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POSSIBILITIES OF USING UNMANNED AERIAL VEHICLES IN HEALTHCARE WITH AN EVALUATION OF THE BENEFITS AND THREATS*

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Abstract. This paper explores the potential applications of unmanned aerial vehicles (UAVs) in healthcare, focusing on their implementation in real-world scenarios. UAVs, commonly known as drones, have shown significant promise in improving healthcare services, particularly in the rapid transport of medical supplies such as blood, vaccines, and laboratory samples. Through a systematic review of existing literature, this study identifies five key areas where drones are already being utilized or hold potential for further integration: sample transportation, emergency medical services (e.g., AED delivery), organ transport, disaster relief, and mosquito population control. The study highlights both the benefits and risks associated with UAV deployment in healthcare, including increased efficiency and accessibility of medical supplies versus concerns over safety, battery life, and regulatory challenges. The paper concludes with an evaluation of the readiness of these technologies for widespread adoption, suggesting that with further improvements and regulatory adjustments, drones could become integral to modern healthcare systems.

Keywords: drones, economic efficiency; decision-making; healthcare; medical supply transport; emergency medical services; organ transport; disaster relief; mosquito population control

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1. Introduction

Current demographic trends, such as a growing and aging population, are placing unprecedented pressure on healthcare infrastructure and delivery. While the number of patients requiring medical care is increasing, current systems are lagging behind in many areas, leading to long waiting times and inadequate diagnostics. In response to these challenges, modern technologies, including unmanned aerial vehicles (UAVs), are coming to the fore, with the potential to automate and streamline logistics processes. The main objective of this article is to search for and analyse available information on the commercial use of UAVs in healthcare and, based on the findings, discuss recommendations for their implementation in practice.

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The need for innovative solutions is most urgent in regions with low levels of infrastructure and health security, such as sub-Saharan Africa, where road transport often fails or is too slow for urgent cases. Drones can play a key role here not only in supporting the so-called SMART (Speed Metrics Automation Remote Technologies) laboratories and sample collection automation, but also in saving lives in crisis situations where minutes are crucial. The article therefore focuses on identifying real existing solutions, as well as on the results of scientific research in this area.

Based on a systematic review of the literature and analysis of available sources, five key areas in which the application of drones appears to be the most promising were identified: transportation of biological samples, transport of external defibrillators (AEDs), logistics in natural disasters, organ transport and mosquito population control. These areas are categorized in the work according to the degree of their technological readiness and real deployment, from theoretical concepts to systems fully implemented in practice.

In the following sections of the article, the current state in each of the five identified areas will be discussed in detail, while the work will focus on analysing existing problems and the ways in which the introduction of drones solves them. The discussion will then assess the main risk factors associated with these solutions, such as safety, legislative restrictions, and battery life. The conclusion of the paper will provide a synthesis of the findings and an assessment of the readiness of these technologies for wider adoption in modern healthcare systems.

2. Theoretical background

According to UN reports, there are well-known statistics that say that there is and will be a steady increase in the demands on healthcare provision and therefore on healthcare infrastructure. In particular, there are statistics on the constant population growth - the projected population in 2030 is 8.5 billion and 10.9 billion at the end of this century. At the same time, there are areas where fertility rates are as high as 4.6 live births per 1 mother. However, areas with high fertility are also areas with low infrastructure and low health security, such as sub-Saharan Africa (hereafter referred to as "SSA") The current health system is lagging behind the increasing number of patients who have to wait long periods of time to be examined and receive poorly comprehensive diagnoses (Mannello & Plebani, 2022).

Another worrying statistic is the constantly ageing population, which is once again increasing the number of patients who are referred for medical assistance. The UN reports that in 2018, for the first time, there were more people over 65 than children under 5 in the world. At the same time, by 2050, it is projected that there will be twice as many people over 65 as children under 5 in the world, and more of them than adolescents aged 15 to 24 (World population prospects, 2024).

Drones have found their use in a variety of fields and industries where they simplify, digitise and automate routine activities. One prominent area is healthcare, within which they are considered an integral part of laboratory healthcare for the decade starting in 2020. Drones could form part of so-called SMART laboratories to support their automation. The greatest potential is seen in the collection and transport of various samples taken from patients. (Mannello & Plebani, 2022; Shapira, 2025)

Within the scope of the paper, it will be analysed in more depth what areas within the healthcare sector present problematic issues and possible solutions need to be found. It will also analyse how the use of drones could help within those areas.

3. Research objective and methodology

The main goal of the paper is to search for available relevant information considering commercial usage of unmanned aerial vehicles (UAV) in healthcare. Based on our findings we discuss common recommendations for commercialization of these type of solutions. We have focused the search on two major areas: 1) real existing solutions; 2) solutions presented as results of science and research in relevant scientific databases.

The process of creating the methodology consisted of 6 main steps. The first step was a search of available literature and publications on the topic of drones in healthcare using keywords such as "drones in healthcare", "drone capabilities", "drone usage". The scientific databases Scopus and Web of Science were used for the search. In addition to the keywords, a publication-year filter was applied. The search primarily targeted publications from 2021 to 2025 to reflect the most recent technological capabilities, regulatory developments, and real-world implementation of UAV solutions in healthcare. Older publications were included only in cases where they provided substantial scientific value (e.g., seminal or frequently cited evidence relevant to the research topic).

