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Opportunities and Challenges of Drones and Internet of Drones in Healthcare Supply Chains under Disruption

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Abstract

This study investigates the use of drones and the Internet of Drones (IoDs) in healthcare supply chains (HSCs), highlighting the opportunities and challenges of integrating them to respond to disruptions, an area that is currently under-examined in supply chain literature. The article employed a multi-method approach. First, an integrative literature review was conducted to identify, assess, and synthesise knowledge about the application of drones and IoDs in HSCs. Next, the opportunities and challenges of using drones and IoDs were analysed by using the PESTEL Framework. Third, the SCOR model is applied to analyse the literature and propose a hierarchical process model. Lastly, the study examines how drones and IoDs can address disruptions in HSCs. Our findings reveal how drones and IoDs can potentially enhance healthcare and vaccine supply chains in response to disruptions. The study establishes important contributions. Firstly, it evaluates and integrates current research to provide new insights for dealing with HSC disruptions such as pandemics and other similar emergencies. Secondly, the PESTEL framework is used to systematically examine the existing research, revealing relevant Political, Economic, Social, Technological, Environmental, and Legal influencing factors to respond to HSCs disruptions. Thirdly, the analysis through the SCOR allowed us to develop a hierarchical process model for HSCs enabled by drones and IoDs. Fourthly, from the research findings, the paper develops a framework for a shift from people-dependent HSCs to technology-dependent HSCs under disruption. Future research directions are indicated to advance the supply chain research on this vital research topic.

Keywords – Healthcare Supply Chain; Unmanned Aerial Vehicles; Internet of Drones; COVID-19; Logistics; Drones; Supply Chain Management.

1. Introduction

Unprecedented situations such as the recent COVID-19 pandemic and geopolitical tensions have exposed several global challenges for supply chains (SCs) (Queiroz et al., 2022). Disruption propagations and uncertainties (e.g., supply and demand uncertainties, risk management, global and local sourcing, and information availability) have affected even the most well-prepared SCs (Finkenstadt & Handfield, 2021; Queiroz et al., 2022). Since the first reports of coronavirus, the pandemic has affected supply chains and regions across the globe, resulting in millions of deaths (CSSE, 2021). Developed countries like the US and UK, along with emerging economies such as India (WHO, 2021a), Turkey (Genç, 2021), and Brazil (Dall'Alba et al., 2021), have been affected by the pandemic, resulting in significant social disruptions in global, national, regional and local healthcare supply chains (HSCs). This scenario reinforces the need to revisit HSCs strategies as well as review the current and future supply chain strategies against large-scale disruptions (Flynn et al., 2021; Ivanov, 2021).

The HSCs literature advocates the promising role of disruptive technologies in minimising supply chain disruptions caused by extreme conditions and events (Choudhury et al., 2020; Zhang et al., 2021; Hoek, 2020). Consequently, recent research reveals the contributions of emerging technologies such as artificial intelligence (AI), Internet of Things (IoT), virtual reality (VR), Big Data, Blockchain, and drones for delivering medicine and food, sterilising public places, helping home care assistance, and accelerating tests in HSCs (Agarwal et al., 2020; Brem et al., 2021; Kumar et al., 2020). In the context of this study, drones or unmanned aerial vehicles (UAVs) are defined as aircraft without a pilot on board (Rejeb et al., 2023). Already, the Internet of Drones (IoDs) refers to an infrastructure that provides access to and control of multiple operating drones and their users over the Internet (Abdelmaboud, 2021).

Research on drones and IoDs in HSCs has recently evolved as an emerging research topic (Moshref-Javadi & Winkenbach, 2021). Due to the nascent stage of this research topic, the potential use of drones and IoDs for handling extreme conditions in HSCs remains unclear in the supply chain literature and offers promising opportunities to manage HSCs issues. Although some works have examined the use of drones in the context of pandemics (e.g., Agarwal et al., 2020; Kumar et al., 2021), a consistent understanding of the short-term, medium-term, and long-term opportunities and challenges of involving these technologies to deal with disruptions in HSCs is still missing. This is because the rapid pace of knowledge generation in this emerging technology makes it difficult to generalize, synthesize, and integrate findings. We aim to contribute to this debate by examining the role of disruptive technologies of drones and IoDs in HSCs. Specifically, this study focuses on identifying the main opportunities and challenges of implementing these specific technologies in HSCs to respond to disruptions. Consequently, this research is guided by the following questions:

RQ1. *What are the main opportunities and challenges of integrating drones and the Internet of Drones into HSCs?*

RQ2*. What strategies can overcome the main issues of integrating drones and the Internet of Drones into HSCs?*

More specifically, these research questions explore the opportunities and challenges concerning the delivery (e.g., pick, pack, load, ship, receive of items) and return (e.g., return and disposition of defective products or items in excess) activities in HSCs with particular attention to political, sociocultural, economic, technological, environmental, and legal factors (Dhote & Limbourg, 2020; Hill & Westbrook, 1997; Laksham, 2019). Anchored in the recent research on empirical applications of drones and IoDs, this study implements a multi-method qualitative approach to invoke future research directions for scholars, authorities, governments, and policymakers. As a result, it was possible to draw practical, theoretical, and policy contributions to accelerating the pandemic response and preparing HSCs for the future.

We anticipate that this study provides important contributions to supply chain literature and practice. Firstly, we conducted a comprehensive and integrated analysis of the extant literature, which is growing exponentially and suffers from fragmented opinions and viewpoints (Torraco, 2016). Secondly, the study critically analyzed the current literature using the PESTEL (Political, Economic, Sociological, Technological, Legal, and Environmental) framework (Dhote & Limbourg, 2020) to understand the challenges and opportunities of using drones and IoDs. Thirdly, we developed a hierarchical process model for HSCs by scrutinizing the literature through the lens of the Supply Chain Operations Reference (SCOR) model (APICS, 2012), with a focus on delivery and return activities. Fourthly, the study proposed and demonstrated the need to transition from people-dependent HSCs to technology-dependent HSCs. Then, we conducted a comparative analysis between drones and traditional road transportation systems to help managers in HSCs make informed choices about different transportation modes. Lastly, we guided OSCM scholars in future research by posing a series of research questions.

The remaining of the paper is organized as follows. Section 2 reviews relevant and recent literature on drones and IoDs in HSCs. Section 3 details the research methods and the steps of the research protocol adopted for data collection and analysis. Section 4 introduces the results and provides answers to the research questions. Section 5 presents the findings, implications, and strategies that can be explored to overcome the main challenges of integrating drones and IoDs into return and delivery activities in HSCs. The paper closes with the research conclusions, limitations, and research agenda.

2. Theoretical Background

2.1 Healthcare supply chains

Recently, we have observed that COVID-19 has exposed the underlying vulnerability of HSCs worldwide (Miller et al., 2021). Their complexity can explain one aspect of the vulnerability of HSCs. Healthcare supply chains are inherently complex mainly due to the presence of a myriad of stakeholders such as government bodies, non-government organisations, donors, aid organisations, public and private healthcare units, pharmaceuticals, medical equipment and drug suppliers and distributors (Spieske et al., 2022). Consequently, like any other supply chain, an HSC takes the shape of a network consisting of hospitals, clinics, pharmacies, corporations, and different types of intermediaries (Marques et al., 2020). As a result, the underlying exposure to disruptions in HSCs is more than that of any other type of supply chain.

Falagara Sigala et al. (2022) suggest that disruptions in HSCs due to a pandemic such as COVID-19 fall into four categories: (i) disruptions due to direct effects of outbreaks; (ii) disruptions induced by policies; (iii) disruptions induced by a pandemic such as COVID-19; and (iv) disruptions induced by supply chain strategies. They argue that the direct effects of an outbreak are workforce shortages due to disease contraction, whereas policy-induced disruptions are due to isolation and government bans. They also note examples of pandemic-induced disruptions, such as hoarding and panic buying, and supply chain strategy-induced disruptions, such as single sourcing practices and lack of risk management plans. In this regard, possible supply chain strategies to mitigate disruptions due to COVID-19 are to expedite, standardise, collaborate, and innovate (Kovács & Falagara Sigala, 2021).

The vulnerability of HSCs during COVID-19 has also been portrayed through significant shortages of critical materials such as personal protective equipment, test kits, vaccines, and ventilators during the peak of COVID-19 (Zamiela et al., 2022). According to Goodarzian et al. (2021), demand and supply situations in medical supply chain networks have historically been uncertain, which contributes to the supply shortages of critical materials and equipment. To address these issues, Spieske et al. (2022) suggest that it is essential to ensure the availability of critical materials to increase the resilience of HSCs. Key enablers for the resilience of HSCs are redundancy collaboration, robustness, agility, and sensitivity/awareness (Zamiela et al. (2022). Overall, the key message of the literature in the area claims that the inherent complexity, uncertainty, and vulnerability of HSCs call for innovative ways to manage them. Consequently, integrating drones and the internet of drones can create the required agility, sensitivity, and awareness to impart necessary resilience and robustness in HSCs.

2.2 Drones and Internet of Drones in healthcare supply chains

The recent developments of UAVs or drones and IoDs have rapidly expanded their utilization in commercial and business activities, including delivery businesses, aerial surveying firms, line inspection services, geography consulting firms, films, and engineering services (Choudhury et al., 2020; EUCHI, 2020). In parallel with these discoveries, COVID-19 has compelled the international community to include new measures that might expand the use of these disruptive technologies in social applications, particularly in removing bottlenecks in HSCs (EUCHI, 2020; Kumar et al., 2021).

For instance, Kumar et al. (2021) proposed a multi-layered IoD architecture for dealing with pandemics in real-time. The system was effective in rural and densely populated regions, where wireless and Internet access is a significant concern, and the likelihood of COVID-19 spreading is considerable. Other practical interventions in HSCs have also demonstrated the potential of drones and IoDs. The Swiss Port recently concluded 3.000 flights with quadcopter drones for healthcare services in a 20 km range with a payload of 2kg (Poljak & Šterbenc, 2020). According to Moshref-Javadi & Winkenbach (2021), the Moscow Technology Institute of Technology experimented with drones with a payload of 3 kg travelling up to 50 kilometres for transporting defibrillators. Other studies investigated drone usage in humanitarian logistics in Malawi against the immunodeficiency virus (Unicef, 2017) and in Papua New Guinea against tuberculosis (MSF, 2014). Even though these research findings are instrumental, a more comprehensive knowledge gap in research is the lack of understanding of the technological opportunities and challenges of drones and IoDs in responding to HSCs under disruption.

