



# Risk analysis in last-mile drone delivery

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### **Risk analysis in last-mile drone delivery**

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### **Abstract**

In the 21st century, as science and technology have advanced and society has changed, unmanned aerial vehicles, or UAVs, have brought opportunities as well as challenges to most logistics' organizations. Drones are being investigated by an increasing number of logistics organizations globally for last-mile delivery. However, there is still opportunity for development in terms of the stability, safety, accuracy, and efficiency of drone delivery. These days, a lot of scholarly research concentrates on addressing impending urban logistics issues, resolving delivery last-mile paradoxes, and increasing last mile delivery efficiency. However, existing literature has not provided a comprehensive description of risk analysis for driving the last-mile drone delivery and the actual scenarios that enterprises face. The information about specific factors regarding risk analysis for last-mile drone delivery from current literature is limited, leading to the need for this study.

The authors employed qualitative research methods to identify and categorize potential dangers as well as suggest solutions to help logistics organizations lower the risks generated by last-mile drone delivery. The author collected data through theoretical literature and semi-structured interviews, and finally compared and analysed to draw conclusions.

The research findings indicate that three potential solutions, including advanced technological support, comprehensive risk assessment testing for drones, and the proposal of innovative delivery concepts, can effectively address the potential risks faced by logistics enterprises in last-mile drone delivery. These solutions help reduce the risks associated with last-mile drone delivery. Furthermore, this study which serving as a case study related to risk analysis for last-mile drone delivery, can provide data and insights for future quantitative analysis of potential safety risks in drone delivery. Additionally, relevant drone logistics enterprises can utilize the research data from this study to develop practical approaches and establish theoretical data models for drone delivery risks, thereby reducing potential safety risks in last-mile delivery.

### **Keywords/tags (subjects)**

Drone, Last-mile delivery, Drone delivery, Unmanned aerial vehicles (UAVs), Potential risks.

### **Miscellaneous (Confidential information)**

None.

## Contents

<b>1</b>	<b>Introduction</b>	<b>3</b>
1.1	The Drone delivery	3
1.2	The last mile drone delivery	3
1.3	Realized risks in last-mile drone delivery	4
1.4	Objectives	5
<b>2</b>	<b>Last-mile delivery</b>	<b>6</b>
2.1	The definition	6
2.2	Significance and Development	7
2.3	The current focus of enterprises	9
<b>3</b>	<b>Drones in Logistics</b>	<b>13</b>
3.1	The performance of drones in last-mile delivery	13
3.2	Different types of drones	16
3.3	The drone delivery mode for last-mile delivery	18
3.4	Products delivered by drones	25
<b>4</b>	<b>Risks related to last-mile drone delivery</b>	<b>27</b>
4.1	The general risks of last-mile drone delivery	27
4.2	Some solutions in legal and quality risks	29
<b>5</b>	<b>Methodology</b>	<b>30</b>
5.1	Structure of the whole research process	30
5.2	Qualitative research	31
5.2.1	Literature review	32
5.2.2	Interview	34
<b>6</b>	<b>Result and Analysis</b>	<b>35</b>
6.1	Precise positioning of drones	36
6.2	Potential Risks in Last-Mile Drone Delivery and solutions	36
6.3	Drone delivery of goods and prospects	38
<b>7</b>	<b>Conclusion</b>	<b>39</b>
<b>8</b>	<b>Discussion</b>	<b>43</b>
	<b>References</b>	<b>47</b>
	<b>Appendices</b>	<b>50</b>
	Appendix 1. Interview invitation letter to logisitcs company	50
	Appendix 2. Interview questions with drone technicians, delivery personnel, and sales representatives	51

## Figures

Figure 1. Summary of the three key issues that companies are focusing on the Last mile delivery .....	10
Figure 2. An Amazon drone with a package .....	11
Figure 3. Ele.me Approved as China's First Food Delivery Drone Route .....	14
Figure 4. Multi-rotor Drone .....	17
Figure 5. NM& F300, new high performance fixed wing Drone .....	18
Figure 6. Isometric view of a multi-level fulfillment center designed for drones .....	19
Figure 7. Parallel distribution mode of drones and vehicles. ....	21
Figure 8. A drone take-off and landing delivery in the same truck mode .....	22
Figure 9. The drone take-off and landing delivery in different trucks mode. ....	22
Figure 10. The Drone-public transportation collaborative delivery mode .....	23
Figure 11. Mode of drone delivery and pickup .....	24
Figure 12. Shanghai's Fengxian District uses drones to deliver food .....	26
Figure 13. Last Mile Delivery Risk Framework .....	28
Figure 14. Framework of research steps. ....	31
Figure 15. DJI FC30 meets the needs of material transportation from mountains, shores, rural transportation and various emergency scenarios. ....	37
Figure 16. Lentola's Fixed-wing Drone .....	38

## Tables

Table 1. Comparison of three delivery modes .....	25
Table 2. Theory search process for research topics .....	33
Table 3. Semi-structured interviews of three logistics companies .....	34
Table 4. Summarize of Semi-structure interview .....	35
Table 5. Summarize of the potential risks with last-mile drone delivery .....	41
Table 6. Summarize of Solution to identified risks .....	42

# 1 Introduction

## 1.1 The Drone delivery

The 21st century has witnessed significant developments in drone technology, transforming it from a military tool to an integral part of civilian applications. Drones have become popular in various fields, including filmmaking, entertainment, and surveillance, among others. In the past few years, drone delivery has attracted a lot of attention on a global scale as a possibly novel and very promising customer service approach (Marshall, 2021.)

Countries including the USA, the Kingdom of England, China, as well as Europe are exploring drone delivery options for medical supplies, food deliveries, and emergency response. In which the United States is promoting drone delivery in commercial competition, the United Kingdom is testing the delivery of pizza by drone, medical supplies are being sent by drone to emergency locations throughout Europe.

## 1.2 The last mile drone delivery

According to Eskandaripour & Boldsaikhan (2023) state that shipping, road transportation, and air transportation are the most often used means of transportation for last-mile deliveries of goods. For example, ships are used in shipping, vehicles, bicycles, and railroads are used in land and ground transportation, while airplanes and drones are used in air transportation. However, despite being widely used in last-mile delivery businesses, trucks also have some limitations. For example, they are difficult to use for delivering to certain rural areas, consume polluting gasoline, face delays due to weather conditions, and cause traffic congestion. To consider environmental protection, some companies including DoorDash and UberEats have adopted bicycle delivery services. Bicycle delivery does have certain disadvantages, though, like riders having to deal with traffic hazards, having a heavy workload, and having a restricted amount of luggage capacity. As a result, even although bicycle delivery benefits communities, it might not be effective in cities.

Despite accounting for only 4% of vehicles on American roads, delivery trucks are responsible for 50%, 60%, and 7% of total nitrogen oxide emissions, fine particulate matter emissions, and green-

house gas emissions in the US respectively. Because of this, many retailers—including Amazon, Alphabet Wing, Walmart, UPS, and the Chinese firms Meituan, JD, and SF Express—are looking for unmanned aerial vehicles as a sustainable transportation choice. This is because drone technology offers environmental benefits, faster delivery times, lower operating costs, and reduced manpower requirements (Eskandaripour & Boldsaikhan, 2023.) In comparison, drone delivery is currently one of the most popular last-mile delivery methods and can serve as a supplement to existing transportation methods. This method not only delivers packages quickly and accurately to the destination but also avoids issues such as traffic congestion. Furthermore, with the continuous development and improvement of drone technology, the application prospects of drone delivery are very extensive.

### **1.3 Realized risks in last-mile drone delivery**

“A serious crash in June prompted federal regulators to question the drone’s airworthiness because multiple safety features failed and the machine careened out of control, causing a brush fire” (Soper & Day, 2022).

According to Soper & Day (2022), Amazon Prime Air is the future delivery system for the company’s products. Within thirty minutes after an order, Amazon plans to deploy each package to customers using micro-drone technology that uses GPS. However, there have been some concerns about the safety and regulatory compliance of these drone delivery operations. For instance, in 2021, during a flight test at the Amazon site, an agricultural worker using a tractor passed over the drone's flight path, causing several employees to believe that the test had broken FAA regulations. The team leader believed that the drone was not over the farmer and conducted the test smoothly. However, there have also been incidents where drone technology has failed. When an engine malfunctioned in June of that year, an Amazon delivery drone crashed, and the automatic security features meant to bring the drone to a safe landing did not function. As a result, the drone fell approximately 160 feet and caused a fire that destroyed 25 acres and caused environmental damage.

While Amazon's drone delivery plan can bring convenience to the transportation industry, it also poses potential risks to society and the environment. As noted by Soper & Day (2022), some Amazon employees have expressed doubts about the legality of drone delivery and compliance with regulations, which could potentially pose hidden dangers to residents' safety.

## **1.4 Objectives**

The increasing developments in technology coupled with the growing expectations of logistics firms worldwide for cost-effectiveness, time-efficiency, and environmental sustainability have made drones a more attractive alternative for last-mile delivery. Even though last-mile drone delivery is making considerable strides, there are still several obstacles to overcome. For instance, delivery efficiency, accuracy, stability, and security need to be improved further, and regulations regarding drone operations in most countries are incomplete. The "last mile" between organization hubs and clients must be dealt with through last-mile drone delivery. This includes precise delivery to predetermined destinations and managing unanticipated circumstances like dangerous weather and traffic while making deliveries.

Numerous academic publications focus on the last-mile delivery conundrum, innovative strategies for last-mile delivery in the future, and the design of last-mile delivery networks in urban coordinating contexts. The number of studies on customer perceptions of drone delivery, last-mile drone delivery, and drone delivery in new locations is all expanding. However, there is still a lack in academic discussions of a systematic and scalable methodology for assessing and fully defining the risk factors related to last-mile drone delivery. The material that is currently available for publication falls short of providing a comprehensive explanation of risk assessments or the practical issues that businesses and organizations must resolve to support last-mile drone delivery. Further, even though numerous publications explore risk issues related to last-mile delivery, there is minimal discussion of risk issues specifically related to last-mile drone delivery in the available research on urban organizations and contemporary e-commerce supply chains. As a result, little information about the precise elements influencing risk analysis for last-mile drone delivery is currently available in the literature.

Based on this, the main objective of this thesis is to do a risk analysis of last-mile drone delivery, paying close attention to the following risk analysis issues:

- What are the key issues to analyse and collect when considering last-mile drone delivery?
- What are the potential risks associated with using drones for last-mile delivery?
- How can companies manage the identified risks?

The aim of this thesis is to assist logistics companies in lowering the risks involved in last-mile drone delivery. The process involves recognizing, categorizing, and suggesting remedies for hazards to lower the risk related to last-mile drone delivery. Additionally, this study will examine the relevant risks related to drones in last-mile delivery from a theoretical perspective and offer feasible solutions to make last-mile drone delivery easier.

## **2 Last-mile delivery**

### **2.1 The definition**

The most urgent problem at hand now is how to deal with the challenges last-mile delivery has because of the continuous growth of the logistical sector. Consequently, the definition of the last mile will first clarify what last-mile delivery is, why it matters there, how it developed, and what businesses are currently focusing on.

Lim et al. (2018, p. 309) examined the last mile's historical development and defined the phrase, noting that "The term 'last mile' initially originated from the telecommunications industry, referring to the final stretch of network transmission." As the logistics industry evolved, the term "last mile" eventually came to refer to the last stage of the transport system. It is usually regarded as the most costly and ineffective component in the supply chain, raising grave environmental issues. Esper et al. (2003) assert that e-commerce logistics' "last mile" is a critical stage. It is the process of moving goods from manufacturers or warehouses to final consumers or sales locations. The term "last mile" is commonly used to describe this stage of the procedure. It includes product transportation and delivery services, making it the most important phase in the order fulfillment process. On-time delivery is widely regarded as a critical factor by online shoppers, with a proportion as high as 89%, second only to privacy issues (90%). Additionally, 85% of clients who receive their orders promptly will purchase again from the e-commerce platform, while only 33% of those who do not receive their orders on time will continue to consume. Consequently, improving last-mile delivery services can raise client satisfaction and allegiance.

