Drones and IoD for Emergency Medical Deliveries in the Humanitarian Context

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Abstract

In recent years, the integration of smart connected devices and platforms, such as Unmanned Aerial Vehicles (UAVs) or drones, into the expanding Internet of Things (IoT) network has grown significantly. Drones provide innovative solutions for delivering value-added IoT services across various applications, including monitoring, surveillance, on-demand last-mile delivery, and warehouse inventory management. However, the use of long-range UAV flights with high payload capacities for emergency medical deliveries is still in its early stages, mainly due to technical, regulatory, and operational challenges.

This paper presents findings from several simulated long-range drone flights exceeding 1,000 km, carrying payloads of up to 150 kg. Our experiments reveal the technical and operational requirements needed to facilitate emergency medical deliveries using drones. These requirements are detailed through the description of a UAV system designed for long-range, heavy cargo operations and the medical delivery system needed for large-distance flights with high payloads. Together, these systems aim to enable IoT integration into healthcare supply chains, advancing towards the realization of Healthcare 5.0.

Introduction

UAVs are extensively utilized in surveillance, agriculture, and goods delivery, with their primary application being in military operations [1]. The global drone market, valued at $8.15 billion in 2022, is projected to grow at a compound annual rate of 28.58%, reaching $47.38 billion by 2030 [2]. The use of drones in humanitarian contexts experienced significant growth during the COVID-19 pandemic. This surge was driven by government-imposed measures such as quarantine and isolation [3]. During this period, both China and India employed drones for surveillance purposes. Additionally, drones were utilized to deliver test samples to quarantine zones. However, their primary use during the pandemic was in last-mile deliveries, either with no payloads (e.g., for surveillance) or small payloads (e.g., test samples) [4].

The demand for drone applications in humanitarian contexts is urgent, as large-scale disasters often devastate critical infrastructure, hindering access to affected populations [3]. For example, a recent flood in Pakistan damaged 3,161.5 kms of roads, including 149 bridges (Daily Times, 2022). This disruption slowed and sometimes rendered aid delivery ineffective, as helicopters could not land in remote areas. Additionally, aid dropped from heights risks being damaged. In one tragic incident during flood relief efforts in Pakistan, six military personnel lost their lives in an accident caused by bad weather [5]. Drones have demonstrated their life-saving potential in such situations. They can transport essential items like automated external defibrillators, vaccines, test samples, and blood bags, and they are invaluable in search and rescue operations. Moreover, drones can safely deliver medical supplies without risking the spread of contagion, a critical advantage during epidemics and pandemics [3].

Despite the high potential of drones for life-saving medical deliveries in humanitarian contexts, their adoption and use remain relatively limited. This is due to various technical, regulatory, and operational constraints.

Technically, drones face limitations in payload and battery capacity, restricting their ability to fly long distances with heavy payloads. However, there are notable exceptions. For example, in remote regions of Peru, drones have been used to transport blood samples and antidotes for snake bites. Similarly, in Rwanda, Zipline's drones, which transport blood bags between health centers, can cover a round-trip distance of 100 miles (161 km). However, even these examples face payload limitations, with Zipline's drone carrying a maximum payload of just 1.75 kg [6].

Regulations for cross-border drone operations carrying heavy payloads often create a catch-22 situation. On one hand, there is a lack of regulations governing drones capable of transporting large quantities of emergency goods. On the other hand, the absence of large drones, along with the necessary knowledge, skills, abilities, and investments, hinders the development of such regulations. To make matters worse, the lack of clear operational requirements for medical deliveries further complicates the use of drones in emergency medical situations within humanitarian contexts, rendering their deployment nearly impossible. The situation could be resolved by agreeing to fly under traditional aviation rules.

Against the above backdrop, it is elemental to understand the technical, regulatory and operational environments required for successful drone operation in emergency medical situation in the humanitarian context. Additionally, drones and IoT fall under Industry 4.0 technologies. IoT has enabled the connection of numerous sensors and actuators powered by battery-operated devices [1]. This capability has been extended to integrate drones as entities within IoT, leading to the development of the Internet of Drones (IoD). In the IoD framework, drones can communicate with one another and with remote ground stations, enabling autonomous beyond-line-of-sight operations and leveraging artificial intelligence for smart decision-making. This capacity of drones is especially critical in emergency medical situations in the humanitarian context for life saving purposes [7].

