Drone Delivery: Why, Where, and When

Lailla M. S. Bine
PARADISE Research Laboratory, University of Ottawa
Ottawa, Canada
DCC, Federal University of Minas Gerais
Belo Horizonte, Brazil
lbine016@uottawa.ca

Azzedine Boukerche
PARADISE Research Laboratory, University of Ottawa
Ottawa, Canada
boukerch@site.uottawa.ca

Linnyer B. Ruiz
Manna Research Group, State University of Maringá
Maringá, Brazil
lbruiz@uem.br

Antonio A. F. Loureiro
DCC, Federal University of Minas Gerais
Belo Horizonte, Brazil
loureiro@dcc.ufmg.br

ABSTRACT

Drone technology has the potential to revolutionize various sectors, including healthcare, food, and everyday goods, enabling efficient and convenient deliveries. However, in an expected competitive airspace environment with multiple companies, it becomes crucial to establish organized and coordinated access for drones. The Internet of Drones (IoD) aims to ensure equitable airspace utilization. Despite significant advancements in drone delivery, it remains essential to understand the circumstances where drone delivery offers advantages in terms of why, where, and when it should be employed. This study introduces a comprehensive guideline for developing decision systems for drone delivery within the IoD. Specifically, we present a systematic approach to the drone delivery decision problem that tackles those questions (why, where, and when). To provide practical insights, we examine a real delivery scenario using actual data from motorcycle deliveries in Brazilian cities. Additionally, we propose an algorithm for distributing points to serve as depots or droneports. Lastly, we conduct a case study, implementing the proposed guideline and distribution algorithm. The results demonstrate a 49% reduction in delivery time compared to actual delivery durations.

CCS CONCEPTS

• **Networks** → **Network mobility**; • **Applied computing** → *Avionics.*

KEYWORDS

Drone delivery, Internet of Drones, Guideline

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1 INTRODUCTION

Firms are increasingly exploring automated package-delivery vehicles in response to the growing demand for quick, contactless deliveries [28]. Among these vehicles, Unnamed Aerial Vehicles (UAVs), known as drones, are a promising solution for efficient delivery by circumventing urban traffic and promptly reaching customers. Major companies like DHL, Amazon, and Google have invested in initiatives to turn drone delivery into a viable solution. While the realization of everyday items and food deliveries to the general population has yet to progress as rapidly as initially anticipated by Amazon [6], notable advancements have been made [7], bringing us closer to practical drone delivery deployment.

In global health, using drones for delivery has become practical [6], as numerous initiatives demonstrate the advantages of employing drones in transporting blood, medical equipment, relief food, and medications [33]. Particularly for low- and middle-income countries, drone delivery has resulted in expedited delivery times and reduced waste within healthcare facilities [26]. These countries often encompass communities situated in difficult-to-access regions like villages, rural areas, and remote communities. In such scenarios, drones offer a swift and cost-effective alternative to conventional modes of transportation.

Despite advancements in healthcare support, delivering goods in urban centers continues to pose significant challenges to deployment. The absence of established regulations, the complexities of managing multiple services and applications simultaneously, the potential for continuous drone traffic, and the dynamic nature of the network, all contribute to the intricacy of operating an urban drone network [2, 36]. To address this scenario, one strategy is exploring a decentralized management system based on regional divisions, which facilitates collaboration among drones and enables the formation of a unified network known as the Internet of Drones (IoD) [3].

IoD is an architectural concept that enables synchronized access for drones in the airspace [2, 3]. Drones can be structured into designated airways analogous to roadways in a vehicular network. This organizational approach offers the benefit of clearly demarcating

