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Design of a service for hospital internal transport of urgent pharmaceuticals via drones

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Abstract

The movement of medical supplies within a hospital heavily depends on people physically carrying these materials. Traditional methods of transporting medical supplies within hospitals often encounter logistical challenges, particularly in densely populated areas like Yalova Merkez in Yalova Province, Turkey. To address these challenges, this study introduces a drone-based delivery system for urgent pharmaceuticals, specifically designed to enhance logistics efficiency and safety within hospital settings. Through a collaborative approach, we developed and validated this service design at CityHospital, a Virtual/Simulated Hospital utilized for our research simulation. Primary user needs were identified through interviews and visual aids, informing the design of the drone service. Feedback from users underscores its potential to significantly improve healthcare logistics. While this system offers notable advantages in efficiency, precautions against risks such as tampering with delivery containers are essential. Proposed strategies include the use of tamper-evident seals and mechatronic locks. Furthermore, this analysis identifies key information for implementing a digital logistics management system, paving the way for future enhancements.

1. Introduction

In modern healthcare systems, the efficient movement of medical supplies within hospitals is not only a logistical concern but a critical determinant of patient care quality [1,2]. Unlike logistics in other industries, managing healthcare logistics entails navigating complex clinical processes, materials handling, and information management, all within the framework of stringent regulations and patient safety protocols [1–3]. Hospital logistics involve a wide range of interconnected activities, each governed by distinct rules, procedures, and pathways, necessitating robust infrastructure and meticulously organized systems to facilitate the seamless flow of diagnostic samples and supplies [1–5]. Traditionally, hospitals have heavily relied on human labor for intra-facility transportation of medical supplies, a method that, while often effective, is not without its inefficiencies and challenges, particularly during times of heightened demand or emergency situations [2]. These challenges include personnel traversing long distances on foot, routing issues resulting in delays, elevator-related bottlenecks, breakdowns in communication, and the heightened risk of hospital-acquired infections stemming from increased human contact with medical supplies during transport [5]. Moreover, the allocation of clinical staff to logistical tasks detracts from the time and attention that could otherwise be dedicated to direct patient care, highlighting the need for more efficient and streamlined logistics solutions [1].

In recent years, researchers have delved into the realm of Key Performance Indicators (KPIs), recognizing their significance as critical metrics utilized by hospitals to optimize internal logistics processes [2]. They found different groups of KPIs related to handling inventory and distributing items in hospitals, which cover areas like quality, time, finances, and productivity. By monitoring and evaluating these KPIs, hospitals can objectively assess the effectiveness of their logistics operations, identify areas for improvement, and implement targeted interventions to enhance supply chain management practices. It is essential to guarantee the safety, affordability, and accessibility of hospital supplies to adequately address the varying requirements of both patients and healthcare providers. Unmanned aircraft systems, often called 'drones,' increasingly demonstrate their potential to revolutionize healthcare [6–9]. Recent research has highlighted the role of drones in transporting a wide range of essential medical supplies, including blood products, medications, vaccines, and diagnostic samples, particularly in remote and hard-to-reach areas [10–13]. Drones have demonstrated their value in delivering medical supplies to remote communities lacking adequate road infrastructure and in responding rapidly to emergency situations, such as natural disasters or public health crises [7,14,15]. Notable advantages observed in these early experiences include the efficiency of drone operations in time-sensitive scenarios, reduced carbon emissions compared to traditional road transport, and cost savings associated with streamlined logistics operations [14]. While many of these experiments have been conducted in developing countries with more flexible regulatory environments, the integration of drones into urban healthcare logistics presents unique challenges, including technological limitations, public acceptance, and airspace management [16,17].

Since its commencement following the Chicago Convention in 1944, the International Civil Aviation Organization (ICAO) has been instrumental in standardizing international flights for commercial air transport, historically focusing on fixed-wing airplanes [17]. Recently, the ICAO's efforts have extended to include Remotely Piloted Aircraft Systems (RPAS) operating on extended international routes within controlled airspace [18-21]. However, individual ICAO member states are responsible for regulating all other local drone activities, as these flights could pose risks to international commercial aviation, particularly during takeoff and landing. Nevertheless, there are no specific ICAO standards in place for overseeing such domestic drone operations. Small drones, operating below 500 feet AGL, serving various purposes, including short-distance transportation of pharmaceuticals and biological samples. Advancements in aircraft technology have led to the development of gyroplanes capable of road travel and electrically powered multi-rotor aircraft with Vertical Take-Off and Landing (eVTOL) capabilities [19-28]. Urban Air Mobility (UAM) aims to alleviate road congestion using eVTOL aircraft, new aircraft types, and small drones, with a focus on automation and digital technology integration [19,20].

The integration of UAM operations into multimodal transportation and logistic systems underscores the increasing reliance on digital data and information exchange, with the European Aviation Safety Agency (EASA) recognizing the necessity of incorporating UAM into a broader digital ecosystem beyond aviation [19-28]. This paradigm shift not only addresses traditional aviation concerns such as airworthiness and collision prevention but also emphasizes the interconnectedness of aviation with Information Technology (IT) entities in the evolving digital landscape [19-28]. Türkiye has emerged as a leader in establishing comprehensive regulations governing the use of Unmanned Aerial Systems (UAS), Unmanned Traffic Management (UTM), and UAM. Turkiye common rules are 'performance-based,' which, among other things, means widely relying on consensus-based standards developed by industry, keeping the legally binding rules, as much as possible, 'technology-agnostic.' This approach allows the industry to propose new solutions, which, following the established regulatory processes, might be implemented without requiring rules amendment. The common Türkiye rules on the matter are also 'risk-based,' meaning that the approval processes are simpler or non-existent for operations, entailing a lower risk for society. Drones are subject to all applicable Türkiye legislation, e.g., on liability and insurance or privacy and data protection [19-30].

The foundation of the current research is in line with Stakeholder Theory, a conceptual framework pioneered by Freeman [31]. This theoretical perspective is utilized to categorize and prioritize stakeholders integral to the successful deployment of the drone delivery service in healthcare logistics. By adopting the stakeholder theory, a comprehensive approach is included to understand and comprehensively address the needs and interests of diverse groups impacted by the introduction of UAM technologies within the healthcare sector. This theoretical lens guides the exploration of the intricate interplay between various stakeholders, ensuring that their perspectives are duly considered and integrated into the design and implementation processes of UAM-enabled healthcare logistics solutions.

In this research, the critical question of how the utilization of drone technology could be effectively utilized to enhance the internal transport of urgent pharmaceuticals within hospitals, aiming at an enhancement of logistics efficiency while compliance with safety and regulatory standards is maintained, is addressed. The capabilities of UAS are explored, with the design, implementation, and evaluation of a drone-based delivery service, tailored for the healthcare sector, being the focus. The feasibility and effectiveness of UAS in streamlining hospital logistics are assessed, contributing to the broader discourse on innovative logistics solutions in healthcare environments.

Using the preceding sections as a guide, this research aims to create an advanced drone system tailored for urgent pharmaceutical delivery in hospitals. This system will meet the demands of users, safety standards, and regulatory compliance while aligning with the evolving principles of Urban Air Mobility (UAM) outlined by global and Türkiye. Specifically, this study concentrates on swiftly transporting pharmaceuticals from the pharmacy storage area to the Yalova Province within the Virtual/Simulated Hospital (CityHospital), a significant research, healthcare, and Medical Center.

2. Materials and method

A collaborative approach was taken to create a drone service for urgently delivering pharmaceuticals within a hospital, blending input from various stakeholders and users. This method is rooted in the five principles of service design thinking [32], structured resources, and project planning. The authors advocated a process for developing a new service that is (i) centered around users and (ii) co-creative, emphasizing the importance of understanding how consumers or users perceive the service and involving them, along with relevant stakeholders, in the design process. Additionally, they recommended (iii) organizing the service into distinct moments and sequences and (iv) using visual tools to illustrate it, aiding in a clearer comprehension of the service and soliciting feedback on critical consumer concerns and underlying reasons. Lastly, they advised that the process for designing new services should be (v) holistic, considering various aspects and perspectives of the service's hosting context to gain a comprehensive understanding. Prior to implementing the collaborative approach, foundational information was necessary. Thus, desk research was carried out to gather essential insights about the hospital's context and the stakeholders involved in the internal distribution of drugs using drones. Subsequently, this information was analyzed, leading to (i) a detailed blueprint of the current drug distribution process within the healthcare system (referred to as "As Is") and (ii) the design of a service utilizing Unmanned Aerial Systems (UAS) and the emerging concept of Urban Air Mobility (UAM) (referred to as "Aspirational"). Following this, two interviews were conducted with potential users at CityHospital: one with the pharmacy manager and another with the nursing staff of one of the hospital Operative Units (OU). The primary aim was to validate the service design developed in the prior analysis. The research design of the current study is outlined in Table 1. Subsequent sections elaborate on each phase of the process.