After collecting publications relating to the topic under study, each publication was sorted for suitability and relevance to the research in question. The sorting of publications was done in 2 phases. In the first phase, the abstracts of the publications were studied to assess their relevance to the research. The exclusion criterion in the first phase was also the availability of the full text of the publication. The full publications remaining after sorting from the first phase were studied in the second phase. The criterion for inclusion of a publication in the research was the identification of a link between UAVs and healthcare, i.e., the publication had to clearly define in which area UAVs were used/tested, for what reasons, and what the outcomes were - benefits and threats - from this.

In a third step, the publications thus sorted were grouped according to the areas of use identified in the publications. The fourth step then consisted of creating specific groups of areas in which the benefits of drones for healthcare were identified. Specifically:

- transport of samples,
- AED transport,
- natural disasters,
- organ transport,
- mosquito control.

The identified application areas have created scope for a deeper understanding of the use of drones with respect to a specific area. Therefore, in the fifth step, further information was tracked down to answer the following research questions:

- What is the current state (in terms of process, technology, personnel)?
- What are the resulting problems?
- How can the introduction of drones address the problems?
- Has anyone tried to introduce drones in the area to solve the problems?
- If drones have been introduced, how has this helped the status quo and conversely what other problems and issues has this brought?

Within the subchapters with research findings will be structured based on the 5 areas identified. The sixth and final step was to create categories for the extent to which the identified solutions have been put into practice, and so this will be a systematic classification into 5 categories according to the extent to which they have progressed in their development. The resulting rankings can be seen in Table 1, where category 5 represents the options with the highest degree of development. The categories are formed cumulatively starting with category 1, which represents the baseline. With each successive category with a higher number, development is rated as better. This means that any category contains all the developmental stages reached by all categories below it (with a lower number) and in addition has reached a new, further developmental stage. In category 2, clinical trials represent a superstructure above experiments, as they mean that the technology has already been put into practice in a systematic way, but has not yet been officially launched as it collects and evaluates data from the pilot operation.

Table 1. Classification of the uses of drones identified in the analytical part into 5 categories

Category	Category description	Examples of use
1	High application potential	General: transport of laboratory-produced organs for transplantation Specifically: • EHang + Lung Biotechnology PBC
2	Category 1 + studies known to have been carried out	General: transport of AEDs Specifically: • TU Delphi
3	Category 2 + experiments have taken place	General: transport of organs for transplantation, transport of AEDs, transport of specimens at city level, mosquito population control Specifically: • Matternet (Germany, Japan) - samples + medicines, • Everdrone (Denmark) – AED, • Flirtey (USA) – AED, • MedziDroid Project – spraying for mosquitoes, • Nguyen, Krupke, Burbage et al: Using a UAV for Destructive Surveys of Mosquito Population • Carrasco-Escobar et al. (2022). The Use of Drones for Mosquito Surveillance and Control. Parasites & Vectors • Gilmour & Hoff (2025). Drone-Assisted Organ Transport: A Scoping Review of Clinical, Regulatory, and System Readiness.
4	Category 3 + clinical trials have taken place	General: transport of AEDs Specifically: • Everdrone (Sweden) – AED, • Zipline (USA) – vaccines.
5	Category 4+ system is in place and implemented in practice	General: transport of medical supplies (medicines, vaccines, blood, samples for analysis), mapping of areas devastated by natural disasters Specifically: • Zipline (Rwanda, Ghana) – blood + medicines, • Matternet (Switzerland, USA) – samples, • Nepal, • Haiti, • Philippines, • Vanuatu.

Source: composed by the authors, based on Karpstein (2024), Tudelf (2025), Swiss Post (2022), Kolodny (2017), Schierbeck (2023), Everdrone (2020), Dukowitz (2020), Mechan (2023), Nguyen et al. (2018), Carrasco-Escobar (2022), Gilmour (2025), Zipline (2021), Zipline (2025), Edwards (2024), Alfaris (2024), Yucsoy (2025), Bhattacharya (2025), Rattanaamporn (2025)

In the next chapter (results), the domains will be described in order of the category. Within the description of each area, attention will be paid to the description of the current situation and the problems associated with it, options for addressing the current situation, examples of deployment in practice, and the results of deployment in practice.

4. Results

As results we will provide main important information from our search. We present the results with the use of the structure of 5 identified areas of use within the healthcare.