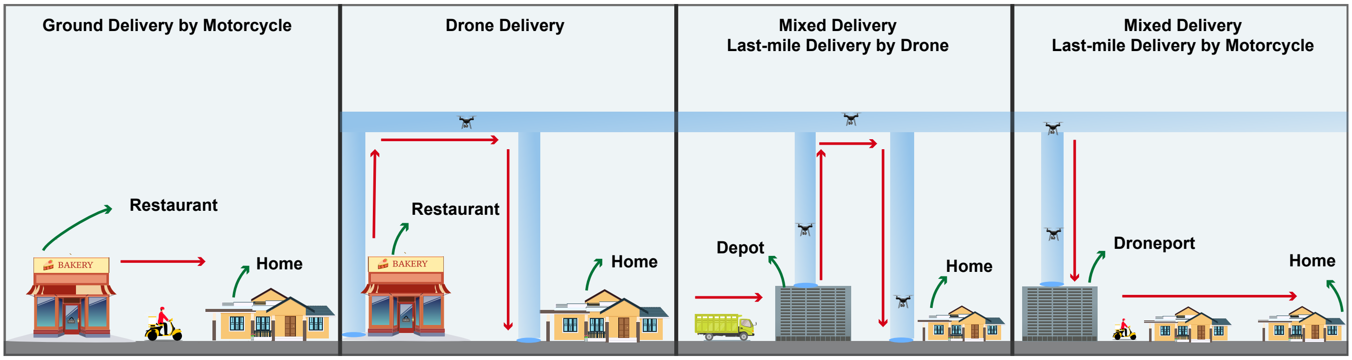


Figure 1: Deliveries approaches overview

authorized drone zones, simplifying regulatory processes, and promoting cooperative airspace utilization. In such a scenario, delivery drones follow a path reminiscent of ground vehicles. Furthermore, the anticipation is that an abundance of drones will traverse the skies for goods delivery [25]. However, at present, only a limited number of trials involving drone deliveries to homes are underway [7]. Consequently, a genuine dataset of drone delivery paths for utilization is currently unavailable.

Similar to Vehicular Ad Hoc Networks (VANETs), where synthetic datasets are used to simulate vehicular networks, in IoD many studies utilize synthetic datasets to simulate a substantial number of drones [1, 27, 35]. In our research, we employ a synthetic dataset of paths generated based on an actual delivery dataset derived from ground vehicles. Considering a scheme in which a delivery can be carried out by drones, ground vehicles, or a mix of them, it becomes necessary to analyze which option is more efficient regarding energy expenditure, costs, and delivery speed. Simulating the same deliveries performed by ground vehicles using drones can contribute to a more equitable comparison. Therefore, some research questions arise: (i) How to distribute droneports or depots in a city to improve home drone deliveries? (ii) Where, why, and when drone delivery can be more efficient than ground delivery? (iii) What guidelines should be considered when deciding the delivery method?

1.1 Main Contributions

This work proposes a decision process guideline for drone delivery. Our main objective is to offer a comprehensive and systematic approach to the drone delivery decision problem. Through this approach, we aim to assist analysts and traffic managers in constructing efficient systems that facilitate the seamless delivery of products to end users. Our main contributions can be summarized as follows:

- we examine various delivery approaches using a dataset of actual deliveries and present decision guidelines that relies on factors such as drone autonomy, distance, and delivery speed;
- we propose an algorithm that focuses on the distribution of deposits or droneports to facilitate home deliveries, considering real-world scenarios of deliveries;
- we present a case study using the guidelines and the proposed distribution algorithm. The results indicate a significant reduction of 49% in delivery time compared to the actual time spent on deliveries.

1.2 Paper Organization

The rest of this paper is organized as follows. Section 2 presents the essential concepts of drone delivery, IoD, and related work. Section 3 discusses the different delivery approaches considering ground delivery, drone delivery, and mixed delivery. Section 4 introduces the drone delivery guidelines and discusses a case study using the proposed procedure. Finally, Section 5 presents our concluding remarks and future work.

2 PRELIMINARIES

In this section, we introduce the concepts of IoD and drone delivery. Also, we provide an overview of related studies conducted in this field.

2.1 Drone delivery and the Internet of Drones

Drone delivery encompasses various categories, including the transportation of healthcare products, food, and small everyday goods. The drone delivery of healthcare products primarily focuses on expedited transportation due to the critical nature of these essential items for saving lives. This category has witnessed significant advancements in recent years [26]. Blood [26], medications [22], and human organs [30] are among the most significant items considered for this type of delivery.