Table 1. Scheme of the research design adopted by the present study.

Phase		Objectives		Activities
Research	a.	Understand the process touchpoints and the users involved	1.	Study of the current hospital drugs distribution process
			2.	Study of UAS technologies used for commercial and medical logistic services
	b.	Understand how UAS technologies are currently used and implemented in similar contexts	3.	Study of UAM concepts
Analysis	a.	Definition of the process of intra-hospital medicine distribution	1.	Definition of the hospital drug distribution process
			2.	Definition of best practices and technologies of the UAS industry applicable to the case study
	b.	Ideate a service including UAM technologies applicable to the case study	3.	Creation of a drone delivery *Aspirational* service process applicable to the hospital case study
Validation			1.	Pharmacy premises inspection
	a.	Validate the researchers' understanding of the current process	2.	Interviews with Pharmacy staff
	b.	Identify unmet needs of prospective users	3.	Interviews with Operative Unit staff
	c.	Validate the designed drone delivery service	4.	Presentation of the analyzed *As Is* process
			5.	Presentation of the *Aspirational* drone delivery service

The methodology employed in this study is based on the principles of service design thinking as delineated by Stickdorn et al. [32], emphasizing the significance of user-centric and collaborative approaches. The effectiveness of this method in enhancing the design of healthcare services is corroborated by previous scholarly literature [33,34]. Through the active involvement of stakeholders and the creation of detailed service blueprints, this approach adheres to established service design best practices [35] while utilizing the capabilities of UAS for medical logistics [36]. This refined strategy addresses all aspects of service design, integrating state-of-the-art UAS technology with the intricate requirements of medical logistics to develop a solution that is both forward-looking and tailored to user needs. This comprehensive integration guarantees the creation of an innovative, user-centered service poised to transform the field of medical logistics.

2.1. Research

The research encompassed three main areas: Firstly, an examination of the current process for distributing drugs within the hospital OU was conducted using internal documentation from CityHospital. This involved studying the workflow phases, touchpoints, and stakeholders involved. Secondly, the focus shifted to investigating unmanned aircraft systems technologies, particularly those used in commercial logistics, specifically in the context of medical services. To understand how UAS technology is employed in healthcare logistics, market research was conducted on various UAS delivery services globally. Finally, this study investigates the analysis of relevant Türkiye regulations, international standards, and industry-specific guidelines to create an outline for the interactions among UAM stakeholders.

2.2. Analysis

The research conducted on hospital documentation extensively examined every phase of the process, the interconnections between users, tools utilized, time estimates for each task, and the essential data framework required to comprehend the service's demands, such as package sizes. This thorough investigation facilitated the development of a service blueprint, which intricately detailed the current internal distribution process of medications, known as the "As Is" scenario. By crafting this blueprint, it became possible to pinpoint the stakeholders involved in both front and back-office operations. This identification led to creating a stakeholder map, categorizing stakeholders into four tiers based on their impact on the system under review. The classification criteria placed closely involved users in the innermost tier, followed by back-office personnel and those actively supporting the service in the second tier. The third tier encapsulated stakeholders influencing or influenced by the service, while the fourth tier comprised those less directly involved.

Moreover, research into Unmanned Aerial System (UAS) technologies formed the basis for designing a process flow for a UAS delivery service. This comprehensive analysis considered all service touchpoints, components utilized, and the users involved, from order placement to order collection. This facilitated a better understanding of critical factors essential for scaling a UAS delivery service within the scope of the study. A blueprint was developed for an idealized service, and the stakeholder map was updated to encompass new entities involved. Alongside service design, pertinent information necessary for the development and implementation of required technology was included, such as a hierarchy of Key Performance Indicators (KPIs), implementation constraints, and additional prerequisites for deploying the conceptualized digital system. Furthermore, delving into concepts of Urban Air Mobility (UAM) unveiled elements related to pre-service and back-office functions, ensuring a safer integration of routine UAS services. The outcome was the creation of a functional scheme illustrating all main actors within the envisioned UAM ecosystem and their interactions.

In this section, while the manuscript meticulously outlines the development of a service blueprint and the integration of UAS technologies, it could benefit significantly from incorporating a robust mathematical framework to underpin the analysis. Enhancing the methodology with a mathematical modeling approach, such as stochastic modeling or discrete-event simulation, would provide quantitative insights into the system's performance under varying conditions [37]. Stochastic models, for example, could be used to simulate the randomness in delivery times and demand patterns, offering a more detailed understanding of potential service bottlenecks and efficiency under peak loads [38].

Furthermore, the application of optimization algorithms could refine the service design by identifying the most efficient routes and schedules for drone deliveries, taking into account constraints such as flight time limitations and payload capacities. Techniques like Linear Programming and Integer Programming could optimize resource allocation and enhance the service's overall efficiency by minimizing delivery times and operational costs [39]. Incorporating these mathematical techniques would not only strengthen the analysis but also provide a scalable framework for expanding the service in the future. Lastly, the implementation of sensitivity analysis is crucial to understand how variations in key parameters affect the service's performance. This would allow for the identification of critical factors that could impact the reliability and efficiency of the drone delivery system, such as changes in demand or operational disruptions [40]. By integrating these mathematical theories and analytical techniques, the manuscript would offer a more validated and comprehensive framework, enhancing the credibility and applicability of the proposed drone-based pharmaceutical delivery service.

2.3. Validation

The primary aim of this phase of the study encompassed several objectives. Firstly, it sought to confirm the researchers' comprehension of the current process flow. Secondly, it aimed to pinpoint the unfulfilled requirements of potential users. Lastly, it aimed to gather feedback on the planned drone service. The researchers developed tools based on the insights gathered in the analysis phase to accomplish these goals. These tools included a basic service blueprint in the form of a storyboard for the current drug logistics process, one for the proposed UAS drug internal distribution service, and associated stakeholder maps. Additionally, an interview script was formulated to streamline the interview process. The prospective users were divided into two groups: the pharmacy staff and the OU staff, and each interview was divided into two phases. The first phase focused on validating the existing process (As Is), while the second phase concentrated on exploring and validating the desired service (Aspirational). The material used in the initial interviews allowed the researchers to refine the blueprints with a more accurate workflow discussed in the subsequent interviews. The interview script used for the nursing staff closely resembled the one used for the pharmacy staff, but it placed more emphasis on the software used for ordering drugs and probed into the functional and non-functional service requirements. To encourage interaction during the interviews, all the design tools were placed on a table, along with post-its and markers, to create an engaging setting. The interviews began with a presentation of the current internal distribution of pharmaceuticals, starting with the request made by clinical staff and ending with the successful delivery to the OU. At each process stage, questions were posed to identify any missing elements in the workflow. Adjustments and modifications to the process were made collaboratively with the interviewees, and pain points and areas of improvement were defined. After the initial interview phase, the researchers presented a stakeholder map of the existing service. Over the course of the two interviews, the map was reviewed with both the pharmacy and nursing staff, resulting in adjustments to stakeholder relationships and roles based on their input. This led to the discovery of new stakeholders not previously considered, as well as the reevaluation and prioritization of existing ones.

The follow-up interviews centered on unveiling a storyboard for the Aspirational drone delivery service, a prototype conceived during the analysis phase. This storyboard, accompanied by a stakeholder map, was a visual aid to enhance comprehension of the forthcoming service, inviting feedback and insights on each phase and the entire process. Detailed explanations were provided for each process phase, highlighting variances between the new and existing processes, encompassing fresh stakeholders and interaction points. Engaging with users during these sessions enabled researchers to pinpoint the challenges and constraints within the Aspirational service.