Last-mile delivery has garnered substantial global attention in urban settings. In the study by Boysen et al. (2021), it is defined as comprising all logistical operations directly associated with the delivery of goods to residential households within these urban zones, while Mangiaracina et al. (2019, p. 901-920) indicated that it is “the final part of business-to-consumer (B2C) parcel delivery services.” It happens in the space between the recipient's selected location and the order contact point. Furthermore, the last mile delivery includes the last few delivery stages from distribution centres or warehouses to the ultimate destinations of customers. Last-mile delivery was once just related to the courier service sector, but thanks to the explosive rise of electronic commerce, it is now an essential part of contemporary supply chain management and logistics.

In addition, as the internet-based business sector has expanded, customers' expectations for prompt delivery and high order volumes have grown, creating more difficult last-mile delivery challenges. Therefore, drone delivery has become the best solution today to address this challenge. Drones can fly in the sky, avoiding busy roads and traffic obstacles, improving delivery speed, and shortening the last-mile delivery time. And drones with their autonomous operating systems and flying range can meet the demand for many consumer orders and avoid the urban traffic problems faced by traditional delivery (Yoo & Chankov, 2018.)

## **2.2 Significance and Development**

The last-mile delivery is characterized by complexity, prohibitive cost, and considerable risk, involving various aspects such as delivery route planning, mode selection, time window management, and quality control. Boysen et al. (2021) examined the last mile delivery process from an operations research standpoint, emphasizing the significance of contemporary last-mile delivery. Even while last-mile delivery is becoming an essential part of modern logistics and supply chain management, its complexity, prohibitive cost, and considerable risk make it a difficult problem to solve. Two global trends that have boosted patronage of last-mile deliveries are urbanization and e-commerce. The need for solutions to the last-mile delivery problem arises from the growing complexity and cost of supply chain management and logistics as more people live in cities and place online orders. Additionally, in electronic commerce providers must overcome a variety of obstacles to solve the last-mile delivery issue, such as cost sensitivity that drives up order fulfillment costs, competition from free delivery services, consumer expectations for prompt delivery, and demands for customization, traceability, and alternate delivery locations.

Moreover, the delivery of goods by express vehicles into city centers has negative impacts on existing infrastructure, traffic congestion, environment, and health. Therefore, sustainability and environmentally friendly operations need to be promoted. Traditional warehouse delivery methods are also problematic, as they are expensive, time-pressured, and challenging for delivery staff. To address these issues, it is necessary to explore new delivery methods such as drones, automated delivery machines, and autonomous delivery trucks (Boysen et al., 2021). It follows that the value of last-mile delivery stems from the fact that it is an essential component of electronic shopping logistics, which is one of the main drivers of current global economic growth.

This means that improving the efficiency and standard of services rendered by e-commerce logistics depends on finding a solution to the last mile delivery problem. According to Mangiaracina et al. (2019), preserving customer satisfaction, enhancing business operations, and regaining market competitiveness all depend on this. The development of last-mile delivery has grown in significance considering this. A rising corpus of published works on the last-mile delivery model has been produced in response to the difficulties encountered by last-mile delivery, and numerous contemporary technologies and concepts have also arisen. Boysen et al. (2021) noted that human-driven transport vehicles, cargo automobiles, as well as self-service are examples of successful last-mile delivery options that have been implemented in day-to-day operations. They also discussed the potential of emerging technologies like drone delivery and autonomous driving delivery, outlining the fundamentals, benefits, and drawbacks of each technology and providing examples and data to support their points. One of the most popular last-mile delivery strategies, where someone who is delivering can drive a van from customer to client, is manual delivery. However, due to issues such as high labour costs and low efficiency, its application is restricted. In contrast, Arnold et al. (2018) pointed out that bicycle couriers and shared freight are more suitable for urban delivery at mid-to-short distances, especially for alleviating excessive delivery traffic in city centres. In addition, to lighten the workload of their delivery employees, some postal vendors are attempting to implement consumer self-service.

Fresh alternatives compared to conventional delivery workers, like autonomous driving and drone delivery, have emerged because of the growth of last-mile delivery. Autonomous transport vehicles are now being investigated by numerous businesses and researchers to improve delivery effectiveness, flexibility, and speed while cutting expenses. Although taxi service providers like Uber

as well as Lyft may be negatively impacted by the emergence of new options like autonomous cars, these alternative delivery methods can help businesses increase their productivity and profitability while also completely changing the transportation sector. Creating value for consumers and business customers, Tesla, Volvo automobiles, and Waymo (Google's autonomous driving vehicle) are vying to introduce their initial unmanned driving experimental vehicle (Grewal et al., 2020)

According to research by Kellermann et al. (2020), drone delivery services in logistics lend several anticipated benefits, such as lower costs for rapidly expanding and cost-conscious logistics companies, better urban transportation, and environmental benefits like a smaller carbon footprint and less noise pollution. Drones are considered a more sustainable logistics and passenger transport technology compared to traditional modes. According to the findings reached by Eskandarpour & Boldsaikhan (2023), a sizable number of retail businesses are currently implementing environmentally friendly and effective last-mile delivery strategies, including drones, to safeguard the environment.

Despite the vast potential of autonomous driving technology and drone delivery, these technologies currently face some challenges. For instance, Boysen et al. (2021) realize that autonomous delivery vehicles need to follow traffic rules and standards that may not suit them, requiring precise mapping and positioning technology, advanced sensors, and computing capabilities to navigate complex urban environments, road conditions, and traffic situations. So just like the point Kellermann et al. (2020) hold, drone delivery has potential issues, including legal problems due to inadequate regulation of unmanned aircraft operations in most countries. As a result, drone delivery needs to follow strict legal requirements, while there is room for improvement in delivery efficiency, stability, safety, and how to handle unforeseeable events such as weather and traffic during the delivery process.

### **2.3 The current focus of enterprises**

Delivery services are now an essential part of the sales process because of the quick and widespread adoption of e-commerce as well as the ever-changing preferences of the consumer. For organizations, last-mile delivery is essential to maintaining elevated levels of customer satisfaction and operational effectiveness. As a result, a lot of businesses are concentrating on boosting last-mile delivery operations through cost management, technological innovation, efficient delivery,

and higher levels of customer satisfaction (Boysen et al., 2021.) and Figure 1 illustrates the three main concerns that businesses address in last-mile deliveries.

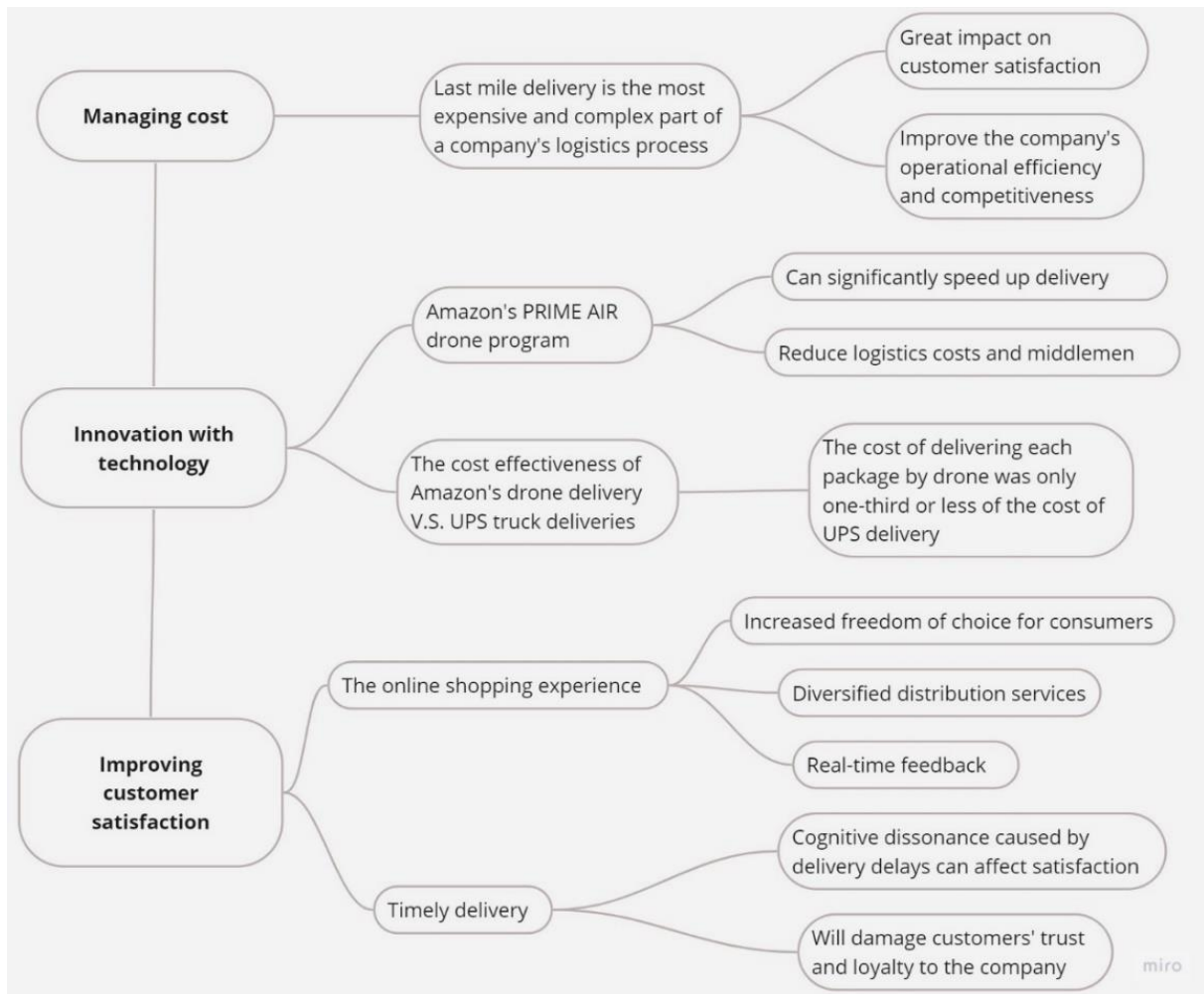


Figure 1. Summary of the three key issues that companies are focusing on the Last mile delivery

### Managing costs

As one of the most important elements influencing customer satisfaction, the last-mile delivery is also the most costly and intricate aspect of the overall logistics process (Mangiaracina et al., 2019). Because of this, last-mile delivery companies need to prioritize cost control and effectively monitor and reduce a range of delivery-related costs, including labour, warehousing, equipment, transportation, and information technology. Effective monitoring and analysis of logistics processes, optimization and adjustment based on relevant data, accurate control of various cost indicators, and

efficient management of last-mile delivery costs are vital in improving a company's operational efficiency and competitiveness (Bosona, 2020.)

### **Innovating with technology**

Cutting-edge technology is essential in the delivery last-mile area. One prime example is the drone service called PRIME AIR by Amazon. The program uses drones for last-mile delivery, achieving significantly faster delivery speeds and reducing intermediaries, as well as lowering logistics costs through the application of innovative technology.



Figure 2. An Amazon drone with a package. (2022). The Needling, Seattle's Only Real Fake News (<https://theneedling.com/2022/11/28/amazon-prime-air-develops-first-remote-control-drone-that-doesnt-break-by-end-of-christmas-day/>).