4.1. Transport of samples

In most cases, only small laboratories are set up at the sites where physical sampling is carried out, covering basic tests that are not intended for bulk processing. Comprehensive diagnostics are carried out in large stand-alone laboratories equipped to handle large numbers of samples with a wide variety of types of tests. It is necessary to transport the collected samples from the collection site to the designated laboratories at regular intervals. An example of the ratio is provided by statistics from the United States, where small clinical

laboratories accounted for approximately 75% of the total number of laboratories, but covered only about 13% of the total tests performed. (Ong, 2022; Shapira, 2025; Stierlin, 2024)

It is possible to consider 2 main directions of solution. The first brings transport via drones and the second via aerial drones. The question with drone transport is to what extent such transport can be safe and whether the samples will not be degraded during flight due to acceleration, braking or changes in temperature and air pressure. However, studies have shown that the transport of biological samples by drones is safe and does not degrade them so that clinical out-comes remain unaffected. However, for a successful deployment of a UAV network in practice, it is necessary to take into account the climatic conditions and test each type of sample individually. Thus, transport of samples is possible but requires adaptation to the conditions of the area. (Nisingizwe, 2022; Wiltshire, 2024)

A pneumatic tube system is similar to a UAV in that it offers fast and efficient transport. It has the advantage of ease of use and safety, but requires a complex network of tubes and appropriate software to avoid collisions. The disadvantages are the high cost of compressed air and sensitivity to vibration. However, the main problem is that this system is only usable within buildings or between closely spaced buildings, as the external tubes are susceptible to damage and take up a lot of space. It is inefficient for connecting larger complexes (Swisslog Healthcare, 2025).

There are 2 known deployments in practice, namely by Zipline and Matternet, both cases with different intentions. Zipline uses centralized warehouses for the distribution of health supplements over the largest possible distances. Matternet, on the other hand, transports samples from health collections within the community over short distances. Due to the purpose of transportation, the solutions also use different types of drones - Zipline uses fixed-wing drones and Matternet uses multi-propeller drones. In both cases, speed and safety are important criteria.

Zipline has partnered with the government in Rwanda to create the world's first commercial medical device delivery service via drone. The transport network mainly provides transportation of blood packages, vaccines and various medicines (Zipline, 2025). Road communication is slow and health facilities routinely find themselves running short of various supplies, especially blood. In the event of an emergency, the blood supply can take several hours to arrive, which can have fatal consequences. Blood is important in a variety of emergencies, such as massive haemorrhage in childbirth, which has long been identified as the leading cause of mortality among women in pregnancy (Figo, 2025), with the highest incidence of cases in central and sub-Saharan Africa (Unicef Data, 2019). Another important link is vaccines. For health workers working in rural areas, their storage at low temperatures as well as maintaining the necessary stock levels is a significant problem (Zipline, 2021). Zipline's solution has been actively helping to reduce the statistics of female mortality starting in December 2016, when Ghislane was rescued and became the first person in the world to owe her rescue to a UAV (Zipline, 2021). Overall mortality rates may have dropped by 38%, but 295,000 deaths in 2017 is still a high number, not to mention that deaths caused by bleeding in childbirth are easily reversible and one might even say unnecessary. (Unicef Data, 2019) Thanks to Zipline's solution, vaccines are stored in optimal conditions, and when needed, healthcare workers receive the necessary amount of refrigerated vaccines, allowing them to attend to patients without having to worry about supplies. (Zipline, 2021) Additional evidence of Zipline's global success can be seen in its entry into several new countries. These include Arkansas since 2021, and Utah, Côte d'Ivoire, Nigeria, Kenya and Japan since 2022. Their growth has extended beyond healthcare. With UAVs rede-signed for urban settings, Zipline has also begun exploring deliveries in the fields of gastronomy and agriculture (Insider Intelligence, 2023).

Switzerland, in collaboration with Matternet Inc. ("Matternet") and the national post-al service Swiss Post, has decided to connect hospitals and laboratories using autonomous UAV devices. These drones are able to load and unload cargo, take off, and land autonomously. The autonomy and safety of the process are ensured by three-meter stations, introduced in 2020, which allow drones to fly without direct contact with humans. Deliveries are made via QR codes, allowing them to be used even in hospitals without dedicated staff. The drones have transported biological samples for rapid diagnosis, such as biopsies during tumor surgery, or blood in emergencies when the hospital ran out of supplies (Swiss Post, 2022). Matternet also operates in the US and,

as of November 2020, is operating in Germany, where it is working with Labor Berlin Charité Vivantes on the EU's first urban medical drone network without visual surveillance. This network connects 3 organizations and can significantly reduce sample transport time and increase lab efficiency (Suas News, 2020). The company is also expanding into Asia in partnership with Japan Airlines from September 2020, where it will transport medicines and medical supplies between Mediceo's ware-house and St. Luke's Hospital in Tokyo. Since the launch of the drone network in 2017, approximately 3,000 successful deliveries have been made. (Brian, 2019) The drone is a multirotor with 4 propellers, is capable of carrying 2 kilograms, has a range of 20 kilometres, and flies at a speed of approximately 36 km/h. (Kolodny, 2017; Molinary, 2024) Swiss Post stated that they have been able to reduce delivery times by up to 45 minutes by using drones. (SWI Swissinfo.Ch, 2020) In addition to time, costs have also been reduced because various ground transport services, such as taxis, as well as emergency ambulances, have been used for emergencies. Andreas Raptopoulos, founder of Matternet, stated that by re-placing emergency vehicles with drones, hospitals can save 20% to 50% of transport costs (Swiss Post, 2022). In January 2019, there was a delivery failure when a drone made an emergency landing on Lake Zurich. Investigation revealed a GPS failure due to a short circuit, but the emergency mode worked properly. In April, operations were restored, but in May another incident occurred in which the parachute ruptured and the drone crashed. Although it did not injure anyone, it highlighted the safety risk (Brian, 2019). Operations were suspended for half a year, and in January 2020 Swiss Post and Matternet introduced new security measures. (Norman, 2020.) The drones did not return to service until late August 2020 after a pandemic hiatus. (Apex Insight, 2020)

