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USING DRONES FOR MANAGEMENT OF AUTOMOTIVE COMPANIES*

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Abstract. The introduction of drones in the automotive industry is a recent phenomenon with immense potential to revolutionize various aspects of production and logistics. This research paper investigates the integration of drone technology within the automotive industry, examining its potential to enhance economic and non-economic efficiency, inform decision-making, and support strategic management. Key findings demonstrate the transformative potential of drones in streamlining inventory management, optimizing logistics, and improving quality control. By leveraging drones for aerial inspections, parts delivery, and data collection, automotive manufacturers can enhance operational efficiency, reduce costs, improve safety, and gain a competitive edge. The study emphasizes the importance of considering economic and non-economic factors, such as environmental impact and social responsibility, in the strategic deployment of drone technology within the automotive sector. As drone technology continues to evolve, we can expect even more innovative applications to emerge in the coming years. Overall, drones have the potential to make automotive manufacturing faster, more efficient, and safer.

Keywords: drones; automotive; economic efficiency; decision-making in automotive companies

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JEL Classifications: J2, L1, G1

1. Introduction

The current era is forcing us to think more about the multifaceted impact of technological progress on society (e.g., Mohammed & Ahmad, 2025). Unmanned aerial vehicles are also included in the rapidly developing modern technology. The drone market is growing rapidly, and its use can be seen in various military, civilian and commercial deployment examples. They have become a tool for saving human lives during natural disasters, transporting medicines to hard-to-reach areas or transporting organs. They help farmers with irrigation, crop protection, and rescuers searching for lost mountain people. The commercial sector, aware of their advantages, uses drones, for example, for transport, mapping, filming and various types of inspections.

Drones open up new possibilities for various industrial sectors by streamlining the course of original processes and offering new, groundbreaking solutions. The automotive industry is significantly influenced by technological advances, especially in automation and robotization. Individual car factories are starting to look

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for ways to use the advantages of unmanned aircraft and gain a competitive advantage. A limiting factor is that there is little information on the use of unmanned aircraft in the automotive industry, and this area can be considered unexplored. For example, it could be the electromobility part of the innovation (Koman et al., 2024). Drone production is one of the world's fastest-growing and dynamically developing sectors (Kapustina, 2021). According to a report by DRONEII, there are already more than 500 manufacturers on the market (Drone Life, 2021). The drone market comprises various segments that cover defence, business, consumer, public safety, and logistics. Currently, examples of commercial drone deployment are growing exponentially. (Laricchia, 2022, b)

Predictions are optimistic, as a steady increase in sales of these devices is expected every year. According to the latest report on statista.com, the global drone market is expected to grow from \$15 billion (2020) to \$90 billion by 2030. This assumption is based on national programs of individual states that plan to increase the deployment of UAVs (Unmanned Aerial Vehicle) for civil and military purposes, as well as the interest of large commercial corporations (Google, Amazon) in purchasing this technology. (Laricchia, 2022, b; Kapustina et al., 2021)

The market's attractiveness is due not only to the current versatile use but also to possible opportunities. These must be constantly explored since the commercial drone market is still in its infancy. (Kapustina et al., 2021) Therefore, there is still room for developing and implementing drone technologies, which can lead to mutual benefits for both manufacturers and operators.

According to a survey conducted by DRONEII, drones were most commonly used for maintenance and inspections worldwide. In addition to comparing individual areas, it also distinguishes between activities carried out by companies in-house and outsourced to specialists, which can be seen in the following Figure 1. (Kapustina et al., 2021)

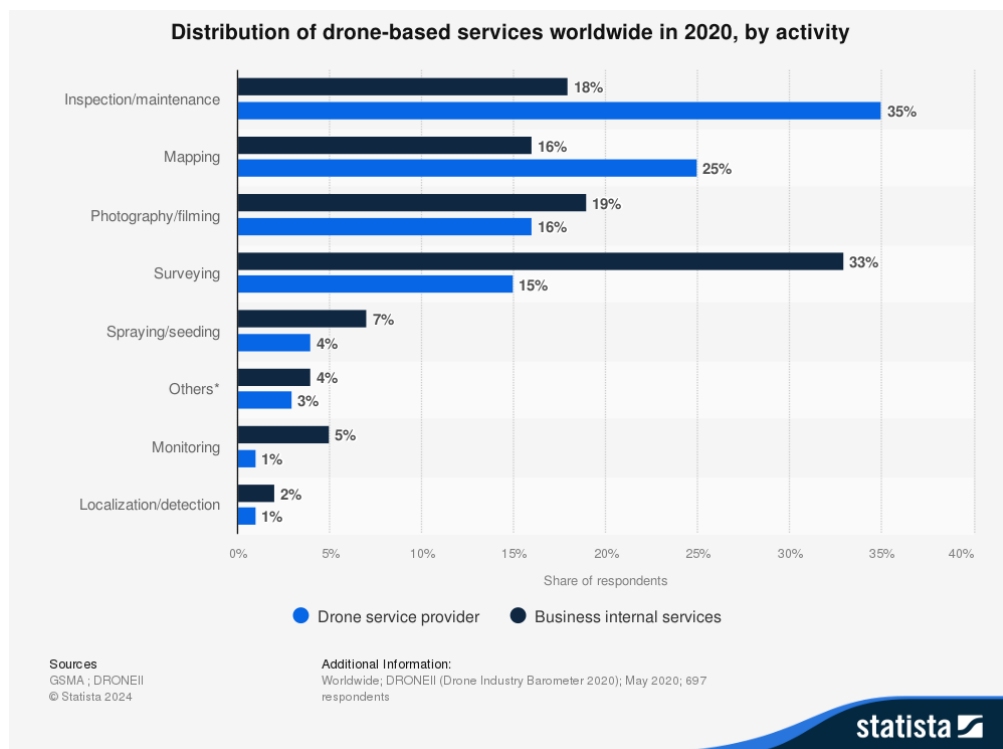


Figure 1. Share of drone services in 2020 by activity

Source: Laricchia, 2022, a

On the demand side, the United States has the highest demand for drones (31%), with 1.1 million devices registered in 2019, according to FAA data. This was followed by China (9%), Russia (8%), and the United Kingdom (6%). (Kapustina et al., 2021; Historia-bahia, 2024)

Based on March 2021 data, the largest market share is held by the Chinese company DJI. By sales volume, its share was as high as 76%, making it the dominant commercial drone manufacturer in the world. It gained a competitive advantage by becoming the first company to offer drones for both commercial and personal use. It received its first permit from the FAA in 2006 and has since produced readily available drones for the public and businesses. It focuses primarily on agriculture, inspections, and public safety. (Tarek and Gorodetsky, 2018; Historia-bahia, 2024) As can be seen in Figure 2, other manufacturers have significantly smaller market shares.