Sudbury & Hutchinson (2016) conducted a cost analysis experiment comparing the cost-effectiveness of Amazon's drone delivery to UPS truck deliveries. Their findings proved the benefits and worth of innovative technology since each box delivered by drone only costs an additional third or lower of what a UPS service would have. To address the exorbitant delivery costs and reduce dependence on UPS, FedEx, and postal services, Amazon is planning to introduce innovative technologies like drones to enhance delivery efficiency and lower expenses. By directly transporting packages to customers, Amazon aims to eliminate intermediaries and achieve savings in transportation expenditures. Successfully implementing a drone delivery program for the final leg would confer Amazon with a significant competitive edge over both online and brick-and-mortar retailers. This

pioneering approach ensures swift and streamlined delivery, thereby enticing more customers to avail themselves of their services.

Nevertheless, Amazon's drone delivery strategy also entails potential risks, as underscored by Soper and Day (2022). Certain Amazon personnel have expressed scepticisms about the legality and compliance of drone delivery, which may pose safety concerns for residents. Furthermore, drone crashes resulting from engine design issues have given rise to environmental problems, such as forest fires, thus accentuating the potential implications of this technology on the environment. Such incidents can precipitate environmental contamination and inflict harm upon local ecosystems, wildlife, and the populace inhabiting the area. To mitigate these challenges, Amazon needs to implement measures that enhance the safety and dependability of drone technology. This encompasses investment in enhanced safety features and risk management strategies, collaboration with pertinent regulatory authorities to ensure adherence to guidelines and regulations, and public education regarding the benefits and potential hazards associated with drone delivery. Only through these actions can Amazon assure safety and garner public support throughout the implementation of their drone delivery plan.

### **Improving customer satisfaction**

Because it has to do with the customer's buying experience and pleasure, last-mile delivery is considered the most important aspect of the entire delivery process in the e-commerce industry. Like how Vakulenko et al. (2019) noted that the causal connection between the web-based purchasing experience and overall buyer happiness is significantly impacted by the last-mile delivery expertise. Most people agree that the last mile delivery is a vital consideration when making an online purchase. A few appealing last-mile delivery options are, for example, complimentary delivery, immediate delivery during a certain time window, store collection, package tracking, return shipping, and arrangement delivery. Additionally, it is also important to emphasize communication and services during the delivery process, such as providing real-time feedback, offering diversified delivery services, and encouraging consumers to provide feedback and evaluations, which enhances their freedom of choice.

Timely delivery is one of the most concerning issues for consumers. Therefore, the delivery company should deliver as quickly as possible and accurately notify consumers of the delivery time. From the perspective of customer experience, cognitive dissonance caused by delivery delays can affect satisfaction and severely impair the trust and commitment of customers to the company (Esper et al., 2003.) In summary, improving consumer satisfaction is crucial for last-mile delivery, and only by enhancing consumer satisfaction, can the success and operational benefits of delivery service be genuinely achieved.

### **3 Drones in Logistics**

#### **3.1 The performance of drones in last-mile delivery**

In recent years, driven by industrial advancements, unmanned aerial vehicle (UAV) technology has significantly progressed. People's interest in Drones continues to grow, and their applications have expanded from entertainment and military tasks to include solutions for large-scale civilian delivery services. Logistics companies are investigating the application of drones for last-mile delivery of goods because of the development of UAV technological advances, as they offer versatility and ease of use (She & Ouyang, 2021.)

Based on research by Frachtenberg (2019), drones are considered a promising "last-mile" tool for package delivery, surpassing traditional car-based alternatives. This is primarily due to their ability to overcome challenges related to accessibility issues in residential areas, ground traffic congestion, and safety concerns. The transportation sector could undergo a fundamental shift if large-scale drone systems are successfully implemented. Drone operators, small aircraft, aerial traffic management, mobile hubs, and direct point-to-point deliveries would take the place of multiple drivers, fuel-powered transport vehicles, traffic on the highways, and centralized distribution hubs. The following all-encompassing change has been shown to reduce traffic congestion in places with inadequate road infrastructure, increase road safety, and improve accessibility in those locations.

The problems with traditional last-mile logistics, such as inefficiency, expense, and environmental damage, may be solved by drone delivery. Well-known companies such as FedEx, UPS, SF Express, and Amazon have been actively developing their own drone delivery systems, with Amazon being

one of the pioneers in exploring this field (Frachtenberg, 2019.) In 2013, Amazon first proposed the idea of using drones for package delivery, which garnered wide attention from scholars and businesses worldwide. Subsequently, companies like Google, Alibaba, and Ele.me also ventured into the realm of drone delivery. Google unveiled the Wing project in 2014 with the goal of investigating package distribution using tiny drones. In 2015, Alibaba Group experimented with delivering boxes of ginger tea to over four hundred customers in three Chinese cities. In 2016, Amazon successfully delivered a 5-pound package over more than seven miles using its Amazon Prime Air fleet (She & Ouyang, 2021.)

According to Wei et al (2023), a review and summary of existing literature reveal that in 2018, Ele.me led a revolution in China's food delivery industry by introducing the innovative concept of using drones for food delivery. They established the first batch of seventeen dedicated drone delivery routes specifically for restaurant takeout orders. Amazon received permission from the Federal Aviation Administration (FAA) in 2020 to use Prime Air delivery drones domestically. The most recent iteration of Prime Air's aircraft is engineered to expeditiously transport parcels, with a ten-mile delivery radius and a 30-minute delivery time guarantee. Moreover, in 2021, a drone base in Sichuan Province, China successfully deployed over one hundred drones. This strategic initiative effectively addressed the logistics challenges of delivering fresh matsutake mushrooms from remote mountainous areas. As a result, this exploration provided an efficient transportation solution for the local region.

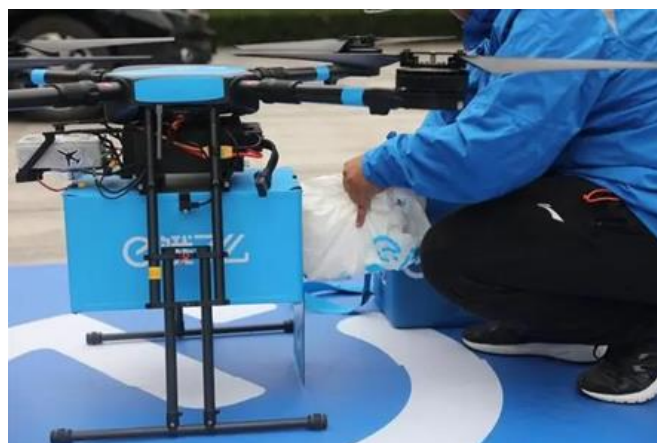


Figure 3. Ele.me Approved as China's First Food Delivery Drone Route (Zhizheng, 2018)

<https://baijiahao.baidu.com/s?id=1601797700690390268&#38;wfr=spider&#38;for=pc>

Drone-based transportation systems have many benefits, but they also face many difficulties. For example, Amazon stated that more than 86% of the cargo by weight is below the five-pound payload capacity of its Prime Air drones, requiring traditional delivery methods for the remaining shipments (Murray & Chu, 2015). While many towns have seen successful drone deliveries of groceries and clothes, there are still inevitable problems due to the drones' limited power and short battery life. If all deliveries were to originate from central warehouses, it would be affected by the limited quantity and performance characteristics of drones, which can only make single deliveries at a time. Therefore, to achieve economies of scale and timely deliveries, a large number of drones are required, alongside the need for more efficient service and operational plans to ensure sustainability and profitability (She & Ouyang, 2021).

Additionally, She & Ouyang (2021) introduced that a news report by CNBC in 2019, UPS recently established a subsidiary approved by the Federal Aviation Administration (FAA) to provide delivery services using both trucks and drones. The innovation of this service lies in significantly reducing the overall delivery time when trucks transport packages to customers who can be served by drones. Drones can be transported over long distances using trucks and launched near customer communities, which is commonly referred to as the "last mile." By combining drones with traditional delivery trucks, a truck carrying drones and all customer packages departs from a central warehouse. Drones are deployed from a delivery vehicle to carry products to specific consumers while the driver makes deliveries. While the drone is in flight, the driver does not need to get involved. The drone then heads back to the truck and the car moves on to the next customer's location. The driver oversees loading items, changing power sources, and getting the drone back onto the truck and securing it during the journey (Murray & Chu, 2015). The goal of this project is to bring together the cost-effectiveness and power conservation of traditional transportation methods with the adaptability of drones.

What is more, to enhance the efficient delivery capability of drones, an increasing number of innovative technologies have been developed in recent years. Among them, addressing the challenge of continuous operation with limited battery capacity has become a top priority. Amazon, as an e-commerce giant, has pioneered an innovative logistics delivery method by utilizing a collaborative system of drones equipped with movable stations. This system achieves continuous delivery service by efficiently replenishing the materials needed for drones. To achieve this goal, researchers

have proposed the concept of aerial warehousing and delivery service, which replaces the traditional truck-based model with flying warehouses known as Airborne Fulfilment Centres (AFC). In this mode, the flying warehouse carries inventory, and when customers place orders, drones descend from the sky to transport the packages. The flying warehouse acts not only as a floating cargo carrier but also as a charging platform, allowing the dispatch of loaded drones from mid-air and saving drone battery consumption. With this new delivery system, AFC, customers can receive their packages within just 10 minutes, expanding the opportunities for Amazon Prime members to utilize drone transportation (Jeong et al., 2022.)

### 3.2 Different types of drones

Unmanned aerial vehicles (UAVs) exhibit variability in their performance and can be categorized according to several criteria. This article summarizes and reviews existing literature to explore this classification. UAVs can be divided into groups according to Hassanalian & Abdelkefi (2017) based on performance attributes such as size, wingspan, wing launching range, highest height, velocity, durability, as well as manufacturing cost. These parameters serve as important design criteria for distinguishing several types of UAVs and providing a useful classification system. For example, drones can be categorized based on weight into micro drones, tactical drones, and strategic drones. The range and endurance of a drone determine its flight capabilities, while wing loading affects its flight characteristics. Maximum altitude indicates the highest altitude a drone can reach, and different engine types have an impact on performance.

Singhal et al. (2018) propose that UAV systems can be classified into multiple types based on aerodynamics, including fixed-wing aircraft, helicopters, multi-rotor UAVs, paraglider UAVs, and gliders. These unmanned aerial vehicles, or UAV, systems are now in the development stage, having adhered to the principles of binary coding throughout the design and construction phases. Each type of UAV system is tailor-made according to specific mission requirements and utilizes its own set of components and commercial technologies.

As a supporting technology for unmanned aerial vehicle (UAV) delivery in smart cities, drones offer multiple options for logistics companies in the last-mile delivery. Based on their manufacturing, delivery drones are categorized into **multi-rotor drones** and **fixed-wing drones**. Regarding payload

ability, adaptability, velocity, flight range, longevity of batteries, and departure or arrival requirements, each model has pros and cons of its own. When selecting the most suitable drone type for last-mile delivery, logistics companies take into consideration factors such as their specific needs, budget, terrain of the target area, and regulatory restrictions. Therefore, several types of drones possess unique strengths and are suitable for specific scenarios. Logistics companies make their choices based on actual circumstances (Sun et al., 2023.)