4.2. AED transport

The importance of resuscitating a patient before the arrival of emergency services is shown in different studies, for example from Sweden by authors Hasselqvist, Riva, Herlitz (2015). They observed data from 30,381 out-of-hospital cardiac arrest cases using the statistical variable "30-day survival rate", which is used in medicine to show survival rates 30 days after an incident. In the study, cardiac arrest is considered an incident. They found that 51.1% of patients received resuscitation before the arrival of emergency services and their survival rate was 10.5% as opposed to patients who did not receive resuscitation and their survival rate was 4%. In addition, they also found the effect of time on the onset of resuscitation performance with the results shown in Table 2 showing that with each minute of not giving resuscitation, the probability of surviving the incident drops sharply. (Hasselqvist-Ax, 2015; Lafrance, 2023; OECD, 2025; Jensen, 2023)

Table 2. Impact of time on survival rates in resuscitation delivery.

Time to resuscitation	Survival rate
within 3 minutes	15,6 %
4 - 8 minutes	8,7 %
9 - 14 minutes	4,0 %
more than 14 minutes	0,9 %

Source: Hasselqvist-Ax, 2015; Lafrance, 2023

However, in addition to resuscitation, a publicly available defibrillator can also play an important role before the arrival of an ambulance. A study also published by The New England Journal of Medicine, where the object of investigation was Japan found that 10.3% of people in cardiac arrest out of 43,762 studied received defibrillation, with a survival rate of up to 38.5%. The authors also point out that the survival rate after cardiac arrest with favourable neurological sequelae has also increased due to the currently freely available defibrillators. The interest of competent organisations in this direction can be seen, for example, in the form of guidelines from the European Resuscitation Council, in which they point to the statistic that defibrillation within 3-5 minutes of the incident will increase the survival rate up to 50-70%. They therefore call for the implementation of publicly available defibrillators, especially in places with a high density of people (Perkins, 2021; Katasako, 2023).

On the other hand, studies point to the under-occupancy of these devices in public areas. For example, a study from the Netherlands highlighted the problem that up to 60% of the placed automated defibrillators were not

visible and only 88% of the devices were ready for use (the remaining ones either had a dead battery or were expired, a combination in the case of the latter) (Kim, 2022). Also, the Philadelphia study indicated that 70-80% of the devices were positioned such that in the event of an incident the estimated distance was a 3-minute walk (Grigoryan, 2025).

Given the potential for increasing survival rates in cardiac arrest with an automated defibrillator, it is worth considering the possibility of transporting such a device to the incident site in the event that none is present. Drone transport, which is independent of road infrastructure and traffic density, enters into consideration as the fastest transport. Much of the research into the practical use of drones in this area has been carried out in Sweden. One study found that in urban areas, the drone arrived at the scene of an incident faster in 32% of the cases, reducing the overall waiting time for help by 1.5 minutes. In rural areas, the drone arrived faster up to 93% of the time and the total time saved was 19 minutes. Such results are encouraging for further consideration to implement a drone defibrillator transport solution. (Schierbeck, 2023; Jakobsen, 2025)

In the second study, 2 different times were experimentally investigated: the first was the time from the emergency call to the departure of the device (ambulance, drone), and the second was the time from the departure of the device to its arrival at the incident site. 18 operations were performed and the median of the measured values was taken as the final time. The first initial time was 3 minutes for the rescue service, and 3 seconds for the drone, and the second time was 22 minutes for the rescue service and 5 minutes and 21 seconds for the drone (Fischer, 2023; Schierbeck, 2023; Jakobsen, 2025). Real deployment examples include Everdrone, Flirtey and TU Delphi.