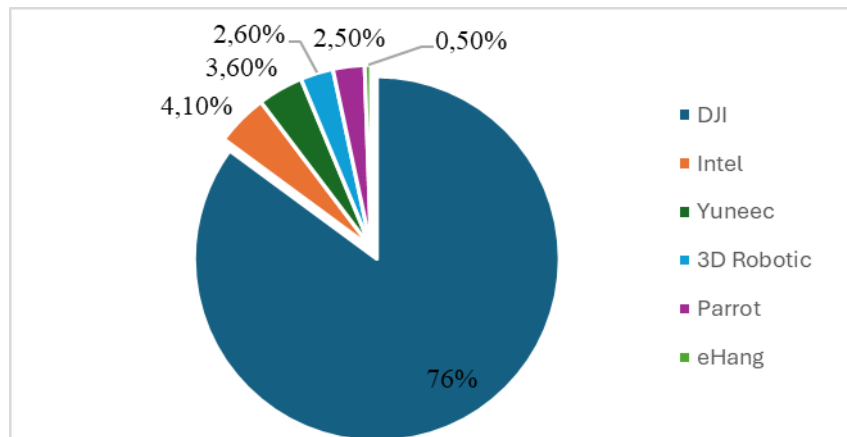


Figure 2. Global market share of commercial drone manufacturers in March 2021

Source: Historia-bahia, 2024

Despite optimistic market predictions, there are some areas where drone technology cannot yet be integrated. This was revealed in a survey by CompTIA, where some companies stated that introducing drones would not bring them process improvements. The most common reason was that they did not need the technology. Other reasons include lack of funding, lack of personnel to operate the equipment, low expected return on investment, legislative restrictions and the absence of drone service providers in their location. (Comptia, 2024)

The latest Drone Market Development Report 2021 lists current technological advances in this area. These include, for example, connecting UAVs to the internet, making them part of the cloud infrastructure. Each UAV acts as a web server, providing resources and services. Cloud integration allows UAVs to be equipped with an application programming interface (API) that offers various services and resources to the operator. Almost all UAVs support Wi-Fi connectivity. (Kapustina et al., 2021; Comptia, 2024) According to the study, the growing demand for UAVs in both the civilian and commercial sectors is driving the market growth. Drone technology also gained prominence during the COVID-19 pandemic, when the demand for contactless deliveries of not only medical supplies increased. (Markets & Markets, 2021) There are several possibilities for using drones. An interesting application is the use in sports and sports activities, not only in their monitoring but also in monitoring sports venues or their sustainability (Varmus & Kubina et al., 2024; Varmus et al., 2024). However, it is important to be careful and incorporate the possible positive and negative impacts on human capital that arise when implementing drone solutions in the commercial sphere. (Štaffenová & Kucharcíková, 2024)

Drones in Modern Industry and Logistics. Drones are a transformative technology with widespread applications in various industries, from logistics and warehousing to construction and agriculture. Their ability to efficiently perform multifaceted tasks and reduce costs makes them an invaluable tool for modern businesses. (Salazar et al., 2023) (Meng et al., 2023) (Zhang et al., 2023)

In logistics and warehousing, drones are revolutionizing how inventory is managed, and internal logistics operations are performed. Their use allows for faster and more accurate inventory tracking, crucial for effective supply chain management. In addition, drones optimize last-mile delivery, achieving cost and carbon emissions reductions compared to traditional delivery methods. Hybrid vehicle and drone models that combine both

technologies are increasingly popular in maximizing delivery efficiency. (Sadok et al., 2024) (Raghunatha, et al., 2023) (Ali et al., 2024)

In urban environments, drones offer the potential for faster and cheaper delivery, but public acceptance remains low. To increase acceptance, concerns about safety, privacy and noise need to be addressed, as well as ensuring sufficient infrastructure and public awareness. (Al-e-Hashem et al., 2024)

The construction industry increases safety and productivity by enabling site monitoring and inspections in hard-to-reach areas. However, their use brings new risks that need to be identified and training and clear safety protocols need to be established. (Karakhan, and I-Mhdawi, 2024) It can also help build smart city concepts. (Vodák et al., 2021)

In agriculture, drones with artificial intelligence are improving crop quality assessment and enabling more accurate monitoring of field conditions. Their real-time ability to collect and analyze crop data helps farmers optimize irrigation, fertilization and pest control. (Baciu et al., 2024) In addition, drones are also finding applications in after-sales service, enabling faster and more efficient delivery of spare parts and enforcing rights. (Li et al., 2023)

Despite their many advantages, some challenges need to be overcome. These include legislative restrictions, technical issues related to battery life and range, and the need to optimize work and planning. (Fehling and Saraceni, 2023)

Drones represent a promising advantage with the potential to transform many industries. Using them to improve efficiency can benefit costs and minimize environmental impact. (Colajanni et al., 2023)

2. Research objective and methodology

The article consists of five main chapters. The first chapter is devoted to unmanned aircraft from the perspective of market development. The second chapter develops the methodology of the work, describing the procedures, sources and methods of obtaining and processing information. The third chapter contains an extensive analytical part and presents the results, which, based on predetermined indicators, describe examples of deployed and potential drone solutions in the automotive industry. The fourth chapter is formulated from them; the discussion contains economic and non-economic evaluations of how it is possible to deploy unmanned aircraft in a commercial environment.

The article aims to find the intersection between what unmanned aircraft offer and what the automotive industry requires, based on the analysis of information from relevant sources. A deployed, tested or potential solution is important if it is a source of economic or non-economic benefits for the company. The object of the work is unmanned aircraft (drones, UAV) and their possibilities for commercial use in the automotive industry. The properties and capabilities of drones are analyzed from the perspective of economic and non-economic values.

After processing the theoretical foundations, the methods necessary for creating the analytical part were determined. The analysis results serve as a basis for developing individual proposals for automotive manufacturers and drone service providers.

Primary sources, such as scientific publications, internet articles, and published statistical data, were used to prepare the article. Current statistical data on the development of the UAV market were obtained from the website [statista.com](https://www.statista.com). Scientific publications were used mainly to categorize drones and describe their technology. The authors primarily drew from the scientific databases Scopus and Web of Science, where they searched for information regarding unmanned aircraft's properties, capabilities and deployment options. Given the limited number of literature related to drones in the automotive industry, the authors linked general literature or drone deployment in other sectors to the automotive industry. This procedure required a thorough understanding of the issue and ongoing processes.

The method of obtaining and processing information was mainly in the form of content analysis of documents. Furthermore, prioritization of the most suitable examples of drone solutions was used based on determining the area of investigation. Subsequently, we assessed the concretization of the deployment of individual uses in specific automotive plants. Overall, to compile the article, we used a synthesis of data that we combined into a coherent text. Primarily, we collected professional information about drone technology and knowledge about processes in the automotive industry. In which a deeper understanding of the issue of economic and non-economic values was studied.

The most important source for the analysis was the analysis of the websites of automotive manufacturers, who described how they managed to implement drones into processes on their media websites. This information was often incomplete, so professional literature from scientific databases was again used to supplement it. Published videos from specific automotive plants were also an important source. The creation of recommendations was primarily based on the author's observations resulting from the findings in the analytical part. The sources of information were also the websites of verified commercial service providers, with an effort to find out what services they can provide and what direction their latest products are taking.

The primary source of information for creating the discussion is knowledge from the analytical part and recommendations. The discussion uses the combination of information from the potential and deployed solution with the latest knowledge from the scientific and commercial fields. Also, the classification presents a synthesis of data for dividing drones into selected categories based on their properties and possible uses. Secondary financial and non-financial indicators supplemented these. The websites of vendors and providers in the UAV area were used to quantify the costs. The potential benefits of introducing drone technology into business processes were determined based on this. The processing of this information fulfils the article's purpose, namely the economic and non-economic evaluation of deploying a drone solution in an automotive plant.