Small everyday goods delivery is a highly sought-after category for companies investing in drone delivery services. Amazon is an example of a company venturing into this field, despite the challenges associated with service regulation [6]. They have initiated testing in select cities in the United States to explore the feasibility of using drones for delivering such goods [7]. Food delivery is another prominent category, which encompasses various scenarios. It involves both time-sensitive deliveries for immediate consumption, such as restaurant orders and small grocery purchases. In recent years, the demand for contactless food delivery has surged, driven by the Covid-19 pandemic [20]. Drones have garnered significant attention as a viable solution for this type of delivery. To integrate drone delivery seamlessly into our daily lives, it becomes crucial to

Table 1: Related studies

Year	Ref.	Category	Source	Main Goal
2020	[40]	Everyday Goods	The data of total e-commerce demand for Singapore was estimated from Statista Portal, Shopee and Amazon	Introduce a practical and effective optimization model that addresses the placement of droneports
2020	[19]	Food	A survey made by the authors about expected drone delivery time in China	Compare the expected delivery time with the real delivery time and analyze the conditions in which the drone delivery outperforms the rider delivery
2022	[26]	Health	Rwanda's Health Management Information System (HMIS)	Evaluate the effect of using drones in terms of time and waste to deliver blood products to remote health facilities
2023		**Food**	**Aiqfome, a Brazilian company operating in the field of online meal delivery**[1]	**Propose guidelines for drone delivery decision in a real city, taking into consideration ground delivery, drone delivery, and mixed delivery**

establish organized airspace that regulates and coordinates drone access. One approach to achieving this organization is through the IoD architecture, where drones utilize well-defined airways to form a continuous flow network in the sky, similar to a vehicular network. Moreover, these airways can overlap ground routes, enabling easier identification and regulation of airspace.

In the first part of Figure 1, we depict the conventional delivery process where a delivery person collects the order from the seller and transports it to the destination. Conversely, the second part represents end-to-end drone delivery, where the vehicle is replaced by a drone that collects the order from the seller and delivers it directly to the customer's home. Furthermore, mixed delivery approaches involve a combination of vehicle types. For instance, a depot could receive orders, and drones could transport the products to the end consumers. This approach, known as last-mile delivery, has garnered significant attention in recent literature [11]. Given the challenges associated with ensuring a safe landing spot for drones at each residence [40], one possible solution is to leverage drones for a portion of the delivery process. The drone would transport the order to designated droneports, and the last-mile delivery could be completed using other vehicles, such as motorcycles.

2.2 Related Work

In the last years, different drones studies have been explored such as hybrid aerial and ground communication [13, 16, 17, 39], specific control of a swarm of drones [5, 8], path planning [1], location privacy Protection mechanism [35, 37], UAV network performance optimization [15], to name a few. Research in the field of drone delivery primarily revolves around studying and forecasting the proliferation of drones within urban environments [19]. Narkus-Kramer [25], for instance, predicted that the number of drones in Washington could reach 1 million by 2050.

As drones are still an emerging technology, significant attention is given to understanding the factors influencing drone delivery service acceptance [9, 20, 29, 38]. It is important to note that acceptance can evolve. A prime example of this is the impact of Covid-19, which has brought a new perspective to this form of delivery as a means of contactless goods transportation to end consumers [20]. Consequently, many individuals have recognized the advantages and the necessity of this type of delivery. Furthermore, certain studies [6, 12] aim to elucidate the reasons behind the slower-than-expected progress of drone delivery, highlighting the challenges and factors contributing to this phenomenon.

Considering this scenario, several related questions have emerged regarding why, when, and where drone delivery benefits society. To comprehend the benefits of drone delivery, certain studies concentrate on healthcare delivery and examine the transportation of specific items such as medicine [14, 31], human organs [30], and blood [26]. In these cases, swift delivery is crucial as human lives can be contingent on the successful arrival of these items. Drone delivery of blood, for instance, is already being implemented, offering the advantage of rapid transportation [26]. Furthermore, these studies also assess whether drone delivery can help mitigate waste, considering that such products require specific storage conditions [26]. Other research endeavors conduct a comprehensive analysis of drone delivery, focusing on the advantages in terms of energy efficiency [21], cost-effectiveness [10, 34], sustainability [10], and delivery time [26, 32]. These studies can be classified into two categories: those that aim to develop more efficient algorithms and models for path planning and drone systems [10, 32], and those that compare drone delivery with ground vehicles [21, 26].