According to Everdrone, 275,000 are hit by cardiac arrest in Europe every year with a survival rate of just 10%, and every minute without help reduces the likelihood of survival by 10%. Their system is available to 80,000 residents who, in the event of an incident after calling for first aid, await the arrival of a drone to reach the scene sooner, in addition to the arrival of the ambulance service. The defibrillator is brought to the ground from a height of 30 meters, from which it is lowered down by a rope. This method is quite innovative, as there are known tests of dropping the defibrillator from different heights or landing the drone with the defibrillator on the ground. Mats Sällström, CEO of Everdrone, claims that they have carried out a number of tests to find the most suitable method, which is precisely the gradual descent from a height argued by the danger of landing the drone close to humans. (Everdrone AB, 2020) The company takes particular pride in the safety of its devices, which is why they have also become one of the few companies that can carry out drone operations in populated areas and fly over people. (Intel Corporation, 2021) In June 2020, a test run of the system was launched. However, no results have been published from the company as of 2021, despite Mats Sällström's expectation that they would be published in January 2021 (Dukowitz, 2020). However, a smooth testing process can be assumed as the company has announced cooperation with Copenhagen Emergency Medical Services in 2021, thus creating room for expansion into Denmark. A delivery network covering more than 100,000 people in areas with long emergency services response times is planned to be launched in the autumn of 2021. Mats Sällström believes in a permanent roll-out of their solution in Sweden. Also, through innovations in technology, processes, or route planning optimization, they will build an efficient and robust solution not only in Sweden but also in Denmark (UAS Vision, 2020; Jager, 2021). Another drone food delivery company that has decided to take its business into the healthcare industry and deliver defibrillators to people is Flirtey Inc. The company teamed up with REMSA Health to create an emergency medical service in the US state of Nevada based on the statistic that cardiac arrest is the leading cause of death in the US (Schierbeck, 2023). In 2019, the FAA permitted them to operate flights outside of visual surveillance (Dukowitz, 2019).

Alec Momot is working on an ambulatory drone project that would incorporate various first-aid medical devices, which would include a defibrillator. He has designed a prototype of the drone, which has been given the name TU Delf. When the emergency services are called, a drone capable of communicating with the surrounding area would arrive at the scene. Thanks to a built-in microphone, speaker, and camera, the paramedic can navigate while administering first aid (Tudelf, 2025).

4.3. Natural disasters

A sporadic but very appropriate use of drones is in natural disasters and catastrophes, in which drones can figure in various ways. In the event of an accident, a drone or group of drones can be sent to the affected site to gather important information about the extent and severity of the damage. Drones can scrutinize the surface and produce 3D maps that are evaluated to provide key information about the most affected areas. This will then allow rescuers to be sent to the places where it is really needed. Once these areas have been identified, medical supplies, food, or water can be delivered to people in need until rescuers arrive. The advantage of tracking the affected area by drone immediately after a disaster is to ensure the safety of people who would normally have to explore many areas in person, putting them at potential risk. Drones were used for this very purpose in Nepal after the magnitude 7.8 earthquake in 2015. In addition to mapping, the drones also contained thermal cameras that were able to identify where people in need of help were located. Using high-zoom lenses, they were able to recognize people's faces from over 300 meters away (Alfaris, 2024; Yucesoy, 2025).

Drones have also been used by the International Organization for Migration since 2012 to monitor 7 camps and their populations in Haiti. Drones were also used after Hurricane Sandy, which killed at least 54 people. After the storm was over, the drones immediately started mapping the environment and had the results 7 days before the first photo was taken by satellite. In collaboration with the OpenStreetMap community, before and after images were then compared to the floods to identify the hardest-hit areas that needed the most help. Historical satellite imagery was added to this data to create a prediction of the locations at greatest risk of future flooding. 3D maps were also created to identify hazardous river reaches used for infrastructure planning and flood protection for densely populated areas (Edwards, 2024). An example is the Philippines, which in 2013 experienced one of the worst typhoons, killing more than 6,000 people and was named Haiyan. The damage was extensive and the whole situation required additional aid. This was provided by SkyEye, with custom built drones locating survivors and assessing the extent of the damage, providing in-sight into possible prioritization of aid (Bhattacharya, 2025).

Another example is the small island of Vanuatu, which suffered significant damage after Cyclone Pam, and 75 000 people were made homeless. National Geographic researcher Patric Meier went to the country on assignment as a crisis cartographer and launched the UAViators programme, which is now a widespread humanitarian drone organization whose mission is to promote the safe, effective, and humanitarian use of drones in a variety of areas. Drones at that stage were mainly used to assess the repairability of houses, as aerial and satellite imagery could not detect all the damage. With this data, they were able to determine the need for funding and the places worth re-pairing. They used a crowdsourcing method to evaluate the vast amount of imagery, where they posted the images online and had volunteers analyse them. Quality control was ensured by showing 1 shot to even 10 people for analysis, which they could afford given the large number of volunteers (Humanitarian UAV Network, 2021; Rattanaamporn, 2025).

Among the most important results of the deployment can be considered the possibility of a quick analysis of the affected area. The UAV can be sent to the site immediately after a natural disaster, regardless of the safety conditions of the affected area, and assess the current status and extent of the damage. This enables rescue forces to make better decisions on how to rescue. Technologies that make it possible to accurately locate survivors are also a major advantage. Based on this, it is possible to send emergency responders to where they are needed. In addition to analysis, UAVs can also be used to deliver life-saving resources such as water, food, and medical supplies until rescue forces arrive on the scene.

4.4. Organ transport

As many as 169 million people in the U.S. registered as donors in 2019, according to statistics from Organdonor, the main federal organization overseeing the nation's trans-plant system. Despite the abundance of donors, organs are still in short supply due to which people are dying every day. Many organs are even lost unnecessarily and inadequate transportation is cited as one of the causes. Organs last only a short while in strictly controlled conditions after removal from the donor and often ambulances, helicopters or planes have to be used to transport them, which is a costly option. (Karpstein, 2024) The integration of drones into the donated organ transport network could be a solution. This topic is actively addressed by Gilmour & Hoff (2025) who have also experimentally investigated the impacts of kidney transport by drone. The concern was in the disruption of

fragile human tissues due to drone vibration and applied pressure. However, the results of the biopsies showed that drone transport did not damage the kidney under study.