### **Multi-Rotor Drones**

Octocopters, hex copters, and quadcopters are examples of multi-rotor drone designs. They could vertically take off and hover, making them ideal for dense last-mile deliveries in urban or compact areas. Although multi-rotor drones usually have small payload capacities, they can quickly and flexibly reach their destinations to deliver packages. The most common kind of delivery drones are multi-rotor aircraft; now, businesses often utilize quadcopters or octocopters for testing. Aerial application by spraying, delivery of goods, photographing, and crowd surveillance are some of their frequent uses. Multirotor drones may fly for shorter periods than fixed-wing drones, and those with an effective cargo capacity can stay in the air for approximately 25 minutes on average. Nevertheless, multi-rotor drones remain one of the most popular and widely used technological innovations, bringing significant convenience and benefits to various industries (Alkouz et al., 2021.)



Figure 4. Multi-rotor Drone (Flemons et al., 2022)

### **Fixed-Wing Drones**

Like conventional aircraft, fixed-wing drones have a longer range and a larger payload capacity. They are employed for long-distance logistics delivery, covering a larger region (Hassanalian & Abdelkefi, 2017). According to Alkouz et al. (2021), drones with fixed wings combine vertical takeoff and landing with fixed-wing characteristics, which enables them to fly at higher speeds and over a longer distance. They can usually fly for a maximum of forty-five minutes, making them ideal for last-mile delivery jobs that need to cover wider areas. They do, however, need specific runways for take-off and landing because they are unable to hover in one location.



Figure 5. NM& F300, new high performance fixed wing Drone (2016). Embention  
<https://www.embention.com/news/nmand-f300-fixed-wing-uav/>

### 3.3 The drone delivery mode for last-mile delivery

This article divides the many drone methods used for delivery in the final mile into three categories: drone-independent delivery, drone-vehicle delivery in parallel, and coordinated drone-vehicle delivery. This is based on an examination and synthesis of the body of available literature. These delivery methods create new prospects for the growth of the logistics industry while effectively dealing with the issues of drone delivery in the last mile.

#### Drone-independent delivery mode

Curlander et al. (2017) proposed the concept of multi-level (ML) fulfillment centers. Before products are dispatched to customers, fulfillment centres—typically big, single-story warehouse facilities with ample capacity—are used to temporarily store goods. Unlike traditional fulfillment centers, ML fulfillment centers can feature one or multiple landing locations and one or multiple deployment locations to accommodate drones. These drones can transport at least some items

from the fulfillment centre to customer-associated locations. What sets ML fulfillment centers apart from traditional ones is their ability to include multiple levels (i.e., floors) in accordance with zoning regulations in different regions. This design innovation significantly enhances the efficiency and flexibility of fulfillment centres. The isometric view in Figure 6 depicts a multi-level fulfillment centers (ML) designed for the landing and take-off of drones.

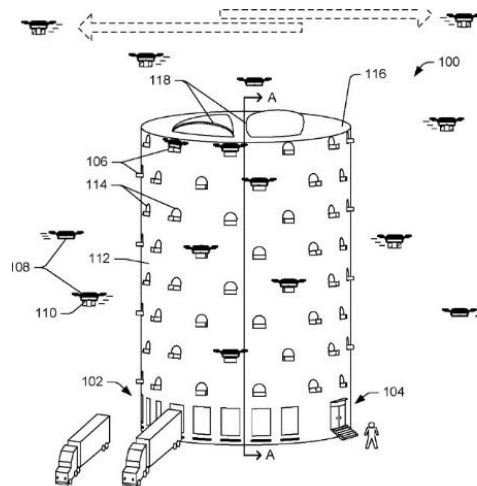


Figure 6. Isometric view of a multi-level fulfillment center designed for drones (Curlander et al, 2017)

The ML fulfillment depots one hundred resembles a high-rise office building but is customized to accommodate goods, drones, and personnel access. It includes a cargo dock position 102 located near the bottom, which receives bulk goods, supplies, and other items. Within the ML fulfillment centers one hundred, the goods undergo various processing operations such as loading, sorting, boxing, or packaging for delivery. The cargo dock position 102 supports traditional delivery methods, while a self-service position 104 allows customers to retrieve their items, reducing delays. Items can be temporarily stored in the self-service position 104, such as lockers or rooms accessible by staff members (Curlander et al., 2017.)

Therefore, the drone delivery model is becoming increasingly feasible. ML fulfillment centers have been designed to accommodate the configuration of drones, where drones receive goods from the centers and deploy them to specific delivery destinations. In some implementation cases, at least a portion of the drones fly within the fulfillment centers, allowing hundreds or even thousands of orders to be processed using these drones every day. Additionally, the centers are equipped with

charging, inspection, and maintenance facilities to support drone operations. Self-service points have also been set up for customers to conveniently collect their packages. Furthermore, some packages are sorted and loaded by robots, enhancing efficiency (Wei et al., 2023.) This innovative concept of multilevel drone fulfillment centers holds the potential to bring greater convenience and efficiency to urban delivery.

### **Parallel drone-vehicle delivery mode**

Murray & Chu (2015) initially brought attention to the groundbreaking delivery plan known as the Parallel Drone Scheduling Traveling Salesman Problem (PDSTSP). Under this plan, distribution tasks are performed independently by trucks and drones. Without coordinating with the vehicles, drones take off from the distribution centre (warehouse), finish their jobs, and land back. The advantage of this parallel delivery scheme is that it maximizes the flexibility and speed of drones while also leveraging the trucks' ability to transport massive quantities of goods. Drones are well-suited for quickly completing short-distance delivery tasks, especially in urgent situations or areas with traffic congestion. On the other hand, trucks are capable of long-distance transportation and have a higher cargo capacity.

In PDSTSP, the delivery paths of the drones and trucks are independent, and there is no need for communication or coordination between them. Each drone and truck have its own delivery route planning, determining the optimal path based on real-time logistics information and delivery requirements (as shown in Figure 7). This independent delivery mode improves delivery efficiency while reducing the complexity and delay that may arise from coordinated delivery (Murray & Chu, 2015).

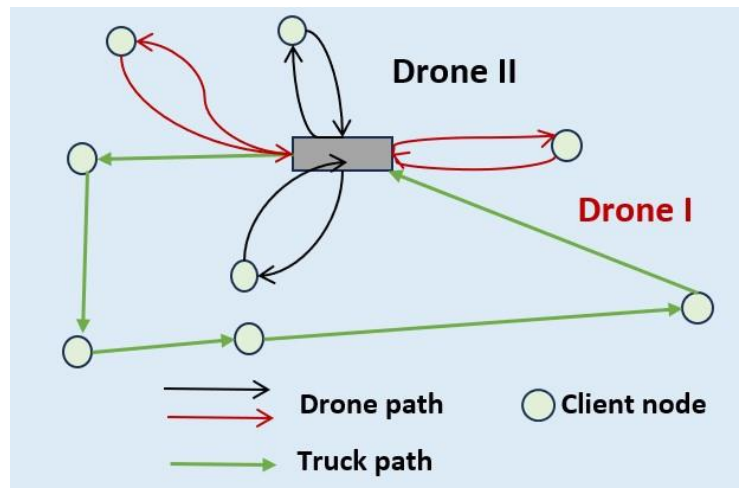


Figure 7. Parallel distribution mode of drones and vehicles.

In summary, PDSTSP provides an innovative delivery scheme that achieves efficient and flexible delivery through the parallel operation of drones and trucks. It is suitable for various delivery scenarios and can meet customer demands to the greatest extent possible.

### Coordinated drone-vehicle delivery mode

Early research on the collaborative delivery problem between drones-vehicles summarized a drone take-off and landing delivery in the same truck mode (as shown in Figure 8). The flying side-kick traveling salesman problem (FSTSP), which was introduced by Murray & Chu (2015), stated that the traditional pairing of delivery trucks and drones involves the drone taking off from the truck at customer nodes, making the delivery, and returning to the truck. Simultaneously, during the truck's delivery process, it can engage in collaborative operations with the drone. This approach expands the effective range of the drone, enabling it to reach remote customers.

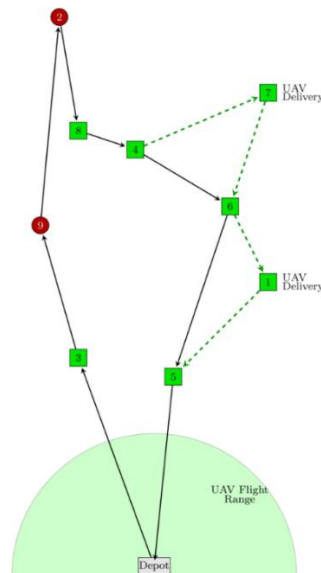


Figure 8. A drone take-off and landing delivery in the same truck mode (Murray & Chu ,2015)

The delivery truck carrying a drone and all customer packages departs from the warehouse. Upon reaching Customer 4, the drone is activated to serve Customer 7. Meanwhile, the truck proceeds to Customer 6 to retrieve the drone, which later serves Customer 1.

However, the traditional drone take-off and landing delivery in the same truck mode suffered from long waiting times, leading to reduced delivery efficiency. As a result, there has been literature studying the drone take-off and landing delivery in different trucks mode, as shown in Figure 9. In this mode, the drone operates independently of the ground vehicle for take-off, landing, and completing the delivery tasks. This mode fully utilizes the flexibility and speed of drones, making it suitable for short-distance, emergency situations, or congested areas (Wei et al., 2023.)

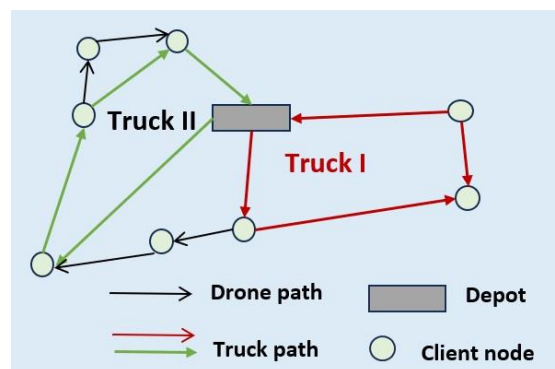


Figure 9. The drone take-off and landing delivery in different trucks mode.

Additionally, some studies consider using the public transportation network as platforms for drone take-off and landing, drone-public transport coordinated delivery mode that it can maximize energy utilization and improves delivery efficiency. As shown in Figure 10, drones collaborate with public transportation vehicles such as buses and subways for delivery purposes. For example, Lasla et al. (2019) proposed a solution to increase the mission coverage distance and time of drones, thus enhancing their performance. The implementation involves drones riding on existing land-based public transportation vehicles, such as city buses, along their routes to reach their designated mission locations. In this scheme, the drones are responsible for transporting goods from distribution centers to public transportation hubs, and then the goods are transported to their final destinations by the public transportation vehicles. Drones' mission and coverage capabilities are impacted by their short flying time, which is a result of their low rechargeable batteries. Therefore, it is necessary to utilize public transportation infrastructure, such as city buses, as much as possible to reduce the energy consumption during drone flights. This delivery mode can fully leverage the extensive coverage and efficiency of the public transportation system, enabling deliveries over a larger area.

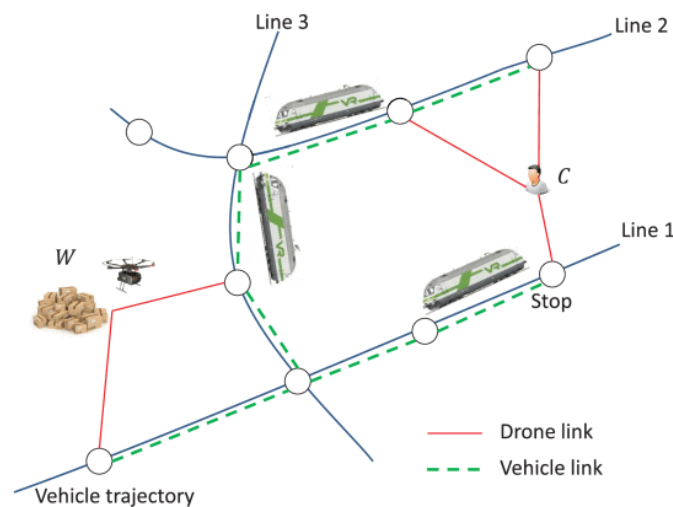


Figure 10. The Drone-public transportation collaborative delivery mode (Lasla et al, 2019)

There are also several research in the literature on the integrated drone pick-up and delivery method. For example, Ham (2018) founded two methods for integrating drone missions in delivery. As shown in Figure 11:

- The first method is that after completing package delivery, drones can return to the truck for further package distribution according to demand.
- The second method is that drones can also be used to retrieve products from customers' places of residence and deliver them back to the vehicle or storage for additional distribution.