This article outlines the technical, regulatory, and operational challenges involved in operating drones over extensive distances of up to 1,000 km while carrying significant payloads. We have developed a robust simulator designed for humanitarian aid and medical delivery missions, which allows for an in-depth examination of the complexities related to long-distance drone operations. The size of the UAV was chosen to exceed economies of scale for larger payloads and therefore larger aircraft . The Bidibidi refugee camp in Uganda serves as the primary site for gathering area-specific and context-related data. The simulation comprises a total of 128 flights, resulting in an overall flight duration of 491 hours and 37 minutes. Through this simulation, we aim to enhance our understanding of the technical, regulatory, and operational requirements necessary for the deployment of long-range UAVs with substantial payload capacities. Furthermore, this foundational work facilitates the potential integration of IoD in the healthcare sector, advancing towards the realization of Healthcare 5.0.

Challenges of Long-Range Large Cargo Drone Operations

The challenges of operating long-range and large cargo drone flights can be grouped into technical, regulatory, and operational categories, each of which is closely interrelated. For instance, limited battery/fuel capacity, a technical issue, leads to operational concerns, such as determining the optimal distance between drone-operated medical service centers. The following section explores these technical, regulatory, and operational challenges in detail.

Technical challenges

The technical challenges for drone deliveries encompass several key factors, including obstacle detection and avoidance, reliable communication systems, cybersecurity measures, operational reliability, unmanned traffic management (UTM) and air traffic management. Drones operating in low-altitude airspace pose a significant risk to manned aircraft, such as helicopters, and critical infrastructure, like power lines, due to the potential for collisions. Ensuring operational safety and security necessitates reliable communication between drones and manned aircraft systems in shared airspace. Additionally, security threats to drones are a growing concern, affecting public acceptance, particularly in densely populated urban areas (Lin et al., 2021). Furthermore, commercial drones currently lack standardized operational reliability requirements, underscoring the importance of standardization and the advancement of UTM systems for effective airspace operations [6].

Additional technical considerations are crucial when employing UAVs for medical deliveries. These deliveries are particularly sensitive, as certain items, such as vaccines, require strict cold-chain management. Many medical supplies also demand vibration control during transportation [8]. To minimize the risk of contagion, disinfection protocols must be implemented. Moreover, connectivity challenges arise in remote locations due to insufficient terrestrial network coverage, complicating long-range flights (LRFs) and emergency medical deliveries [6].

The literature highlights significant progress made through SESAR JU U-Space innovation projects, focusing on the development, testing, and validation of UTM requirements, technologies, and systems [9]. However, integrating drones on a large scale into airspace requires advancements in dynamic trajectory planning, situational awareness, and airspace capacity management [6]. Achieving this will necessitate the development of novel artificial intelligence and machine learning models tailored for aviation, alongside extensive flight data to train these models and establish robust performance benchmarks (SESAR, 2016).

Regulatory Challenges

Regulations governing drone operations vary significantly between countries, creating challenges for deploying drones in emergency contexts. Many nations lack a comprehensive legal framework for drone operations, making it difficult to secure permissions for medical drone use. This regulatory gap complicates the use of drones for emergency responses (Bassi, 2019). In some countries, such as Saudi Arabia, Barbados, and Argentina, drones are completely banned, while others, including Belarus, Nigeria, and Egypt, impose partial restrictions. Countries like Croatia, Mexico, and the EU require drones to operate strictly within the visual line of sight. In the healthcare sector, drone delivery faces additional challenges due to concerns about privacy invasion [6].

Long-range delivery involving large payloads often necessitates drones flying beyond the visual line of sight (BVLOS), a practice frequently prohibited [7]. However, the COVID-19 pandemic prompted regulatory exceptions. For instance, the European Commission allowed BVLOS operations, subject to special approval from national aviation authorities [10]. Nonetheless, issues such as liability and insurance costs in case of accidents remain unresolved [11].

EU Regulations 2019/947 and 2019/945 establish the framework for the safe operation of drones in European airspace [10]. Adopting a risk-based approach, EASA does not differentiate between leisure and commercial drone use. Instead, it evaluates drones based on their weight, specifications, and the intended operations. While the maximum tested payload for drone deliveries is currently 2 kg, regulatory development for larger drones remains insufficient [6].