Similar penetration can be seen in the case of the collaboration between EHang, a company focusing on aerospace technology, and Lung Biotechnology PBC, a company specializing in the production of lungs and other organs for transplantation using advanced technologies. The companies have agreed on a 15-year collaboration to use EHang's 184 drone, which was the world's first autonomous drone capable of transporting a human. The EHang 184 is to be converted into a drone designed exclusively to transport organs for transplantation under a programme called the Manufactured Organ Transport Helicopter System. This ambitious project has generated attention and anticipation (Karpstein, 2024; Gilmour, 2025).

4.5. Mosquito control

In tropical areas such as sub-Saharan Africa, there are mosquito species that carry dangerous diseases such as malaria, chikungunya disease, dengue fever, lymphatic filariasis, West Nile virus disease, or yellow fever. Management of the mosquitoes that transmit them is essential to control integrated diseases. Different authors working at various institutions focused on tropical diseases, microbiology, parasitology, or immunology, have also provided in-sights on this issue. In their publications, the authors discuss various types of diseases occurring in tropical areas, where they attribute their lack of control largely to poor infra-structure and poor staffing of sampling sites and laboratories. The biggest gaps they see are in sub-Saharan Africa, where poor diagnostic infrastructure was evident in the 2014-2015 failure to contain and subsequent outbreak of Ebola. For mosquito management, the spraying method is commonly used. Such indoor and outdoor spraying uses manual ground spraying from a portable backpack sprayer or the more costly and therefore less available and used aerial spraying (helicopter, aircraft). Current spraying using human labour is considered by the project authors to be very inefficient, as these sprays in many cases need to be done on difficult to access terrain with poor climatic conditions, which pose a potential risk of various injuries and direct exposure to disease. At the same time, such spraying requires regularity and precision in the amount of spray chemicals applied, which is not achieved by human factors and leads to wastage (Kitonsa et al., 2020; Mechan, 2023; Ndlovu, 2025).

At the same time, tracking is also used for mosquito population management. Tracking individual mosquitoes is challenging due to their small size, unpredictable flight patterns, and preference for low-light environments. To address this, researchers have conducted tracking studies in confined indoor areas (approximately 4 by 8 feet) or by observing mating swarms against simple backdrops. The primary method for monitoring mosquito populations remains stationary traps, which require weekly inspections, such as encephalitis vector surveillance traps and gravid traps. Although efforts are being made to develop smaller, more cost-effective traps that provide real-time data, these approaches still depend on attracting mosquitoes into the traps. (Nguyen, 2018; Carrasco-Escobar, 2022) Sub-Saharan Africa, although a region of weaker socio-economic development, is subject to the interest of foreign investors. The last decade has been accompanied by the realization that technology can play a key role in the development of SSA, and drones may be one such technology. SSA is on the verge of a technological revolution due to the influx from developed countries (Karpstein, 2024).

According to the World Health Organization (WHO), the systemic solution is based on 3 core components: site surveillance, a coordination center, and a national laboratory. Improving laboratory networks has become an international concern for several countries in recent years, and an important partnership, the Global Health Security Agenda (hereafter "GHSA"), currently composed of 69 countries, NGOs, and private companies, has emerged, which has established 3 pillars for ensuring framework health: prevention of disease outbreaks, early detection of threats, and rapid response. The authors emphasize that new technologies, including UAV devices that provide rapid and efficient transport of biospecimens to laboratories in locations with poor infrastructure, have a very important role to play in meeting the pillars and prerequisites (Kitonsa et al., 2020; Ndlovu, 2025).

Potential solutions include the MedizDroids Project, which aims to find a sustainable and affordable solution using UAV technology based on the automation of indoor residual spraying, outdoor residual spraying, and larval source control. The MedizDroids Project is developing a solution that could replace the currently used spraying methods through multiple drones, which are expected to cost between €85 and €420. The automation of interior spraying involves spraying the interior and exterior walls of living spaces to kill adult mosquitoes

that use these spaces for resting or feeding. The automation consists of 3 stages, where in the first stage (preparatory) households are mapped and the necessary sensors are placed. In the second stage, the actual spraying takes place starting with each wall until every household is covered. In the third stage, the success of the spraying is to be investigated by monitoring the premises. The actual spraying would then take place by having the drone accurately map each dwelling with its walls and floors in advance and then, according to a set schedule, enter the dwelling through the entrance and systematically spray all walls, floors, and ceilings, and finally leave the dwelling at the end (Mechan, 2023).