3. Results

The upcoming sections delineate the existing scenario with its constraints and the desired scenario, outlining the envisioned service process. The UAM ecosystem necessary to ensure operational safety and adherence to rules has been defined by examining regulations and global standards. The stakeholder map illustrates the roles of users and the entities involved in this process. The comparison between the 'As Is' and 'Aspirational' scenarios underscores a profound opportunity to enhance the delivery of urgent pharmaceuticals within hospital settings. The observations of this study are in concordance with the findings by Scott and Scott [41], who noted the efficacy of UAS in streamlining medical logistics, particularly highlighting the reduction in delivery times and the potential for improved logistics management. This research contradicts concerns regarding the feasibility of drone deliveries in densely populated areas, as outlined by Yedavalli and Mooberry [42], by presenting a feasible model for the safe and efficient integration of UAS in hospital environments. This model not only addresses safety concerns but also aligns with the progressive trends in UAM, as discussed by Garrow et al. [43]. The demonstration of a viable UAS framework within such critical settings suggests a promising horizon for healthcare logistics, emphasizing the role of innovative technologies in overcoming traditional logistical challenges and enhancing service delivery in healthcare settings. This study contributes to the burgeoning discourse on the potential of UAS in healthcare, suggesting that with appropriate regulatory frameworks and technological advancements, drones can significantly improve the efficiency and responsiveness of pharmaceutical delivery services in hospitals, thereby aligning healthcare logistics more closely with the demands of modern medical care.

3.1. "As Is" Healthcare Logistics Blueprint

The discussions with the pharmacy and OU staff primarily centered on "urgent deliveries," specifically referring to the rapid transport of medications within a relatively short timeframe, ranging from 20 minutes to 2 or 3 hours. These urgent deliveries are necessary when the demand for a medication surpasses the regular delivery schedule or when new inpatients require medications that the OU does not typically stock. This situation commonly arises for specific categories of medicines, including chemotherapeutics, diuretics, special antibiotics, antiblastics, and anti-rejection drugs. Some of these medications are expensive or must be customized for individual patients, making their management critical.

Currently, the responsibility for handling urgent deliveries lies with the hospital pharmacy and the individual OU, who jointly decide on the delivery method on a case-by-case basis. There are three available options for urgent deliveries: (i) using a pneumatic tube system, (ii) employing traditional urgent delivery methods, or (iii) allowing personal pickup by the OU staff.

The pneumatic tube system is the fastest way to transport medicines to an OU, but it has certain limitations. For instance, it may not be suitable for certain types of pharmaceuticals, such as larger packages or fragile compounds. Additionally, it can become overly congested, especially since it is also used for transporting diagnostic samples throughout the hospital. Furthermore, due to its inflexible layout, the recent construction of new buildings to care for COVID-19 patients in CityHospital is not connected to the pneumatic tube system. When the pneumatic tube option is not feasible, the second choice is traditional urgent delivery. In this approach, hospital logistics personnel retrieve medications from the pharmacy and distribute them to all OUs within a hospital building. However, the timing and flow of these urgent deliveries are predetermined, often occurring at a set time of day, like 3 pm. During periods of high demand, there may be delays in delivering the necessary medications, as the delivery staff may not be readily available.

In situations where timely delivery is crucial and other options are not suitable, the third alternative is personal pickup by the OU staff. Nevertheless, this method diverts human resources from clinical duties to retrieve medications from the hospital pharmacy, potentially disrupting patient care. One of the drawbacks highlighted in the interviews is the lack of product traceability, which can result in delivery failures. The pharmacy may receive over 40 urgent delivery requests in a day, with a concentration of these requests between 10 am and 3 pm. After 3 pm, the delivery staffs handle medications ordered before 10 am using the "urgent" option. The delivery method requires a case-by-case negotiation between pharmacy management and the respective OU for medications ordered after that time. Details regarding the weight and dimensions of the cargo are provided in Table 2.

Our findings show that the personal pickup delivery choice proves to be less efficient due to the periodic use of valuable clinical manpower for transporting individual items. Nonetheless, this option becomes crucial during urgent pharmaceutical needs. The scenario referred to as "As Is" described this delivery method and illustrates the process from placing an order to its delivery and filing. Figure 1 illustrates the areas currently under development concerning Innovative Aerial Services.

Table 2. Payload specifications of the pharmaceuticals urgently transported in the hospital.

Minimum Size (cm × cm × cm)	Maximum Size (cm × cm × cm)	Maximum Weight (kg)	Minimum Delivery Frequency (#/h)	Maximum Delivery Frequency (#/h)
4 × 6 × 4	26 × 14 × 14	1.8	3	10

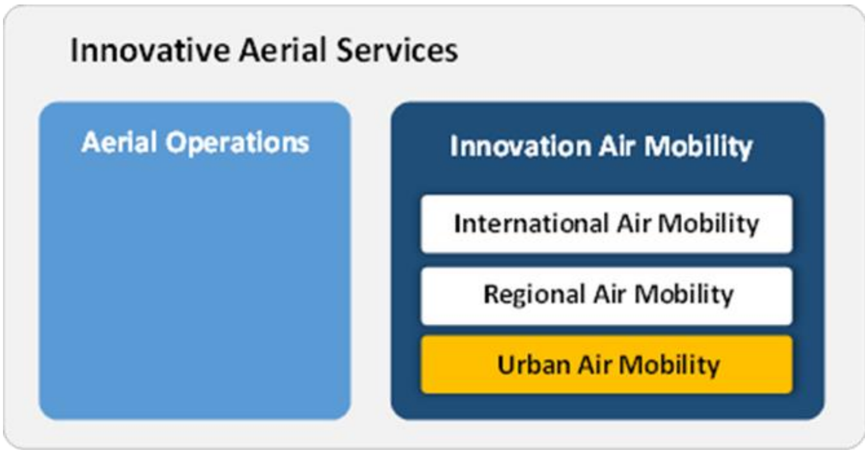

Figure 1. Topics under development regarding Innovative Aerial Services.

3.1.1. Workflow of the *"As Is"* Scenario

The current logistics process begins with the OU coordinator, who has a specific and urgent need for pharmaceuticals outside the regular delivery schedule by the end of the day. To address this requirement, they initiate direct contact with the pharmacy management team for swift negotiations and, if feasible, to place an order. Following successful negotiations and approval from the pharmacy management, the OU coordinator arranges for a personal pickup. Subsequently, the OU coordinator requests one of the nurses or healthcare collaborators to personally visit the pharmacy to obtain the required medications. Concurrently, the pharmacy management team informs the pharmacy coordinator about the placed order and the personal pickup procedure.

While the OU healthcare collaborator is en route to the pharmacy, the OU coordinator proceeds to input the order into the Hospital Management Software. This involves selecting the urgent delivery option and specifying the drugs previously approved by the pharmacy management during their conversation. The order submitted by the OU coordinator is then digitally reviewed and approved by the pharmacy management staff. Once approved, the pharmacy management team forwards the order directly to the pharmacy for processing. Upon arrival at the pharmacy, the pharmacy coordinator generates a delivery note and assigns the task of collecting the drugs to one of their collaborators before the OU collaborator's arrival. The OU collaborator arrives at the pharmacy, collects the prescribed drugs from the pharmacy collaborator, and signs the delivery note. Subsequently, the pharmacy collaborator returns the signed delivery note to the pharmacy coordinator for archiving. Meanwhile, the OU collaborator returns to the OU with the ordered medications.

3.2. 'Aspirational' Healthcare Logistics Blueprint

In the ideal scenario outlined as "Aspirational," the hospital would rely on a drone delivery service. This service could either be managed by an external commercial drone operator, a contracted company responsible for the drones' activities, or it could be an internal asset of the hospital, meaning the hospital itself would operate the drones. Within this scenario, two key roles within the drone operator's organization come into play: the flight manager (FM), responsible for resource allocation (crew and aircraft) for the operations, and the Remote Pilot (RP), in charge of executing the drone flights. The delivery service would utilize highly automated drones equipped with predetermined routes or powered by AI-based software to determine the safest and most efficient flight paths. These flight paths would typically extend from the drone base to a loading point near the pharmacy warehouse. From there, the drones would transport the deliveries to a landing pad located on the relevant floor of the point of care. After completing the delivery, the drones would return to the base. The drone delivery option would be available for OU staff when placing drug orders through the Hospital Management System. Those directly involved with the delivery process would have dedicated software, known as the 'Drone Delivery App,' installed on their workstations or smartphones. This app allows them to interact with the service. Before the operation, the flight manager would use the Drone Delivery App to inform users about drone availability, pickup time, and location. During the operations, users can monitor the delivery's progress using the same software and confirm loading and unloading. This scenario would also necessitate that the regular hospital staff involved in drone operations receive proper training. This training is crucial to ensure that the area is free of people or animals that could be harmed by the drone during loading and unloading. Additionally, it is important to establish a common terminology for effective communication. This is necessary for reporting any issues to the crew or for the crew to instruct hospital staff effectively when needed. The provided flowchart covers the process from order placement to order delivery and filing, specifically focusing on drone operations that have been previously deemed safe, compliant with regulations, and authorized by Türkiye Drone Flight Authorities during the pre-service phase.