In line with the progression of drone technology, an interesting body of literature has emerged investigating drone-based logistics systems (Jeong et al., 2020; Zhang et al., 2021). For instance, Moshref-Javadi & Winkenbach (2021) classified the extant literature on drone-based logistics using four main operational strategies: (i) a pure-play drone-based strategy; (ii) an unsynchronized multi-modal strategy; (iii) a synchronized multi-modal strategy; and (iv) a resupply multi-modal strategy. They encourage scholars to conduct more research to understand the potential of this technology in supply chain operations. Srinivas & Marathe (2021) examined drone applications for last-mile deliveries in logistics operations. They suggest mobile trucks can be used to launch drones and fulfil orders for a set of customers. Spanaki et al. (2022) developed an AI-driven AgriTech drone swarms inspired by bird swarms to address food security in remote areas. The authors argue that drones can help address food security issues by contributing to Sustainable Development Goals (SDG) 1 (Zero hunger), SDG 12 (Responsible Production and Consumption) and SDG 15 (Life on land). Murray & Chu (2015) argued that UAVs are a new paradigm for parcel deliveries. Their research developed two mathematical programming models for scheduling and routing drones and delivery trucks. Similarly, Zhang et al. (2021) developed a cooperative truck-and-drone system to be used by emergency aid networks. Nevertheless, it is evidenced that although different scholarly works discuss traditional road transport systems and drones and IoDs, empirical cost analysis and comparison between drones and traditional road transport systems are still missing.

Beyond being utilized during pandemics, HSCs and disaster response, supply chains continue to employ drones for commercial delivery activities. Drones offer the ability to reach remote locations, lower logistics expenses, and enhance the accessibility of crucial supplies like vaccines and blood bags (Koshta et al., 2021). Early works have found that drones can reduce the delivery time and inventory costs in the blood supply chain and allow a just-in-time blood distribution system (Mora & Araujo, 2022). Burchardt & Umlauf (2023) demonstrate how Zipline’s distribution centres in Ghana supply critical materials to healthcare facilities in remote locations. In another interesting study, the adoption of medical drones in HSCs in Gana has improved the socioeconomic situation of society and decreased the mortality rate in rural areas (Damoah et al., 2021). Gupta et al. (2022) suggest a blockchain-based delivery scheme for Healthcare 5.0 Applications. They underlie that using IoDs to deliver emergency healthcare materials will require a greater focus on the security of drone operations. Collectively, these studies stress the importance of digitalisation in the HSCs. Digitalization must take into account the challenges associated with the changes required in human behavior and culture during social disruptions. However, a widely accepted supply chain framework to assist HSCs practitioners in transitioning from a system reliant on people to one more reliant on technology is still missing.

Additionally, a few recent works (e.g., Abdelmaboud, 2021; Garg et al., 2023; Rejeb et al., 2023) have reviewed applications of drones in supply chains and last-mile operations. For instance, Rejeb et al. (2023) reviewed drones for logistics and supply chain management and proposed a research agenda. The authors suggest that the potential for drones lies in using drones in humanitarian operations, reducing delivery time and cost and increasing flexibility and sustainability. Garg et al. (2023) identified that the current literature does not consider weather, flight duration and battery capacity. The authors also argue that extant literature only focuses on US-based drone operations. Already Abdelmaboud (2021) discusses the challenges, requirements, advances and taxonomy of IoDs. Although these reviews are instrumental and relevant, specific research clusters have been formed because of the rapid pace of knowledge generation in these areas.

Finally, the analysis of the literature reveals that while scholars from engineering, information, and communication technology disciplines tend to approach drones from a highly technical perspective, the research community in operations and supply chain management (OSCM) frequently explores how these technologies can benefit HSCs. This aspect indicates that the accumulated knowledge about drones and their potential applications in HSCs is fragmented, and our understanding of the topic remains unclear (Moshref-Javadi & Winkenbach, 2021). This landscape suggests that integrating and consolidating research in this area could provide valuable insights into effectively addressing disruptions in HSCs. The present research fills the gap in the literature by synthesizing diverse perspectives and opinions, offering a cohesive analysis, and outlining future directions using the PESTEL framework and SCOR model as guiding lenses. The following section delineates the PESTEL framework and the SCOR model, which are utilized to analyze the drone literature and pinpoint opportunities and challenges associated with drone adoption and implementation in HSCs.

3. Research Method

3.1 Research design

This study aims to unveil the main opportunities and challenges of drones and IoD in HSCs under disruption. Recognizing that all research methods have inherent strengths and limitations, a suggested approach to investigating OSCM problems is to adopt a multi-method research strategy, as recommended by Boyer and Swink (2008), to ensure high-quality research outcomes in the OSCM domain. In this research, a multi-method approach was implemented to ensure the trustworthiness of the research results and inferences obtained by addressing the guiding research questions. When effectively conducted, literature review studies can facilitate the development of new theories and knowledge by highlighting areas where research is needed (Garza-Reyes, 2015).

For this reason, in the first research stage, we performed a literature review to identify, assess, and synthesize knowledge from the extant literature on the use of drones and IoD technologies in HSCs. Literature reviews, as a distinct type of review study, analyze recent research and encompass a wide spectrum of topics (Grant & Booth, 2009). They may involve an extensive search process, and the analysis can follow chronological, thematic, or conceptual approaches.

The second research stage focuses on the return and delivery activities according to the SCOR reference model (APICS, 2012; Müller, 2019). We also examined relevant publications to identify the primary opportunities and challenges using the PESTEL framework. The six thematic dimensions of the PESTEL provide an integrative and systemic perspective to the research questions examined in this article. We employed an integrative approach for the third research stage to synthesize the relevant literature associated with the research questions (Torraco, 2016). The research design adopted is explained in Figure 1.

[ADD HERE **Fig.1.** Research design]

3.2 Data collection and literature review protocol

An integrative literature review was implemented to establish criticisms and synthesise relevant materials on a specific subject in an integrated manner, resulting in new perspectives and views on the subject matter (Torraco, 2016). This review method is recommended for exploring novel or emerging topics that may benefit from a comprehensive characterisation and summary of the published literature (Thomé et al., 2016).

A research protocol (Table 1) for the literature review was formulated (Jalali & Wohlin, 2012; Torraco, 2016), and a search strategy, including databases, keywords, period, eligibility/coding criteria, and inclusion and exclusion criteria, was performed. During the literature exploration, we also adopted the snowball process (Jalali & Wohlin, 2012), identifying other relevant works and a cross-reference analysis of relevant studies.

[ADD HERE **Table 1.** Research protocol]

After a rigorous full-text screening, application of the inclusion and exclusion criteria, and the elimination of duplicates, the research yielded 58 articles (Fig. 2). A content analysis of the selected papers was performed and a synthesis of the literature. This understanding contributed to the discussion and assisted in the reflections on the research implications.

[ADD HERE **Fig.2.** Flow diagram of literature review]

3.3 PESTEL framework

PESTEL is a broad and structured framework (Rengarajan, 2021) that has been widely used not only for conducting macro-environmental analyses of companies (Thakur, 2021) but also for investigating the challenges and opportunities that the deployment of modern technologies may encounter. For instance, Kaplan & Haenlein (2020) applied the PESTEL framework to examine the challenges and opportunities of artificial intelligence. Furthermore, Zhou et al. also employed the PESTEL framework to determine the challenges and opportunities for the implementation of blockchain technology in the maritime sector. Taher (2021) established the opportunities and challenges of the adoption of Industry 4.0 technology in the construction industry based on the PESTEL. Jain et al. (2023) used the PESTEL to assess the challenges and opportunities of implementing Big Data Analytics in sustainable supply chains. Similar to those studies, we applied the PESTEL framework as a structured approach to identify the primary opportunities, challenges and impact of employing drones and the IoDs in HSCs. In this context, the six thematic dimensions of the PESTEL provided an integrative and systemic perspective to address the research questions examined in this article.

In the context of the PESTEL framework, “P” refers to the political aspects, which is the degree to which government and public policies can influence drone integration. “E” refers to the economic considerations that affect many aspects of the economy and its functioning, including unemployment, raw material costs, and taxation. “S” refers to the social variables and considers various social contexts and trends as well as education, culture, and behaviour. “T” refers to the technological factors and relates to innovation and development, including digitalization, automation, R&D, manufacturing, and logistics. The other “E” refers to environmental factors that are related to climate, ecology, recycling, carbon footprint, waste disposal, and corporate social responsibility. Lastly, “L” refers to the legal factors and relates to national and international laws pertinent to HSCs (Dhote & Limbourg, 2020; Rengarajan et al., 2021).

The different aspects of the PESTEL framework can aid in the implementation of some Industry 4.0 technologies in healthcare supply chains, particularly drones and IoDs. For instance, government incentives to invest in such technologies can contribute to minimising the obstacles to their adoption (Turk, 2023). Moreover, the push for decarbonization and sustainability within the industry can help to reduce environmental emissions, making it easier to incorporate drones and IoDs within HSCs, as observed by Jha et al. (2024). Additionally, regulations that are favourable towards these technologies can further facilitate their integration into healthcare supply chains (Ryan et al., 2020).

3.4 The SCOR model

The Supply Chain Council developed the SCOR model, which is a tool for measuring supply chain performance. The SCOR model entails five processes, including plan, source, make, deliver, and return (Liu et al., 2014). The planning process involves collecting and gathering information about resources. The sourcing process includes procuring those resources, scheduling for delivery, and receipts of order resources. The making process relates to the conversion of resources into products and services. The delivery process in the model involves the fulfilment of customer orders by picking the correct order, packing and sending it to the right customer. Lastly, the return process entails reversing the flow of goods from customers (Georgise et al., 2017). In this paper, we only focus on the return and delivery activities of the SCOR model because of the subject matter in concern, i.e., applications of drones and IoDs in HSCs.

Version 12 of SCOR recognizes the significance of digitalizing supply chains by embracing Industry 4.0 technologies to accommodate shifts in supply chain business practices, including Additive Manufacturing and the IoT (APICS, 2017). The proposals of Industry 4.0 and Supply Chain 4.0 are synergically interconnected (Srhir et al., 2023). For example, within the delivery process outlined by SCOR, the Supply Chain 4.0 concept advances data transparency by facilitating real-time data flow (Srhir et al., 2023). This capacity suggests that leveraging drones and IoDs can enhance the delivery of real-time information to both suppliers and customers. Additionally, autonomous vehicles like drones can enhance delivery efficiency while reducing the environmental impact (Figliozzi, 2020). Industry 4.0 technologies can also reduce logistics costs and minimize waste in the logistics process (Ferrantino & Koten, 2019). Industry 4.0 technologies can also enable closed-loop supply chains by enhancing the return process (Toth-Peter et al., 2023). Moreover, Industry 4.0 technologies, such as drones and IoDs, can facilitate returns for maintenance and repair purposes (Kamble et al., 2020).

Similar to the PESTEL framework, the SCOR model has been widely used to analyse supply chains (Thunberg & Persson, 2014). For instance, Chehbi-Gamoura et al. (2020) applied the SCOR model to gain insights from big data analytics in the supply chain. Finkenstadt & Handfield (2021) utilised the SCOR model to identify major gaps in the COVID-19 vaccine supply chain. The rationale for using the SCOR model in this paper is twofold. First, it enables a structured evaluation and comparison of HS's activities, such as process types, process categories, process hierarchies and process metrics from a logical perspective. Second, the SCOR model is the dominant reference model in the literature for innovative research on SC problems (Ebrahimi et al., 2021).

