical sensors, high-resolution cameras, obstacle detection systems (LiDAR), and communication modules enabling real-time data sharing. This allows them to be used not only in the delivery process but also for monitoring transport infrastructure, controlling warehouse inventory, and conducting technical inspections of logistics facilities. In this way, drones are becoming an integral element of a complex supply chain management ecosystem (Chen M., 2020 pp. 90-92.).

From a development perspective, the genesis of UAVs in logistics can be divided into three stages. The first encompasses the conceptual research period (2000–2010), which focused primarily on developing technical designs and autonomous flight capabilities. The second stage (2010–2020) is the commercial testing phase, with courier companies and logistics operators conducting pilot deliveries over short distances, often in a controlled environment. The third, current stage, launched after 2020, is characterised by the integration of UAVs with intelligent logistics management systems and the dynamic development of the legal framework governing their operation (Haoyang L., 2023 pp. 22-33). The scientific literature emphasises that the technological development of UAVs is a natural consequence of digitalisation and automation of logistics, referred to as "Logistics 4.0." UAVs, as autonomous means of transport, bring an element of mobility and flexibility to this model, which enables quick response to changes in demand, as well as effective management of the so-called "last mile" (Cichosz M., 2020 pp. 417-422). Progress in this field is supported by the parallel development of related technologies, such as the Internet of Things (IoT), cloud computing, and artificial intelligence (AI), which enable the creation of next-generation integrated logistics systems.

The history of UAV development indicates that this technology has evolved from a military tool to a key element of modern logistics systems. The combination of technological innovations with the increasing automation and digitisation of transport processes means that unmanned aerial vehicles are no longer a vision of the future, but a real factor in the transformation of global logistics.

2. PRACTICAL ASPECTS OF IMPLEMENTATION AND OPERATIONAL EFFICIENCY OF UNMANNED SYSTEMS IN LOGISTICS

The use of unmanned aerial vehicles (UAVs) in logistics is entering a phase of intensive commercialisation, with UAV technology becoming a viable tool for streamlining the flow of goods and information. Practical implementations of UAVs are primarily focused on areas related to parcel transport, infrastructure monitoring, inventory management, and delivery in hard-to-reach locations. UAVs in logistics are relatively new, but their development in this area is exceptionally dynamic. One of the breakthroughs came in 2013, when Amazon presented the concept of drone-based parcel delivery as part of the Amazon Prime Air programme. Although initially considered experimental and far-fetched, this idea sparked a global discussion on the potential use of UAVs in freight transport. Amazon is conducting intensive testing of autonomous deliveries using drones with a range of up to 25 kilometers and a load capacity of up to 2.27 kilograms. The aim of the project is to shorten the delivery time to 60 minutes from the moment of placing the order (Rymsza A., 2025). Amazon has obtained approval from the Federal Aviation Administration (FAA) to conduct limited commercial operations in specific air zones (Rosinski K., 2025). In 2024, Amazon began commercial use of the next-generation MK30 drones as part of the Amazon Prime Air programme. This device was developed by the company's internal team of engineers specialising in UAV design. The MK30 model represents a significant technological leap over its predecessors – it is equipped with advanced safety systems that enable precise dropping of parcels weighing up to 2 kilograms from a height of approximately 4 metres. The perception and safety system used in the Amazon MK30 model is one of the most technologically advanced solutions in the field of modern unmanned aerial vehicles. Its structure integrates a multi-module system of high-resolution sensors and cameras, enabling comprehensive monitoring of the surroundings in real time. During descent and delivery, the drone utilises an autonomous obstacle detection and avoidance system, allowing for the precise identification of dynamic and static objects, such as trampolines, wires, laundry lines, and elements of small infrastructure, which are not captured by standard satellite data. A key component of

the system is an advanced perception algorithm based on machine learning methods, which enables the analysis of visual and audio patterns to classify encountered objects. The artificial intelligence models used were trained on datasets covering diverse operational environments, enabling precise recognition of people, animals, terrain obstacles, and other aircraft in the operational space (Greenawalt T., 2024). Compared to previous models, the MK30 is characterised by increased resistance to unfavourable weather conditions, including rainfall, which significantly expands the scope of its practical use. The MK30 drone implementation process included extensive certification testing conducted in cooperation with the Federal Aviation Administration (FAA), which oversaw the system's compliance with applicable regulations for unmanned aircraft operations.