3. Results

The analysis results are aimed primarily at automotive plants, whose production halls are large, and the management's goal is not only to streamline processes (in logistics and control) but also to focus on socially responsible business. The proposed drone solutions are also suitable for companies that want to follow concepts such as Industry 4.0 or smart factories because they open up new possibilities for automakers to implement original processes.

3.1 Inventory of final products in the outdoor parking lot

The first analysis is based on the deployed solution of Audi AG within drone technologies, which is considered to be the solution with the greatest potential for practical implementation. Approximately 15,000 to 100,000 vehicles are usually placed in the parking lot of an automobile plant. According to UAV system manager Danijel Jovanovic from Exponent Technology Services, manually searching for a specific product would take 3 to 4 days. Therefore, we recommend involving an unmanned aircraft in the inventory process and thus locating a particular asset within a few minutes. (Exponent, 2024, b)

Implementation of the German manufacturer AUDI AG, which uses RFID (Radio Frequency Identification) technology and a drone to identify assets. Our recommendation is based on this example and on information from Exponent Technology Services, which is engaged in integrating UAVs into the continuous operation of commercial enterprises and specializes in the use of passive RFID technology. It considers this method of inventory to be groundbreaking in the field of innovation and, in terms of economic indicators, fast, accurate and cost-saving. (Exponent, 2024, b; Exponent, 2024, b)

We propose to carry out the process with a fully autonomous commercial hexacopter or quadcopter. Autonomous flight following pre-programmed flight plans allows for more complex and repeatable missions. To ensure the greatest possible reliability of the system, it is advisable to use a finished product - a drone offered on the market instead of an assembled device. The drone must be equipped with a payload that reads data and is integrated with software for further data processing.

A tag must be placed in each vehicle to use RFID technology to track manufactured cars in a sales parking lot. A drone flying over the parking lot uses a reading device to transmit electromagnetic waves, which the tag responds to. In this way, assigning each tag its geographical location is possible. The system can send inventory data to an in-house ERP (Enterprise-Resource-Planning). The technology is compatible with, for example, SAP (the name of the company that develops programs for the system), which is used by large companies such as automobile plants. (GlobalSpec Engineering360, 2024)

The manufacturer can encode any information about the vehicle on the tag, such as its identification number, colour, model, date of manufacture and, above all, the VIN identifier. The result of the scanning is the display of the position of each vehicle on a map. The provider, Exponent Technology Services, also offers Exponent's UTM portal software, which complements the entire solution. It displays the necessary information about the drone flight and points on the map representing individual vehicles. The software user interface is shown in Figure 3. 28. (Exponent, 2024, a)

An automobile plant can use this technology to monitor products regularly, locate a specific vehicle, and identify vehicles ready for sale. We also recommend that the process, once implemented by an external provider, be carried out by internal company employees after thorough training and understanding of the process.



Figure 3. Vehicle location using RFID technology

Source: Exponent, 2024, b

Exponent technology argues that it can ensure process accuracy of up to 99%, making it a reliable service provider. More and more providers on the market aspire to automate inventory for car parks. In Slovakia, GEFCO company is engaged in storage in the automotive industry. Dispatch parking lots with dimensions of several dozen hectares are an ideal place for deploying drone technology since inventory by human force is time-consuming. (GEFCO, 2022; RTVS, 2021)

3.2 Automated inventory of warehouse stocks indoors

Warehouse drones are a successfully deployed solution in various industries. This solution also has potential for automotive warehouses. Several companies specializing in the implementation of drone inventory in warehouses are already operating on the market. We are based on the implementation at Renault Trucks. The solution, therefore, also has high potential, as it is not new on the market; it is continuously improved, and it is known what can be expected from it. Companies providing these services can already estimate the return on

investment, which is essential for management. For example, GEFCO, a logistics company in the automotive industry, states that implementing drone inventory in a warehouse measuring 10,000 m² has a payback period of approximately 17 months. (GEFCO, 2022)

Drones represent a key technology for companies aiming to automate warehouse operations intelligently – given their ability to autonomously fly, hover, carry payloads (primarily a camera for the proposed process), avoid obstacles, navigate indoors with precision, land autonomously and be remotely controlled. (Heureka, 2024, a). Unmanned aircraft can be deployed semi-automatedly, as in Renault Trucks with the Eyesee drone. An employee places the drone at the starting position from where they want to take inventory and uses an app to launch it. This solution is halfway to the fully automated process we propose.

The recommended technological solution includes two autonomous quadcopters with sensors and a camera. Data capture can be based on barcodes (linear or matrix) or radio frequency. (Dimitris, 2021) For even greater efficiency, we suggest equipping the drone with a thermal camera (but only for relevant stocks), which can be used to determine whether the temperature of the stocks is within the required range. The drone should be equipped with a security system with the necessary functions.

From a process perspective, the drone should have a map of the entire warehouse and identification of individual objects (pallets, floor, shelves) should be performed using a neural network that enables understanding of the space. Neural networks are elements of artificial intelligence. The drone flight for a given process ranges between 30-40 minutes, after which the device needs to be charged. While in a semi-automated process, charging is done manually (batteries are replaced by operators), in a fully autonomous drone, we suggest charging via platforms, which are shown in the following Figure 4. The drone remembers the last location of the scan and continues its operation after charging. The scanned data is transferred to the corporate WMS and compared with the data. (UVL, 2024; RTVS, 2021)

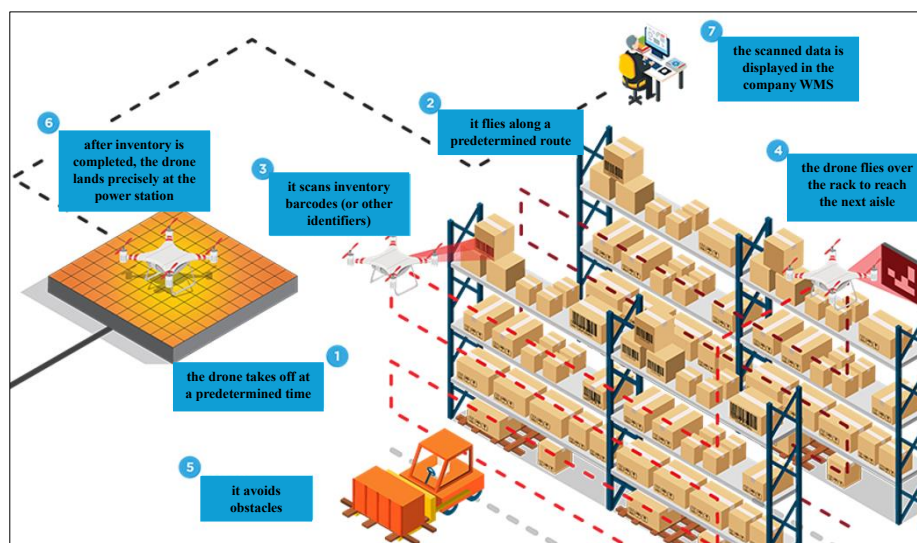


Figure 4. Recommended process of warehouse inventory using drones

Source: Supplychain247, 2019, a

To significantly streamline the process, we recommend using two hexacopters simultaneously. The reason is that the drone's service time is longer than the operational time. Charging via power platforms is slower because this technology does not yet allow a larger current to flow. The improved solution is, therefore, built on the principle that while one drone is capturing data, the other drone is being powered. Since inventory needs to be regularly performed in the warehouse, the drone solution would not be a one-time activity. Still, it would become a fixed part of the business processes.