3.2.1. Workflow of the Aspirational Scenario

The sequence is initiated by the OU Coordinator in case of an emergency requiring swift delivery of a specific pharmaceutical. Operating from their workstation, they opt for urgent drug delivery via drone through the Hospital Management Software. The order is then transmitted to the pharmacy management staff, who pass it to the pharmacy. The pharmacy coordinator generates a delivery note and assigns a collaborator to gather the required drugs. Simultaneously, the pharmacy coordinator submits a request for drone delivery using the Drone Delivery App. The flight manager (FM) receives the drone delivery request, checks the availability of both the drone and the Remote Pilot (RP), and organizes the necessary resources for the operation. A notification is sent to confirm drone availability and identification to the pharmacy manager and their collaborator. The collaborator proceeds to the drone base with the drugs and the delivery note, loading them onto the delivery container attached to the drone. Using the Drone Delivery App, they confirm the successful loading of the drone (also here, we can use RFID tags for packs of medicine to confirm them on delivery for both sides). The RP conducts a pre-flight checklist to ensure the drone's operational readiness and safety, verify flight authorization, assess weather conditions, consult available UTM services, ensure the drone parts are undamaged and unobstructed, check battery charge, and confirm clear communication.

Upon completion of the pre-flight checklist, the drone activates its motors, ascends, and flies towards the OU pickup point, following predetermined flight paths under the RP's supervision. The Drone Delivery App notifies the OU collaborators about the drone's approach. Upon landing, the nurse unloads the drone and confirms the unloading via the Drone Delivery App. This confirmation triggers the drone to automatically activate its motors, ascend, and return to the base, notifying involved users that the drugs have been delivered. After landing at the drone base, a notification is sent to the FM about the completed delivery, and the RP conducts a post-flight checklist. In brief, incorporating drone delivery would present an additional choice for OU to obtain medicines. If it demonstrates effectiveness and efficiency, the service could be expanded by incorporating additional drones and resource persons. However, the central link between the drone system and the digital infrastructure would be the FM, potentially requiring around-the-clock staffing in the future.

3.2.2. Hierarchy of KPIs for the urgent intra-hospital transport of medicines

Based on previous research, a framework of Key Performance Indicators (KPIs) for urgent pharmaceutical deliveries within a hospital was formulated [2]. This study further segmented the aspect of 'responsiveness' (timely delivery) into 'preparation time' and 'transport time' to cater to specific scenarios under investigation. 'Responsiveness' here signifies the total duration from the initiation (i.e., order submission intent) to the availability of the requested products for the requesting Operating Unit (OU). The 'preparation time' measures the duration from initiation to cargo loading, while 'transport time' tracks the period taken to move products from the pharmacy to the OU. Moreover, this study introduced 'resolution time' to gauge the interval required to respond to a subsequent request of a similar nature using the same resources after fulfilling the prior order. Although this metric doesn't impact a single delivery, it evaluates the continuity of the ongoing service. The intention behind creating this hierarchy was to steer the development and appropriate scaling of such a service, especially for medium to large-sized hospitals. For instance, this entails determining the right number and types of drones, as well as the necessary charging and delivery container requisites. The primary focus in structuring these KPIs was the prospective advantage for the primary users, while the financial constraints, outlined as 'distribution cost' KPI, were addressed separately. Figure 2 illustrates the KPI hierarchy, with those at higher levels expected to significantly impact users and, consequently, patient care. The KPIs with greater influence from the perspective of Operating Unit staff are detailed on the left side, while those more impactful for pharmacy users are depicted on the right.

The established hierarchy is specific to the use case examined in this study. The planned service is meant to become an integral part of the pharmacy's daily operations, so the key performance indicators (KPIs) focused on the efficiency and accuracy of logistics activities take top priority. Within this study, the primary benefit identified is the reduction in non-clinical tasks performed by clinical staff. Therefore, the measurement of workload distribution, particularly the time clinical staff spend on delivery activities, is of utmost importance, as the implementation of the drone service would significantly impact them. The time taken for preparation significantly affects the workload of pharmacy staff and could potentially influence other Operational Units (OUs) placing orders. KPIs lower in the hierarchy would have a minor to moderate effect; the use case primarily involves medicines needed beyond regular schedules, possibly required by OUs within a few hours. Consequently, responsiveness and delivery frequency were not given high priority. Table 3 displays the time-related KPIs outlined in [2] and introduced in this study, estimated for the Aspirational scenario, and compared with those of the current scenario (As Is).

3.2.3. Constraints for the drone service implementation

The key performance indicator (KPI) of 'distribution cost' was specifically evaluated to address financial constraints regarding the implementation of the proposed service. As the aim wasn't profit generation but rather enhancing the hospital's efficiency and healthcare outcomes—factors challenging to quantify economically—outsourcing this service might not be the most practical choice. The benefits are mainly expressed in terms of innovation, time saved in transport, and improved patient care. Given that the current scenario involves simple drone flights within the hospital's limited airspace, managing this service internally appears feasible for a hospital. This in-house approach would involve initial costs such as certifying the organization as a drone operator, employing one or two staff to manage operations, purchasing the drone fleet, appropriate delivery containers, necessary physical infrastructure (like landing pads, automated drone recharge stations), and an IT platform (comprising fleet management software and a Drone Delivery App). Operational costs encompass employee training and expenses linked to regulatory compliance. Marginal costs include electricity and internet services, which can be minimized by ensuring proper wireless networking coverage along the flight corridors.

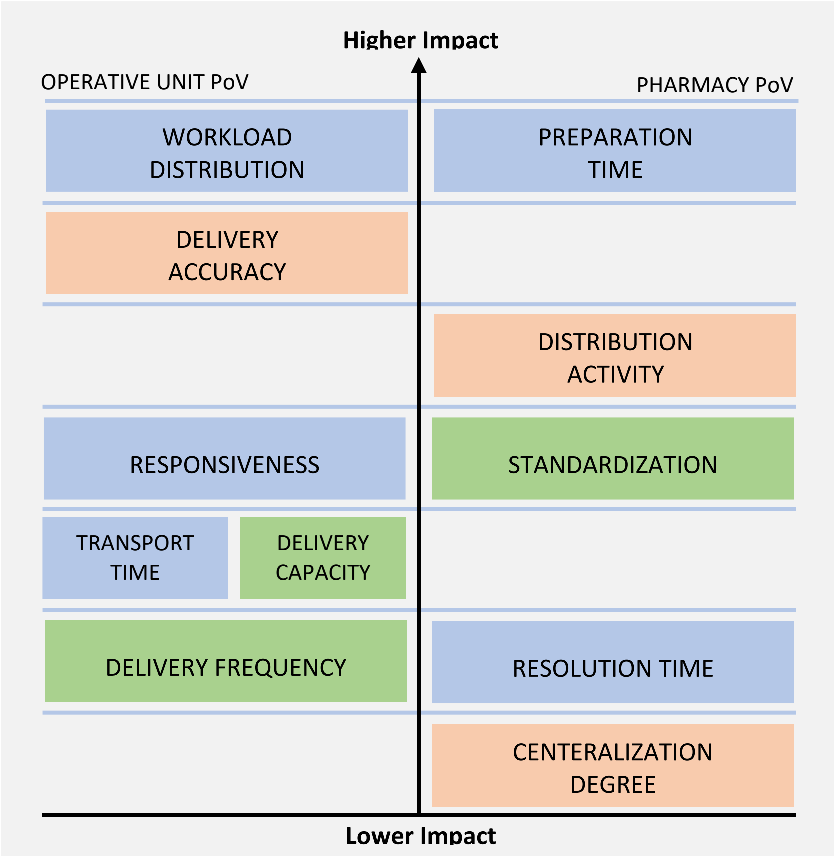

Figure 2. Hierarchy of KPIs for the urgent intra-hospital transport of medicines (time category in green, quality category in blue, productivity category in red).

Table 3. Estimated KPIs in the time category for the investigated scenarios.