As part of the optimization of traps using UAVs, there is the possibility of using electrical discharges. This topic was addressed by Nguyen, Krupke, Burbage et al, who aimed to design a UAV capable of systematically destroying mosquitoes. The authors also created a pilot model to test the solution. A custom-built six-armed drone was used as the UAV, in which the Pixhawk autopilot flight controller and ArduPilot Mega flight software were employed. The board consists of 2 aluminum mesh panels separated by a 3-millimeter gap. These are protected around the perimeter by fiberglass rods to ensure that the mesh is not damaged when the drone lands. After the overall construction, the net, weighing 0.948 kg, provided an effective area of 0.161 m² (Nguyen, 2018; Carrasco-Escobar, 2022).

Several tests were performed to properly adjust the UAV (especially the position and inclination of the mesh), including monitoring the airflow in the wind turbine. In addition, the authors also proceeded to experimental verification of functionality. The authors chose an area of 120m x 15m on which they performed 8 autonomous flights with predefined routes during different parts of the day. During each flight, the possibility was provided to manually take control of the drone in case of any failure or unexpected situations. At the same time, each flight was recorded audiovisually, which also served to verify the number of discharges. The experiments yielded significant findings, especially in terms of localizing the occurrence of mosquitoes during the day and night. They were found to be most active in the early morning and early evening and to have their highest concentrations in areas with trees. As pointed out by the authors themselves, such test flights alone can significantly help to understand where mosquitoes occur and at what times and in which places they do not occur. The study refers to other possible means of control, such as traps mimicking human bait or genetically modifying mosquitoes to reduce their reproductive capacity or ability to transmit disease. Another method currently used is insecticides, which, although inherently effective, are a burden on the planet in the long term and mosquitoes are gradually building up resistance to them (Nguyen, 2018; Carrasco-Escobar, 2022).

5. Discussion

Drones represent a significant contribution to healthcare, particularly in the area of rapid delivery of medical materials such as medicines, samples and blood products to remote or hard-to-reach areas. Their use can speed up diagnostic processes, improve access to healthcare and reduce logistics costs. With further advances in technology and improvements in security measures, drones have the potential to transform the efficiency and quality of healthcare services worldwide. We state five main risks factors of the analysed solutions. The 5 areas of the potential use of drones in healthcare analysed are associated with similar risks that they carry. For this reason, the risks for all 5 areas are presented together.

Security and safety

The biggest risk of using drone networks is their security. Drones can weigh between a few kilograms and 20 kg, and dropping them from a height of, say, 100 meters poses a risk of injury. Although there are no reported fatalities with commercial drones, minor injuries such as scratches or bruises do occur, with the most serious being damage to the eye. A 2019 study by the ASSURE organization examined the impacts of drone collisions on humans, with only one out of 512 tests resulting in a visible skull injury in a high-speed collision. The research results suggest that drones are made of flexible materials that can absorb much of the energy of a collision. Drones today use sophisticated safety systems, including 3D mapping, intelligent route planning, emergency landing, and obstacle avoidance sensors. For example, Intel's advanced RealSense technology, which can detect both stationary and moving objects (Perz, 2024; Ní Aoláin, 2023; Kusnirova et al., 2024; Staffenova et al., 2025; Svatý, 2025).

The airspace

Another risk is a collision with another UAV, which can be difficult to predict and avoid, as drones can fly at speeds of up to 100 km/h and sensors may not be able to detect an object moving at such speeds. Zipline solves these problems with a patented system based on decentralized monitoring centres that communicate with drones. The UAV devices contain sensors that monitor the surroundings and send the data to a center that adjusts the flight trajectory. The drones also share information about obstacles so that other devices can optimise their routes. For example, if one drone encounters a thunderstorm, the other drones may choose a different route. Before taking off, each drone must get permission and has an optimal route calculated based on a 3D map, including elevation movements (Lendel et al., 2021; Hamissi, 2023).

Contamination

The transport of biological material such as blood is a risk in itself, as there is a risk of contamination of the environment if the equipment fails and collapses. This problem was addressed, for example, by Amukele et al. (2015) in their study testing the possibilities of transporting blood by drone. They reported that blood samples for diagnostics were classified as potentially infectious biological material, requiring packaging in 3 layers so that in the case of liquids, the packaging had an absorption capacity 2 times greater than the material being transported (Amukele et al., 2015; Shapira, 2025; Miciak et al., 2025).

Battery life

As outlined above, the battery is one of the biggest obstacles to full UAV deployment as it is responsible for range capabilities. Many transportation network solutions using drones call for the use of multi-rotor types, which are very energy intensive to operate. Therefore, a trade-off has to be made between the weight of the equipment (and therefore the potential cargo) and the flight time. If the main concern is to have the longest possible range, the lowest possible payload must be taken into account, and if the main concern is to carry more weight, the transport must be carried out over a short distance. Improving UAV battery life can be achieved in a number of ways, such as using lightweight materials to reduce the weight of the device or planning routes with a minimum of turns that are energy intensive. Another option is to swap a dead battery for a charged one at strategic locations or to set up stopovers for recharging. An interesting proposal was presented by Huang et al. in 2019, where the drone uses public transport for part of its route, thus saving energy. Using long-distance lines, trains or logistics vehicles could also be a solution (Huang et al., 2019; Cokyasar et al., 2021; Demjanovicova et al., 2021).