The manager of the logistics company GEFECO lists the advantages of this process, which include, for example, acceleration of the process, autonomous flight of the drone, and the ability to operate at heights and perform inventories more regularly, which results in more accurate information about warehouse stocks. (UVL, 2024) Other advantages include high accuracy, reliability and cost savings. The authors also recommend the drone solution from a safety perspective. In the original processes, employees performing inventory are exposed to height risks due to the high height of the inventory racks in automotive warehouses, as shown in Figure 5. For example, the process is carried out using a forklift and employees placed in a cage.



Figure 5. Mercedes Benz car factory warehouse

Source: Williams, 2018

3.3 Transport – drone as a means of transport in internal and external logistics

In the last decade, aerial delivery systems have been seen as a promising solution to the worsening traffic situation on congested roads. A study on drones in the supply chain lists the following potential benefits of integrating UAVs into the logistics process: shorter delivery times, lower costs, greater flexibility and a contribution to sustainability. (Abderahman et al., 2021; Kusnirova et al., 2024) SEAT has successfully tested the transport of parts between a logistics company and a production plant. The transport involved category A parts, which must be precisely delivered to the line to the second.

This is the potential for future delivery, a proposal for drone delivery that is currently more feasible and does not pose a risk to car plants. First of all, we recommend that any transport be carried out within the plant premises or between an adjacent factory (supplier) and the plant, with no other built-up area in between, which could lead to more significant legislative restrictions. Given UAVs' limitations and current technological level, we recommend transporting objects whose delivery may not be accurate to the second. Suitable examples include C-type components, protective equipment, tools or spare parts. The transport of spare parts and tools was pilot-tested at the German ZF Friedrichshafen AG plant.

The delivery of these components does not threaten the continuous operation of production lines. However, it can still bring time savings and greater flexibility to the car plant and contribute to reducing emissions produced by the original transport. Delivery does not occur regularly but in the event of an emerging need, which activates the drone flight plan for a given mission. Specific examples of deployment may vary, and for all loads, it is necessary to consider the maximum carrying capacity of the drone, which is why we recommend transporting lighter and smaller objects.

The first possible example of transport. A certain number of spare parts must be available in stock. These are usually brought from suppliers by trucks, which are a source of CO₂ emissions. Thanks to integrating a drone into the process of delivering spare parts between the manufacturing plant and the supplier, the requirements for their warehouse stocks would decrease. If a spare part needs to be used from the warehouse to production, the replenishment of the warehouse from the supplier would be ensured by an air drone. The manufacturing plant thus gains greater flexibility in storing spare parts thanks to the fact that drone delivery can be made when necessary. Therefore, there is no need to accumulate a large number of parts.

The second example of transport. An employee working within the premises of the manufacturing plant suddenly needs tools or protective equipment to perform their work, which are missing or damaged. Instead of someone having to walk to get the item or use a vehicle, the UAV transports the necessary item faster by air. From a technological point of view, the solution can be set up in two ways, depending on the nature of the transported item and the process's requirements. Variant A: The transport is semi-autonomous, and the components are transported in a box. We recommend a carbon fibre capsule, which is durable and lightweight. The box can be attached to the drone using an electromagnet, or the drone can grab it using its grippers. The drone is operated by an employee who places the load in the capsule. An alternative is a winch, which Amazon also used for transport. The flight itself takes place autonomously along a pre-programmed flight path. Variant B: The transport is fully autonomous. The drone uses its grippers to grab and transport the object to a designated location. In the automotive industry, helmets, gloves, protective shields, or other equipment can be transported this way if necessary. A special recommendation is to use UAVs within the plant's interior to transfer parts from place A to place B. Lines and AVG devices are used to move material within the production plant. Problems and inefficiency arise when transferring material from one device to another is necessary. In the Dacia production plant, employees transferred components manually. (Dacia, 2018)

The employee performing this non-ergonomic, inefficient and repetitive task can be replaced by autonomous UAVs equipped with jaw grippers. The parts would be transported at a designated location a few meters away, with no employees or machines in the drone's flight zone. The potential transfer of parts, in which the drone moves autonomously within the plant and ensures delivery to parts, for example, directly to the production line, is complicated by the movements of robotic arms and other equipment. Two different UAVs must be used to transport parts inside and outside the plant, which differ significantly in their characteristics. These differ primarily in their design. Exterior drones are built to withstand various weather conditions, such as wind or rain. Therefore, they are constructed differently from interior drones, which must primarily be lightweight and smaller in size so as not to damage the car plant's equipment and be easier to manoeuvre. They would be unsustainable outdoors. However, it should be considered that the relationship between the maximum load capacity of the drone and its weight is directly proportional. The heavier the load that must be carried, the larger the drone platform. The load capacity of an indoor drone is, therefore, significantly limited.

There is also a difference in the drone's navigation. While GPS works reliably and accurately outdoors, more complex technologies such as LiDAR and SLAM, which enable navigation based on spatial vision, must be used indoors. For better orientation indoors, we recommend laser rangefinders, ultra-wideband radio signals (a type of indoor GPS), and a UWB system for tracking and locating the device. Outdoors, we recommend including a hexacopter with a load capacity of at least 5kg. We recommend a device with a 30 to 40 km speed per hour to save time. For indoor use, we suggest a quadcopter with a load capacity of 2kg and a speed of at least 8 km per hour. From a safety perspective, securing the propellers with a cage or other protection is advisable, as shown in Figure 6.

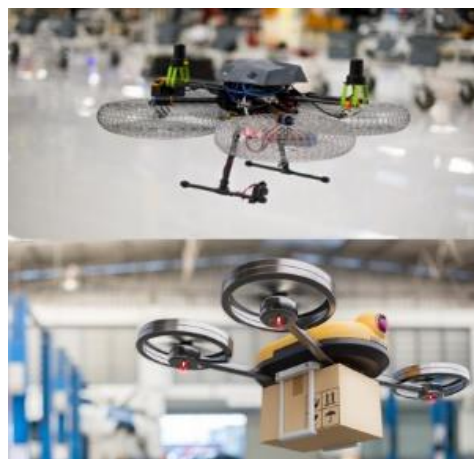


Figure 6. Indoor drones for transport

Source: Volkswagen Group Homepage, 2021; Baur and Manfred, 2024

3.4 Inspection services – technical management of the interior and exterior of the premises in combination with a 3D model

One of the most common uses of UAVs is inspections. Drones have proven themselves in performing inspections of hard-to-reach places, such as oil platforms, bridges, monuments, windmills, solar panels, and tall buildings. Car factories occupy large areas, and it is necessary to check not only large roofs but also various even more difficult-to-access structures, such as the chimneys of the largest car factory, Volkswagen Wolfsburg Plant. The built-up area of this plant is up to 1.6 km². The areas of other plants are also large; for example, in Slovakia, it is 0.57 km² for the car manufacturer Kia Slovakia s.r.o. (KIA,2024).

Another proposal is to use drone technology to perform inspection work in the exterior and interior of production plants. The recommendation is based on the successful use at Ford Dagenham. Inspections should be performed preventively at least once a year for new plants, and their frequency should increase as the building ages. Inspections should be performed even if a problem has already arisen or if there is suspicion that some damage may have occurred, for example, after a storm, hail, frost or other adverse weather conditions. Therefore, preventive, predictive and service actions can be performed during the inspection.