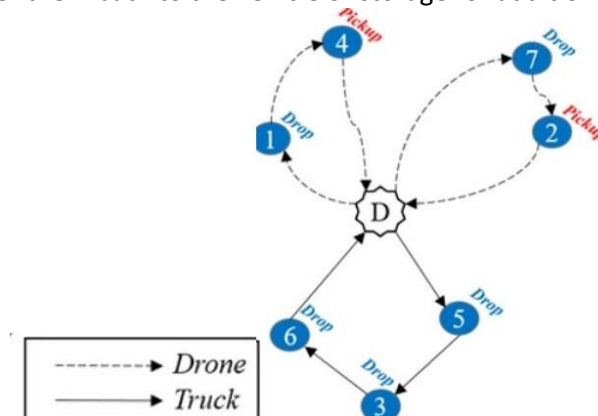


Figure 11. Mode of drone delivery and pickup (Ham, 2018)

In this mode, drones are not only responsible for delivering goods to the destination but also capable of picking up goods at the destination. By reducing human involvement, this mode improves delivery efficiency. This integrated pick-up and delivery mode demonstrates logic and novelty (Wei et al., 2023.) In conclusion, collaborative delivery—in which drones can be deployed, recharged, and recovered on vehicles—is the newest way of delivery. It inherits the advantages of traditional transportation vehicles while improving their disadvantages. This mode is considered a potential option for logistics companies seeking a more convenient, efficient, and cost-effective last-mile delivery solution.

### Summary of three different delivery modes

This summary compares three delivery modes: drone-independent delivery, parallel drone-vehicle delivery, and coordinated drone-vehicle delivery. It provides a comprehensive evaluation and comparison in terms of delivery efficiency, delivery carrying capacity and delivery cost (Wei et al., 2023).

The comparison study (as presented in Table 1) leads to the following results. Firstly, in the drone-independent delivery mode, it offers high efficiency and low cost, but has limited capacity and cannot manage large-sized goods. Secondly, in the coordinated drone-vehicle delivery mode,

there is no limitation on delivery capacity, as both drones and trucks can transport small and large-sized goods. The cost falls within a moderate range, but the delivery time is slow. Lastly, in the parallel drone-vehicle delivery mode, compared to the other two modes, it incurs higher costs due to considering the average cost of both drones and trucks. Its delivery capacity is considerable, but its efficiency is moderate, contingent on the average delivery time of both vehicles and drones. Drones are responsible for delivering small-sized goods, while trucks manage large-sized goods.

Reason	Deliver efficiency (Fast, medium and slow)	Delivery carrying capacity (Large and small)	Delivery cost ( high, medium and low)
<b>Drone-independent delivery</b>	Fast	Small	Low
<b>Parallel drone-vehicle delivery</b>	Medium	Large/Small	High
<b>Coordinated drone-vehicle delivery</b>	Slow	Large/Small	Medium

Table 1. Comparison of three delivery modes.

### 3.4 Products delivered by drones

In drone delivery mode, it is necessary to consider the payload capacity and limited range of rotary-wing drones. Therefore, the objects being delivered are often more specific. For example, drones can be used to transport small packages such as express deliveries, documents, letters, and electronic products using their cargo holds. It can also be used for delivering food and beverages such as takeout, coffee, fast food, and snacks. Drones are capable of transporting emergency medical supplies like medications, emergency equipment, and blood samples. Furthermore, they can be utilized for delivering items with special purposes, such as construction tools, surveying equipment, scientific instruments, and agricultural supplies (Wei et al., 2023.)

Drones have been extensively used internationally in the past few years to deliver healthcare products, including blood. Drones are being investigated increasingly as a potential answer to the problems associated with delivering medical goods, such as last-mile organ delivery, vaccinations, medications, emergency blood supply, and diagnostic tests. According to Eichleay et al. (2019), for instance, Zipline has been using drones to transport up to three liters of blood to medical facilities in as little as thirty minutes on behalf of the Rwandan government since 2016. Moreover, Xia et al. (2023) provided proof of an Unmanned Emergency Blood Dispatch (UEBD) system that is intended

to offer prompt emergency response for occurrences involving severe trauma. The Binjiang Campus of Zhejiang University School of Medicine's Second Affiliated Hospital has effectively adopted this approach. Since organs and elements of blood can only be obtained through donations and cannot be produced artificially, it is crucial to protect them. In this instance, the remaining mile can be covered by drone transportation, lowering the possibility of organ damage from lengthy transit durations (Amicone and others, 2021).

And in January 2020, Chinese company Meituan introduced innovative contactless delivery services to address the spread of the novel coronavirus pneumonia and reduce the risk of cross-infection. In February of the same year (as figure 12), drone delivery services were launched in Fengxian District, Shanghai, delivering live fish, fresh vegetables, and other daily necessities to isolated residents within just five minutes. In April, a courier company in Wuhan, Hubei Province successfully used drones to deliver medical and epidemic prevention supplies to Wuhan Jinyintan Hospital, demonstrating the unique advantages of contactless delivery in drone logistics (Wei et al., 2023.) These initiatives highlight the potential of drone technology in enhancing healthcare services, especially in remote areas or situations where timely access to medical supplies is critical. By utilizing drones for medical transport, logistical challenges can be overcome, rapid responses can be achieved, and lives can be saved by providing necessary medical support.



Figure 12. Shanghai's Fengxian District uses drones to deliver food. From Mingsheng Li [Photograph], by Xinmin Evening News, 2020.

<https://baijiahao.baidu.com/s?id=1658847085908381943&#38;wfr=spider&#38;for=pc>

Additionally, drone delivery scenarios have certain particularities. When conducting drone delivery, it is necessary to comply with local regulations and requirements, especially regarding safety, privacy protection, and restrictions and permits for specific items. And drone delivery needs to

consider factors such as weather conditions, flight distance, charging time, and the flight capabilities of the drones. The applicable range of products for drone delivery will depend on technological advancements and legal regulations.

However, there is currently limited research directly applicable to general parcel last-mile delivery practices. Existing studies mostly simplify the problem into ideal mathematical planning models and use specific algorithms for solutions. These studies often overlook practical environmental factors that drones may face during actual operations, such as communication limitations, terrain obstacles, and airspace control. Therefore, more innovative solutions need to be proposed, considering these practical environmental factors to address the challenges in drone delivery. This may involve developing intelligent path planning algorithms to overcome terrain obstacles and avoid other aircraft. It would also involve establishing robust communication and management systems between drones to ensure safety and collaboration. And relevant policies and regulations need to be formulated to govern and supervise drone delivery activities, ensuring their safety and compliance (Wei et al., 2023.)

## **4 Risks related to last-mile drone delivery**

Thanks to ongoing advances in science and technology, drone delivery is a new delivery method that can boost efficiency and speed. However, there are dangers connected to this delivery strategy as well, especially when it comes to last-mile deliveries.

### **4.1 The general risks of last-mile drone delivery**

Although drone delivery has made some progress in the last-mile delivery field, it also brings many risks and challenges. For example, it is necessary to further improve the efficiency, accuracy, stability, and safety of drone delivery, reduce environmental pollution, track package delivery, prevent occasional delivery delays, and keep pace with advanced technology. Additionally, it is essential to consider the technical limitations of drone range and delivery distance to ensure that customer needs within the delivery range can be met. The societal effects of drone delivery must also be considered. It may cause concerns about drone safety among residents due to its frequent appearance in the sky (Yoo & Chankov, 2018.)

The risks related to last-mile drone delivery were categorized by Mismar et al. (2022) using the Bayesian Belief Network (BBN) model, and the relative probabilities and severities of each risk were ascertained. The study's conclusions show that the biggest risks are IT, natural disasters, and privacy issues. Furthermore, it proposed a last-mile delivery risk framework (as shown in Figure 13) which identifies and lists the relevant nineteen risks, categorizing them into five main criteria: financial risk, operational and technological risk, environmental risk, quality risk, and legal-related risk. Mapping these nineteen risks into three separate situations leads to the following conclusions: The Triple Bottom Line (TBL), which considers social, ecological, and economic factors, is the foundation of the first scenario. The strategy known as TBL states that minimal results in terms of the economy, society, and environment should be attained. Whether the risk is internal or external to the organization determines which of the two scenarios applies. The final scenario classifies the risks into financial, quality, and operational risks based on their impact. This study will help companies that provide logistics services choose the best last-mile delivery options. This will result in improved competitiveness, market share, and reduced delivery cost.

Criteria	Risk	Reference	TBL			Internal/External		Financial/Quality/Operational	
			Economical	Environmental	Social	Internal	External	Financial	Quality
Financial Risk	Customers unavailability	[15], [16], [17], [24]	X				X	X	
	Package damage/loss	[21], [23], [25], [65], [66]	X				X	X	
	Customers Density	[18], [25], [26]	X				X	X	
	Cash on delivery		X			X		X	
	Shipment return		X				X	X	
	Competition		X				X	X	
	Economic conditions		X				X	X	
Operational & Technical Risk	Traffic congestion	[19], [67], [68], [25]		X			X		X
	Size and weight limitation	[69]	X			X			X
	Capacity fluctuations		X			X			X
	IT risks		X			X			X
	Delivery location identification		X				X		X
Environmental Risk	Noise pollution	[19, 25]		X			X		X
	Harmful emission	[19], [25], [67], [68]		X			X		X
	Natural disaster			X			X		X
	Operations waste			X		X			X
Quality Risk	Delivery inconvenience	[23], [70]	X			X			X
	Delivery window	[18], [71]	X			X			X
	Customer Service quality	[72], [25], [27]	X			X			X
	Delivery time	[3], [27], [29]	X			X			X
	Privacy concerns				X	X			X
Legal related risk	Workforce Protection	[22]			X	X			X
	Laws and regulations				X	X			X

Figure 13. Last Mile Delivery Risk Framework (Mismar et al., 2022)

The potential risks connected to drone delivery were outlined in the scientific assessment done by Kellermann et al. (2020), including security concerns, privacy hazards, and legal issues. Compared to ground vehicles, drones face greater safety challenges at the security level. For instance, weather conditions can impact drone delivery, especially high winds, rain, and snow, which can reduce flight efficiency and even pose risks to flight safety. Additionally, drones encounter technical limitations in last-mile delivery, such as limited payload capacity and endurance, which restrict their flight time and result in weaker delivery capabilities compared to traditional transportation methods (Wei et al., 2023).

## **4.2 Some solutions in legal and quality risks**

### **Legal related risk**

The quick growth of the drone business has resulted in several risks and restrictions imposed by airspace management regulations. These include the unauthorized entry of drones into military restricted areas and incidents such as crashes and injuries caused by im-proper operation or sudden malfunctions during flight. Consequently, the relevant governments have put in place the necessary laws and policies to direct the drone industry's growth in a safe and orderly manner. For instance, in 2017, US President Donald Trump signed a memo launching the Unmanned Aircraft Systems Integration Pilot Program. The program's goals were to lessen onerous government regulations, hasten the integration of drones into the nation's airspace, and assist in the expansion of e-commerce in general. In 2019, China also implemented drone-related airspace management regulations, emphasizing aerial flight management and drone operations (Wei et al., 2023.)