This implementation is not only of operational significance, but also symbolic – it serves as a benchmark for the entire industry, setting the direction for the development of last-mile logistics, which is the final stage of delivery, i.e., delivery to the customer's preferred point. According to estimates, expenses related to the implementation of the so-called last-mile delivery constitute from 13% to as much as 75% of total logistics costs (Gevaers R., Van de Voorde E., Vanelslander T., 2011 pp. 56-71). Their level is influenced by a number of operational and spatial factors, such as the density of delivery locations, delivery times, as well as the size and type of shipment. It is precisely in these smallest shipments that unmanned aerial vehicles would minimise delivery costs. Economic aspects are one of the most important factors motivating the development of research into the use of drones in last-mile logistics. The use of unmanned aerial vehicles can significantly shorten delivery times and simultaneously lower its total cost, which is a significant competitive advantage in the logistics services market. This is particularly important in the context of the fact that expenses related to with handling the final stage of deliveries can exceed 50% of the company's total logistics costs. Lower transport costs achieved with drones are mainly due to due to the relatively lower purchase price of these devices compared to traditional transport vehicles such as delivery vans or trucks. Drones also feature lower operating costs and reduced maintenance requirements. Another key factor in reducing operating expenses is reducing human labour costs. In the case of autonomous systems, human involvement is reduced to monitoring and controlling the flight of multiple units simultaneously, significantly reducing the number of operators required. Such solutions contribute to improving the economic efficiency of logistics processes and support the trend of automation and robotisation in modern transportation.

In Europe, a significant example of UAV implementation is the "Matternet" project. Matternet is considered one of the world's leading manufacturers of commercial drone delivery systems for urban and suburban environments. The company developed the Matternet M2 drone along with a dedicated software platform and implements its solutions independently or in collaboration with logistics partners such as UPS. In 2017, Matternet was the first company in the world to obtain approval for commercial drone flights beyond visual line of sight (BVLOS) in urban areas in Switzerland. Another breakthrough came in 2019, when, in cooperation with UPS, it launched an air delivery service in the United States. In 2022, the M2 model became the first UAV delivery system to receive both type and production certification from the Federal Aviation Administration (FAA), a significant milestone.

The Matternet M2 system is being used in Switzerland, among other places. In Zurich, the company launched a medical delivery route between hospitals and laboratories, which is one of the longest urban corridors dedicated to UAVs (Matternet). The company also collaborates with hospitals and pharmacies to deliver medical supplies. Additionally, Matternet has partnered with the cargo airline Ameriflight, which also holds an FAA license and uses M2 drones for on-demand deliveries in the US, particularly in the healthcare and e-commerce sectors. This operation allows for the scalability of delivery services in densely built-up areas and provides the ability to manage multiple units from a single control centre (UASWEEKLY.COM, 2022). Matternet's experience shows that integrating drones in medical logistics translates into significant reductions in sample transport times. On routes operated in the Zurich metropolitan area, the average delivery time for diagnostic materials is 5–10 minutes. For comparison, transport by road vehicles during rush hours takes up to 35–45 minutes (Matternet).

In Switzerland, Matternet unmanned aerial vehicles have become part of the permanent logistics infrastructure between hospitals and laboratories, supporting the transport of blood, diagnostic samples and small medical cargo. In the US, M2 is used for medical supply deliveries, including on hospital campuses in North Carolina, where drones have replaced couriers driving cars in congested urban areas. The partnership with Ameriflight enables the integration of drones into networks of small, fast deliveries that were not cost-effective using larger cargo aircraft. In this case, drones serve a complementary function, enabling immediate delivery of shipments without having to wait for the next logistics cycle.