Possible heat leaks, surface damage, cracks, corrosion, seal failures, blocked drains, etc. are checked during exterior inspection work. A drone equipped with the appropriate useful equipment is a suitable solution for determining the asset's condition and identifying possible problems. The car plant's advantages are time savings and cost reduction, and Figure 7 captured by a thermal imaging camera. These can detect problems based on unreasonably increased or decreased temperature.

In the plant's interior, it is necessary to inspect, for example, gantry cranes, high-rise structures, pipes, roofs and various large-sized machines. In the original inspection processes, employees had to overcome height differences of several tens of meters, which was dangerous and time-consuming. The process required interrupting production for several days, using extendable platforms, erecting scaffolding and then dismantling it again. We therefore recommend replacing all these devices with an inspection drone, which will replace many steps and resources in the process, significantly reducing the inspection time and, thus, the costs resulting from the need to interrupt operations.

Implementation of a successful drone deployment at the Ford Dagenham car plant, which argued that there was no need to interrupt operations at all for drone inspections. However, it is possible that it will be necessary for certain inspections to suspend production, but the duration of its suspension will be significantly shorter. For example, the drone inspected an area of the car plant in 12 minutes, while in the original process, it took workers up to 12 hours.

The inspection process begins with programming the drone's flight path. While the UAV performs the inspection, employees can monitor the flight and evaluate the data in real time, thanks to actual camera photos. After landing, the data is transferred to the appropriate processing software, as shown in Figure 7, where it is analyzed in detail. Workers evaluate drone footage without entering dangerous zones and taking unnecessary risks from heights associated with the original inspection process. The drone should have a vibration damper and gimbal to stabilize the actual photo and allow independent movement of the cameras. (ATP Journal, 2019)

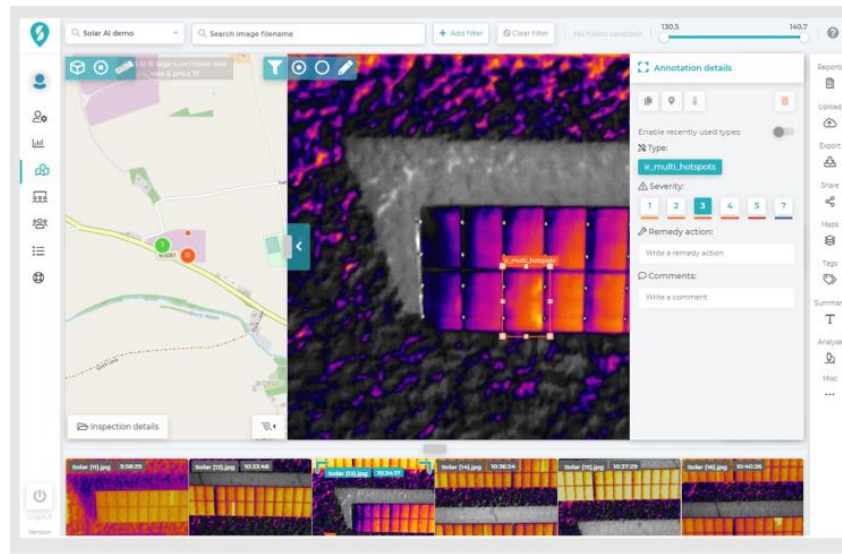


Figure 7. Software for processing drone inspection records

Source: Capterra, 2024

Similar to transportation, smaller and lighter devices are recommended for interior inspections that do not pose a major risk to property or employee health. Indoor drones can also operate autonomously if equipped with more advanced technology (LiDAR, SLAM) that can scan the surroundings. An alternative is operator-controlled flight. The device recommended for this process is the DJI Mavic 2 Pro, which is equipped with a safety cage. The attached payload should include a thermal camera and an orthophoto camera. The weight of such a device is around 1kg. The Mavic is equipped with sensors that detect distances to obstacles, but the operator who monitors them is still required to participate.

For exterior inspections, we suggest a more durable, heavier drone weighing 5 to 10 kg that can carry a payload (in this case, various types of high-quality cameras) weighing 2 to 3 kg. Since, in the outdoor environment, it is possible to rely on an accurate sleeping GPS, we propose an autonomous drone that performs an inspection along a pre-programmed route, and employees are responsible for evaluating the real photo in the software. The drone is equipped with several types of cameras, including the aforementioned thermal imaging camera, a Full Frame camera, and a camera with a 300 mm lens enabling detailed zooming. Photos can be taken from a safe distance, and the object can be zoomed in more than 1:1.

For inspections to be carried out when necessary and not only when the weather allows, we recommend a device with an operating temperature of -20°C to 50°C and wind resistance of up to 15 m/s. A reliable and robust solution on the market is, for example, the DJI Matrice 300 RTK drone. The process needs to be supplemented with a software platform for evaluating the captured real photo; we recommend the DJI FlightHub9 platform when using DJI technology. (Dronerepublic, 2024)

Before integrating drones into inspection processes, we suggest using UAVs to create an accurate digital 3D model of the plant as an improvement. It is up to the car plant to consider whether to create a digital twin, which is an extension of the 3D model, because it simulates the processes in the plant. From an inspection perspective, the 3D model itself also brings advantages when evaluating the captured photo. This allows workers to review the photo and create a more comprehensive conclusion more easily. For example, employees can see damage to a certain part of the asset in a detailed photo and, thanks to the 3D model, see where this damage is located and what impact it may have on the given area. Drone inspection is also advantageous for the car plant because 80-90% of inspection cases will be carried out without identifying problems that need to be fixed manually. (Flyability, 2024)

4. Discussion

The discussion focuses on economic and non-economic evaluations of selected solutions, with attention paid to the benefits of introducing drone technology into the company, as shown in Figure 8. The discussion includes economic evaluations for each proposal separately. Part of the analysis is devoted to the main costs and the most significant benefits of introducing the drone solution. The authors go into more detail about calculating the initial investment costs. The car manufacturer will also encounter operating costs related to the maintenance of the equipment, which must be carried out after approximately 200 flight hours (Enterprise-insights, 2024). However, they are not a significant item when using the equipment correctly. Subsequently, the advantages of the drone solution for individual recommendations are analyzed, which, although they cannot be economically quantified, are expected to be a source of specific benefits for the company in the private sector.