Scenario	Responsiveness (min)	Preparation Time (min)	Transport Time (min)	Resolution Time (min)	Workload Distribution (min)
As Is	28–41	15–26	10–17	1–4	18–33
Aspirational	9–20	8–15	3–9	1–2	4–9

For reliable service, it is essential to maintain a continuously charged drone fleet to swiftly respond to new requests. The constraints to consider here involve the frequency of delivery requests, average distance, and cargo weight. These factors help determine the most suitable technical specifications for the drone fleet, including the number of drones, their autonomy, delivery speed, and battery recharge rate. Strategies can range from having charged batteries available when needed to more advanced options like automated drone recharge stations. The researchers used a custom-made drone for their example due to its technical data. They considered a 30-minute drone autonomy (with a maximum loadable weight of 2.7 kg, including the delivery container) and a flight speed of 3 m/s for safety. Estimating an average round trip distance of about 1000 meters at CityHospital, a delivery would require less than 3 minutes of drone activity. The time spent on loading and unloading is not factored in, as the drone would be turned off. A drone could safely conduct at least ten deliveries with a pair of batteries. The drone model's battery recharger can recharge two pairs of batteries in almost 60 minutes, ample time for the activities of a single drone.

The solution's design must also address risks associated with the potential loss of regulated or expensive pharmaceuticals. This study evaluated these risks based on their likelihood and impact levels, identifying mitigations in the service to address them (Table 4). They categorized likelihood as low for rare events (below 0.1%) and medium for occurrences between 0.1% and 1%. The impact was deemed low for minor delivery delays, medium for longer waits (30 minutes to hours), and high for medicine loss or potential damage. The Drone Delivery App could aid risk management by integrating an 'error reporting' feature for all involved users to prompt relevant interventions.

3.2.4. Requirements for the Rollout of the Drone Delivery App

The prioritization of key performance indicators (KPIs) in the current scenario (Figure 2) underscores the primary emphasis on reducing the time involved in delivery tasks for both the pharmacy and operational unit (OU) staff. Therefore, digital tools enabling precise and timely information exchange play a pivotal role in the ideal scenario. The 'Drone Delivery App' performs various functions in the proposed service, aligning with the logistics plan (Figure 2).

To create an application like the one suggested in this study, the authors recommend utilizing the co-creation approach to gather and confirm requirements. Subsequent development stages must consider the initially identified requirements and functions (Table 5).

Table 4. Identification, evaluation, and mitigation of the risks of loss of pharmaceuticals.

Risk	Likelihood	Impact	Mitigation
Loading failure	Low	Low	Loading confirmation via Drone Delivery App
Unloading failure	Low	Low	Unloading confirmation via Drone Delivery App
Mistaken medicine	Low/Medium	Medium	Delivery note check
Mistaken delivery destination	Low	Medium	Geo-localization feature
Stolen medicine	Low	High	Tamper-evident seal or mechatronic lock
Vehicle crash	Low	High	Crash-proof delivery container; drone operator's emergency response plan

Table 5. Milestones outlined for the development of the Drone Delivery App.

Step	Activities	Tools
Requirements' collection	• Identifying the objectives of the *Aspirational* service • Identifying the users' needs and pain points • Writing user stories regarding the elicited system functionalities	Users' interviews, user journey maps, storyboard, users' stories
Requirements validation	• Identifying the objectives of the *Aspirational* service • Creation of app's mockups • Validation of the proposed solution functions with prospective users • Identifying the objectives of the *Aspirational* service	Users' interviews, user journey maps, low-definition prototypes use case description
Predevelopment planning	• Identifying the objectives of the *Aspirational* service • Selecting where the application will be hosted, on cloud or on-premises servers, depending on legal aspects and data storage security • Selecting the software building language • Data modeling • Starting to set up test cases based on the requirements and defined use cases • Identifying the objectives of the *Aspirational* service	Specification language (software testing)
Quality assurance testing	• Identifying the objectives of the *Aspirational* service • Definition of non-functional metrics • Tests and threshold assessment definition • Validation of the defined metrics • Identifying the objectives of the *Aspirational* service	To be defined depending on the specific metrics
User acceptance testing	• Identifying the objectives of the *Aspirational* service • Definition of usability tests protocol • Recruitment of the target users • Usability test execution • Identifying the objectives of the *Aspirational* service	Usability surveys

3.3. The UAM Ecosystem

The service's design relies on a digital infrastructure that ensures safety and compliance and guarantees the efficiency of the service. Rapid exchange of information among users before, during, and after delivery is crucial. Many of these IT participants are not directly engaged in piloting the drone. The functional diagram in Figure 4 illustrates how information is exchanged among all identified participants and the elements facilitating this communication, known as a UAM ecosystem. This digital ecosystem includes participants from the primary end-user organization (such as the hospital), the UAS operator, and various actors from both aviation and non-aviation backgrounds. These individuals are responsible for coordinating the various activities within the boundaries of their respective establishments. This role represents another component within the digital ecosystem, with no predetermined or restricted count of involved parties.

3.4. Stakeholder map

The pharmaceutical delivery service stakeholders were categorized based on their varying levels of interest. Figure 5 displays the stakeholder map, delineating different tiers. The primary tier encompasses key service users: OU staff, pharmacy staff, and RP, directly engaged in the delivery process. The second tier involves staff whose roles would notably change with the introduction of the new solution, along with those collaborating closely with the main users (such as pharmacy management coordinators, HSR delivery operators, FM, and geo zone managers). The third tier of stakeholders includes hospital personnel, executives, domain enterprises, and other parties regularly interacting with the most affected users, capable of influencing daily service operations and availability.

In the current 'As Is' scenario, the involved stakeholders include doctors, specialized students, patients, the Health and Safety (H&S) manager overseeing safe movement within the hospital premises, and the surveillance coordinator responsible for implementing safety measures. In the 'Aspirational' scenario, additional stakeholders are introduced. This involves roles like the clinical and research area managers within the hospital, capable of approving or denying airspace use above healthcare and research buildings. Additionally, the fourth tier includes stakeholders like suppliers, regulators, and those not directly linked to the use case but distantly connected to service operations (e.g., pharmacy suppliers and delivery staff. All stakeholders and their role descriptions and levels of interest are detailed in Table 6.

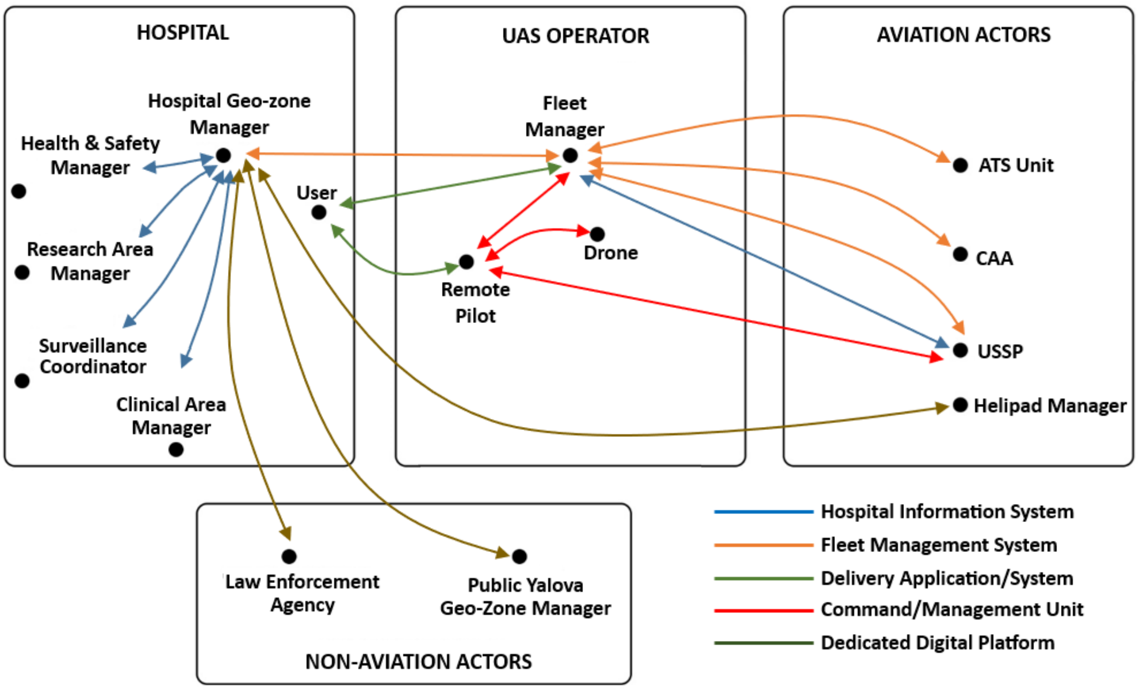

Figure 4. The UAM ecosystem sustains the drone delivery service.