Medical deliveries are particularly complex as they must also comply with regulations governing medical cargo. These regulations specify who is authorized to handle, send, and receive certain types of medical goods. For instance, in the EU, organizations must obtain certificates to operate drones for specific purposes, such as medical deliveries [10]. However, only a limited number of organizations are currently able to issue these certificates.

Operational Challenges

Medical supply chains are intricate systems involving a diverse network of stakeholders collaborating to deliver medical goods and services to patients. These goods can be broadly categorized into five main groups: pharmaceuticals (e.g., vaccines), medical devices (e.g., ventilators), medical supplies (e.g., intravenous kits), personal protective equipment (e.g., gloves), and blood. Key stakeholders include government organizations, financial institutions, donors, non-governmental agencies, and private and public healthcare providers. The complexity of both the products and stakeholders introduces significant challenges that must be addressed to ensure successful medical deliveries [12].

For instance, delivering vaccines via drones necessitates maintaining a cold chain throughout the flight and at the administration site. Health facilities or NGOs in remote areas receiving these deliveries must have adequate infrastructure to support storage and handling. Additionally, medical distribution systems differ globally. Some countries employ a decentralized approach, where hospitals procure medicines directly from pharmaceutical companies through transportation providers. Others follow a centralized model, with regional or national agencies managing procurement and distribution [6]..

Medical supply chains are also subject to stringent regulations [13]. Importing and exporting drugs involve unique rules, including variations in “drug lists” across countries. Handling certain drugs requires specialized screening and licenses. Further requirements include strict controls on humidity, temperature, hygiene, storage, material handling, and transport conditions. During epidemics and pandemics, these regulatory demands intensify as minimizing contagion becomes paramount. Drone deliveries have been proposed as a solution to reduce human contact between quarantine and non-quarantine zones. For example, smaller drones have been used to deliver COVID-19 test kits and samples [14]. However, larger and longer-range drones are necessary to scale up operations for delivering personal protective equipment (PPE) to quarantine zones or distributing vaccines to entire populations during pandemics.

A UAV System for Long-Range Large Cargo Drone Operations

Every UAV system comprises three main components: (i) a flying platform or aircraft or drone or UAV, (ii) a ground control station (GCS), and (iii) a communication system connecting the drone and the ground control station.

Flying platform or Aircraft or Drone or UAV

The aircraft’s primary function is to transport payloads. In transport flights - from one location to another. Additionally, it serves other purposes, such as carrying onboard equipment, engines, wings, control surfaces, and antennas. Essential installations within the aircraft include electrical systems, fuel systems, anti-icing mechanisms, oil systems, and autopilot systems. Moreover, the aircraft requires control, navigation system, landing assistance, power, and camera systems for effective operation.

To ensure proper drone operation, it is crucial to provide the pilot with accurate information about the aircraft’s position in airspace. A basic satellite navigation system is required for this purpose and must be duplicated to maintain operational reliability. The secondary navigation system, known as the inertial navigation system (INS), collects data from sensors onboard the aircraft. The INS also serves as a backup in emergencies, such as the loss of a GPS signal.

The power system of the UAV in the project comprises two combustion engines, each delivering approximately 25 to 50 horsepower. Aircraft with high horsepower are generally constructed using metal, and includes a rear section with an opening ramp to facilitate loading and unloading. Additionally, a permanent or temporary hull should be considered during the preliminary design phase.

Ground control station (GCS)

The Ground Control Station (GCS) is a critical component of a UAV system. In case of operating IoD, a distributed control architecture is considered more effective, with multiple ground control stations located in different regions. For instance, operating 20 drones would necessitate 20 ground control stations distributed globally. This worldwide network of ground control stations would also require a centralized control room to manage operations effectively. A control station needs to be equipped with a high-performance computer to provide the display screens for the drone pilot. These screens serve two key purposes: one displays the drone’s status, similar to the dashboard of a commercial aircraft cockpit (see Figure 1), while the other provided a visualization of the flight path and the drone’s geographic position within the airspace (see Figure 2).

The airplane status screen layout includes the following panels:

- **Information Panel** : Displays the aircraft’s speed and inclination.
- **Altitude Panel** : Shows the current altitude and estimated altitude.