However, airspace management policies can also limit the development and widespread application of drones. Marshall (2021) pointed out that autonomous drones face regulatory challenges in the United States, resulting in limitations on their use. Companies such as Amazon, DHL, and UPS hope to eventually lift these regulations to fully utilize the potential advantages of this technology. Despite efforts made, the risks associated with drone delivery remain a significant issue that requires appropriate risk assessment and management strategies before implementation. In contrast, Li (2021) emphasized that the Civil Aviation Administration of China has conducted comprehensive risk assessments for drones operating in densely populated areas and approved trial operations of urban environmental coordination drone services by Antwork. Such assessments are

crucial in mitigating potential risks associated with drone delivery and ensuring safe and sustainable service operations.

### **Quality risk**

The many modalities of the revolutionary drone delivery mechanism can effectively mitigate the quality concerns related to last-mile deliveries. Murray & Chu (2015) introduced the Flying Sidekick Traveling Salesman Problem (FSTSP), which deals with drone and vehicle coordination. Drones can recharge, launch, and recover on vehicles in this mode where they are used as transport carriers. This delivery model efficiently resolves the efficiency constraints and takes advantage of the long endurance range provided by the vehicles.

Furthermore, Yoo & Chankov (2018) identified an innovative delivery idea designated "Drone Delivery with Autonomous Mobility (DDAM)" that uses a combination of drone and self-driving car technology to meet the order demand of high delivery, short delivery, and solves future urban logistics challenges like time and complex traffic congestion. As stated by Mismar et al. (2022), it may efficiently address the quality risks related to delivery inconvenience, delivery window, customer service quality, and delivery time in the last-mile drone delivery risk classification framework. These problems could be solved if DDAM is used as a last-mile delivery method.

## **5 Methodology**

This research aims to help logistics firms reduce the potential risks involved in last-mile drone delivery. The procedure entails identifying, classifying, and recommending remedies for risks related to last-mile drone delivery. Furthermore, this research will examine the potential hazards associated with drones in last-mile delivery from a theoretical standpoint and propose feasible solutions to facilitate last-mile drone delivery.

### **5.1 Structure of the whole research process**

The study employs a qualitative research methodology, including semi-structured interviews to gather data and assist logistics organizations in mitigating the risk associated with drone delivery

in the last mile. The goals of the study are met, and its issues are tackled by using qualitative research to analyse the risks connected with drone use in last-mile deliveries from the standpoint of relevant literature. Conversely, to learn how these linked hazards are avoided and how they address them, semi-structured interviews are done with three distinct logistics organizations that use drone delivery. The feedback data gathered from interviews is finally compared, examined, and coupled with knowledge from relevant literature and real-world examples. The specific steps of the research process are illustrated in the diagram below (Figure 14):

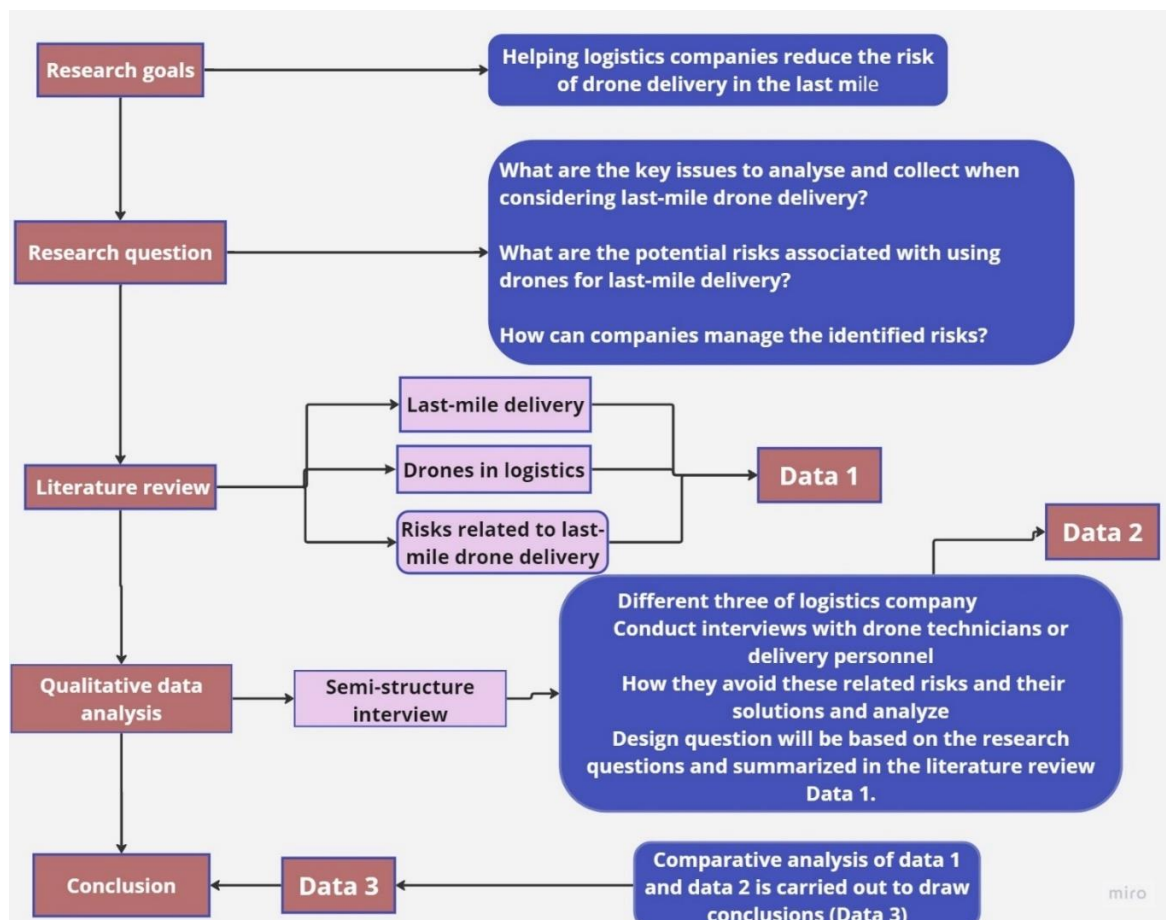


Figure 14. Framework of research steps.

## 5.2 Qualitative research

Cypress (2015) defines qualitative research as an approach to study that does not rely on quantitative methods such as statistical analysis to draw conclusions. In comparison to quantitative research, qualitative research not only provides numerical data, statistical models, and investigates causal relationships, but also delves into understanding the underlying reasons behind related

phenomena and conducts exploratory studies. However, qualitative research also has its limitations, as experts with a sceptical view of methodology point out its lack of objectivity, universality, practicality, and its inclination towards subjective narratives, which can generate controversy.

This study makes use of qualitative research for two reasons: first, many related studies that tackle the problem of last mile delivery are quantitative in character, obtaining novel techniques or network designs for last mile delivery in the not-too-distant future through testing analysis and pertinent experimental data. This indicates that the aim of the study is to use qualitative research methods to offer an organized and scalable framework for delineating and contrasting the various risk concerns related to last-mile drone delivery. However, this work uses qualitative research to gather data face-to-face without interfering with the natural environment because of the distinctiveness of this kind of research (Cypress, 2015). Additionally, the researchers independently collect data without relying on tools developed by others or single-source data, including interviews, newspaper articles, magazines, and other formats.

### **5.2.1 Literature review**

According to Snyder (2019), the review of literature is a study technique that, by summarizing prior research findings, can significantly and successfully enhance theoretical progress. A literature review can answer research problems and play a crucial role in developing theoretical frameworks and conceptual models by incorporating various empirical research findings and points of view. Therefore, this paper chooses to conduct a qualitative study using one of the methods of literature review to address the limited information provided in the current literature regarding specific factors in the risk analysis of last-mile drone delivery. Through this method, an attempt will be made to establish a structured and scalable framework to comprehensively describe and compare the risk issues associated with last mile drone delivery.

"Last-mile delivery," "Drones in logistics," and "The related risks of last-mile drone delivery" are the three key issues of this study's literature evaluation. These themes were chosen because they are critical aspects of the research purpose and questions. Through in-depth study and comprehensive overview of these three themes, key factors related to the research questions can be identified, and the necessary sources and materials can be determined. The goal of the research is to

help logistics firms lower the risks involved in the last-mile drone delivery. The following are the three research questions:

- What are the key issues to analyse and collect when considering last-mile drone delivery?
- What are the potential risks associated with using drones for last-mile delivery?
- How can companies manage the identified risks?

Due to collect materials, this study used various methods, including using academic search engines and professional databases such as Google Scholar, Google Search Engine, and the JAMK Library Database; manually searching for professional books, journals, and publications, such as ScienceDirect and IEEE; referencing the bibliographies of other literature reviews, books, and academic articles; and seeking advice from experts and mentors in the field of logistics. Using pertinent keywords associated with the three themes—such as "last-mile," "last-mile delivery," "drone delivery," "type of drones," "safety," "accuracy," "risk assessment," "risk category," and phrased statements centred around the pertinent questions—this study searched for materials during the material collection phase (as shown table 2). In addition, the study chose a variety of sources, including books, periodicals, websites, news stories, academic publications, theses, and periodicals, to guarantee the validity, viability, and dependability of its sources.

Last-mile delivery	Drones in logistics	Risks related to last-mile delivery
<ul style="list-style-type: none"> <li>•Keywords of "last-mile" and "last-mile delivery"               <ul style="list-style-type: none"> <li>•Why it matter and development</li> </ul> </li> <li>•What the company is focusing on right now</li> </ul>	<ul style="list-style-type: none"> <li>•Keywords of "type of drones"and "Drones delivery"</li> <li>•How drones and what the criteria are for classification               <ul style="list-style-type: none"> <li>•Different of drone delivery</li> </ul> </li> <li>•What kind of products can be delivered by last mile drone delivery?</li> </ul>	<ul style="list-style-type: none"> <li>•Keywords of "safety", "accuracy", "risk assessment" and "risk category"</li> <li>•Defining the general risks of last-mile drone delivery               <ul style="list-style-type: none"> <li>•How is risk classified? safety risks? internal or external?</li> </ul> </li> <li>•A researcher's suggestion or new improvement to solve the general risks of drone delivery in the last mile.</li> </ul>

Table 2.Theory search process for research topics

### 5.2.2 Interview

The usefulness and applicability of this work will be ensured by combining semi-structured interviews and text analysis with qualitative research methods to assess the data gathered. Through the review of relevant literature, some information has been acquired regarding the risks that relate to using drones for last-mile deliveries. Therefore, this study conducted interviews with three different logistics organizations to learn how they minimize these risks and investigate alternative solutions to further confirm the feasibility and credibility of the information supplied in the literature review. The viewpoints and experiences of the interviewees will also be examined.