Legislation

The biggest constraint to putting drones into practice is state legislation. Restrictions can vary from country to country. Generally speaking, restrictions can be placed on flying over populated areas, spraying any chemicals and dropping objects. These legislative re-strictions can be overcome with proven safe technology. An example of countries that have issued such permits for the commercial operation of drones, and a significant mile-stone is the granting of permission for drone flights over populated areas in Germany, as the first European Union country to do so.

5.1 Limitation

When interpreting the presented results, it is necessary to take into account several limiting factors that could have affected the scope and depth of this study. The first significant limitation was the set time frame and the number of researchers involved in the project. Limited personnel capacities reduce the time available for detailed research, which may lead to some specific aspects of the issue not being examined as thoroughly as would be desirable in the ideal case.

The second fundamental limitation is the chosen methodology, which relied exclusively on content analysis of available sources. Although this method provides valuable theoretical data, it can be considered one-sided, as it does not allow for direct interaction with the elements of the studied system. The study could have yielded more comprehensive and diverse results if it had been supplemented with other research methods, such as questionnaires or in-depth interviews with practitioners.

The absence of empirical fieldwork and the reliance on secondary data may affect the general applicability and accuracy of the conclusions in the dynamically changing health technology environment. These factors suggest that while the study provides a strong theoretical overview, further research with a broader methodological scope would be needed to fully validate the proposed solutions.

6. Conclusions

The aim of this article was to analyse the available information on the commercial use of unmanned aerial vehicles (UAVs) in healthcare and assess their readiness for implementation in real practice. Through a systematic literature review from the Scopus and Web of Science databases, we identified key areas of application and categorized them according to their level of technological and process development. The methodology included not only a theoretical analysis of benefits and threats, but also the creation of a five-category classification system that made it possible to assess whether the solutions in question are only at the experimental stage or are already systematically used.

The results of the analysis confirmed that drones represent a significant benefit for healthcare, especially in the area of rapid transportation of medical supplies to hard-to-reach areas. Of the five areas studied, the transportation of laboratory samples appears to be the most developed, where there are already functioning commercial solutions. High application potential has also been confirmed in the transport of AEDs, where drones can radically shorten the response time in case of cardiac arrest, and in the management of natural disasters, where they are used for mapping and distributing aid. On the other hand, areas such as organ transport or mosquito population control require further verification of safety and effectiveness. However, implementation encounters barriers, which are mainly legislative restrictions, air traffic safety and battery life limits.

The evaluation of the analysed solutions will be presented, highlighting their strengths, weaknesses, and potential for future application. First is transport of samples. The use of drones to transport samples between healthcare providers and laboratory diagnostic providers is very realistic. Solutions exist, capacity is expanding and more providers are entering the market. Demand is coming mainly from states, regional and municipal governments. Solutions should be deployed in places where there is a lack of sufficient transport infrastructure and, conversely, in places where traffic is heavy with an increasing trend. Typical examples of the former are some regions in Africa, typical examples of the latter are densely populated urban agglomerations. In this case, UAV-based solutions represent a fast and relatively safe mode of transport. The biggest challenge here is the effective airspace management and overall safety of the deployed solution.

Second is AED transport. Time plays a critical role in the provision of emergency medical assistance, especially in circulatory arrest conditions where even a few minutes can mean permanent brain damage or a person becoming unresponsive. The response time of ambulance providers is limited by several factors, including the length of the route to the patient or the traffic situation. At the same time, the availability of an AED can be a critical factor in rescuing a person with a heart attack, and since most of these cases occur in the home, an AED is usually not available. A drone can bring the AED device to the patient at a breakneck time compared to the arrival of the medical service, and with the use of a system to lower the AED from a height without landing the drone, the safety of such acts is also increased.

Third is natural disasters. Drones have also proven themselves in practice in natural disasters, where they can be sent into areas that could potentially be dangerous for humans. At the same time, they can bring necessary commodities such as water, food, medicine to survivors before rescuers can reach the site. In addition, they can help identify areas where survivors are located so that rescue forces can be utilized efficiently to the places where they are really needed.

Organ transport is fourth. Within organ transport, drones can reduce transport time, increasing the chances of delivering undamaged organs in the right time. For deployment, the effects of transport on organ integrity need to be investigated.

Five is mosquito control. The systematic destruction of mosquitoes and the management of their population is an increasingly debated topic. Drones can be used to apply sprays to areas that are difficult for humans to reach. At the same time, drones can apply the spray efficiently - mapping which areas to spray and which not to and counting the correct amount of spray, thus reducing spray wastage. At the same time, other methods of destruction, such as electric plates, can also be used.

The direction of further research should focus on overcoming the limitations of this study, which was based primarily on a content analysis of the literature. Future work could enrich the knowledge with primary data obtained through questionnaires or interviews with practitioners, which would provide a more comprehensive view of the issue. From a technological point of view, it is essential to investigate the impact of vibrations and overload during flight on the integrity of sensitive biological materials, such as organs for transplantation. It will also be important to monitor developments in the field of legislation and safety systems, which are key to the widespread integration of drones into modern healthcare systems.

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