- **Engine Gauges** : Indicate engine RPMs.
- **Ramp Status Indicators** : Display whether the front and rear ramps are open or closed.
- **Master Caution Indicators** : Highlight system issues, such as problems with flight controls, communication, servo motors, power systems, and anti-icing systems.
- **Flight Controller Panel** : Displays barometer readings, inertial navigation data, and GPS information.
- **Communication Panel** : Shows the status of ground-to-air (uplink) and air-to-ground (downlink) communications.

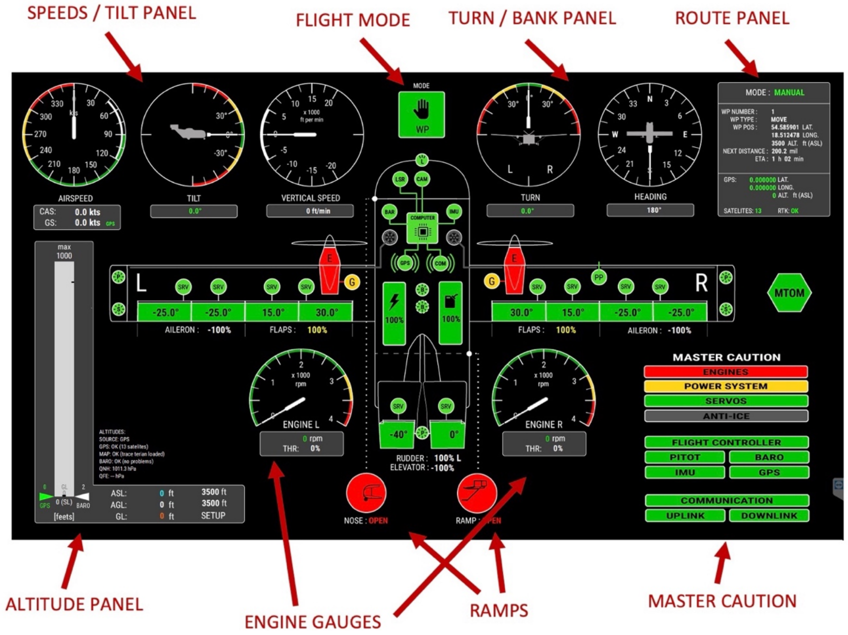
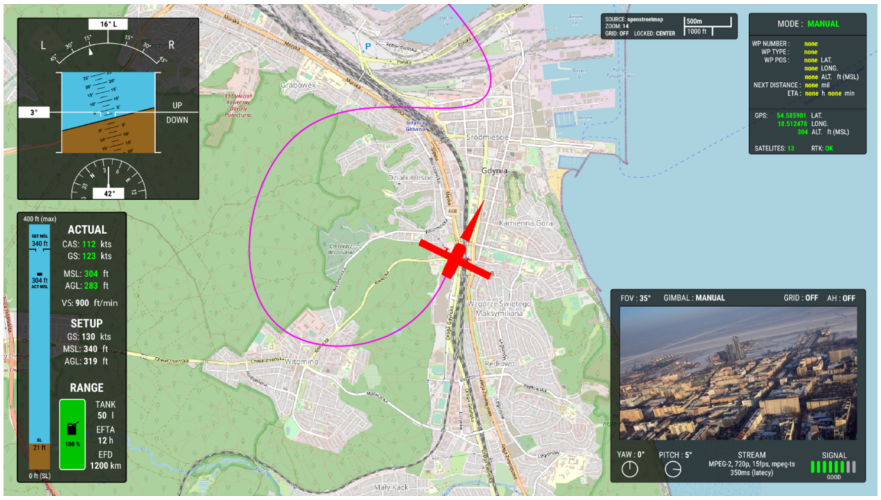


Figure 1: System status screen of a ground control station

- **Maximum Take-Off Weight Indicator** : Alerts if the aircraft exceeds its maximum take-off weight.
- **Route Panel** : Tracks the programmed route, including distance traveled, remaining distance, and estimated flight time.
- **Turns/Bank Panel** : Provides details on the aircraft's heading, roll, and position during turns.
- **Flight or Control Mode Indicator** : Displays whether the controls are set to manual or automatic mode and displays fight modes of the aircraft
- **Flight Status Panel** :
- Displays, altitude meter, and camera status.
- Indicates the status of the onboard computer, barometer, IMU, GPS, and transceiver.
- Shows fuel and onboard battery levels.
- Displays: engine conditions, anti-icing system status, main and backup alternators, and the efficiency of control plane servos.
- Indicates the deflection angles of ailerons and flaps, as well as navigation and strobe light conditions.