3.5 Data analysis

The collected data underwent analysis in three primary stages. The first stage included a content analysis of the PESTEL categories in the selected studies. The central information blocks retrieved from each chosen publication were grouped into a compressive spreadsheet, after which the research team conducted a cross-analysis to uncover convergences and complementarities between the results in the PESTEL dimensions. Next, researchers performed a causal analysis to identify patterns and associations. This integrative process revealed unique insights for HSCs by exploring and interrogating the existing literature through critical perspectives. Finally, we consolidated the findings, concentrating on the significant opportunities and challenges of integrating drones into HSCs in return and delivery operations. Following the SCOR model definition (APICS, 2012) for return and delivery, we analysed the studies considering the processes for delivery and return activities, such as dispatch, transport, and packaging.

We critically reviewed the synthesised information during the second round of data analysis. The research team performed a new content analysis to identify the strategies for integrating drones and IoD into HSCs in return and delivery operations. As a result, it was possible to extract the key contributions and information from the selected publications that address how to reduce the significant challenges and inconsistencies barring the deployment of drones and IoD in return and delivery activities of HSCs under disruptions. The findings and knowledge generated are discussed and synthesised in the following section.

4. Findings

In this section, at first, the primary insights from the literature were organized into six relevant thematic categories, namely political, economic, socio-cultural, technical, environmental, and legal aspects. Next, a hierarchical process model is developed using the SCOR framework, concentrating on delivery and return processes. Lastly, a cost comparison is given between a drone-based and a traditional transportation system in order to specify the economic feasibility of using drones in HSCs.

4.1 Political dimension

During the recent pandemic, we have experienced governments using drones as surveillance tools to monitor the lockdown status. For instance, drones equipped with IoD-connected surveillance devices in India helped the police monitor sensitive areas in cities. Similarly, drones were used in China to survey areas, observe crowds, and announce the Chinese government’s guidelines to ensure compliance with public preventive measures to combat the pandemic (Chamola et al., 2020). Furthermore, equipped with thermal sensors and cameras, drones were also used to monitor disease and track high-risk patients (Abdel-Basset et al., 2021; Agarwal et al., 2020). Kumar et al. (2021) demonstrated the usefulness of a real-time drone-based networked system for pandemic sanitation, thermal imaging, and record-keeping processes in India. An IoT-assisted drone solution was proposed to improve the safety of medical personnel and rehabilitate infected patients (Angurala et al., 2020).

The literature shows that although drones offer effective control mechanisms for governments, they also pose threats of being hacked by individuals with disruptive mindsets who can weaponize drones for criminal activities such as terror attacks (Ayamga et al., 2021; Yaacoub et al., 2020). Moreover, the Ukraine war shows the game-changing effect of drones in military operations (Kunertova, 2023). Drones can also fly in urban and suburban areas and invade people's privacy (Boccadoro et al., 2021). The extant literature reveals that the regulations for flying commercial drones vary considerably from country to country. In the United States, the principal regulatory authority is the Federal Aviation Administration (FAA), and in Europe, it is the European Aviation Safety Agency (EASA) (Ilker, 2015). Different regulations between countries may impose barriers to using drones during a health emergency such as the COVID-19 pandemic.

Furthermore, we observed that certain countries (e.g., Bhutan, Madagascar, and Saudi Arabia) did not have any regulations for drone flights in place until the time of this research's development. The absence of airspace regulations and unmanned traffic management (UTM) for drones (Decker & Chiambaretto, 2022) in underdeveloped economies may pose operational and safety challenges in delivering urgent medical supplies and vaccines. Finally, drone flights can also create safety risks for manned aviation, such as helicopters. In line with the PESTEL analysis objective of identifying opportunities and challenges to enhance decision-making, the main political aspects identified can be summarized as follows:

Opportunities:

a) **Public health surveillance and monitoring:** Drones with IoT and sensors adoption to monitor lockdowns and track disease spread.

b) **Pandemic sanitation and record-keeping:** Drone systems can effectively manage sanitation, thermal imaging, and record-keeping.

c) **Improved safety of medical personnel:** IoT-assisted drones can reduce medical personnel exposure while delivering medical supplies.

d) **Effective control mechanisms for governments:** Drones can enhance real-time governmental surveillance and compliance with health measures.

e) **Global adoption potential:** Regulations in the U.S. and EU facilitate a broader drones adoption globally in different supply chains, including HSCs.

Challenges:

a) **Security risks and hacking:** Drones' vulnerability to hacking raises safety concerns and risks.

b) **Privacy invasion:** Drones raise privacy concerns, posing ethical and legal challenges.

c) **Regulatory inconsistencies:** Heterogeneous drones regulations hinder rapid emergency deployment during health crises.

d) **Absence of regulations in developing countries:** Lack of drone standardised regulations creates operational challenges for medical deliveries especially in less industrialized nations.

e) **Safety risks for manned aviation:** Drone flights increase accident risks for manned aviation without management.

f) **Operational challenges in underdeveloped economies:** Lack of airspace regulations hinders safe drone healthcare delivery operations.

g) **Impact on military operations:** Drones' military use can complicate regulations for peaceful applications (e.g., the Ukraine war).

Overall, the evidence from the literature suggests that while national and international policies have been adopted in the United States and the EU, there is still a long way to go to demonstrate the attainment of drones and IoD systems globally, given the safety and security challenges for manned aviation, critical infrastructure, and general mass (Merkert & Bushell, 2020).

4.2 Economics dimension

Empirical evidence from the literature asserts that drones hold significant economic potential for delivering emergency medical supplies. Poljak & Šterbenc (2020) indicated that within the next five years, the need to reduce traditional transportation costs as well as increase timeliness and delivery efficiency would foster the adoption of drones in HSCs. Similarly, the former Director-General of WHO, Margaret Chan, agrees that using drones to deliver emergency medical products can overcome infrastructural challenges (Laksham, 2019). Jeong et al. (2020) examined the humanitarian logistic warehouse that uses drones to deliver health supplies to hard-to-reach regions timely and safely. Furthermore, drones can be used for small shipments instead of human labour (Dhote & Limbourg, 2020).

Moshref-Javadi & Winkenbach (2021) claimed that apart from increasing travel velocity and removing infrastructural barriers, drones improve the responsiveness of healthcare systems. The same authors further argue that medical products have restricted size and weight coupled with urgency and delivery value. Hence, the literature collectively underscores that employing drones and IoDs has the potential to enhance life-saving strategies during emergencies in HSCs. One primary reason is that drones possess the capability to rapidly deliver small payloads to virtually any location, as highlighted by Chen et al. (2021).

In most applications, a network of connected drones, IoDs or drones integrated with IoT was used to enhance system capabilities (Chamola et al., 2020). For example, drones are already incorporated into the medical delivery system of Africa to simultaneously reduce response time and increase the efficiency of medical services (Ayamga et al., 2021). In this context, existing literature suggests that drones, when integrated with IoT network peripherals such as smart devices, can effectively enhance the agility of HSCs systems during pandemic scenarios. Moreover, the IoT-empowered systems that have been developed can enable distant clinical care and remote monitoring of patients. Furthermore, once the capital cost of installing and maintaining the system is paid off, drones can increase vaccine availability and, at the same time, decrease total supply chain costs (Haidari et al., 2016).

However, on the downside, the literature indicates that pandemics could pose a threat to the infrastructure investment necessary for the widespread implementation and adoption of drone technologies (MSCI, 2020). Moreover, drones can create a digital divide when small delivery start-ups may not be able to fight giant companies like Amazon (Barnes, 2020). In some extreme cases, the number of delivery employees in the supply chain may also be reduced when the industry adopts technology-intensive delivery solutions (Brem et al., 2021). Similarly, Ayamga et al. (2021) add that a possible negative aspect is the incidence of unemployment among delivery personnel who deliver using the road network. On a positive note, the authors suggest that training these workers to provide healthcare emergency supplies could create a new category of specialised workers.

In terms of the operating costs for drones in SCs, D'Andrea (2014) estimated an operating cost of 1 cent per kilometre to deliver a payload of 2 kg. The total delivery cost per kilometre is expected to increase if capital costs, maintenance costs, insurance and liability costs, and airspace access fees are further added. A recent study found that using drones to deliver vaccines saves up to \$0.21 per dose compared to conventional delivery. These results indicate that drones can help increase vaccine availability at a competitive cost, thus compensating for overhead expenses due to capital and maintenance costs for drones (Enayati et al., 2023; Griffith et al., 2023). According to Johns Hopkins (2016), autonomous vehicles have the potential to decrease supply chain costs through different means, including reducing overall shipping expenses, lowering accident rates and associated liabilities, cutting driver wages, and minimizing fuel consumption and greenhouse gas emissions. Griffith et al. (2023) argue that drones reduce costs because they can access remote regions, reduce labour costs, and replace vehicle fleets that have high fuel costs.

Our results also show that the lack of access to medical supplies due to limited, unreliable, or poor road infrastructure has driven several companies to offer commercial medical drone services worldwide (Scott & Scott, 2020) (see Appendix A). The literature recognizes Zipline, a California-based company, as a case study of using drones in the medical supply chain. The application offers commercial drone services for on-demand, instant delivery of medical supplies in Rwanda (Ackerman & Koziol, 2019; Ackerman & Strickland, 2018). In an overall estimate, the EU Drone Outlook Study from the Single European Sky Air Traffic Management Research forecasts that the last-mile delivery of lightweight goods is expected to create an economic impact of €2.9 billion by 2050 in Europe. The expected economic impact across the value chain of drone products is around €700 million, and drone services are about €1.4 billion (SESAR, 2016). Based on the literature, the opportunities and challenges related to the economic dimension can be summarized as follows:

Opportunities:

a) **Cost Reduction in HSCs:** Drones lower transportation costs and enhance efficiency in remote deliveries.
b) **Addressing infrastructure barriers:** Drones can bypass unreliable infrastructure, aiding medical delivery in difficult terrains.
c) **Improved responsiveness in HSCs:** Drones enhance healthcare responsiveness, rapidly delivering supplies during crises.
d) **Enhanced system agility:** Drones and IoT integration boost agility for rapid response scenarios.
e) **Economic growth potential:** The economic growth potential of this technology can be illustrated by the EU forecasting of €2.9 billion in economic growth from drone delivery services by 2050.

f) **Environmental and cost efficiency:** Drones reduce supply chain environmental impact by lowering shipping and fuel expenses.

g) **New job opportunities:** Training displaced workers in drone operations creates specialized jobs.

h) **Competitive vaccine delivery:** Drones enhance vaccines delivery, increasing availability and reducing costs in HSCs.