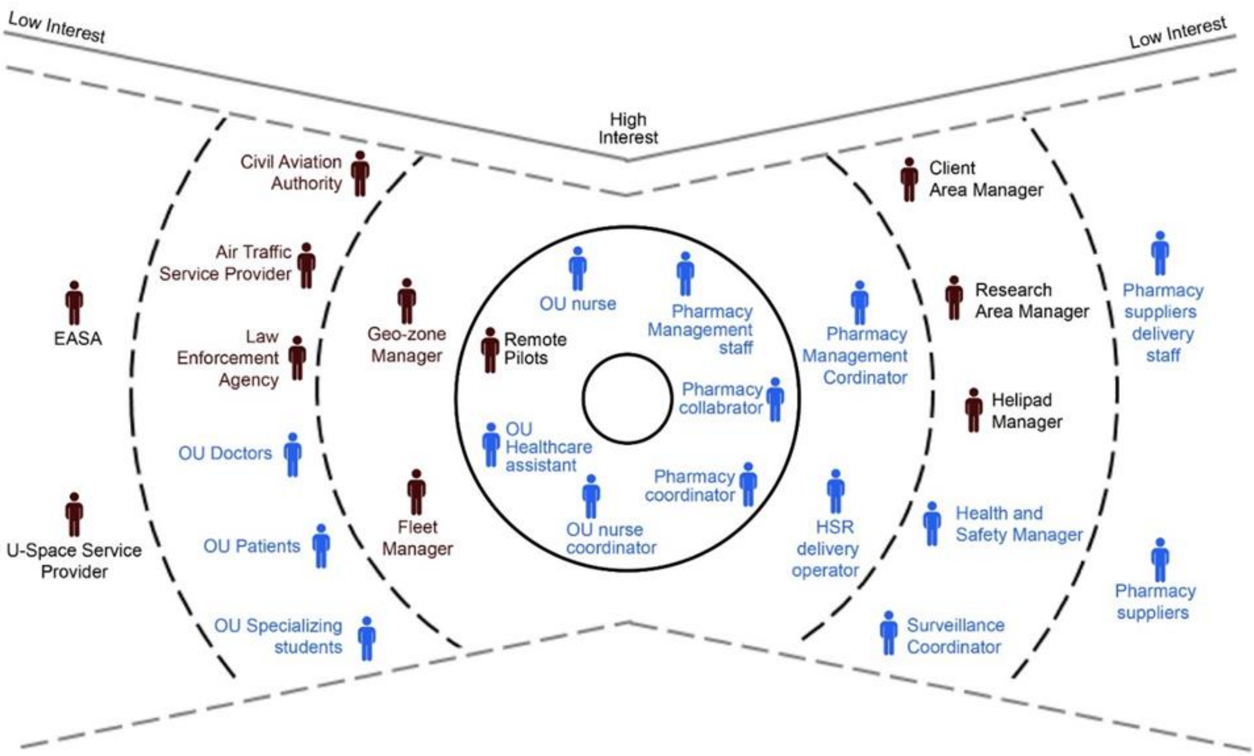

Figure 5. Stakeholder map of the *As Is* (blue) and *Aspirational* (blue and black) scenarios.

Table 6. Summary of the stakeholders' roles and interactions in the investigated scenarios.

Name	Role	Description	Tier
OU Nurse Coordinator	User	Places drug orders, manages the relationships with the Pharmacy Management, manages nurses and healthcare assistants	1
OU Nurse	User	Collects the ordered drugs, unloads the drone	1
OU Healthcare assistant	User	Collects the ordered drugs, unloads the drone	1
Pharmacy Management Staff	Operational support	Manages drugs orders, manages pharmacy relationships	2
Pharmacy Coordinator	User	Manages ordered drugs, manages pharmacy workflow, manages pharmacy personnel, places drone delivery orders	2
Pharmacy collaborator	User	Collects the ordered drugs, loads the drone	2
Remote Pilot	User	Authorizes and supervises the drone delivery	2
Flight Manager	Operational support	Manages the hospital's drone fleet	3
Geo-zone Manager	Regulator	Approves or withdraws permission for airspace use	3
HSR delivery operators	Operational support	Delivers drugs to the operative units in urgent orders with traditional delivery	3
Pharmacy Management Coordinator	Operational support	Manages pharmacy relations	3
Health & Safety Manager	Regulator	Defines the drone service safety rules and limitations in the hospital premises	3
Surveillance Coordinator	Operational support	Implements the drone service safety rules managing the surveillance staff in the hospital	3
Research Area Manager	Regulator	Defines drone service limitations in the airspace above the research department	3
Clinical Area Manager	Regulator	Defines drone service limitations in the airspace above the research department	3
Air Traffic Service Provider	Regulator	Manages the traditional aviation in proximity of the hospital through the relevant ATS unit	3
Civil Aviation Authority	Regulator	Conducts technical regulation and inspection, certification, authorization, coordination and control activities in Italian aviation	3
OU doctors	Other	Define the treatment of patients in the OU	3
OU specializing student	Other	Supports OU doctors	3
OU patients	Other	Trigger the need for pharmaceuticals	3
Law enforcement	Other	Monitors the security of the operations and can enforce the interruption of the drone flights upon the city prefecture's decision	3
Helipad Manager	Other	Is responsible for the area where the Helicopter Emergency Ambulance Service operates	3
Pharmacy supplier	Supplier	Provides drugs for the hospital pharmacy	4
Pharmacy supplier's delivery staff	Supplier	Delivers the ordered drugs to the hospital pharmacy	4
U-Space Service Providers	Supplier	Provide U-Space digital services to the drone operator	4
EASA	Regulator	It carries out certification, regulation and standardization for civil aviation safety in Europe	4

4. Discussion

The Aspirational scenario proposal was formulated to enhance the efficiency of pharmaceutical delivery within hospitals by implementing drone technology. To achieve this goal, the primary end-users were consulted using a collaborative approach. According to the authors, the proposed design would notably enhance all-time key Performance Indicators (KPIs). Specifically, it was anticipated that drones would considerably decrease service response times. Transportation time would be significantly reduced by utilizing drones instead of human walkers, who can be slower and encounter obstacles such as elevator congestion. Furthermore, reducing human interactions between the pharmacy and the OU staff would positively impact preparation time. It is important to note that the maximum efficiency gains wouldn't solely be due to using drones but also to integrating the drone and its operator into a service-focused digital framework. Regarding Quality KPIs, they encompass delivery accuracy, centralization degree, and the disruption of distribution activities. Delivery accuracy measures the successful deliveries as a percentage of the total operations. The centralization degree refers to consolidating all logistic activities under one organizational unit, while the disruption of distribution activities gauges any disturbances caused. In the proposed scenario, it is not expected that there will be significant changes in centralization degree and disruption of distribution activities. This is because the new service isn't meant to replace existing transportation methods but rather to provide an additional, reliable, and swift option for intra-hospital deliveries.

In the Productivity KPI category, three key factors must be considered: delivery capacity, delivery frequency, and standardization [2]. Delivery capacity is a critical aspect of logistics. Based on interviews, it was found that urgent orders typically involve a single item not exceeding 4 liters in volume and with the largest dimension under 26 cm, as indicated in Table 1. This research doesn't delve into delivery containers, assuming that the drone service can handle this capacity and that the weight of ordered items isn't a concern for most urgent requests. The delivery frequency for urgent drug requests in the case study varies from one request every thirty minutes during low demand to approximately eight minutes in high demand (Table 1).

These requests are fulfilled using pneumatic tubes, dedicated hospital staff for intra-hospital delivery, or personal pickups from OUs, depending on the availability of the first two options. The achievable delivery frequency with a drone service depends on the number of drones in the fleet. According to time estimates, one drone could fulfill a delivery request every 10–17 minutes. Thus, it makes sense to consider having at least 2–3 drones to enhance service availability and reliability. Lastly, the degree of standardization is crucial for performance. Interviews revealed that pharmacy management follows specific rules to prioritize different transport modes based on the availability of pneumatic tubes and delivery staff rather than the specific medicine to be transported. However, the digital forms of requests are filled out only after a vocal negotiation between OU staff and pharmacy management, potentially leading to ambiguity and reduced time efficiency compared to a fully digitized system. The current study identified the primary financial limitations of implementing an in-house managed drone service. It was argued that the economic benefits would be challenging to quantify, as the main goal is to enhance hospital efficiency and patient care. Nonetheless, one could argue that introducing a drone service for pharmaceutical delivery might be more cost-effective if the same Unmanned Aerial System (UAS) were utilized for other services during periods of low demand. Potential applications in a hospital include transporting diagnostic samples and medical supplies, monitoring infrastructure integrity, and surveillance. This emphasizes the pivotal role of Facility Management (FM), which may involve multiple drones and Remote Pilots (RPs).