Figure 2 illustrates the Ground Control Station (GCS) map screen, which serves as the primary interface for geographical orientation during the LFR flight. This map screen provides real-time data on the aircraft's position, including its geographical location and altitude, as well as its spatial orientation and course.



400 ft (max)
SET MSL 340 ft
304 ft ACT MSL
GL 21 ft
0 ft (SL)

ACTUAL
CAS: 112 kts
GS: 123 kts
MSL: 304 ft
AGL: 283 ft
VS: 900 ft/min

SETUP
GS: 130 kts
MSL: 340 ft
AGL: 319 ft

RANGE
100 %
TANK 50 l
EFTA 12 h
EFD 1200 km

SOURCE: openstreetmap
ZOOM: 14
GRID: OFF LOCKED: CENTER
500m
1000 ft

MODE : MANUAL
WP NUMBER : none
WP TYPE : none
WP POS : none LAT.
none LONG.
none ALT. ft (MSL)
NEXT DISTANCE : none mil
ETA : none h none min
GPS: 54.585901 LAT.
18.512478 LONG.
304 ALT. ft (MSL)
SATELITES: 13 RTK: OK

FOV : 35° GIMBAL : MANUAL GRID : OFF AH : OFF
YAW : 0° PITCH : 5°
STREAM
MPEG-2, 720p, 15fps, mpeg-ts
350ms (latecy)
SIGNAL
GOOD

Figure 2: Flight plan and geographic positioning of the drone

In addition to the main map, the screen includes several smaller panels:

- **Upper Left Corner** : An artificial horizon display shows information about ascent or descent, left or right banking, and the aircraft's course. It helps the pilot determine whether the plane is climbing, descending, or tilting without splitting your attention between screens. The blue portion represents the sky, while the brown portion signifies the ground.
- **Below the Artificial Horizon** : The height control panel provides altitude information relative to the ground, speeds data and sea levels. It also displays fuel-to-distance data.
- **Lower Right Corner** : A live camera feed from the nose of the aircraft is shown.
- **Upper Right Corner** : Displays details about the aircraft's route.
- **Central Section** : Features a map with an airplane icon representing the aircraft and its flight route. The icon indicates the direction the plane's nose is pointing, while an arrow shows the direction of flight.

Communication System

The communication system is the final component of a UAV system, enabling radio connectivity between the ground control station and the drone. A reliable radio communication system is essential for commanding and controlling the UAV and maintaining a continuous link for emergency operations. Small drones typically operate within radio frequencies (RF) ranging from 5 GHz and 2,4 GHz. For long line cargo flights a satellite communication is crucial.

In real-world long cargo flight scenarios, ground control stations, UAVs and mission personnel can be dispersed globally. To facilitate seamless communication, LTE/5G technology is utilized to establish voice communication channels between the UAV pilot, the UAV platform, and ground personnel. Additionally, radio communication compliant with the International Civil Aviation Organization (ICAO) standards is required to maintain contact with the local airport traffic control tower or local ATM

Figure 3 illustrates the Regional UAV Pilot Centre (RUPC) connected to the Airlifts Coordination Centre (ACC) via a Virtual Private Network (VPN) and a voice channel. This setup ensures the reliable transmission of control signals to the ACC, which then relays them to the 5G antenna assembly. The voice channels enable communication with technicians at the ground control station, while 5G/LTE technologies are used to transmit control signals to the aerial platform. Through this platform, air traffic services are coordinated.

Figure 3 highlights the pivotal role of the ACC as a satellite communication terminal. Satellite connectivity becomes crucial when 5G network reliability is compromised, ensuring continuous flight operations. Additionally, when multiple IoD share the same airspace, establishing communication between different drone coordination centers is essential.