Based on the flexibility, consistency, and theoretical impetus of interviews, this study opted for a semi-structured interviewing approach conducted through online face-to-face communication. To make sure that the information acquired from the interviews could address the research questions, the interview questions were formulated in accordance with the notions, objectives, and research questions presented in the previously cited literature (as noted in Appendix 2). Additionally, email invitation letters were addressed to the relevant logistics businesses to confirm the viability of the interviews; they are included in Appendix 1. The interviewed companies include Lentola Logistics Oy in Finland, DJI, and a company in China (anonymous), and in view of the ethical principles of the research, the logistics company from China wishes to remain anonymous. The interviewees consist of drone technicians, delivery personnel, and sales representatives from the three different logistics companies (table 3):

Logistics company	General business	Interviewees	Time
<b>Lentola Logistics Oy</b>	Lentola Logistics Oy is a Finnish logistics company specializing in last-mile drone delivery. It has its own unique Lentola delivery system and Lentola drones specially developed and designed for Nordic people and have obtained US and European patents.	Managing director	90mins
<b>DJI</b>	A technology company that produces and sells drones. Its products include consumer, commercial, and professional drones, including one of the DJI Flycart 30 models that specialize in last-mile delivery services.	Drone's technicians and sales representatives	60mins
<b>A logistics company from China (anonymous)</b>	Due to ethical principles, the company hopes to conduct interviews in anonymous which has a research project on drone delivery. Through the operation and testing of drones, the accuracy of drones can be determined.	Drone's technicians, delivery personnel, and sales representatives	75mins

Table 3. Semi-structured interviews of three logistics companies

## 6 Result and Analysis

The data from the semi-constructed interviews with three different logistics companies will be compiled and analyzed in this chapter. The following details regarding the dangers of drone delivery in the last mile are based on pertinent information gathered from the interviews and are displayed in table 4 below:

<b>Precise positioning of drones</b>	<ol style="list-style-type: none"> <li>1. Drones rely on RTK (real-time motion) and powerful GPS signals for positioning.</li> <li>2. Used to collect latitude, longitude, and ground height, and continuously calibrate to achieve precise positioning and ensure accurate delivery.</li> <li>3. The use of some less accurate inertial systems may result in collisions with trees during deliveries.</li> <li>4. Drones face certain technical challenges in computer vision systems during winter conditions."</li> </ol>
<b>Potential Risks in Last-Mile Drone Delivery</b>	<ol style="list-style-type: none"> <li>1. External risks include animal disturbance (such as birds), terrain conditions, radar interference, weather conditions, wind speed, power lines, Human accidents, and local regulations.</li> <li>2. Internal risks involve the drone's payload capacity, flight endurance and GPS signal reliability.</li> <li>3. The most important risks should be considered: GPS signals, weather conditions such as rain, fierce winds and wind speeds, and human-caused accidents</li> </ol>
<b>The company's solution with potential risks</b>	<ol style="list-style-type: none"> <li>1. Chinese companies: Take preventive measures, when choosing a drone, you need to understand factors such as wind resistance, rain protection, obstacle avoidance, and the ability to return home autonomously. Weather conditions and wind speed also need to be considered before flying.</li> <li>2. DJI: The DJI Flycart 30 drone uses RTK technology and has an IP55 rainproof rating.</li> <li>3. Lentola Logistics Oy: attempt a successful landing with the help of the best radar and vision systems. Lentola's drone adopts a fixed-wing structure. The design structure of the drone has been patented and applies an efficient anti-icing system.</li> </ol>
<b>Drone delivery of goods and Prospects</b>	<ol style="list-style-type: none"> <li>1. The types of goods delivered by drones include express packages, documents, letters, and takeaway food and depend on the weight ability and endurance of the drone itself.</li> <li>2. The delivery scenario of DJI drones is related to the weight of the goods. These scenarios include maritime transport (short distances or establishing base stations), emergency transport (flood control, firefighting, and rescue operations) and vertical transport (transporting supplies from downhill to the top of a mountain).</li> <li>3. Special shipments of pharmaceuticals and blood products are a growing trend in future transportation.</li> <li>4. Chinese logistics company technicians are dubious about the drones' weight and landing location in the concurrent delivery strategy including trucks and drones.</li> </ol>

Table 4. Summarize of Semi-structure interview

## 6.1 Precise positioning of drones

According to the technical personnel from these three different companies, in the last-mile delivery, drones primarily rely on RTK (Real-Time Kinematic) and strong GPS signals for positioning. These technologies are used to collect latitude, longitude, and ground height, continuously calibrating, and achieving precise positioning to ensure accurate delivery. The technical personnel from the Chinese logistics company also mentioned that the application of GPS depends on the number of satellites that the drone can detect. During autonomous flight, drones require as many satellites as possible for positioning. Therefore, the more satellites they can detect, the smoother and safer the flight will be. Lentola logistics Oy also emphasized the necessity of GPS, as using some inertial-based systems with lower accuracy could potentially result in collisions with trees during delivery. Additionally, drones face certain technical challenges in terms of computer vision systems during winter conditions.

## 6.2 Potential Risks in Last-Mile Drone Delivery and solutions

### Internal and External Risks

The respondents stated that there is some danger associated with last-mile drone delivery, resulting in getting broken down into internal and external risks. External risks include animal interference (such as birds), terrain conditions, radar disturbances, weather conditions, wind speed, power lines, human-induced accidents, and local regulations. Internal risks involve the drone's payload capacity, flight endurance, and GPS signal reliability.

The sales personnel from DJI emphasized that the most significant factor affecting the DJI Flycart 30 (as shown figure 15) drone delivery service is the GPS signal. When the GPS signal is weak, the drone is unable to accurately identify its position, assess weather conditions, recognize altitude, monitor temperature, and detect obstacles in its flight environment. Lentola logistics Oy stated that the greatest potential risk for drone delivery, whether in winter or summer operations, is weather conditions such as rain and strong winds. Additionally, considering risks from a different perspective, human-induced accidents are identified as a major risk factor. Technical personnel from a logistics company in China also pointed out that wind speed and weather conditions have

the most significant impact on delivery, as sudden factors can interfere with the flight environment which impact is significant in mountainous areas, while in urban areas, it is the opposite.



Figure 15. DJI FC30 meets the needs of material transportation from mountains, shores, rural transportation and various emergency scenarios. (2023). DJI News

<https://www.dji.com/cn/newsroom/news/fly-cart-30-cn>

### **The company's solution**

Regarding the DJI Flycart 30 drone, when facing weather and compass interference, DJI suggests flying the drone in open areas and considering the use of RTK technology. The drone has an IP55 rainproof rating. Interviewees from a Chinese logistics company expressed that there is currently no workable solution for external risks and can only take preventive measures. Due to the uncertainties involved in drone delivery, it is important to understand factors such as wind resistance, rainproof capabilities, obstacle avoidance ability, and whether the drone can autonomously return when choosing a drone. Additionally, it is necessary to consider weather conditions and wind speed before flight.

In the event of sudden drone failure, Lentola Logistics Oy has attempted successful landings with the assistance of the best radar and visual systems. However, compared to the other two companies using multi-rotor drones, Lentola's drone adopts a fixed-wing structure with unique design features that enable thrust vector control during flight. The drone's design structure has been granted patent approval in the US as well as Europe. It incorporates an effective anti-icing system on two propellers (refer to figure 16), enabling it to function well in freezing winter conditions and reduce the danger of fierce winds.



Figure 16. Lentola's Fixed-wing Drone

### 6.3 Drone delivery of goods and prospects

The type of goods delivered by drones depends on their payload capacity and endurance, such as courier packages, documents, letters, and takeout food. Sales representatives from DJI mentioned that the delivery scenarios for DJI drones are primarily related to the weight of the cargo. These scenarios include maritime transportation (short distances or establishing base stations), emergency transport (flood prevention, firefighting, and rescue operations), and vertical transport (transporting supplies from the bottom of a mountain to the top).

Regarding special deliveries of medicines and blood products, interviewees from all three companies agreed and considered it a growing trend in future transportation. However, technical personnel from Chinese logistics companies expressed negative about the parallel delivery mode using drones and vehicles who pointed out that this delivery mode is challenging to implement in future research and practice. Firstly, the issue of payload needs to be addressed, considering the use of medium to large-sized drones and appropriately sized vehicles. Secondly, the landing locations for drones need to be considered. Current research indicates that medium to large-sized drones cannot land on vehicles due to insufficient positioning accuracy. Thirdly, although parallel delivery with drones and vehicles partially solves the limitation of drone battery capacity and flight time, payload remains a significant drawback.

## 7 Conclusion

After going over the goals and concerns outlined in Chapter 1, this research aim is to assist logistics firms in reducing the hazards involved in last-mile drone delivery. Within the context of this, a comparative analysis of pertinent literature and data from logistics company interviews will be used to identify and categorize potential risks, and then solutions will be suggested to mitigate these risks. The research questions were addressed during the previously outlined research procedure, and the following are the responses to the research questions:

### **Key issues to analyze and collect when considering last-mile drone delivery**

Like Yoo & Chankov (2018) pointed out, using drones for delivery can increase last-mile delivery performance. Nonetheless, it has risks and challenges associated with flying. Therefore, to meet customer demands within the delivery range, delivery services must consider the drone's endurance and payload capacity. Additionally, safety risks associated with drone use in inclement weather must be addressed, along with package tracking and the avoidance of occasional delivery delays.

Simultaneously, the study's findings demonstrate that, in last-mile delivery, it's crucial to guarantee drones' exact location while also considering their weight capacity, endurance, and safety concerns in inclement weather. Additionally, cutting-edge technology like GPS and RTK must be used to guarantee accurate location, package monitoring, the avoidance of sporadic delivery delays, and the stability and precision of drones.

### **Potential risks associated with using drones for last-mile delivery**

Drones used for last-mile delivery carry Nineteen possible dangers, according to Figure 13 in the literature (Chapter 4.1). These risks can be categorized into five main categories: financial risks (Customer unavailability, Destroyed items, Client density, Cash on shipment, shipment returns, Competition, Economic factors, etc.), operational and technical risks (Traffic congestion, Size and weight limitations, IT risks, Delivery location identification, etc.), environmental risks (Noise pollu-

tion, Harmful emission, Natural disaster, Operational waste, etc.), quality risks (Delivery inconvenience, Delivery windows, Customer service quality, Delivery time, Privacy concerns, etc.), and legal risks (Workforce protection, Laws and regulations). Additionally, these 19 risks can be observed in three different scenarios. For example, the first scenario is based on the Triple Bottom Line (TBL) and covers social, environmental, and financial aspects. The second scenario depends on whether the risks are internal or external to the company, where internal risks include Cash on delivery, Size and weight limitations, IT risks, Operational waste, Delivery inconvenience, Delivery windows, Customer service quality, Delivery time, Privacy concerns, etc. While external risks include Customer unavailability, Package damage, Customer density, Shipment returns, Competition, Economic conditions, Traffic congestion, Delivery location identification, Noise pollution, Harmful emission, Natural disaster, Workforce protection, Law, and regulations. Lastly, the final scenario categorizes the risks into financial risks, quality risks, and operational risks based on their impact.

Therefore, according to the analysis of interview data in this study, logistics companies classify the potential risks of drones as internal or external risks, which aligns with the "second scenario" described by Mismar et al. (2022) in Chapter 4.1. External risks include animal interference (such as birds), terrain conditions, radar interference, weather conditions, wind speed, power lines, human accidents, and local regulations. Internal risks involve payload capacity, flight endurance, GPS signal reliability of the drones. The most significant influencing elements for logistics firms today are wind speed, weather, GPS signal strength, and human mishaps. Table 5 provides extensive theoretical and interview data on the dangers related to last-mile drone delivery.