3. IMPLEMENTATION BARRIERS AND DEVELOPMENT PROSPECTS

Despite growing interest in unmanned aerial vehicle technology and subsequent successful commercial implementations by companies such as Amazon and Matternet, the operation of unmanned delivery systems faces a number of regulatory, technological, infrastructural, and social barriers. Many of these stem from the fact that this technology is still in the phase of intensive development and its integration with existing logistics models requires an appropriately adapted organisational environment and legal. Therefore, the analysis of constraints is an important element in assessing the real possibilities of scaling unmanned aircraft systems in urban and suburban logistics.

Airspace regulations remain one of the most significant barriers to the widespread implementation of unmanned aerial vehicles in logistics. Despite the dynamic development of UAV technology, and increasing market pressure, regulations regarding flights beyond the operator's visual line of sight (BVLOS) are very restrictive, significantly limiting commercial opportunities. In the European Union, drone regulations have been unified in EU Regulations 2019/947 and 2019/945, which define operational categories and safety requirements for UAVs (Commission Implementing Regulation (EU) 2019/947 of 24 May 2019). According to these regulations, BVLOS flights belong to a category labelled as *Specific*, which entails the obligation to conduct a risk analysis, the so-called SORA (Specific Operations Risk Assessment), or to use from ready-made PDRA (Predefined Risk Assessment) analyses. This generates additional time and burden for companies using UAVs for cargo delivery. Additionally, the U-Space concept is being developed within the European ecosystem, a set of UAV traffic management services that is intended to enable safe UAV operations in densely urbanised airspaces. The descriptions of geozones in EASA regulations also introduce restrictions.

In the United States, there are also significant limitations. The FAA (Federal Aviation Administration) requires UAS (unmanned aircraft systems) certification for airworthiness. Obtaining such certification involves testing the design, system redundancy, and meeting high safety standards, which generates significant costs and extends implementation time. In Poland, UAS flights require approval from the relevant aviation authority (Civil Aviation Authority). This procedure is conducted by the Civil Aviation Authority (CAA), and the application must include, among other things, drone data, equipment, an operations plan, and a risk analysis. According to the CAA report, BVLOS operations are possible, but only in designated airspaces, which further limits the operational scope of

commercial drones in Poland. Furthermore, the process of reserving time zones for BVLOS flights can be lengthy – in some cases, it can take up to 100 days (CAA). The examples cited above clearly illustrate that one of the most serious challenges for implementing unmanned aerial vehicles in logistics remains the complex and multi-layered system of legal regulations. Although a legal framework has been created at the European Union level to unify the rules of UAV operations, member states – implementing these regulations into their own legal systems – introduce additional requirements and restrictions as well as administrative procedures. In practice, this leads to significant differences in operational conditions between individual EU countries. In some countries, the process of obtaining approval for BVLOS flights is relatively quick and based on clearly defined procedures, while in others, it requires months of analysis, additional certifications, airspace reservations, or the implementation of equipment with enhanced safety parameters. This creates "regulatory islands" that hinder the development of a broad, cross-border drone-based logistics network. Such discrepancies mean that the large-scale deployment of UAVs encounters significant barriers, not only technologically but also legally. Operators must adapt their systems and procedures to varying local regulations, which increases operating costs and slows the pace of development for the entire industry. As a result, uniform EU regulations, while providing the foundation for harmonisation, still do not eliminate regulatory fragmentation, which remains a major obstacle to the full commercialisation of UAVs.