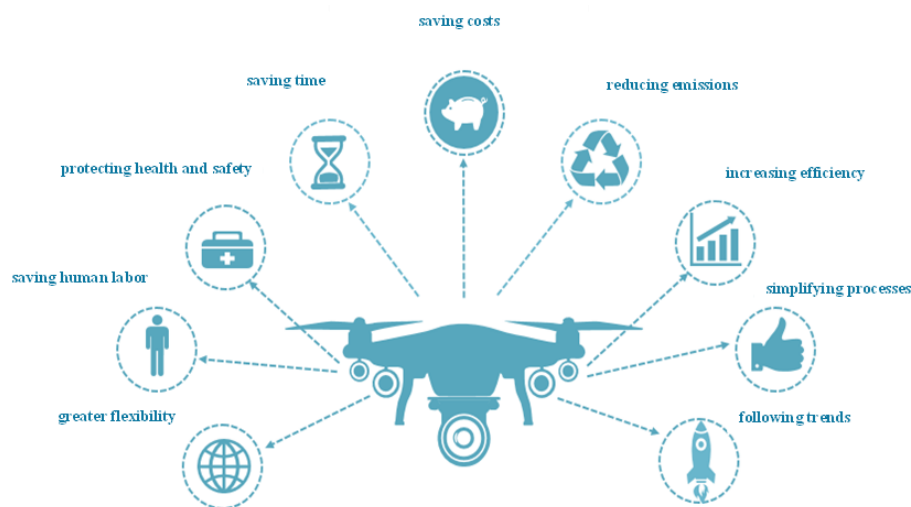


Figure 8. Benefits of introducing drones to the automotive industry

4.1 Inventory of final products in the outdoor parking lot

The initial costs for an automotive plant to implement drone RFID inventory include the following main items. The basic item is the drone. Considering the expert opinion, the authors selected the DJI Matrice 200 V2 device from a reliable commercial manufacturer, which costs 6954 euros. (Sunbeltsales, 2024) The reason for the selection is its features (robustness, durability, a maximum flight time of up to 38 minutes, anti-collision systems, etc.) and its successful pilot testing by the Normandy Flight Company in the RFID detection process. (DJI, 2024, b; NAE, 2022) Another cost is the useful equipment the drone must be equipped with. We recommend the DJI Zenmuse X5S camera, which is compatible with the drone and has a low weight. (Heureka, 2024, b) It is also necessary to place a high-frequency passive RFID reader on the drone, which is low in weight and has a range of at least 5 meters. For these criteria, an estimated indicative price of 1500 euros is determined based on a survey of readers with similar characteristics.

RFID technology cannot function without placing a passive tag in each vehicle. The price is 0.11 euros per tag when purchasing 20,000 units. The number of units will naturally vary depending on the needs of the car factory. (Rfid4u, 2024) The initial cost is also the processing software, the price of which is estimated at 5,000 euros after research. (Software Connect, 2024) After installing the solution, we suggest that the inventory be carried out by internal employees who need to be trained. The price per employee is 150 euros, and we recommend training six at the beginning. (Aprop, 2024) For a clear view, the costs are listed in Table 1. The costs for the implementation of RFID inventory for 20,000 vehicles are listed. The costs that arise but cannot be quantified include the integration of RFID into the corporate information system and the installation of the entire solution. (Yen et al., 2007) The authors assume that their price will be the largest item in the solution.

Table 1. Selected initial costs for implementing RFID inventory

Item	Price in euros
DJI Matrice 200 V2 Drone	6 954
DJI Zenmuse X5S Camera	2 199
RFID Tags	2 200
RFID Reader	1 500
Processing Software	5 000
Employee Training (4 Employees)	900

The solution's benefits can be economically evaluated based on the data: Time savings are considered the biggest benefit of the first recommendation. The drone can fly over the parking lot in a few minutes. The exact time depends on the size of the parking lot and the mission, but time savings of up to 80% are estimated. Greater accuracy. Process providers argue for a greater possibility of obtaining more accurate asset data and achieving up to 99% process accuracy.

Since the improved process is simpler and takes only a few minutes, the car plant's advantage is the labour cost savings. The original inventory process required more labour, which had to be paid. However, the labour price cannot be accurately quantified because it is not sure whether this activity is performed manually by warehouse workers or by technical workers with the help of specific software, whose salaries vary significantly.

Non-economic evaluation. The introduction of UAVs into this activity replaces employees. Still, it follows the concept of a smart factory, which is manifested in simplifying logistics workers' work and making the company more efficient. While the drone performs this manual task, logistics workers can focus on activities that require thinking and creativity, thereby creating value for the company. The drone solution also introduces greater flexibility into logistics processes. A car factory can use a drone to identify vehicles ready for sale, for regular asset inventory, identify vacant spaces or find a specific vehicle for any purpose. Flexibility is also manifested in the fact that any information about the car can be placed on the tag.

4.2 Automated inventory of warehouse stocks indoors

In the economic evaluation of the first proposal, the authors calculated the cost of implementing an inventory using RFID, which was the most suitable method for the given solution. For inventory in the warehouse, the costs of implementing a solution using barcodes or QR codes will be calculated. The main cost item for the second recommendation is two identical autonomous drones involved in the process in parallel. The reliable DJI Mavic 3, an ideal interior inspection drone, was chosen for the process. It has the necessary sensors (including for omnidirectional obstacle detection), is lightweight (895g), and, therefore, does not threaten people or property. The price of one drone, 4,800 euros, also includes two built-in cameras. (Alza, 2024) The choice of this type of UAV is also based on the fact that providers used its previous series for this purpose.

The drone must be charged using a power platform for a fully automated process. One drone should perform the inventory for the most efficient inventory in larger warehouses while the other charges on the power platform. When choosing the devices, we, therefore, also took into account the flight time and power supply time. We decided on the HEISHA DNEST 2 platform, which can be integrated with the DJI Mavic 3. The device charges in 45 minutes and then flies for 46 minutes, a prerequisite for a smooth and autonomous inventory process. The DJI Mavic 3 and its power platform are new on the market. Data on its price is not yet available, but the price of the previous model of the platform for HEISHA DPAD for Mavic 2 is 5,080 euros. (Ozrobotics, 2024; Heishatech, 2024; DJI, 2024, e)

An initial cost is also the scanner, which needs to be attached to each drone for scanning codes. The scanner must have a low weight (usually no more than half the weight of the drone) and sufficient range. The price of such a scanner from Siemens is 3,231 euros, while it weighs only 250 grams and has a range of up to four meters. (Distrelec, 2024) After integrating the solution, we suggest the provider carry out the process by internal employees, who must undergo training. An overview of the quantifiable costs is in the following Table 2.

Table 2. Selected initial costs for introducing drone inventory into a warehouse

Item	Price in euros
DJI Mavic 3 (2 pcs)	9 598
HEISHA DNEST Power Platform (min. price)	5 082
Scanner (2 pcs)	6 462
Employee Training (4 employees)	900

Like the previous process, the significant cost of implementing the solution into the company and integrating it into the internal warehouse management system is also the internal inventory. The amount depends primarily on the size of the warehouse, the required inventory frequency and the expected accuracy; therefore, it is impossible to quantify it, and the providers do not disclose it. (Agvnetwork, 2024) Given that drone inventory is already a solution offered on the market, it is appropriate for the car plant to cooperate with a provider that will not only implement the drone solution but also provide the hardware.

Among the benefits, both the solution providers and the company Renault Trucks implemented the solution, which considers time savings to be the main benefit. Both parties state that the process was accelerated by up to 10 times. The inventory of a location in the Renault warehouse took 6 seconds, while it took 1 minute manually. Another economic benefit results from the savings in labour costs. For example, it is possible to compare the cost of labour for a warehouse worker in the original process with the improved one. For instance, if the original process took 20 hours, the improved one is estimated to take only 2 hours, representing a saving of 198 euros. (Platy, 2024; Podnikajme, 2024)

Non-economic evaluation. Providers and users of drone technologies often struggle with uncertainty when calculating the return on investment of UAV implementation in a company. The advantage of indoor inventory inventory is that providers of this service can approximately calculate the payback period. Another benefit is the shift towards socially responsible business in the area of employee health and safety. In the manual process, warehouse workers were exposed to height risks when scanning inventory located in high places. They use various platforms and forklifts for this. This activity is also considered non-ergonomic and leads to damage to the musculoskeletal system. The consequences of such work are also called RIS and, according to OSHA, affect up to 1.8 million workers annually. (OSHA, 2021) Workers can be relieved of this unpopular and dangerous activity and focus on other areas of the logistics process from the safety of the ground.