Table 1 provides an overview of the relevant studies conducted in the field. Zeng et al. [40] focused on estimating and allocating droneports based on e-commerce data specifically from Singapore. However, they did not consider the comparative advantages of utilizing drones in different scenarios. Jiang and Ren [19] compared drone delivery with traditional rider-based delivery, but did not incorporate actual delivery data. On the other hand, Nisingizwe et al. [26] evaluated the use of drones for delivering blood in Rwanda, utilizing data from existing operational drone deliveries. However, that study primarily focused on providing specific products to hospitals, which may not encompass broader scenarios that aim to serve the entire population, such as delivering food and everyday goods. Therefore, this work aims to comprehensively compare delivery times, considering various delivery options, including ground delivery, drone delivery, and a combination of both (mixed delivery), utilizing real delivery data.

Our objective is to comprehend the factors influencing the efficiency of using drones over conventional delivery methods, primarily in medium-sized cities. We achieve this by conducting a comparative analysis, contrasting an actual ground delivery dataset with a synthetic drone dataset derived from the same delivery routes utilized by ground vehicles. This approach allows us to discern the circumstances, locations, and timings where the adoption of drones proves to be more efficient. In prior studies [19, 26], while the time metric for drone delivery was analyzed, the scenarios studied often focus on a very specific case like blood delivery. In this paper, we address this limitation by utilizing genuine delivery orders of food. Specifically, we tap into the pool of real users who have made actual food requests through a delivery app. These authentic orders serve as the foundation for simulating drone deliveries, employing the attributes of an operational delivery drone. Furthermore, we conducted a comprehensive comparison between the simulated drone deliveries and the corresponding real-world delivery instances. This approach distinctly enhances realism in comparison to previous methodologies.

3 DELIVERIES APPROACHES

In this section, we introduce the dataset employed in this study and utilize it to examine three different delivery approaches: ground delivery, drone delivery, and mixed delivery.

3.1 Study Setting

Aiqfome[1] is a Brazilian food delivery company founded in 2007, exclusively operating within Brazil. Presently, the company boasts a user base of over 5 million individuals and collaborates with approximately 25,000 registered restaurants across around 700 cities in Brazil. Aiqfome operates by facilitating connections between restaurants, deliverers, and consumers. Table 2 provides an overview of the collected data from deliveries conducted in six cities where Aiqfome operates, covering the period between July 22, 2022, and May 19, 2023.

The Aiqfome dataset comprises a collection of motorcycle delivery records, including information such as the restaurant's coordinates, the departure time of the delivery person from the restaurant, the coordinates of the delivery destination, the arrival time of the delivery person at the destination, the distance in kilometers of the route suggested by Google from the restaurant to the delivery location, and the distance in kilometers traveled by the delivery person. All analyses and algorithms presented in this study were implemented using Python 3.11. Table 2 summarizes this data and displays the estimated population figures for each city in the dataset.

Table 3 highlights the key distinctions between motorcycle-based delivery and drone delivery. We considered data from the drones used in Amazon's Prime Air[2] service to conduct this comparison. Drones for delivery typically transport only one package at a time, whereas motorcycles can accommodate multiple packages. Regarding food delivery, it is common for a motorcycle courier to handle various deliveries simultaneously. Regarding capacity differences, motorcycles can travel around 40 km per liter and typically have a fuel tank capacity of 9 liters. In comparison, Amazon drones have a range of 12 km for a round trip.

One advantage of drones is their autonomy, as they operate without a human operator, which can be cost-effective. Although motorcycles have a higher maximum speed in theory, traffic congestion and urban speed limits often result in lower average rates than drones, which can reach a maximum speed of 80 km/h. Safety is another differentiating factor between these vehicles. While motorcycles are susceptible to traffic accidents, drones may face issues such as attacks. Lastly, weather conditions are crucial, as rain and particularly strong winds can affect or even interrupt drone services.

3.2 Ground Delivery

Different types of vehicles, such as cars, motorcycles, and trucks, can perform Ground Delivery. The AiqFome dataset represents real data from deliveries performed by motorcycles. It is worth noting that in Brazil, most deliveries are carried out using motorcycles. This choice of vehicle is due to factors such as the climate, ease of parking, and cost-effectiveness in terms of fuel for the deliverers. In this section, we analyze and summarize the data from this dataset for comparison with other types of deliveries.

Table 2 presents the average delivery time, considering the departure time from the restaurant and the arrival time at the destination. By analyzing the time spent on deliveries and the distance traveled, we calculated the average speed of the deliverers. Also, we computed the average distance covered by the deliverers and the average distance recommended by Google. Google tends to propose shorter or more efficient routes, considering factors such as traffic conditions and permitted speeds on the roads. However, the average distance the deliverers takes exceeds the average length suggested by Google. There are various reasons for this discrepancy, including the deliverers choosing their routes for convenience, avoiding unsafe areas, and even simultaneously making multiple deliveries using different delivery applications.