In addition to regulatory barriers, significant limitations on the operational use of drones in logistics also stem from their current technological limitations. Even advanced aerial systems such as Matternet M2, equipped with control systems, obstacle avoidance algorithms, and partially automated navigation, are not immune to key limitations resulting from the current power technology. Typical cargo drones remain limited in range and flight time. These limitations are primarily due to limited battery capacity and the weight of the batteries relative to the payload and the ship's structure. For example, a Portland State University study found that many multi-rotor drones operate for 20-30 minutes in practice, which combined with loading restrictions significantly limits the operational range to approximately 15–35 km (Figliozzi M., Tucker C., Polikakhina P., 2019 pp. 1-9). Many UAV models use lithium-polymer (Li-Po) or lithium-ion batteries, which have a limited number of charge cycles and their efficiency can drastically decrease with use. Additionally, environmental conditions—temperature and wind—negatively affect battery performance and shorten actual flight time (Zhao T., Zhang Y., Wang N., Feng W., 2025). Achieving the significantly higher battery energy required for long-range and high-lift logistics operations will require a technological breakthrough.

Effective integration of unmanned aerial vehicles (UAVs) into supply chains requires not only advanced flight technologies but also a developed ground and digital infrastructure. This challenge has many dimensions: physical operational points (take-off/landing zones), the logistics of charging or replacing batteries, as well as the air traffic management system (UTM, responsible for coordinating a large number of drones). The lack of a comprehensive and standard infrastructure makes it difficult to scale operations beyond pilot programmes and limits their potential for commercial applications. Experience with the implementation of delivery systems using UAVs shows that a key part of the infrastructure are dedicated take-off and landing zones—often referred to as *vestiports* or *vertihubs*. There is a lack of such points in urban areas, which means that UAV operations must be limited to industrial areas, airports, or logistics campuses. As the authors of the UAM (Unmanned Aerial Mobility) infrastructure review emphasise, optimising the location of these facilities requires an analysis of operating costs, spatial conditions, and logistics demand (Hou W., Fang T., Pei Z., Qiao-Chu H., 2020). Despite ambitious UTM and U-Space plans, many systems remain in the testing or pilot phase. In Poland, an example is the PANSA-UTM system, which enables flight planning and separation from conventional air traffic. However, its operability is limited to specific zones and flight types, which limits the commercial use of drones outside of special operations. Insufficient logistical infrastructure, including physical take-off and landing stations, battery charging points, and digital traffic management systems (UTM/U-Space), poses a significant barrier to the development of mass drone delivery operations. Without significant investment and broad coordination among operators, regulators, and infrastructure stakeholders, scaling these systems will remain limited to test or niche scenarios.

SUMMARY

The use of unmanned aerial vehicles in logistics indicates that this technology is in an advanced stage of development, but still faces significant regulatory, technological, and infrastructure limitations. Examples of systems such as the Amazon MK30 and Matternet M2 demonstrate that modern delivery drones have achieved high levels of autonomy, reliability, and operational resilience. The use of multi-layered systems for perception, detection, and avoidance of obstacles, as well as the ability to operate in limited weather conditions, proves that the industry is developing and adapting the technology for mass-scale use. At the same time, operational case studies confirm that commercial implementations are possible and bring tangible benefits—especially in medical transport, time-sensitive shipments, and

point-to-point deliveries. From an economic perspective, drones can reduce the costs of last-mile operations, which are the most expensive element of the supply chain. A logistics model based on autonomous ships reduces labour costs, operating costs, and fossil fuel consumption, making drones a potentially more efficient alternative to traditional vehicles. In practice, however, full utilisation of this potential requires the removal of significant structural barriers. The most significant limitation remains the legal regulations regarding BVLOS operations, which are interpreted and implemented differently at the member state level, despite the EU U-Space framework. Certification processes conducted by the FAA and EASA are essential to ensuring safety, but still time-consuming, expensive and inconsistent. This means that even certified technologies like Matternet M2 still face barriers to implementing a broad, cross-border operational network.

Research hypothesis: Unmanned aerial vehicles are playing an increasingly significant role in the development of modern logistics systems, constituting a real trend in automation and optimisation of transport processes **has been proven** in the present research. Unmanned aerial vehicles are becoming one of the most promising tools transforming last-mile logistics. They enable logistics companies to increase competitiveness, shorten delivery times, and reduce the environmental impact of transportation operations. At the same time, implementing these systems fosters the development of more flexible and resilient supply chains, prepared for dynamic market and technological changes.

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