The proposed design offers several additional advantages, including potentially reducing nosocomial infections by minimizing people's movements between clinical and non-clinical areas. Furthermore, it would alleviate the burden on clinical activities as pharmaceuticals would directly reach the point of care. Product traceability is ensured by associating each order with a designated drone identifier and a predefined route for each possible drone. A tamper-evident seal with the order identifier on the container could be applied to enhance traceability and security, a system already used for valuable goods in hospitals. Further security can be achieved by applying a mechatronic lock controlled by users through the Drone Delivery App on the delivery container. It is essential to emphasize that the implementation of drone services should consider public acceptance at all stages.

4.1. Regulatory challenges surrounding automated flight

To summarize, the proposed Aspirational scenario is designed to address the unmet service needs of users and to improve overall efficiency. However, a thorough assessment is essential to implement this service safely and in accordance with regulations. A key safety issue is the high degree of automation suggested for the system. The Joint Authorities for Rulemaking on Unmanned Systems (JARUS) have outlined various potential automation levels for Unmanned Aircraft Systems (UAS) [21, 22, 44].

(i) In a manual Unmanned Aircraft System (UAS), the flight is directly and continuously controlled by a Remote Pilot (RP) who actively manipulates the flight controls.

(ii) There are four advancing levels of automation in UAS. In these, specific operations are automated, yet human oversight remains essential, with the capability for immediate human intervention to modify the aircraft's flight path.

(iii) A fully autonomous UAS characterizes a system that operates independently, managing itself without human intervention.

In this advanced stage of development, the need for human intervention or supervision to change the flight path of the aircraft is no longer essential. However, this does not negate the continued importance of a flight manager (FM) in organizing the operation, initiating commands, and activating emergency protocols as necessary. There are various levels of automation/autonomy, often described using phrases such as 'human in the loop,' 'human on the loop,' or 'human out of the loop.' Autonomous drones are theoretically allowed under the 'specific' category in Turkey. However, the compliance requirements for technical, safety, and operational standards are much stricter, requiring significantly more resources than less autonomous solutions. Currently, international and national bodies focused on integrating these systems into regulated airspace are not considering fully autonomous civilian Unmanned Aircraft Systems (UAS). It is widely agreed that completely autonomous options won't be ready for commercial use in the immediate or medium-term future. Most developers of electric Vertical Take-Off and Landing (eVTOL) vehicles for passenger transport envision a gradual progression:

1. Having a pilot on board;
2. Shifting to a remote pilot, with each pilot controlling only one eVTOL at a time;
3. A remote pilot managing multiple eVTOLs simultaneously;
4. Eventually, replacing the remote pilot with a flight manager responsible for overseeing the operations of an entire eVTOL fleet.

In the scenario described, drone flight operations are automated but overseen by a Remote Pilot (RP), responsible for simultaneously controlling multiple drones. A key safety requirement is the RP's ability to intervene and manually control the drone at any moment. For operations falling under the 'specific' category, getting approval from the Drone Aviation Authority is necessary. This approval process includes a Specific Operations Risk Assessment (SORA), which assesses risks on the ground, such as the potential for harm to people nearby [21, 22, 44].

To ensure safety, a combination of technological and operational tactics is critical. The exact measures depend on the nature of the operation. For example, strategies might include routing the drone over the tops of buildings (Figure 3), equipping the drone with a parachute for emergency landings, and having a Flight Termination System (FTS) that works independently to prevent common mode failures. In inherently higher-risk situations, these safety measures may need to comply with certain technical standards. The strategy should include procedures that are well-understood by the pilot and tailored to the specific local environment.

4.2. Envisioning the UAM Ecosystem

The growing necessity for Unmanned Traffic Management (UTM) becomes evident when multiple drone operators occupy the same airspace to prevent conflicts among aerial vehicles. While managing a single operator's fleet in a designated area is straightforward, this study explores environments where several operators are permitted to fly drones in hospital airspace. The goal is to develop a scalable solution. This research facilitates assessing the practicality of such a service on a larger scale, such as utilizing the airspace above a large hospital campus for drones controlled by different organizations for various purposes. Establishing a robust digital infrastructure and operational framework is critical for reducing risks. Urban Air Mobility (UAM) entails a systematic sharing of information among various stakeholders to guarantee safety, laying the groundwork for a UAM system that incorporates multiple participants in a 'smart city' setting. An instance of this would be a geo-zone manager implementing temporary airspace restrictions for drone operations within their jurisdiction, coupled with coordination with air ambulance services to avoid interference with emergency helicopters at adjacent helipads.

Fundamentally, it is apparent that multiple parties must work together within the broader ecosystem. For instance, clinical staff could use a software interface to place orders with the pharmacy, while pharmacy staff might use another interface to verify drone availability. Thus, communication between hospital personnel and Fleet Management (FM) is essential. However, it is likely that a single provider might not be able to supply all the varied software and interfaces needed for this system. As a result, the interoperability of technological components is vital for the viability and adaptability of this system to meet various future requirements.

4.3. Limitations

This study has certain limitations that should be considered. It is important to investigate if other medical facilities use similar methods for delivering pharmaceuticals during the final stages. Engaging with representatives from different hospitals to examine the wider relevance of these findings could lead to broader implementation of the study's conclusions. The Key Performance Indicators (KPIs) hierarchy, the identified challenges in service implementation, and the requirements for the Drone Delivery App might be relevant for other institutions with similar needs, such as urgent intra-hospital pharmaceutical delivery, and could possibly extend to other medical supply and diagnostic sample scenarios. Further research involving potential users is necessary to confirm these possibilities.

One aspect that was not addressed in this study is the design of the delivery container. There is currently no universally recognized standard by aviation regulators or standardization bodies for containers used to transport potentially hazardous materials via drones. It is critical to ensure both the product's integrity and bystander safety for an effective design. However, the specifications may differ depending on the type of material being transported. Monitoring acceleration forces, temperature, and humidity within the container could improve the assurance of the product's integrity. As recent studies have highlighted, understanding how various stresses and physical changes during drone flights affect drug stability is crucial. It has been proposed that each pharmaceutical should be evaluated according to pharmacopeia standards to determine its suitability for drone transportation.

5. Conclusion

In conclusion, the adoption of drone technology for the internal transport of urgent pharmaceuticals within hospitals presents a groundbreaking solution to the pressing challenges of efficiency and safety in healthcare logistics. This innovative approach not only promises to streamline the delivery process but also to significantly reduce delivery times, ensuring that critical medications reach patients faster than ever before. By utilizing the speed and agility of drones, hospitals can overcome physical barriers and congestion, enhancing their ability to provide timely care.

The implementation of this drone delivery system also highlights the importance of security measures and regulatory compliance. Through the use of tamper-evident seals and mechatronic locks, the system ensures the integrity and safety of pharmaceuticals during transit. Furthermore, by aligning with Urban Air Mobility principles and engaging with stakeholders, the project sets a precedent for future advancements in hospital logistics and urban transportation. This collaborative approach not only addresses technical and operational challenges but also promotes an environment of innovation and regulatory cooperation.