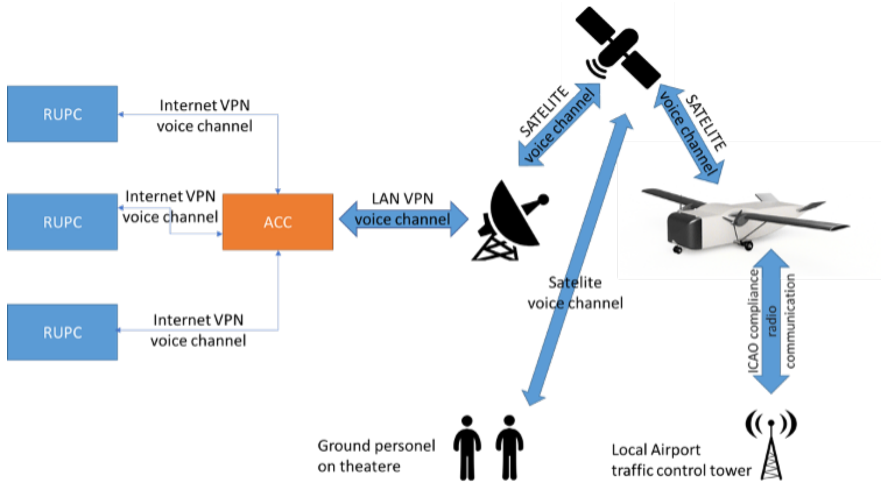


Figure 3: Satellite voice communication diagram

A long-range drone delivery system for healthcare supply chains

The regional warehouse can be managed by a healthcare provider (e.g., a hospital) or a supplier of medical goods (e.g., a supplier of masks, vaccines, test kits, medicines). Healthcare facilities, such as hospitals or other care centers, can operate the healthcare center. To initiate a medical delivery from a warehouse to a healthcare facility, the healthcare center must submit a delivery request for a specific medical item (e.g., vaccines or tests). This request must be approved by the regional warehouse. Once approved, the warehouse's materials handling personnel prepare the requested items for drone transport, which includes retrieving the goods from storage, packing them for drone transport, and preparing the necessary delivery documentation.

Hosted file

`image4.emf` available at https://authorea.com/users/899263/articles/1274922-drones-and-iod-for-emergency-medical-deliveries-in-the-humanitarian-context

Figure 4: A drone delivery system

Simultaneously, a delivery request is sent to the drone service provider managing the airlift coordination center (ACC). The ACC selects a certified pilot to conduct the flight within or between regions. The ACC then identifies suitable landing points at the warehouse and healthcare facility. The selected pilot prepares the flight plan, checks weather conditions along the flight path, and follows all aviation regulations for the route.

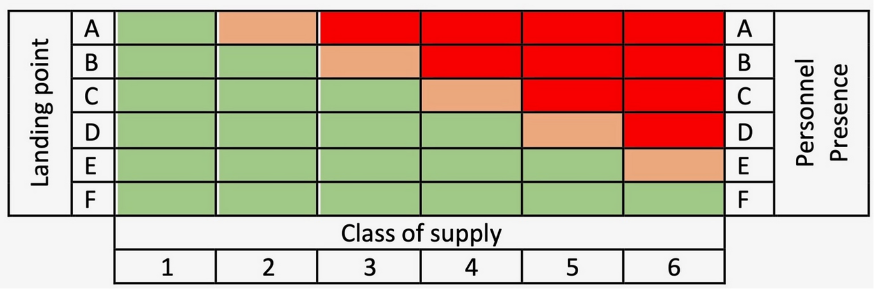
Upon arrival at the warehouse, authorized materials handling personnel load the drone with the medical goods. Communication between the pilot and the warehouse team ensures that the items are loaded correctly. The pilot verifies that the load is within the drone's maximum take-off weight, then takes off and follows the flight plan. Before landing, the pilot communicates with the healthcare facility team to prepare for the delivery, inspects the landing area, and adjusts the drone as necessary. If landing is not possible (e.g., in flood-affected or mountainous areas), the pilot may need to deploy parachutes to drop the items safely.

It is essential to develop guidelines to facilitate long-range medical deliveries by drones and the Internet of Drones (IoD) due to regulatory challenges. One example of such a guideline is the delivery mission code, shown in Table 1. As outlined in Table 1, three types of information are crucial for medical deliveries: the landing point, the required personnel, and the classification of the items being delivered. The latter two are interrelated. It is important to note that regulations vary between countries regarding the personnel authorized to receive certain types of medical items, such as whether a delivery needs to be attended and, if so, whether a nurse, pharmacy technician, or medical doctor is required.