Providers, as well as users of this service, also argue for greater accuracy. Drone inventory is significantly shorter and, therefore, can be performed more regularly, resulting in more accurate information about the state of the warehouse. Properly deployed drones are also less error-prone compared to humans. Thanks to precise warehouse information, a company can eliminate downtime in production.

4.3 Transport – drone as a means of transport in internal and external logistics

For outdoor transport, the initial load is a drone suitable for outdoor use. The authors have again chosen a reliable and proven solution: the DJI Matrice 600 Pro hexacopter. Its parameters meet the requirements for the given deployment because it is durable, has a load capacity of 6 kg and reaches a speed of 65 km/h. The market price of this type is 7,000 euros, and it is also necessary to equip the device with a camera. We recommend the compatible DJI Zenmuse X5S camera, which costs 2,200 euros. (Heureka, 2024, a; DJI, 2024, d) The number of drones for this process cannot be estimated because it depends on the plant, to what extent they want to use the drone and what they want to carry with it.

For safe landing outdoors, landing platforms are used, which are also an initial load. Their price varies; therefore, a specific platform designed for the proposed DJI Matrice 600 Pro was chosen. It is the HOODMAN LAUNCH PAD 5FT, which is around 180 Euros. (Heliguy, 2024, b) A different type of device with different features is required for indoor use. A suitable solution is, for example, the DJI MATRICE 200, the price of which, including the camera, is 5,600 euros. This drone, weighing only 3.8 kg, can carry up to 2.34 kg of payload, which does not pose a great risk for indoor use but can still carry various components. The drone needs to be equipped with

protective elements (blade covers), which do not represent a large cost item. The number of indoor drones again depends on the needs of a particular plant. Still, if the device is to be used in continuous operation (transferring material from place A to B), at least two quadcopters must be available for one activity. This results from the need to replace the batteries. (Dronenerds, 2024, b; DJI, 2024, c) Both types of UAVs also need to be equipped with a useful device that will be used to transport the cargo. The item is not significant in terms of price (therefore, it is not listed), but it is key to implementing the process. The car plant can choose between a winch, a jaw gripper or a capsule (box).

A significant initial cost is, again, the cost of implementation, which will be increased by the "training" of the drone's neural network when the UAV is integrated into the plant's interior. The drone's movement within the car plant is more demanding than the exterior. The device must learn to recognize obstacles using a neural network to respond correctly to stimuli in the process. The cost also includes the amount of employee training, but its amount depends on the number of workers involved in the drone process. However, it is impossible to determine it in this recommendation because the solution is designed as a framework with several variations.

Benefits. As with the previous recommendations, an improved transportation process is a source of time savings. This will vary depending on the process and distance. Still, for a rough approximation, the authors provide two calculations: Based on the results of the international CASE conference, drones can significantly speed up logistics operations within the plant premises. The report cites malfunctioning or missing parts that need to be secured for a certain process during automotive production. Under normal circumstances, an employee runs or cycles to the warehouse to retrieve a part, which takes 10 to 15 minutes. With a drone, it is possible to fly over the infrastructure and carry out the transport in 3 to 4 minutes. The study states that these results are actual measurements in a car factory. (Markus et al., 2019) The transport of parts between the SEAT factory and the supplier production line described in Section 3.3 is 6 times faster over a distance of 2 km. The original process required 90 minutes; the improved one was 15, while the drone flight time was only 4 minutes.

It is also possible to calculate the savings in labour costs for an employee who transported parts from place A to place B roughly. This work is usually performed by a production operator, and assuming that he works full-time 8 hours a day, the production plant would save approximately 24,340 euros per year. The amount was calculated based on the average salary of an operator at the Kia Slovakia s.r.o. production plant, and therefore, it will vary according to the salary policy of a particular plant. Ultimately, however, the amount will be three times higher because production runs continuously in three shifts, and wages must be paid to three workers. There is also a reduction in costs when transporting parts to the warehouse. These include, for example, fuel costs, driver costs, but the obvious one is the reduction in inventory costs. The drone delivering type C parts and spare parts to the warehouse allows the car manufacturer to follow the trend in Just-in-Time inventory management, i.e. just in time.

Non-economic evaluation. Since the authors proposed incorporating UAVs for various transport options, their non-economic evaluations will also vary. If the drone replaces a motor vehicle (truck or other transfer vehicle), we expect it to contribute to social responsibility in the field of the environment. Transport was the main polluter in terms of CO₂ production in 2020. Drones do not pose a burden on the air, as they do not produce CO₂ emissions. Thanks to the Just in Time inventory management system, logistics becomes more flexible because transport is carried out when needed, and the necessary parts are always available without downtime in production. The use of vertical space is also an advantage in indoor transport. Air transport brings new possibilities for efficient use of space, which "saves floor space". Employees' original manual transfer of objects from place A to place B was also repetitive and unsuitable for the musculoskeletal system. When transferring protective equipment and parts, a drone acts as an assistant. It can transport the required cargo quickly and reliably, allowing the employee to resume the necessary activity without a long wait.

4.4 Inspection services – technical management of the interior and exterior of the premises in combination with a 3D model

The initial costs of implementing drone inspection services will differ for exterior and interior deployment. The DJI Mavic 2 Pro is a suitable device for interior inspections, the price of which, with the camera and recommended thermal sensors, is approximately 5,560 euros. (Heliguy, 2024, c) We recommend purchasing

the HELIGUY Mavic 2 drone Cage protective client for 600 euros to ensure the greatest possible security of the drone and property. (Heliguy, 2024, a) We assume the interior inspection drone will be deployed only a few times a year. Therefore, it is necessary to purchase a protective case, which is not a significant item from a cost perspective since its price is around 140 euros. (Dronerds, 2024, c) We suggest that internal employees conduct internal inspections after the provider has trained them. The cost of training is also an initial cost, which is reflected in the price of implementing the entire solution, which, due to its complexity, cannot be quantified. However, employees must also complete a course to legally fly the drone, which costs 150 euros per employee. (Aprop, 2024) For exterior inspections, we recommend the most advanced technology on the market today, which is the compact DJI M30 drone. Its features are described in detail in recommendation number 5, as it is a suitable candidate not only for exterior inspections but also has the potential to be used for multiple solutions. The DJI M30 costs 9,300 euros, but we recommend purchasing it with the DJI dock, which is also described in subsection 4.5. The total hardware price is 25,000 euros. (DJI, 2024, a) The operating cost for interior and exterior inspections is also the license for the DJI FlightHub Drone Management Software – Advanced, which costs 2,800 euros per year. (Dronerds, 2024, a)

Benefits. The proposed improved process is a source of time savings for the company. The total time savings for exterior inspections are estimated to be 95%. The car plant will also save the cost of paying external companies that would perform manual inspections for a significantly more extended period. The time savings for interior inspections can be estimated based on data from Ford Dagenheim, which successfully implemented a drone solution into its processes. While the original process took 12 hours to inspect one location, the drone captured the necessary data in 12 minutes. The internal inspection of the entire plant was carried out for 3 weeks, while the drone inspection took only one day. This time saving can be assumed in general for car plants. Another benefit is labour cost savings because employees spend significantly less time conducting inspections. Human labour is also saved in the sense that the improved process requires the cooperation of fewer workers.