In the dataset, for the most populous city (Maringá), the average delivery time is approximately 13.51 min, covering a distance of 4.99 km at an average speed of 38.93 km/h. On the other hand, for Tietê, the smallest city in the dataset, the average delivery time is 10.51 min, with the delivery person traveling 5.23 km at an average speed of 40.22 km/h. When examining the relationship between these population statistics and the average distance traveled during deliveries, it becomes apparent that city size alone does not necessarily dictate the distance covered in deliveries. Several factors come into play when determining the distance traveled by deliverers. Factors such as the size of the city, the layout of neighborhoods, the presence of commercial quarters, and the types of restaurants registered in the application all contribute to this variation. In larger cities, for instance, restaurants may only offer delivery services within specific areas, whereas in smaller cities, restaurants might cater to a broader geographic range.

3.3 Drone Delivery

In this section, we delve into goods delivery utilizing drones. Specifically, we explore the concept of end-to-end drone delivery. Numerous companies may be involved in providing drone delivery services (e.g., Amazon, Google, DHL, Uber), simultaneously managing a significant fleet of drones within the airspace. Therefore, we examine the IoD architecture, wherein drones have coordinated access to airspace. We employ well-defined airways that closely align with existing land routes to facilitate drone airspace coordination. This approach ensures that drones avoid unauthorized areas such as airports and government buildings while simplifying navigation in densely populated areas with buildings, towers, and antennas. Additionally, this strategy promotes public acceptance by providing

[1]https://bit.ly/43oADwo (in Portuguese)
[2]bit.ly/3prbX7B

Table 2: Aiqfome dataset overview covering the period between July 22, 2022, and May 19, 2023

City	State	Population (thousands) [18]	# Deliveries	Average real driving distance (km)	Average estimated Google driving distance (km)	Average real driving time (min)	Average real driving speed (km/h)
SORRISO	MT	94.941	3525	8.36 ± 5.62	6.65 ± 5.22	13.84 ± 9.58	41.22 ± 25.81
CERQUILHO	SP	50.631	2096	4.77 ± 2.71	3.45 ± 2.15	7.69 ± 5.02	41.32 ± 19.42
TIETÊ	SP	42.946	1736	6.30 ± 4.25	5.23 ± 4.12	10.51 ± 7.02	40.22 ± 31.51
MARINGÁ	PR	436.472	1459	7.86 ± 4.20	4.99 ± 2.90	13.51 ± 7.64	38.93 ± 22.96
CONSELHEIRO LAFAIETE	MG	130.584	1356	5.66 ± 3.34	3.73 ± 2.32	10.96 ± 7.51	35.83 ± 20.41
COLATINA	ES	124.283	1139	8.34 ± 5.45	5.52 ± 3.69	15.12 ± 12.05	40.29 ± 31.67

Table 3: Motorcycle × drone delivery

	Motorcycle	Drone (based on Prime Air [2])
Capacity	More than one package	Usually 1 package (2.2 kg)
Autonomy	40 km/l (tanque 9 liters)	12 km
Autonomous	No	Yes
Speed	40 km/h (average based on Table 2)	80 km/h (maximum)
Safety	Subject to traffic accidents	Subject to attacks and hardware problems
Weather	Usually unaffected by rain	Strong winds can shut down the service

clear localization of drone flight paths and avoiding drones directly over residential areas.

By considering the IoD concept with well-defined airways, we conducted simulations of deliveries using drones on the Aiqfome dataset. The distance results are presented in Table 4. Notably, in the city of Maringá, it is observed that a drone with a 12 km range (similar to Amazon's Prime Air drone) may face challenges in completing the delivery and returning to the point of origin. Another point is a significant disparity in the distance covered by drones compared to real distance. This disparity is quantified by the distance shortening rate (DSR), which represents the percentage by which the drone delivery distance is smaller than the actual distance traveled by the delivery person. On average, the drone covers 61% less distance compared to the courier's actual travel distance. Colatina exhibits the largest disparity with an average reduction of 75%, while Maringá showcases the smallest difference, with the drone route being 44% shorter than the actual route.