Challenges:

a) **High capital and maintenance costs:** Initial drone infrastructure costs hinder widespread adoption, especially in resource-limited areas.

b) **Unemployment and job displacement:** Drones delivery may reduce traditional jobs in logistics deliveries, raising unemployment concerns.

c) **Digital divide and market dominance:** Smaller companies may struggle against large corporations in drone delivery.

d) **Safety and liability issues:** Operating costs may rise from liability, insurance, and access fees.

e) **Infrastructure investment risks:** Pandemics and other crises can hinder infrastructure investments needed for drone implementation.

f) **Regulatory and airspace challenges:** Varying regulations and airspace management complicate drone operations globally.

g) **Potential workforce reduction in traditional supply chains:** Advancing drone technology may reduce traditional supply chain manual labor roles (e.g., last-mile deliveries).

4.3 Social dimension

From a societal perspective, medical drone services are becoming a game-changer in saving lives by transporting blood and urgent medical supplies quickly and efficiently (Ackerman & Koziol, 2019; Ackerman & Strickland, 2018; Mora & Araujo, 2022). In pandemic situations, drones can help reduce the spread of the virus by enabling delivery staff to maintain the need for social distancing (Skorup & Haaland, 2020). In a similar tone, EUCHI (2020) stated that drones enable HSCs to decrease the need for human contact and thus lower the danger of contamination. He also argued that drones could assist home care facilities and avoid the need to mobilize health personnel in multiple locations for multiple tasks, reducing virus exposure.

In addition, drones can handle emergencies, such as delivering urgent clinical samples; in fact, experiments in Germany have indicated that drones can deliver 8 to 12 times faster and are pollution-free (Kallgren, 2020). Empirical studies in Madagascar, Malawi, Senegal, and other African regions (Knoblauch et al., 2019; Nyaaba & Ayamga, 2021) also indicated the contributions of drones in strengthening healthcare facilities in regions facing pandemic disruptions.

Our findings suggest that drones employed for medical services systems can promote a better image and social acceptance. Bailey & Breslin (2021) concluded that drones could relieve pressure on stressed healthcare workers by minimizing their exposure to the virus or new variants. In addition, the extant literature provides evidence of positive results from using drones to transport medical supplies (Dubin et al., 2020; Mora & Araujo, 2022). Drones can also be efficient in terms of costs and time for mass monitoring and controlling, sterilizing, and distributing medical supplies, diagnostics, testing kits, and COVID-19 vaccines in remote regions (Kumar et al., 2021; Kumar et al., 2020). The same rationale is valid for quarantine areas and places of difficult access, such as favelas, refugee camps, and indigenous tribe areas. However, it seems that drones still face challenges in establishing a positive reputation for providing medical services, mainly due to concerns surrounding privacy and safety.

The literature evidence that drones can also protect vulnerable groups of people who must isolate themselves in quarantine and, therefore, cannot leave their homes to buy food or medicine due to isolation rules (Poljak & Šterbenc, 2020). The literature also suggests that drones can help remotely treat patients with typical cold and flu symptoms to avoid contact with medical personnel or infected COVID-19 patients (Abdel-Basset et al., 2021). Chen et al. (2021) concluded that the first and last miles and rural deliveries are the most promising aspects of drones. Aligned with these HSCs strategies, drones and IoD, along with other disruptive technologies such as Big Data, can be used to identify individuals who have not taken the first vaccine dose or for whom the second dose is pending. Multi-UAV networks and IoD also play a critical role in disaster management (Saif et al., 2021). In this case, using multiple drones enables the operations of search and rescue collaboration models for administering large disaster-affected areas efficiently and effectively.

The results also indicate that while drones and IoD present several social opportunities, there are concerns about the apparent resistance against the mainstream adoption of these devices in other areas and sectors of the economy. Haidari et al. (2016) affirm that the perception of drones for use in medical product deliveries may restrict the long-term viability of the technology's potential for amplified use. In addition, high technical skills may be required to perform co-related tasks using drone operations in SCs (Poljak & Šterbenc, 2020). Moreover, delivery in crowded cities can be dangerous (Kumar et al., 2020). He, Zhang, & Li (2021) warn that there is a need to gain public trust in drones that require sharing personal and private data (e.g., location and delivery address). Therefore, the main opportunities and challenges associated with the social aspects can be synthesized as follows:

Opportunities:

a) **Rapid and efficient delivery of medical supplies:** Drones enable rapid, eco-friendly delivery of critical medical supplies, saving lives.
b) **Reduced human contact and virus exposure:** Drones minimize human contact in healthcare systems, reducing virus transmission during pandemics.
c) **Enhanced access to remote and high-risk areas:** Drones facilitate deliveries to remote areas, providing essential pandemic supplies effectively.
d) **Support for quarantine and positive impact on healthcare workers:** Drones deliver food and medicine to quarantined individuals, minimizing virus exposure. They reduce healthcare workers' exposure to diseases, improving their working conditions.
e) **Disaster management and search and rescue:** Multi-UAV networks enhance search and rescue efficiency during large-scale disasters.
f) **Support for vaccination campaigns:** The integration of drones, Big Data, and IoT track vaccinations contributes to enhancing public health monitoring.
g) **Social acceptance and public image:** Drones adoption for life-saving services enhances social acceptance and public image.

Challenges:

a) **Privacy and safety concerns:** Drones and IoD raise privacy concerns, risking public distrust and safety issues.
b) **Technical skill requirements:** High technical skills for drone and IoD operations may hinder widespread adoption.
c) **Resistance to mainstream adoption:** Societal resistance may limit drones adoption in non-healthcare sectors.
d) **Reputation challenges**: Drones' medical service potential is hindered by privacy and safety concerns.

e) **Risk in crowded areas:** Urban drones operations pose accident risks, hindering services expansion.
f) **Economic disruption and public trust issues:** Drones may cause delivery job losses and erode public trust through data mishandling.

4.4 Technological dimension

The findings show that in order to unlock the potential of drones and IoD for adoption in private and public HSCs, a technological framework is required for more safe, secure and scalable drone operations beyond visual line of sight (BVLOS) in various dynamic environments (e.g., rural and dense urban areas). This framework, enabling drones and IoD technologies and systems, includes, but is not limited to, the principal elements and infrastructure discussed in the section below (Nouacer et al., 2020).

4.4.1 Obstacle detection and avoidance

Drone flying in low-level airspace poses risks of collision with manned aircraft (e.g., helicopters) and physical infrastructures (e.g., power lines and buildings). Existing technologies and systems, such as the Traffic Alert and Collision Avoidance System (TCAS), Automatic Dependent Surveillance-Broadcast (ADS-B), Synthetic Aperture Radar (SAR), and Light Detection and Ranging (LIDAR) have the potential to mitigate the risk of collisions. The trade-off, however, is that deploying these systems for UAVs is limited by power, payload, weight, and size (Yu & Zhang, 2015).

4.4.2 Reliable communication

It is critical to enable and support reliable communication among unmanned aircraft systems operating in the shared airspace with manned air traffic management (ATM) systems to ensure the operational safety and security of drones and IoDs. Terrestrial cellular networks, such as long-term evolution (LTE), a wireless broadband communication standard for mobile phones and data terminals, offer a feasible solution for leveraging the existing network infrastructure to enable UAV communication. However, the biggest challenge is that cellular networks are unsuitable for aerial coverage because existing base stations are designed and optimized for operating terrestrial user equipment (Nguyen et al., 2018).

Another communication technology impacting drones and IoD applications in supply chains is the 5G technology network. 5G technology will improve the capabilities of enhancing drone-to-ground control systems communication, as well as drone-to-drone and drone-to-air traffic management system communication. 5G networks will help improve drone ecosystems' effectiveness beyond the visual line-of-sight range (Yang et al., 2018). Previous research suggested that 5G networks have significantly improved the technical capabilities and specifications of drone ecosystems to provide seamless coverage and connectivity of drones and IoD in several environments, including healthcare systems (Chamola et al., 2020; Ullah et al., 2019; Yang et al., 2018).

4.4.3 Cybersecurity

Our results also suggest that drones and IoDs are vulnerable to malicious attacks on communication and positioning systems, posing a risk to the safety and security of people and critical infrastructure (Yaacoub et al., 2020). The lack of communication and data exchange security standards in drones and IoD systems could lead to privacy and security attacks, leading to breaches of identity, location, and sensitive data (Choudhury et al., 2020; Lin et al., 2018). The International Civil Aviation Organization (ICAO), responsible for developing policies and standards for international civil aviation, stresses the need for a robust security framework to address malicious attacks on disrupting communication between unmanned aircraft systems and the Global Navigation Satellite System (GNSS) (ICAO, 2020).

4.4.4 Operational reliability of drones

Drones' operational reliability has been evidenced in empirical logistics systems. Zipline and Matternet demonstrated reliable operations of drones contributing to the resilience of HSCs by overcoming barriers due to poor road infrastructure and challenges due to road-traffic conditions to ensure the delivery of critical medical supplies, blood, and vaccines (Ackerman & Strickland, 2018; Ling & Draghic, 2019). Zipline medical delivery drones, referred to as Zips, minimize the impact of mechanical failures using redundant motors and ailerons to help maintain drone flight in the event of a mechanical failure. In an inevitable emergency, when Zips cannot return to the nest due to high crosswinds or mechanical failure, it autonomously deploys a parachute to safely bring itself to the ground. Emergency parachute deployment occurs on one in a thousand drone flights, according to the estimates from Zipline (Ackerman & Koziol, 2019). However, future drone solutions for HSCs may need to incorporate fault-tolerant control systems (Fourlas & Karras, 2021; Mirk et al., 2016) and failsafe systems (Tofterup & Jensen, 2019) to mitigate drone failures and further enhance drone reliability.

4.4.5 Unmanned traffic management

Unmanned traffic management (UTM) is key to enabling scalable commercial drone operations to deliver vaccines and urgent medical supplies in all user environments, from remote and rural to dense urban areas. The ICAO envisions UTM systems as a subset of air traffic management systems aimed at safe, efficient, and economic unmanned aircraft systems operations management that provides collaborative integration of humans, information, technology, facilities, and services (ICAO, 2020). The future UTM system architecture (CORUS, 2019; FAA, 2021) represents a complex system of systems, which comprises various stakeholders, technologies and systems that shall operate coherently, according to standards and regulations, to support the operations of unmanned aircraft between themselves as well as between unmanned and manned aircraft in a safe, secure, and seamless manner.

The literature suggests that, over the past few years, significant efforts have been devoted under the FAA UTM Pilot Program (Aweiss et al., 2018) and SESAR JU U-Space innovation projects (SESAR, 2020) for the development, testing and validation of requirements, technologies, and systems for UTM. In addition to ongoing developments, tests and validation activities, considerable research and development efforts are required for the progressive convergence of ATM and UTM systems to enable all kinds of airspace users to benefit from different services (Emanuilov, 2018), including common collaborative decision-making processes and standard altitude reference system (SESAR, 2020). However, these recent developments would also require the establishment of roles, responsibilities, and liabilities among UTM/ATM stakeholders supported by regulations.