	Potential risks (External and Internal)
<b>Theory</b>	<p>External risk: Customer unavailability, Package damage, Customer density, Shipment returns, Competition, Economic conditions, Traffic congestion, Delivery location identification, Noise pollution, Harmful emission, <b>Natural disaster</b>, Workforce protection, <b>Law and regulations</b>.</p> <p>Internal risk: Cash on delivery, <b>Size and weight limitations</b>, <b>IT risks</b>, Operational waste, Delivery inconvenience, Delivery windows, Customer service quality, Delivery time, Privacy concerns.</p>
<b>Real-life company with interviews</b>	<p>External risk: <b>Animal interference (such as birds)</b>, <b>terrain conditions</b>, radar interference, <b>weather conditions</b>, <b>wind speed</b>, power lines, human accidents, and <b>local regulations</b>.</p> <p>Internal risk: <b>Payload capacity</b>, <b>flight endurance and GPS signal reliability</b></p>
<b>Combine with theory and interviews</b>	<p><b>External risk: Natural disaster (Animal interference, such as birds and weather conditions)</b>, <b>Law and regulations</b>.</p> <p><b>Internal risk: IT risks (GPS signal reliability)</b>, <b>drones of the payload capacity and flight endurance</b></p>

Table 5. Summarize of the potential risks with last-mile drone delivery

### The enterprise's approach to managing identified risks

Based on the literature and interview data analysis of this study, logistics companies currently employ three management approaches when facing identified risks. These approaches include advanced technological support, comprehensive risk assessment testing for drones, and proposing innovative delivery concepts to address future logistics challenges (as shown on below table 6).

Solutions to manage the risks <sup>↵</sup>	What are the Issues/topic <sup>↵</sup>
Technological support <sup>↵</sup>	<p>1. When faced with external risks that including “animal interference (such as birds), terrain conditions, radar interference, weather conditions, wind speed, power lines”, in which using advanced technologies such as GPS, RTK, optimal radar, and vision system.<sup>↵</sup></p> <p>2. Considering the wind resistance, rain resistance, obstacle avoidance and autonomous return capabilities of the drone model (DJI’s Flycart 30 drone model has an IP55 rain-proof rating and uses RTK technology; Lento’s drone has a patented design structure certification and is equipped with a winter anti-ice system.)<sup>↵</sup></p>
Comprehensive risk assessment testing for drones <sup>↵</sup>	<p>1. Mitigate potential risks associated with drone delivery, ensure safety, and maintain service operations (In China)<sup>↵</sup></p> <p>2. Focusing on “laws and regulations” external risk<sup>↵</sup></p>
Proposing innovative delivery concepts <sup>↵</sup>	<p>1.To address internal risks and future urban challenges, "Drone Delivery and Autonomous Mobility (DDAM)" will use "The distribution inconvenience, Delivery window, Customer service quality, Delivery time."<sup>↵</sup></p> <p>2. Regarding the parallel delivery model of drones and vehicles, it is necessary to solve the internal risks of drone <b>payload and delivery positioning identification in the future.</b><sup>↵</sup></p>

Table 6. Summarize of Solution to identified risks

When confronted with external risks, logistics companies typically utilize advanced technologies such as GPS, RTK, optimal radar, and visual systems to resolve issues. In selecting drone categories, logistics companies also consider factors such as wind resistance, rainproof capabilities, obstacle avoidance, and autonomous return capabilities. For example, DJI’s Flycart 30 drone model

has an IP55 rainproof rating and utilizes RTK technology; Lentola's drones have design structure patent certification and are equipped with winter anti-icing systems. What is more, like Li (2021) noted in China, logistics companies operating in densely populated areas have taken comprehensive measures to assess the risks associated with drones. Such assessments are essential for mitigating potential risks associated with drone delivery, ensuring safety, and maintaining service operations. In addition, like presented in theory (chapter 3.3) shows the different models of drone delivery mechanisms, including parallel delivery modes of drones and vehicles, as well as Yoo & Chankov (2018) provide the innovative idea of "Drone Delivery and Autonomous Mobility (DDAM)" to oversee upcoming urban logistics difficulties. It has the potential to become a novel solution for addressing the quality risks outlined in the last-mile drone delivery risk classification framework proposed for Mismar et al. (2020), such as delivery inconvenience, delivery windows, customer service quality, and delivery time.

However, interview data indicates that some Chinese's logistics companies currently hold a skeptical attitude towards this series of innovative delivery models and point out the challenges in implementing parallel drone and vehicle delivery modes in future research and practice, such as payload limitations of drones and the difficulty in accurately determining landing sites for medium to large drones.

## **8 Discussion**

### **Significances for research**

In the 21st century, as science and technology have advanced and society has changed, unmanned aerial vehicles, or UAVs, have brought opportunities as well as challenges to many logistics' organizations. Drones are being investigated by an increasing number of logistics organizations globally for last-mile delivery. However, there is still opportunity for development in terms of the stability, safety, accuracy, and efficiency of drone delivery. These days, a lot of scholarly research concentrates on addressing impending urban logistics issues, resolving delivery last-mile paradoxes, and increasing last mile delivery efficiency. Also, a thorough explanation of risk analysis for last-mile drone delivery and the real-world situations that businesses encounter has not been included in the literature that is currently available. This study is necessary since the available literature on risk analysis for last-mile drone delivery provides insufficient details about certain parameters.

This thesis seeks to assist logistics companies in lowering the hazards involved in last-mile drone delivery. The process involves recognizing, categorizing, and suggesting remedies for possible hazards to lower the potential risks resulting from last-mile drone delivery. The present study establishes an investigation topic through an examination of the objectives, data collection from interviews and research material, and comparative analysis. It ends with some suggested solutions for risk assessments in last-mile drone delivery.

### **Research validity, reliability, and ethical reviews**

While Cypress (2017) pointed out that reliability and validity are two key aspects in any research, with particular importance in qualitative studies. This is because researchers' subjectivity can easily influence the interpretation of data, leading to frequent questioning of research outcomes.

In terms of validity, effective research needs to demonstrate the existence and accuracy of actual results by utilizing valid tools or measures to effectively assess the intended content and establish clear connections between relevant theories and practices (Mellinger & Hanson, 2020). This study used qualitative methods to make sure the research was valid. The study's author used semi-structured interviews with corporate staff members and a review of pertinent literature to get feedback (answers and insights) from industry professionals about the topic of the re-examination.

Conversely, repeatability, stability, and replicability of findings or observations are ideas related to reliability. Reliability is based on the consistency, stability, and repeatability applied throughout the research process, analysis, and conclusions. In other words, the more the research results are repeated, the more stable and reliable the phenomenon will be (Cypress, 2017.) The researcher selected academic search engines, professional databases, specialized books, journals, and publications considering the credibility of the research retrieval sources to guarantee the relevance and consistency of the information used and the research topic. Additionally, references from other literature reviews, books, and academic articles were included. Considering the credibility of the relevant retrieval sources, the researcher utilized various types, including academic papers, theses, books, journals, news reports, and websites. Additionally, semi-structured interviews were conducted with technical personnel, delivery personnel, and sales representatives from relevant logistics companies.

Furthermore, the author thoroughly examined and carried out the study, making sure it complied with research ethical reviews. All respondents were made aware of the purpose of the study before the interviews began, guaranteeing that stringent protocols were followed to safeguard both personal and business privacy. The author also sought permission for the use of subsequent interview data. Furthermore, the feedback data from the interviews were appropriately utilized, considering social ethics and considerations for the company's reputation. The use of relevant literature in the study followed proper source citation and referencing, in accordance with ethics reviews. Lastly, the collection, analysis, and summarization of all research data complied with ethical standards, legality, and confidentiality.

### **Suggestion of future proposals**

While the project has yielded valuable findings and results, it also has its limitations and shortcomings. Because of time limits and respondent autonomy, the study only included logistics organizations in specific regions (such Finland and China) for interviews, which may have an impact on the trustworthiness of the research findings in terms of generalizability. Additionally, there are discrepancies in the collection of interview data, with some data obtained from China, potentially affecting the consistency of the research data.

Moreover, the study's information discovery on "comprehensive risk assessment of drones" is limited, as it is solely based on the Chinese drone market. Furthermore, logistics companies expressed skepticism about the "parallel delivery mode of drones and vehicles," which could be further explored in future research. Additionally, due to ethical principles and differences in national policies and confidentiality across different regions, the study did not cover the relevant laws, regulations, and social cultures related to drone delivery worldwide.

From a future perspective, the advancement of technology and the rapid and extensive application of e-commerce have led to increasing demands in cost-effectiveness, time efficiency, and environmental sustainability for last-mile delivery. Therefore, drones have become a significant trend in future logistics city delivery, and logistics companies will strive to ensure their future growth by preserving a high standard of customer happiness, technological innovation, and improving delivery costs. This study serves as a case study for risk analysis of drone last-mile deliveries, which can

aid in quantitative analysis of future safety issues associated with drone delivery and offer information and insights. Furthermore, by using the research data in this study to create a theoretical data model for drone delivery risk, relevant logistics firms for drones might lower the possible safety hazards associated with last-mile delivery.

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## Appendices

### Appendix 1. Interview invitation letter to logisitcs company.

Invitation to participate in semi-structured interviews "Risk Analysis on Last Mile Drone Delivery."

Dear, XXX team.

Hello,

I am a fourth-year student majoring in Logistics and Purchasing Engineering at JAMK University of in Finland. As I work on my academic thesis for JAMK, I would like to extend a sincere invitation to your organization to take part in a semi-structured interview related to my research project, "Risk Analysis of Last-Mile Drone Delivery." I hope to work with your organization to further study in this innovative subject because I am really interested in your knowledge and experience in drone technology and delivery.

The aim of my thesis is to assist logistics companies in lowering the risks involved in last-mile drone delivery. The process involves recognizing, categorizing, and suggesting remedies for possible hazards to lower the risk related to last-mile drone delivery. Additionally, this study will examine the relevant risks related to drones in last-mile delivery from a theoretical perspective and offer feasible solutions to make last-mile drone delivery easier. I believe that your company has unique insights and practical experience in this field, and I hope to gain valuable insights and suggestions from your professional knowledge.

I understand that your company is busy, and time is limited, so I offer flexible interview arrangements to ensure your participation is as convenient as possible. Firstly, you can choose an appropriate interview method according to your company's preference, including face-to-face meetings, phone conferences, or online video conferences. In this manner, you can take part in the interview from your office or any other convenient location without having to spend additional time and effort traveling. Secondly, your company's decision will dictate the time and length of the interview. I promise to honor your timetable and make an effort not to interfere with your job. I anticipate that the semi-structured interview will take around an hour, but I'm open to modifying it to meet your needs and guarantee a full discussion of the subject matter. During the interview, I will ask a series of questions to your company's relevant experts, covering areas such as drone technology, risk management, and delivery operations. And welcome your professional insights, experiences, and opinions during the interview to facilitate deeper communication and learning. This will be an opportunity for mutual exchange and learning, and I believe that through collaboration, we can achieve better research outcomes.

Kindly respond to this email to indicate your company's interest in taking part in my research and offering expert opinions and recommendations. Additionally, please let me know when times work best for the interview. I am eager to start this fascinating partnership with your business.

Thank you once again for your attention and support to my research topic. I am eagerly awaiting your response!

## **Appendix 2. Interview questions with drone technicians, delivery personnel, and sales representatives.**

### **Questions:**

1. What is your company about? Can you tell me more details about your company's research?
2. Is there any research on the last mile drone delivery?
3. What kind of drone does your company currently use for research operations? Is it a multi-rotor drone or a fixed-wing drone?
4. What are the relevant factors that need to be collected or considered for your company drone to carry out accurate positioning in last-mile delivery?
5. What potential risks (internal or external) does your company need to consider when conducting research (e.g., delivery or something else), such as weather impacts, technical risks of the drone itself, laws, and regulations?
6. Among these potential risks, what is the one that has the greatest impact on your company's research operations?
7. How does your company address the risks that may arise in research operations? Do you have any specific solutions? For example, weather interference, and radar impact.
8. What goods does your company use drones to deliver? Any limitations?
9. Does your company consider "the delivery model parallel to drones and vehicles"?
10. Do you have any thoughts on the future development of drones? Examples include drone and truck delivery services and drones for special deliveries such as blood and medical support.