Table 1: A delivery mission code

Landing point	Personnel Presence	Class of supply				
A	Unknown	No data in the database	A	No personnel	1	Water
B	Little Known	Last delivery more than six months ago	B	No trained personnel	2	Band Ai
C	Possible	Last delivery is within six months	C	Trained personnel	3	Food, Dr
D	Confirmed	Last delivery within 3 months	D	Basic medical training	4	Medicine
E	Known	Last delivery within 1 month	E	Medics	5	Simple
F	Regular	Last delivery yesterday	F	Doctor	6	Special

To address these challenges, the three points have been integrated into a go-no-go matrix, depicted in Figure 5.



Landing point	1	2	3	4	5	6	Personnel Presence
A	🟩	🟧	🟥	🟥	🟥	🟥	A
B	🟩	🟩	🟧	🟥	🟥	🟥	B
C	🟩	🟩	🟩	🟧	🟥	🟥	C
D	🟩	🟩	🟩	🟩	🟧	🟥	D
E	🟩	🟩	🟩	🟩	🟩	🟧	E
F	🟩	🟩	🟩	🟩	🟩	🟩	F

Figure 5: A go-no-go matrix

On the left side of Figure 5, the landing point is indicated, while the required personnel are noted on the right. The bottom line illustrates the supply class. The letters (e.g., A, B) and numbers (e.g., 1, 2) correspond to the same meanings as shown in Table 1. The colours indicate whether a particular combination of landing point, personnel presence, and supply class is permissible. Green signifies that deliveries are allowed, red indicates they are not, and orange denotes deliveries requiring special consideration.

Discussions, conclusions, and future research

This paper represents a major step toward a future where drones and the Internet of Drones (IoD) are utilized for life-saving purposes. It details the technical, operational, and regulatory requirements for executing medical deliveries, particularly in emergencies. While most drone and IoD literature focuses on last-mile delivery with drone carrying small payload (less than 2 kg), this paper discusses long-range drone flights (over 1,000 km) with high payload capacities (more than 150 kg).

Drones capable of flying long distance and carrying heavy payloads are important innovation because they can reach areas where humans cannot venture. For medical and humanitarian cargo deliveries, drones offer the advantage of not needing an onboard pilot. However, drones are not devoid of limitation. They are susceptible to weather conditions and are constrained by various legal, organizational, and technical challenges. For example, there are currently no regulations for drones with a load capacity of 150 kg, no standardized system for organizing drone deliveries, and no certification process for high-payload flights. Consequently, future research should address these gaps because of changing environment of world in the era of epidemic, pandemics and burgeoning wars.

The UAV system presented in this research lays the groundwork for future IoD-based medical deliveries. Future scholars should focus on enhancing the various components of this UAV system, such as drones, ground control stations, navigation other than satellite, and communication systems, to enable seamless medical deliveries, especially in emergencies where manned aircraft cannot be deployed due to security threats or remote locations.

The medical delivery system proposed in this paper specifies all necessary requirements for transporting medical goods over long distances and across borders. We highlight the importance of what being transferred (e.g., blood, vaccines, test kits) as well as who should handle these deliveries (doctors, nurses, medics, technicians). Future research should develop more delivery mission codes and go-no-go matrices for different types of medical products.

Additionally, the paper stresses the need for regulatory frameworks to enable medical deliveries using drones. Standardizing regulations across regions is crucial for facilitating cross-border medical deliveries. It is also vital to allow drones to operate beyond the visual line of sight by incorporating IoD and global control stations. The delivery mission code and go-no-go matrix presented in this paper will support the development of these regulations. Enabling medical deliveries with drones and IoD could lead to air traffic management challenges in low-altitude airspace, necessitating new regulations and standards for drones and IoD operations.

To summarise, in a world where drones are increasingly deployed for warfare, it is imperative to harness their potential for saving lives. These findings aim to assist researchers and practitioners in leveraging drones and the Internet of Drones (IoD) for long-distance, high-payload emergency medical deliveries, paving the way for life-saving applications of this technology.

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