Additionally, the large-scale integration of drones in the airspace involves, among others, dynamic planning and allocation of trajectories, conflict resolution, airspace situation awareness, capacity management and dimensioning (Doole et al., 2018). To manage a high volume of drone traffic safely and efficiently within the airspace, onboard UAV system functions and UTM technical systems should incorporate a higher level of autonomy to reduce and/or minimize interactions between UAV and UTM systems. In this regard, AI and ML techniques play a central role in developing autonomy within the systems in the air and on the ground (EASA, 2020; Kistan et al., 2018). This potential to improve autonomy, on the one hand, requires further research efforts to develop novel AI and machine learning models for aviation and ensure the trustworthiness of models and methods (EASA, 2020). On the other hand, AI and ML require considerable flight data to train the models and establish performance requirements (SESAR, 2020). Together, these studies indicate that for the standardization to be globally harmonized, close collaboration and engagement among international stakeholders, including ICAO, should occur globally. In summary, the key opportunities and challenges related to the technological dimension can be synthesized as follows:

Opportunities:

a) **Obstacle detection and avoidance:** Technologies like TCAS and LIDAR enhance drones safety in low-level airspace.
b) **Reliable communication**: 5G networks enhance drones and IoD communication, improving efficiency in HSCs.
c) **Operational reliability:** Drones ensure timely delivery of medical supplies, enhancing reliability with future solutions.
d) **Unmanned traffic management:** UTM systems enable safe drone operations, ensuring efficient HSCs integration.
e) **AI and ML for autonomy:** AI and ML enable UTM and UAV autonomy, minimizing human intervention.
f) **Cybersecurity measures:** ICAO and global organizations stress robust security frameworks for safe drone operations in HSCs.
g) **Positive integration in HSCs:** Drones enhance healthcare reliability, reducing response times and delivering supplies to remote areas.

Challenges:

a) **Obstacle detection and avoidance trade-offs:** Technologies like LIDAR and TCAS face technological limitations due to UAV power and size constraints.
b) **Challenges in communication:** Terrestrial LTE networks limit effective drone communication due to terrestrial optimization.
c) **Cybersecurity vulnerabilities:** Drones and IoDs face cyberattack risks, threatening identity and sensitive data security.
d) **Failures and mechanical issues:** Despite advancements, mechanical failures in drones can compromise reliability and safety.
e) **UTM and ATM convergence:** Large-scale drones adoption requires integrated UTM and ATM systems with advanced automation.
f) **High dependency on AI and ML for UTM:** Training AI models for UTM is challenging due to the need for extensive flight data.

g) **Regulatory and stakeholder coordination:** Global harmonization of UTM standards may hinder large-scale drone integration.

4.5 Environmental dimension

The findings of this study suggest that environmentally, drones are beneficial for first and last-mile deliveries because they can reduce the negative impacts of pollution or road congestion (Dhote & Limbourg, 2020). As a result, heavily populated urban areas with lots of traffic will benefit from drones and IoDs that can replace traditional road transportation systems (Moshref-Javadi & Winkenbach, 2021). In addition, studies have demonstrated that the transportation industry accounts for 20% of the total gas emissions contributing to global warming. Therefore, using drones to substitute truck routes can decarbonise the transportation industry and reduce total greenhouse gas emissions (Dhote & Limbourg, 2020; EUCHI, 2020; Khorasani et al., 2022). Similarly, drones can access remote areas, reducing the need to travel by car or truck.

Furthermore, aerial drones can efficiently and effectively facilitate medical personnel's task performance without getting close to infected patients (Ayamga et al., 2021). Technologies like AI, for example, can be used to address the sustainability challenges and development of medical drones in HSCs (Damoah et al., 2021). Battery-powered drones are only considered CO2-neutral if the batteries are charged with renewable energy sources. The average amount of CO2 emitted at power generation facilities to meet the energy consumption of drones needs to be considered when evaluating the environmental impact of drone-based delivery models (Goodchild & Toy, 2018).

While drones can provide multiple environmental benefits, the ability to fly in all weather conditions is still challenging (Dhote & Limbourg, 2020; EUCHI, 2020). In this regard, factors such as air temperature, wind speed, and precipitation could affect drone flight's endurance, airframe integrity, and aerodynamics (Gao et al., 2021). Furthermore, drone flight in very low-level airspace can be a source of noise pollution, which may impact its wider public acceptance in urban areas (EUCHI, 2020; Schäffer et al., 2021). In conclusion, the key opportunities and challenges related to the environmental dimension can be summarized as follows:

Opportunities:

a) **Reduction of pollution and congestion**: Drones minimize pollution and traffic congestion in urban areas.

b) **Decarbonization of transportation**: Drones can help to decarbonize logisitics transportation, reducing greenhouse gas emissions.
c) **Access to remote areas**: Drones enhance delivery efficiency by accessing remote areas that conventional vehicles cannot.
d) **Infection prevention in medical tasks**: Drones enable medical tasks without close contact, enhancing safety during sanitary crises.
e) **Sustainability through AI**: AI can enhance sustainability and advance drone applications in HSCs.
f) **CO2-neutral drones**: Battery-powered drones can be CO_2-neutral with renewable energy, promoting sustainability in HSCs and delivery systems.

Challenges:

a) **Weather-related challenges**: Drones encounter operational challenges in adverse weather, impacting flight performance and safety.
b) **Noise pollution**: Drones in low airspace create noise pollution, affecting public acceptance in urban areas.
c) **CO_2 emissions from non-renewable energy**: Battery-powered drones lose environmental benefits if charged with non-renewable energy.

4.6 Legal aspects

The legal framework for commercial drone operations represents a complex matter of policies and legislation. As it is now, there is a lack of a comprehensive legal framework regarding legal liability, obligations, roles, and responsibilities for forming an integrated UTM system (Ryan, Al-Rubaye, Braithwaite, & Panagiotakopoulos, 2020). This lack is a significant barrier to the wider use of drones for commercial purposes in SCs. The other barriers include technological advancement and the associated economic growth that the drone industry can potentially offer (Bassi, 2019).

Moreover, to effectively combat pandemics, drones must operate BVLOS and fly over people. However, the operation of drones BVLOS and over people are not allowed under US federal regulations. Such rules restrict the effective and broader use of drones. As a first step towards the incremental integration of drones into the National Airspace System, companies have been granted permission to operate BVLOS (FAA, 2017). The FAA recently permitted drone operations over people (FAA, 2021). The European Commission regulations for drones also permitted drones to be flown BVLOS subject to the approval of Specific Operations Risk

Assessment (SORA) by the competent authority (EASA, 2021). The main opportunities and challenges found associated with the legislation aspects can be summarised as follows:

Opportunities:

a) **Incremental integration of drones**: FAA permits BVLOS and over-people drones operations, enabling wider supply chain use.
b) **European regulatory flexibility**: European regulations enable BVLOS drones operations, promoting flexibility and innovation in supply chains.
c) **Economic growth potential**: The drone industry presents technological advancements and economic growth potential.

Challenges:

a) **Lack of comprehensive international legal framework**: Lack of a cohesive legal framework hinders drone operations in supply chains more extensively.
b) **Regulatory restrictions**: US regulations, for example, restrict BVLOS and over-people operations, limiting drone effectiveness.

4.7 Developing a hierarchical process model: A SCOR perspective

We also examined the related literature using the SCOR framework to analyse the relevant information. Table 2 presents the results of that analysis in the form of a hierarchical process model for HSCs enabled by drones and IoDs.

[ADD HERE **Table 2.** Key points of analysis of literature based on the PESTEL framework.]

As depicted in Table 3, the focus is on the delivery and return processes of the SCOR model. The delivery process categories are delivering vaccines or other emergency supplies, whereas return is the return of defective or excess supplies and medical devices.

[ADD HERE **Table 3.** Hierarchical process model for HSCs enabled by drones and IoDs.]

The literature suggests that a number of HSCs activities can be performed using drones and IoDs, including monitoring and surveillance of emergency goods, tracking and tracing packages and temperatures, and delivering emergency goods to remote locations. Drones have already been successfully used for surveillance operations in India and China (Chamola et al., 2020). Furthermore, the drone delivery of blood, as well as vaccines in remote regions, have also been tested out (Ackerman & Koziol, 2019; Ackerman & Strickland, 2018; Griffith et al., 2023). Consequently, it is observed that drones can be effective in emergency medical situations in HSCs for delivery and return activities.

4.8 Comparing drones with the traditional road channels of transportation

Systems involving drones and IoDs in HSCs can potentially offer benefits over on-road traditional transportation channels like trucks. In a recent study, Nguyen et al. (2022) provided a detailed quantitative analysis that compares key parameters for the logistic operations (e.g., speed, payload capacity and cost per km) between drones and the traditional mode through trucks. Some of the critical parameters they have used based on the data reported in the literature are provided in Table 4.

[ADD HERE **Table 4.** Parameters used for trucks and drones.]

Using the data from Figure 3, we can empirically analyse a medical package delivery from destination A (hospital/medical infrastructure) to destination B (requesting medical supply). Assuming that the drone has an endurance of 0.6 hours (Nguyen et al., 2022), the maximum distance it can travel is 24km (0.6 x 40 km). In this analysis, we assume the Euclidean distance between destinations A and B to be 20 km. We can consider three typical scenarios of a medical package delivery: (i) ideal shortest-distance routes, (ii) medium-distance routes, and (iii) long-distance routes. In practical applications in HSCs systems, it is possible to identify all these three types of situations depending upon the regions in which the destinations are located. For example, less populated areas may have an ideal short- or medium-distance route, whereas densely populated urban areas may have long-distance routes (Fig. 3).

[ADD HERE **Fig. 3.** Different truck routes and Euclidean distance between destinations A and B.]

In this case of the medical package delivery, the distance covered by the drones will always be equal to the Euclidean distance, assuming that there are no obstacles at the height at which the drone is flying between destination A and B. In contrast, the distances covered by the truck will be different in the three scenarios analysed. We calculated the cost for each of the three cases according to results from Nguyen et al. (2022), which are presented in Table 5.

[ADD HERE **Table 5.** Quantitative analysis of the performance of trucks and drones in different types of routes.]

The variables speed and cost and the corresponding payload capacities are also considered in the above analysis. The three different routes were taken based on a typical medical aid set-up to show the relative costs and time taken. It is also considered that the drones can directly travel the Euclidean distance between the destinations with very few or no obstacles in the line of sight, whereas the truck has to take the road route to reach destinations A and B. Therefore, from the quantitative analysis presented in Table 5, it is evident that drones can assist HSC systems in delivering medical equipment faster than trucks on the road, although at an increased cost. Even though the percentage increase in cost for drones is significant compared to trucks, the absolute value of $25 may represent a cost-effective measure for emergency situations such as pandemics.