Looking forward, the successful integration of drones into hospital logistics has the potential to revolutionize not just the healthcare industry but also urban mobility at large. As this technology matures and regulatory frameworks evolve, the possibilities for its application are boundless. This study not only contributes valuable insights into the feasibility and benefits of drone-based pharmaceutical delivery but also opens the door for further research and development in this exciting field. With continued innovation and collaboration, drone technology can significantly enhance the efficiency, safety, and quality of healthcare services, ultimately leading to better patient outcomes.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Volland, J., Fügener, A., Schoenfelder, J., & Brunner, J. O. (2017). Material logistics in hospitals: A literature review. Omega, 69, 82-101. https://doi.org/10.1016/j.omega.2016.08.004
2. Moons, K., Waeyenbergh, G., & Pintelon, L. (2019). Measuring the logistics performance of internal hospital supply chains–a literature study. Omega, 82, 205-217. https://doi.org/10.1016/j.omega.2018.01.007
3. Vancroonenburg, W., Esprit, E., Smet, P., & Vanden Berghe, G. (2016). Optimizing internal logistic flows in hospitals by dynamic pick-up and delivery models. In Proceedings of the 11th International Conference on the Practice and Theory of Automated Timetabling, Udine, Italy, 371-383.
4. Medical Device Coordination Group. (2019). Guidance on qualification and classification of software in regulation (EU) 2017/745–MDR and regulation (EU) 2017/746–IVDR. European Commission.
5. Zhou, F., Li, J., Lu, M., Ma, L., Pan, Y., Liu, X., ... & Cai, L. (2020). Tracing asymptomatic SARS-CoV-2 carriers among 3674 hospital staff: a cross-sectional survey. EClinicalMedicine, 26, 1-8.
6. Hiebert, B., Nouvet, E., Jeyabalan, V., & Donelle, L. (2020). The application of drones in healthcare and health-related services in north america: A scoping review. Drones, 4(3), 30. https://doi.org/10.3390/drones4030030
7. Ayamga, M., Akaba, S., & Nyaaba, A. A. (2021). Multifaceted applicability of drones: A review. Technological Forecasting and Social Change, 167, 120677. https://doi.org/10.1016/j.techfore.2021.120677
8. Euchi, J. (2021). Do drones have a realistic place in a pandemic fight for delivering medical supplies in healthcare systems problems?. Chinese Journal of Aeronautics, 34(2), 182-190. https://doi.org/10.1016/j.cja.2020.06.006
9. Merkert, R., & Bushell, J. (2020). Managing the drone revolution: A systematic literature review into the current use of airborne drones and future strategic directions for their effective control. Journal of Air Transport Management, 89, 101929. https://doi.org/10.1016/j.jairtraman.2020.101929
10. Turan, V., Avşar, E., Asadi, D., & Aydın, E. A. (2021). Image processing based autonomous landing zone detection for a multi-rotor drone in emergency situations. Turkish Journal of Engineering, 5(4), 193-200. https://doi.org/10.31127/tuje.744954
11. Zeybek, M. (2021). Classification of UAV point clouds by random forest machine learning algorithm. Turkish Journal of Engineering, 5(2), 48-57. https://doi.org/10.31127/tuje.669566
12. Akay, S. S., Ozcan, O., Şanlı, F. B., Bayram, B., & Görüm, T. (2021). Assessing the spatial accuracy of UAV-derived products based on variation of flight altitudes. Turkish Journal of Engineering, 5(1), 35-40. https://doi.org/10.31127/tuje.653631
13. Amukele, T., Ness, P. M., Tobian, A. A., Boyd, J., & Street, J. (2017). Drone transportation of blood products. Transfusion, 57(3), 582-588. https://doi.org/10.1111/trf.13900
14. Nyaaba, A. A., & Ayamga, M. (2021). Intricacies of medical drones in healthcare delivery: Implications for Africa. Technology in Society, 66, 101624. https://doi.org/10.1016/j.techsoc.2021.101624
15. Haidari, L. A., Brown, S. T., Ferguson, M., Bancroft, E., Spiker, M., Wilcox, A., ... & Lee, B. Y. (2016). The economic and operational value of using drones to transport vaccines. Vaccine, 34(34), 4062-4067. https://doi.org/10.1016/j.vaccine.2016.06.022
16. Wang, N. (2021). "As it is Africa, it is ok"? Ethical considerations of development use of drones for delivery in Malawi. IEEE Transactions on Technology and Society, 2(1), 20-30. https://doi.org/10.1109/TTS.2021.3058669
17. Bauranov, A., & Rakas, J. (2021). Designing airspace for urban air mobility: A review of concepts and approaches. Progress in Aerospace Sciences, 125, 100726. https://doi.org/10.1016/j.paerosci.2021.100726
18. International Civil Aviation Organization (1944). Convention on International Civil Aviation (Chicago Convention); International Civil Aviation Organization: Chicago, IL, USA.
19. ISO/DIS 23629-5 (2022). Unmanned Aircraft Systems—UAS Traffic Management (UTM)—Part 5: UTM Functional Structure. International Organization for Standardization: Geneva, Switzerland.
20. ISO/DIS 23629-12 (2021). UAS Traffic Management (UTM)—Part 12: Requirements for UTM Service Providers. International Organization for Standardization: Geneva, Switzerland
21. Jarus FAQ (2021). http://jarus-rpas.org/
22. Joint Authorities for Rulemaking of Unmanned Systems (2019). JARUS Recommendation for Remote Pilot Competency (RPC) for UAS Operations in Category A (Open) and Category B (Specific). JARUS.
23. European Union. (2019). Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on Unmanned Aircraft Systems and on Third-Country Operators of Unmanned Aircraft Systems; Official Journal C/2019/1821; European Union: Brussels, Belgium
24. European Union (2019). Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the Rules and Procedures for the Operation of Unmanned Aircraft; Official Journal C/2019/3824; European Union: Brussels, Belgium.
25. European Union. (2012). Commission Implementing Regulation (EU) 2021/664 of 22 April 2021 on a

regulatory framework for the U-space; Official Journal C/2021/2671; European Union: Brussels, Belgium
26. European Union Aviation Safety Agency (2021). Study on the Societal Acceptance of Urban Air Mobility in Europe; European Union: Brussels, Belgium.
27. European Cockpit Association. Unmanned Aircraft Systems and the Concepts of Automation and Autonomy. (2020). ECA Briefing Paper 2020; ECA: Brussels, Belgium
28. European Union Aviation Safety Agency. (2021). Provisions Applicable to both 'Open' and 'Specific' Category. https://www.easa.europa.eu/the-agency/faqs/drones-uas
29. European Union. Commission (2021). Implementing Regulation (EU) 2021/666 of 22 April 2021 Amending Regulation (EU) No 923/2012 as Regards Requirements for Manned Aviation Operating in U-Space Airspace; Official Journal C/2021/2673; European Union: Brussels, Belgium
30. ISO 21384-3 (2019). Unmanned Aircraft Systems—Part 3: Operational Procedures. International Organization for Standardization: Geneva, Switzerland
31. Freeman, R. E. (2010). Strategic management: A stakeholder approach. Cambridge University Press.
32. Stickdorn, M., Hormess, M. E., Lawrence, A., & Schneider, J. (2018). This is service design doing. O'Reilly Media, Inc.
33. Jones, P. (2013). Design for care: Innovating healthcare experience. Rosenfeld Media.
34. Clack, L. A., & Ellison, R. L. (2019). Innovation in service design thinking. Service design and service thinking in healthcare and hospital management: Theory, concepts, practice, 85-92. https://doi.org/10.1007/978-3-030-00749-2_6
35. Blomkvist, J., Holmlid, S., & Segelström, F. (2010). Service design research: yesterday, today and tomorrow. This Is Service Design Thinking, 308-315.
36. Euchi, J. (2021). Do drones have a realistic place in a pandemic fight for delivering medical supplies in healthcare systems problems?. Chinese Journal of Aeronautics, 34(2), 182-190. https://doi.org/10.1016/j.cja.2020.06.006
37. Law, A. M., Kelton, W. D., & Kelton, W. D. (2007). Simulation modeling and analysis (Vol. 3). New York: Mcgraw-hill.
38. Hillier, F. S., & Lieberman, G. J. (2015). Introduction to operations research. McGraw-Hill.
39. Taha, H. A. (2017). Operations research: an introduction. Pearson Education India.
40. Saltelli, A., Tarantola, S., & Campolongo, F. (2000). Sensitivity analysis as an ingredient of modeling. Statistical science, 377-395.
41. Scott, J., & Scott, C. (2017). Drone delivery models for healthcare. Proceedings of the 50th Hawaii International Conference on System Sciences, 3297-3304.
42. Yedavalli, P., & Mooberry, J. (2019). An assessment of public perception of urban air mobility (UAM). Airbus UTM: Defining Future Skies, 2046738072-1580045281.
43. Garrow, L. A., German, B. J., & Leonard, C. E. (2021). Urban air mobility: A comprehensive review and comparative analysis with autonomous and electric ground transportation for informing future research. Transportation Research Part C: Emerging Technologies, 132, 103377. https://doi.org/10.1016/j.trc.2021.103377
44. Joint Authorities for Rulemaking of Unmanned Systems (2019). JARUS Guidelines on Specific Operations Risk Assessment (SORA). JARUS. http://jarus-rpas.org/sites/jarus-rpas.org/files/jar_doc_06_jarus_sora_v2.0.pdf