The analysis shows that drones reduce labour costs and the costs that result from stopping operations. The amount cannot be precisely quantified, but significant savings can be expected, as the original process required a shutdown of operations for several days. Drone inspection can be performed without a shutdown—time savings where the original process of inspecting one area took 12 hours. The improved process allows for a detailed inspection in 12 minutes. An inspection of the entire manufacturing plant can be performed in one day, whereas in the past, it was performed over three weeks in the summer, during which production was shut down. (Ferris, 2018; Ford Media Center, 2018)

Non-economic evaluation. An automobile plant can expect greater employee health protection from drone inspections. When inspecting high equipment, machines, cranes and roofs, they originally had to overcome dangerous height differences of several tens of meters. Falls from such places can lead to tragic consequences. Thanks to UAVs, employees can monitor the entire process from the safety of the ground and evaluate the data in real-time. The data is displayed in processing software, allowing for more accurate damage identification. Storing photos helps prevent problems associated with workers' different opinions on a given defect and ambiguities during inspection work.

The company can strengthen prevention and conduct interior and exterior inspections more frequently by eliminating complexity. A drone can survey high and hard-to-reach places without building auxiliary scaffolding or various other platforms that need to be dismantled. This complex process requires the cooperation of multiple company resources, while a drone provides a simple solution. The analysis shows that a properly deployed drone is less error-prone than human work. During inspections, an employee may overlook a location or component.

5. Conclusion

The article's purpose was fulfilled by creating recommendations describing possible deployments of drones in automotive plants. The most frequently mentioned benefit is time savings, and the authors see the greatest potential in vehicle inventory in an outdoor parking lot. A significant finding was that the preferred solution is an autonomous, multi-rotor drone from a reliable manufacturer. A device from the technology company DJI

was chosen for most solutions. The authors believe that unmanned aircraft do not threaten employees' work by replacing them. People are still needed in improved processes. Drones collaborate with them and make their work easier and more efficient. While drones perform monotonous, non-ergonomic and sometimes dangerous tasks, people can focus on work requiring innovation and critical judgment.

It is important to mention that only a small number of drone applications in the automotive industry have been listed. They mainly act as a platform for data collection or as a device capable of transporting objects. Automotive companies, manufacturers and drone service providers are therefore faced with the opportunity to introduce innovations in the form of drone technologies into their processes and thus gain a competitive advantage. In addition to the four main analyses of economic and non-economic evaluation and the benefits of the recommendations, the authors also propose a universal compact drone that can cover multiple activities for the company. The authors are aware that the automotive plant requires a high level of reliability for the solution, so the selection of specific equipment was also adapted. The most reliable solution is a commercially offered drone that meets the company's requirements, and no further modification of the equipment is necessary that could jeopardize the platform's reliability.

The article in question demonstrates that unmanned aircraft have the potential to be used in the automotive industry. The authors assume that with the advancement of technology, current limitations will be overcome, and drones will find their application in more and more processes.

The analysis of drones in the automotive industry is a recent phenomenon with immense potential to revolutionize various production and logistics aspects. Here is a glimpse into how drones are transforming the automotive landscape:

- **Inventory Management in Large Parking Lots:** Manufacturing plants often have sprawling parking lots for storing finished vehicles. Traditionally, locating a specific car could be a time-consuming manual process. Here's where drones come in. Equipped with RFID technology, drones can efficiently scan and identify vehicles, streamlining the inventory management process and significantly reducing search times.
- **Enhanced Safety and Security:** Drones can be deployed for security purposes, patrolling manufacturing facilities and perimeters to deter unauthorized access and prevent potential security breaches. They can also be used for aerial inspections of rooftops and other hard-to-reach areas, identifying safety hazards and potential maintenance issues.
- **Delivery of Parts and Materials:** Large automotive manufacturing facilities often require the movement of parts and materials across vast distances. Drones offer a faster and more efficient solution than traditional ground transportation methods. They can navigate traffic congestion and deliver parts directly to assembly lines, minimizing delays and disruptions in the production process.
- **Quality Control Inspections:** Drones equipped with high-resolution cameras can be used to conduct detailed inspections of car bodies and painted surfaces, detecting even the slightest imperfections. This can significantly improve quality control processes and ensure the production of defect-free vehicles.

These are the main findings on how drones are transforming the automotive industry. As drone technology continues to evolve, we can expect even more innovative applications to emerge in the coming years.

The novelty of this research lies in its comprehensive exploration of drone applications within the automotive industry, examining both economic and non-economic benefits. The study provides valuable insights into how drone technology can transform various aspects of automotive manufacturing, from inventory management and logistics to quality control and safety inspections. This research contributes to the field in several novel ways:

- **Comprehensive analysis:** It offers a holistic view of drone applications in the automotive industry, encompassing various aspects of manufacturing, logistics, and management.
- **Economic and non-economic perspectives:** It evaluates the benefits of drone technology from both economic and non-economic standpoints, considering factors such as cost savings, efficiency gains, environmental impact, and social responsibility.

- Focus on strategic decision-making: It highlights how drone technology can inform and support strategic decision-making in the automotive industry, enabling companies to optimize operations and gain a competitive edge.
- Real-world examples: It draws on real-world examples of drone deployments in automotive plants, providing practical insights and demonstrating the feasibility of implementing drone technology.
- Specific recommendations: It offers concrete recommendations for automotive manufacturers and drone service providers, outlining potential applications and suggesting suitable drone models and technologies.

By combining a comprehensive analysis, a balanced evaluation, and practical recommendations, this research provides valuable insights for the automotive industry and contributes to the growing body of knowledge on drone technology applications.

However, the research has limitations. The study primarily focuses on the potential benefits of drone technology, with less emphasis on the challenges and risks associated with implementation. The economic evaluations are also based on estimated costs and potential savings, which may vary depending on specific plant characteristics and drone models. For instance, the study does not address potential issues such as:

- Technological limitations: Battery life, payload capacity, and flight range can restrict the types of tasks drones can perform.
- Regulatory hurdles: Obtaining necessary permits and licenses for drone operations can be complex and time-consuming.
- Data security concerns: Protecting sensitive data collected by drones from unauthorized access and cyberattacks is crucial.
- Employee training needs: Operating and maintaining drones require specialized skills and training, which can incur additional costs and time.
- Integration challenges: Integrating drone technology with existing manufacturing and logistics systems may require significant investment and expertise.

Weather dependence: Drone operations can be affected by adverse weather conditions, limiting their reliability and efficiency.

Public perception and acceptance: Concerns about privacy, noise pollution, and safety can impact the public's acceptance of drone technology.

Addressing these limitations in future research would provide a more balanced and comprehensive understanding of drone implementation in the automotive industry.

Further research could investigate the challenges and risks of drone implementation, such as regulatory hurdles, data security concerns, and employee training needs. Additionally, future studies could conduct more detailed cost-benefit analyses using real-world data from automotive plants that have implemented drone technology. Examining the impact of drones on employee roles and the organizational structure of automotive companies could also provide valuable insights. Finally, exploring the potential of drones in other areas of automotive manufacturing, such as research and development, could further contribute to the field.

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