The above analysis demonstrates that drones are an acceptable option because medical services are time-critical, and using drones can save significant time in HSCs. This proposition is in line with the findings by Samaras & Stolaroff (2018). These authors argue that delivering a small package over short distances by drones was more energy-efficient (0.42 kg of greenhouse gas emissions per small package) than truck deliveries (0.92kg of greenhouse gas emissions per small package). Furthermore, in some circumstances, using a combination of both trucks and drones may also provide optimized final solutions for SCs (Goodchild & Toy, 2018).

5. Discussions and implications

This research identifies opportunities and challenges for integrating disruptive drones and IoD technologies to improve HCSs, focusing on return and delivery activities. Our research findings contribute to the theory and practice of the supply chain discipline and drone-based logistics systems by evaluating and integrating extant research to capture novel insights for dealing with pandemics and other similar emergencies. The main insights and implications are as follows. First, based on the PESTEL framework, we scrutinise the drone and IoD literature and reveal theoretical and practical insights into healthcare processes, activities, and performance. Our findings suggest that while some authoritarian governments worldwide have used drones as a control mechanism, they can pose a severe threat to individual privacy (Boccadoro et al., 2021).

Moreover, the recent geopolitical tensions (e.g., the Russia-Ukraine war) demonstrated that drones could be used as airpower or ammunition in the context of war supply chains, which is again a threat to the sovereignty of countries (Kunertova, 2023). Our results also reveal that drones and IoDs have the potential to reduce maintenance and capital costs as well as increase vaccine availability in the HSCs (Enayati et al., 2023; Griffith et al., 2023; Johns Hopkins, 2016). Our analysis shows that although drones and IoDs positively impact combatting the COVID-19 pandemic, on the social aspect, drones are still frowned upon (Kumar et al., 2020).

The technological dimension of the PESTEL framework was the most eye-opening. For instance, we discover that there are connectivity challenges in remote locations such as mountains, seas, and deserts, where terrestrial networks are not deployed or there is insufficient coverage. In such situations, a satellite communication link can also be considered to enable UAV and IoD communications (Hosseini et al., 2019). Furthermore, mitigating cybersecurity threats, such as spoofing and jamming, plays a vital role in the broader use of drones for commercial applications and HSCs. As a result, security frameworks for the management, communication, and authentication of drones and IoDs need to be established, which requires further research (Boccadoro et al., 2021).

The research also discovered that no formalized standards establish operational reliability requirements for commercial drones (Schenkelberg, 2016). This implies that UTM systems' development, maturation, and standardization are expected to play a significant role in defining and establishing drone reliability and performance requirements for airspace operation. Equally imperative is the role of stakeholders and organizations within the logistics and supply chain management and operations ecosystem to establish reliable goals and requirements for drone-based delivery services and operations. These requirements, on the one hand, would allow the testing, validation, and benchmarking of reliable performance of drone-based delivery services, while on the other hand, would pave the way for the wider adoption and integration of drones within the supply chain and logistics, including HSCs. While moving forward with further research and development efforts, the evidence from the literature indicates that there is an emergent need for UTM system standardization to enable stakeholders and technical systems to interact and cooperate using a common reference for making the UTM system operational in a safe, secure, and seamless manner (SESAR, 2020).

Our findings also show that further research and efforts are needed to advance the flyability of drones to ensure the service availability of delivery drones in demanding weather conditions. Moreover, the development of drone weather analysis tools is required to assess the operational feasibility of drone flight under various weather conditions considering drone weather constraints (Lundby et al., 2019).

The analysis of weather constraints on the flying ability of drones reported by Gao et al. (2021) shows that commercially available weather-resistant drones can operate in weather conditions having air temperature of -20 °C to 50°C, wind speed of up to 12 m/s and maximum precipitation of 10 mm/h. The Zipline Zip, registered as a small delivery drone in the FAA's list of commercial registrations, can operate in air temperatures between -20°C to 46°C with resistance to wind speed and precipitation of 14 m/s and 50 mm/h, respectively. Furthermore, drone flights would require technological improvements in drone design to mitigate noise concerns (Schäffer et al., 2021).

Based on the potential of drones and IoDs observed in the literature review, a hierarchical process model structure for HCSs is proposed. The model structure enables the implementation of strategies for integrating drones and IoDs into delivery and return activities within HSCs in four potential configurations (Moshref-Javadi & Winkenbach, 2021). Firstly, pure drone-based operations can be developed to deliver medications, vaccines, and protective equipment directly from distribution centers to the location of use, such as hospitals and clinics and centers of vaccination. Secondly, an unsynchronized multi-modal operation can be applied that combines multiple modes of transport, such as trucks, cars, bikes, and drones in HSCs. Thirdly, a synchronized multi-modal strategy can be used where assisting vehicles such as vans or trucks act as a movable hub for drone operations. In such cases, drones are launched from the assisting vehicle to make deliveries and return activities. Lastly, a multi-modal resupplying drone can be operated, where supporting vehicles resupply drones with packages such as medical supplies, testing kits, and vaccines along the supply chain.

The potential impact of drones in HSCs is substantial, and conducting a comparative analysis between drones and traditional road channels can offer valuable opportunities for HSCs managers and policymakers. By quantifying the areas accessible via drones and contrasting them with conventional transportation methods, stakeholders can make data-driven decisions and optimize the supply chain. In pandemic scenarios where access to remote areas is restricted, drones offer an agile response mechanism that can potentially save lives. Therefore, it is important to have a response strategy that includes the use of drones. The study conducted by Merkert and Bushell in 2020 corroborates this argument, highlighting the importance of embracing drone technology in HSCs for a more efficient and effective response during emergencies. Emergency response systems require a service level of up to 100%, and comparing the service level of drones-enabled HSCs to traditional methods can be a crucial indicator of performance.

Furthermore, while the COVID-19 immunization rates have been normalized worldwide, several challenges, such as multiple stakeholder management of vaccine supply chains, vaccine transport, and vaccine stock management, have impacted the speed of immunization in many countries (Alam et al., 2021). Therefore, based on the findings from the literature, we call for future research to look into how to best incorporate cutting-edge digital technologies, such as drones, into the conventional vaccine supply chain. Our findings indicate that drones can be a viable technology for transporting vaccines, particularly those that are stored at room temperature (Tian et al., 2021). The flexibility, agility, and independence of drones and IoDs can contribute to more equitable access to vaccine supplies, which is critical for vulnerable populations, particularly in developing economies facing pandemics (Dall'Alba et al., 2021; Genç, 2021; WHO, 2021b).

5.1 A novel framework for changing from people-dependent to technology-oriented HSCs

This study has revealed that drones and IoDs can be effective in addressing the consequences of pandemics, such as quarantine requirements and social distancing, that disrupt supply chains in most nations. However, while social distancing measures have proven highly effective in reducing virus transmission, as seen during the COVID-19 pandemic, they require significant changes in human behaviour and culture, which are dependent on people. In fact, different regions around the world have faced challenges due to the general public's lack of awareness and discipline in following social distancing guidelines and protective measures. Demonstrations against social distancing policies in Europe (Euronews, 2021) and North America (CBC, 2021) attested to these challenges. Therefore, the research findings also enable us to call for supply chain scholars to move from a people-dependent paradigm approach to research in this area to a more technological-intensive-dependent perspective (Fig. 4).

We argue that the integration of drones and IoDs with blockchain, big data, and AI can foster the much-needed digitalization of HSCs (Ayamga et al., 2021; Brem et al., 2021; Finkenstadt & Handfield, 2021; Sodhi & Tang, 2021). The pandemic has given us the right opportunities to make the transition towards more digitalized HSCs.

[ADD HERE **Fig. 4.** Shifting from people-dependent to more technology-oriented strategies in pandemic situations.]

A technology-intensive-dependent logic would require the current supply chain strategies for delivery, return, and distribution to be more technology-oriented (Agarwal et al., 2020). The magnitude of the technological shift required will most likely depend on factors such as population awareness, future waves of infections, virus retransmission rates, etc. Such a technology drive would be beneficial, especially in a 'constellation of variants' scenario and the likely cause of inadequate global immunization (WHO, 2021a). We also found that the combination of drones and IoD anchored in safety Blockchain protocols could improve the connectivity, agility and resilience of SCs, facilitating coordination among various stakeholders (e.g., governments, hospitals, centres of vaccination) of HSCs.

5.2 Practical contributions

The findings also offer important practical implications. First, managers responsible for public and private HSCs and vaccine supply chains can significantly benefit from the study findings if they rethink traditional emergency responses and incorporate disruptive technologies such as drones and IoDs. Second, our analysis using the PESTEL framework informs managers need to be aware of the political, economic, social, technological, environmental, and legal aspects of using disruptive technologies in HSCs. Without understanding the challenges and opportunities of disruptive technology integration, it will be difficult for managers to make these technologies viable for HSCs. Third, the literature provides enough evidence that drones and IoDs can improve the service levels of SCs by reducing response times and promoting contactless healthcare systems (Lee & Lee, 2021). Therefore, integrating drones into HSCs and vaccine supply chains can help supply chain practitioners achieve service-level objectives. Fourth, we provide a hierarchical process model using the SCOR framework so that managers can make informed decisions on where in HSC to integrate drones and IoDs. Finally, findings also shed light on the costs and time comparison of using drones versus traditional transportation. This will help supply chain practitioners understand the feasibility of implementing drones and IoDs.

5.3 Policy and social implications

Implications for policymakers, governments, and health authorities are as follows. First, the research shows that the crisis requires urgent responses and quick policy changes. To foster drone developments, policymakers and regulatory bodies must develop effective overarching policies to support healthcare systems more broadly. Second, appropriate policies for the commercial use of drones for return and delivery activities in HSCs and vaccine supply chains are crucial to reducing the consequences of the pandemic and developing preparedness against the subsequent waves of disruptions. Our findings demonstrate that governments in developing and developed nations can revitalize existing regulations on the commercial use of drones to address the public health risks posed by the pandemic. Our results suggest that two critical aspects of flying drones in cities are allowing them to fly BVLOS and over people. Third, the transportation and distribution of vaccines require maintaining a cold chain. Specific policies are needed to enable drones to transport those families of vaccines that can be stored at higher temperatures. Collectively, the research findings of this study unveil specific and generic strategies and challenges for envisioning the HSCs and vaccine supply chains coordination against disruptions caused by pandemics and beyond.

5.4 Theoretical implications

The main theory-building implications of the present study are as follows. First, the proposed integrative hierarchical process model derived from the findings (Table 3) can foster theory development in HSCs and vaccine supply chains domains to cope with disruptive situations. The paper contributes to the development of theory in the context of innovative supply chain configurations and frameworks enabled by drones and IoD to respond to social disaster situations. For instance, there have been many wildfires in recent years due to the impact of climate change. Drones and IoD can monitor and locate any fire outbreak that contributes to saving lives. Second, this study also extends extant literature on disruptive technologies for transportation for humanitarian issues in HSCs that are limited in research scope. For example, Jeong et al.'s (2020) study is restricted to examining the context of warehouses and specific types of drones and does not focus on HSCs, vaccine supply chains, or IoD, as is the focus of our research. Third, our paper addresses the knowledge gaps mentioned by Chowdhury et al. (2021), a study focused on contemporary and general supply chain themes that do not emphasise HSCs, drones or IoD.

Overall, this article answered calls from the recent literature to respond to how drones and IoD can be connected with other modes of transportation. This study also presents a combination of strategies, such as a hierarchical process model, a framework for transitioning from people-dependent HSCs to technology-dependent HSCs and a decision analysis framework for making an informed choice between road transportation systems and drones. We hope that these strategies will enhance HSCs resiliency by reducing technical difficulties of implementing these strategies during disruptions (Chowdhury et al., 2021).

6. Conclusions and future research agenda

This article aimed to identify the main opportunities and challenges of integrating disruptive technologies such as drones and IoD to improve HSC's response to pandemics. The adopted research methodology uncovered unique insights by exploring and interrogating the frontiers of knowledge technologies through critical and distinct perspectives. This investigation has shown that policymakers can immediately adopt some of the proposed solutions examined, while others require more in-depth analysis. Nevertheless, regulatory and legislative limitations restrict the development of specific short-term logistics solutions. The study found that disruptive technologies such as drones can be beneficial when there is uncertainty about the course of the COVID-19 pandemic in the future, e.g., if the risk of new virus mutations necessitates a temporary increase in resilience and agility across HSCs.

The findings of this research are subject to at least two limitations. First, the study only considers publications in English. Second, the rapid pace of knowledge generation on the topics discussed in the current paper made it difficult to include and analyse all available publications. We have also found an apparent lack of research investigating the solutions in SCs and vaccine supply chains to strengthen the fight against the pandemic. Therefore, future research can explore a number of topics listed below.

First, UTM is currently plagued with challenges concerning (i) human safety, (ii) the lack of a globally synchronized legal framework that establishes legal liability, obligations, roles, and responsibilities of stakeholders when flying UAVs, (iii) the lack of an aircraft taxonomy to support a consistent and robust treatment of all flying objects in the sky, and (iv) the lack of mechanisms to enable investigations and traceability for enforcing accountability of drones and other unmanned aircraft. Some of these challenges and limitations of UTM may fall out of the remit of OSCM researchers. However, OSCM researchers can support multi-disciplinary research to investigate, for example, the effects and implications that, or the lack of, these frameworks, taxonomies and/or mechanisms may have on HSCs.

Second, future research can focus on developing an integrated air traffic system that accommodates the current mechanisms and IoT and other related technologies such as AI, machine learning or cloud computing. Third, how to integrate unmanned air traffic from a human/behavioural, technological and systems perspective in the current ATM, as well as the implications that this may bring to the management of HSCs. Fourth, the field of the IoDs is still relatively unexplored, and many areas of research warrant further investigation. One important area is the architecture of IoDs, along with the security risks and threats that are associated with them and their communication networks. Additionally, IoDs can create vulnerabilities due to the coordination and scheduling requirements involved in their operation. These vulnerabilities should be investigated in more detail in future research. Finally, privacy is a major concern when it comes to IoDs, and researchers should investigate the implications for people's privacy if many drones are flying around urban areas.

Finally, we invite OSCM researchers to explore the following specific research avenues in future studies:

(i) What are the potentials and challenges of drones and IoDs in the upstream supply chain of the SCOR process, such as sourcing and making?

(ii) What are the adequate digital architectures and platforms to support drones and IoD adoptions in HSC? Similarly, what is the proper architecture for a long-distance connectivity system using drones and IoDs?

(iii) What are the challenges of using drones during the pandemic in indoor applications (e.g., in hospitals, vaccination centres, and quarantine areas)? What are the primary challenges in implementing solutions for collision avoidance and mobility support for IoDs?

(iv) What are the credible night logistics applications of drones in indoor and outdoor operations used to facilitate the activities of HSCs? How can 5G networks facilitate the realization of IoDs in HSCs?

(v) What protocols for the authentication, security keys, digital signatures, and communication are recommended to ensure the integrity and privacy of SCs? In this same line, what protocols enable the immediate incorporation of small, unmanned aircraft systems into the National Airspace System?

In conclusion, this research makes significant contributions to OSCM by conducting an integrative review of a wide-ranging and varied body of literature on drones and IoDs. The utilization of the PESTEL framework has allowed for the structured presentation of the opportunities and challenges associated with the use of drones and IoDs. The analysis has yielded several findings, such as the absence of regulations for the commercial use of drones and IoDs, the viability of drone deliveries in HSCs, and the imperative for digitalization in HSCs. The hierarchical process model presented in the research outlines the delivery and return activities that can be facilitated by drones and IoDs, along with relevant performance metrics. The research also highlights the successful use of drone and IoD-based deliveries and returns for time-critical medical services, as compared to traditional road systems.

Overall, this research discovered that drones have already fostered a new era of UAVs by offering numerous advantages primarily because of their flexible, independent, easy-to-use nature and low energy consumption and cost. Several companies (e.g., Zipline, Amazon, UPS Flight Forward, Matternet, and Flytrex) have successfully demonstrated using drones under the FAA Integration Pilot Program to combat COVID-19. However, even if drones are used only for HSCs and in emergencies, their large-scale commercial usage in the absence of UTM can lead to the rise of safety, privacy, and security challenges. In this study, we argue for the need to continually examine the recent advancements in and knowledge base on the use of drones and IoDs to provide a clear scenery for the scientific community, relevant authorities, managers, and governments across the globe. We hope this research will help scholars, practitioners, and policymakers respond to the new pandemic waves in the 'new normal' context and address future challenges in HSCs posed by similar emergency events.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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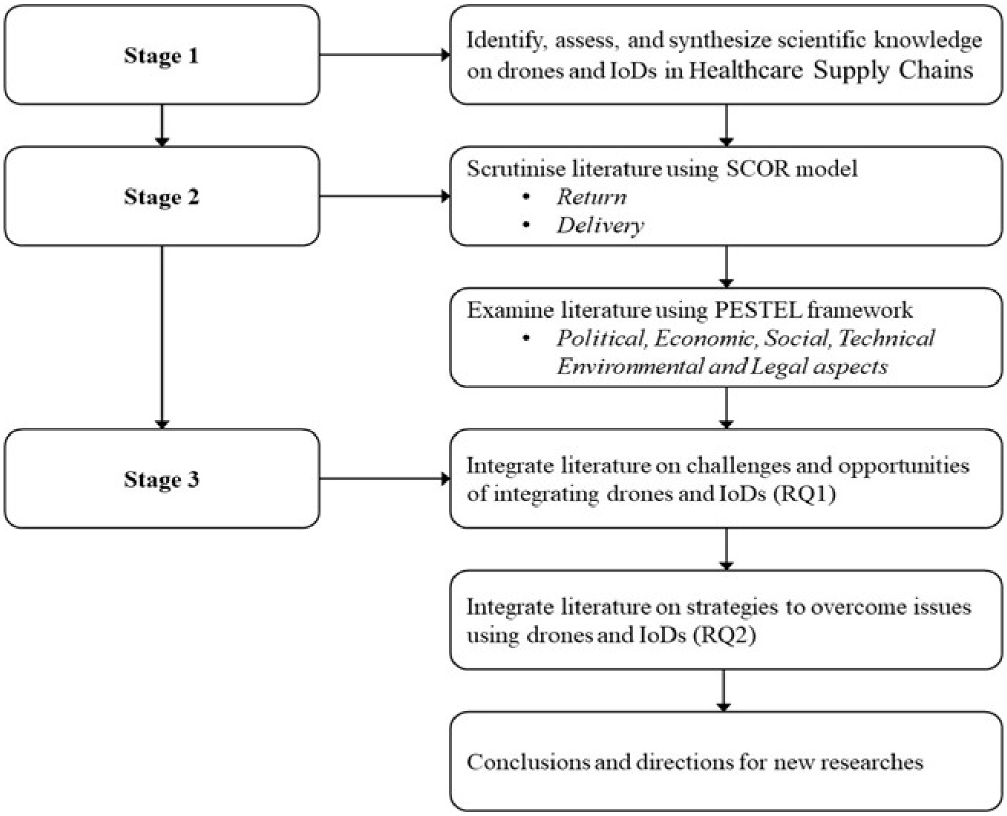
Appendix A

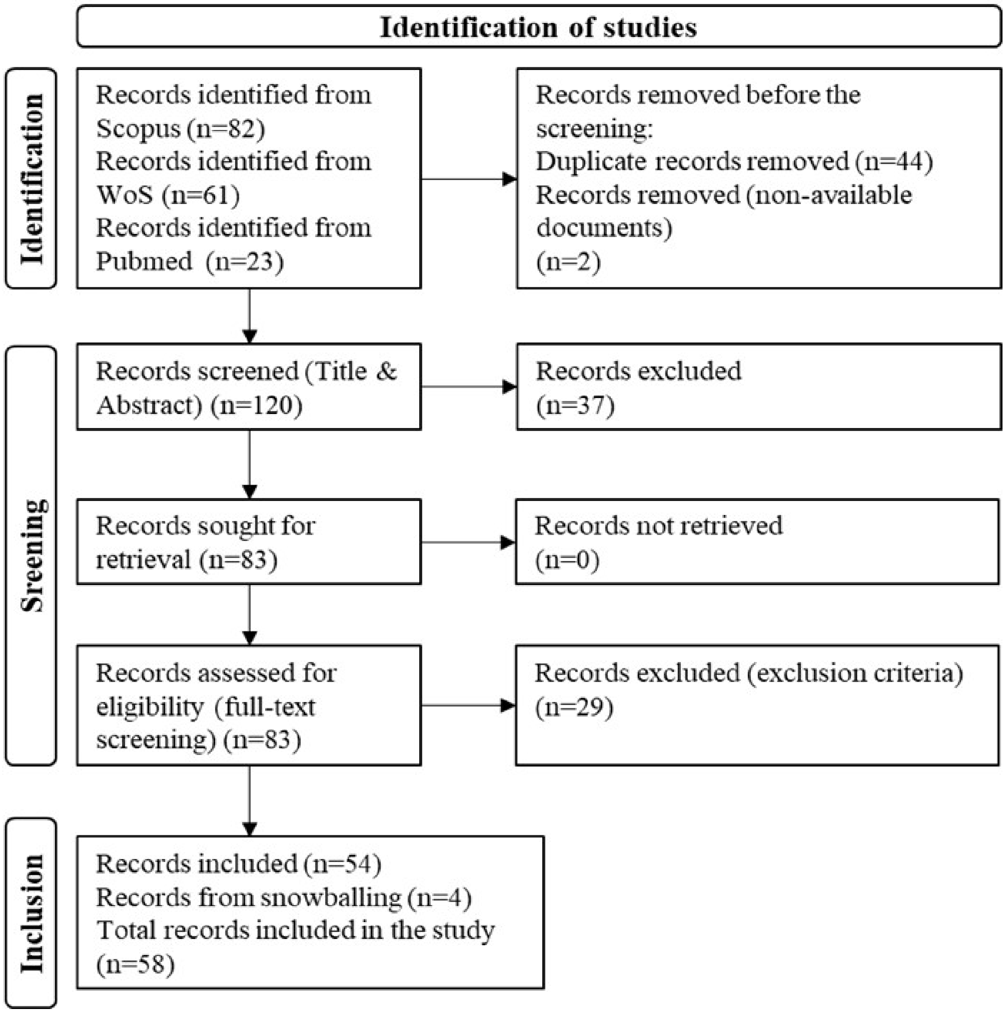
Table A1. List of medical drone service providers in healthcare supply chains

Service Provider	Origin	Specifications (Type, Payload, Speed, Range)	Services	Website
UPS Workhorse Horsefly	USA	Quadcopter, 4.5 kg, 74 km/h, N/A	Medicine, other	https://workhorse.com/horsefly.html
DHL Parcelcopter 4.0	Germany	Hybrid VTOL, 4 kg, 130 km/h, 65 km	Medicine, (Operational in Tanzania)	http://dpdhl.com/parcelcopter
Flirtey	USA	Hexacopter, 2.5 kg, 45 km/h, 32 km	Medicine, other	https://www.flirtey.com/
Amazon Air-MK27	USA	Hybrid VTOL, 2.3 kg, 111 km/h, 24 km	Medicine, other	https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011
Matternet	USA, Switzerland	Quadcopter, 2 kg, 50 km/h, 20 km	Medicine, other	https://mttr.net/
Zipline	USA	Fixed Wing, 1.5 kg, 100 km/h, 150 km	Blood, Vaccines and medicines (expected) Operational in Rwanda	https://flyzipline.com/
Wing	USA	Hybrid VTOL, 1.5 kg, 113 km/h, 20 km	Medicine, other	https://wing.com/
Wingcopter	Germany	Hybrid VTOL, 2 kg, 130 km/h, 100 km	Medicine, other	https://wingcopter.com/
Volansi (VOLY C-10 GEN2)	USA	Hybrid VTOL, 4.5 kg, 96 km/h, 80 km	Medicine, other	https://volansi.com/

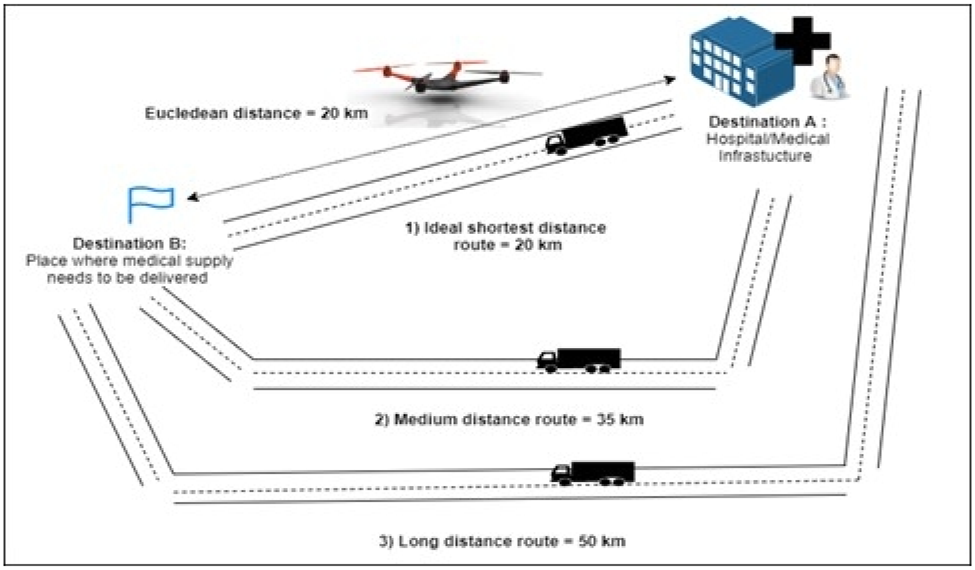
Source: Heike Würbel (2017), Scott et. al. (2020) and websites of the respective medical drone service providers.



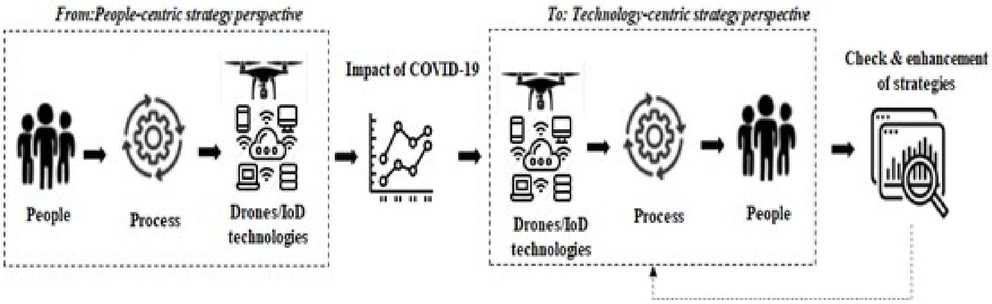
138x111mm (120 x 120 DPI)



118x119mm (150 x 150 DPI)



128x74mm (96 x 96 DPI)



147x45mm (96 x 96 DPI)

Table 1. Research protocol

Research protocol	**Details description**
Research databases	Scopus, Web of Science (WoS), and PubMed
Publication type	Peer-reviewed journals
Language	Papers in English
Data range	2014 to 2023
Search fields	Titles, abstracts, and keywords
Search terms: applied in Titles in the Scopus, WoS and Pub Med database and Titles, Abstracts, and Keywords	“unmanned aerial vehicle” OR “drone” OR “Internet of Drones” AND “Covid-19” OR “coronavirus” OR “Sars-cov-2” OR “infectious diseases” AND “resilience” OR “healthcare” OR “supply chain”
Inclusion criteria	(i) papers developing models, tools, or methods related to research questions 1 and 2; (ii) papers proposing the implementation of drones and IoD in SCs against pandemics; (iii) papers demonstrating experimental, theoretical, and practical results on the use of drones and IoD in healthcare and vaccine SCs in pandemics in return and delivery activities; and (iv) papers examining the combination of drones and IoD with other disruptive technologies in healthcare and vaccine SCs in pandemics.
Exclusion criteria	(i) Papers lacking methodological rigour and failing to demonstrate a clear presentation of the methodological procedures or contributions; (ii) studies considering high quantitative approaches, making it difficult to obtain relevant qualitative findings; and (iii) unpublished works.
Data extraction	Originality and relevancy were the primary factors considered for the selection of studies during the screening process. We focused on research that provided insights into existing issues and prospects.
Data analysis and synthesis	The content analysis of selected works was organized through descriptive analyses in a worksheet.

Table 2. Key points of analysis of literature based on the PESTEL framework.

PESTEL Framework	Key points
Political Aspects	• Employing drones for surveillance, disease monitoring, and tracking. • Utilizing drones for potentially unethical or criminal activities. • Absence of regulations governing drone usage.
Economic Aspects	• Drones enable lower transportation costs for small deliveries. • Drones have the potential to enhance the responsiveness of HSCs. • IoDs can be integrated with IoTs to establish more resilient HSCs. • Drones may contribute to the creation of a digital divide and unemployment. • The critical availability of emergency medical supplies like vaccines can balance the high infrastructure costs associated with drone operations.
Social Aspects	• Drones have the potential to reduce the necessity for social contact during emergencies such as pandemics. • Drones can facilitate access to remote regions such as favelas, refugee camps, and indigenous areas. • Drone deliveries in densely populated cities can present safety concerns. • Issues of trust and protection of personal data are significant considerations for the social use of drones.
Technological Aspects	• Drones may pose risks to manned aviation. • A reliable communication system is critical for drone operations shared with manned air traffic management systems. • Long-Term Evolution (LTE) and 5G communication serve as the primary communication systems for drone and IoD operations. • The lack of communication and data exchange security standards in drones and IoD systems could lead to privacy and security attacks. • Drones must incorporate fault-tolerant control systems and failsafe systems to enhance operational reliability. • Significant efforts have been devoted to the development, testing and validation of requirements, technologies, and systems for UTM. • AI and ML techniques can play a central role in developing autonomy within the systems in the air and on the ground.
Environmental Aspects	• The utilization of drones can assist the transportation industry in reducing greenhouse gas emissions. • Employing renewable energy sources to charge drone batteries can render drones carbon neutral. • Drones are susceptible to weather conditions. • Drones may create noise pollution in urban áreas.
Legal Aspects	• A comprehensive legal framework regarding legal liability, obligations, roles, and responsibilities for forming an integrated UTM system is missing.

PESTEL Framework	Key points
	• Drones flying beyond the visual line of sight require the approval of Specific Operations Risk Assessment (SORA) by the competent authority.

Table 3. Hierarchical process model for HSCs enabled by drones and IoDs

Process types	Process categories	Process hierarchy	Activities and decision areas	Process metrics affected (main)	Drones	IoDs
Delivery	Deliver stocked vaccines/ other emergency medical supplies	Route shipments	Monitoring and surveillance of shipping containers to prevent stealing, misappropriation, or loss	Delivery accuracy Transportation cost	X	X
		Pick, pack, load, ship	Ensuring vaccine transportation within the prescribed temperature range throughout the supply chain	Delivery accuracy Delivery cycle time Delivery volume Transportation cost	X	X
		Pick, pack, load, ship	Facilitating the vaccine delivery and medical supplies in remote regions	Delivery cycle time Transportation cost	X	X
		Receive	Tracking, tracing, and notifying vaccine recipients for the second dose	Delivery cycle time Order cost	X	X
Return	Source return defective products	Return and disposition of defective product	Returning and disposing of vaccine containers from remote regions	Source return cycle time Return cost Disposition cost	X	X
		Return and disposition of defective products	Returning of ageing inventory or obsolete medical products and vaccines (e.g., expired, insufficient for use, spoiled)	Return cost Disposition cost	X	
	Source return excess products	Return excess product	Returning excess or unused medical products and vaccines	Return cost	X	

Table 4. Parameters used for trucks and drones.

Parameters	**Truck**	**Drones**
Speed	30 km/h	40 km/h
Payload capacity	1300 kg	2.27 kg
Cost per km	\$0.03	\$1.25

Source: Nguyen et al. (2022).

Table 5. Quantitative analysis of the performance of trucks and drones in different types of routes

Route	**Trucks**		**Drones**	
	Time (minutes)	**Cost** ($)	**Time** (minutes)	**Cost** ($)
Ideal shortest distance route (20 km)	40	0.6	30	25
Medium distance route (35 km)	70	1.05	30	25
Long-distance route (50 km)	100	1.5	30	25

23x27mm (220 x 220 DPI)

26x28mm (220 x 220 DPI)

23x32mm (220 x 220 DPI)

28x33mm (220 x 220 DPI)

30x37mm (220 x 220 DPI)