We also compared the actual route couriers took and the distance Google suggested. Aiqfome relies on a route provided by Google's API for the delivery person, and this distance is recorded to determine if the courier followed a distance similar to the suggested one. Table 4 provides the DSR, comparing the distance couriers traveled with the route Google suggested. We observed that the route suggested by Google is approximately 25% shorter than the actual route taken by the couriers. This indicates that even if couriers followed the suggested route, drone delivery would still be shorter in terms of distance. The distance traveled also has an impact on delivery time. Table 4 also shows the delivery time in each of the analyzed cities. We compared the actual delivery time with the projected delivery time of drones assuming they operated at the same average speed as ground delivery. Additionally, we presented the delivery time if the drones operated at their maximum speed, given that the reference drone has a maximum speed of 80 km/h. Consequently, if the drone operated at the average speed of motorcycles, the delivery time would already be faster.

3.4 Mixed Delivery

The concept of mixed delivery involves utilizing multiple vehicle types for product delivery. Given that our dataset primarily consists of deliveries made by motorcycles, we consider both motorcycles and drones in our study. Some previous studies suggest that drones are well-suited for last-mile delivery scenarios due to their limited autonomy imposed by battery constraints [11]. Therefore, we examine the possibility of motorcycles transporting goods to a central depot, where drones take over for the last-mile delivery. However, it is worth noting that other studies emphasize the need for safe landing areas for drones, known as droneports [40]. In certain urban settings, individual homes may not provide a secure landing spot for drones. To address this, one possibility is to establish droneports strategically located throughout the city, while motorcycles handle the last-mile delivery. This section first delves into distributing droneports or depots within a city. Subsequently, we simulate mixed-delivery scenarios, where drones are responsible for the last-mile delivery in one scenario, and motorcycles handle the last-mile delivery in the other scenario.

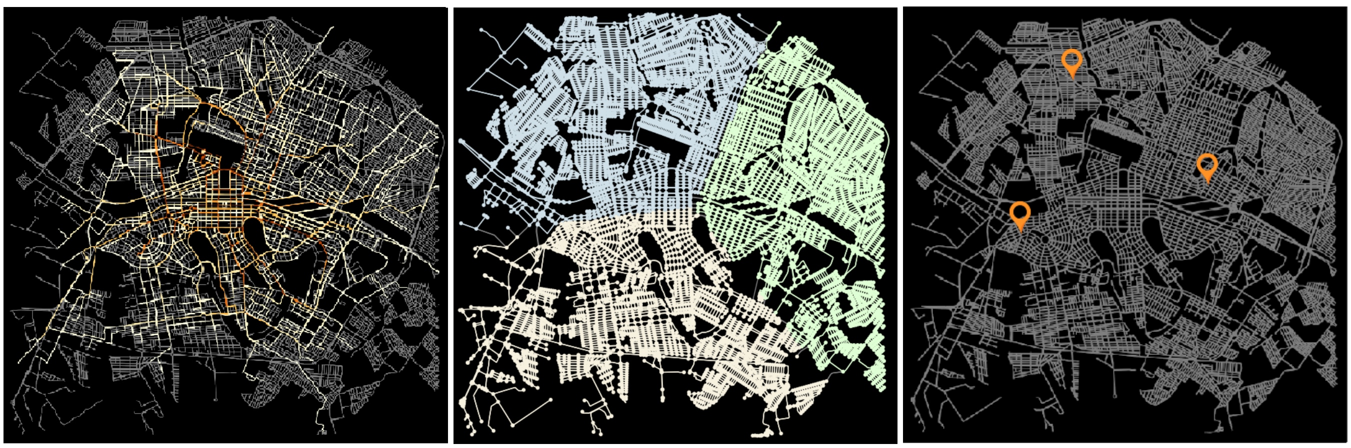
3.4.1 Depots and Droneports Distribution. In the mixed delivery scenario, we focused on the city of Maringá. This city is the largest population within the dataset and presents unique characteristics in the end-to-end drone delivery results. Specifically, it demonstrated the potential for routes exceeding the 12 km round trip capacity of the reference drone used in this study. To address this, we established a flight autonomy of 10 km to ensure an appropriate safety margin. Consequently, we considered that the drone could cover a radius of 5 km, encompassing an area of approximately 78 km². According to the Brazilian Institute of Geography and Statistics, Maringá has an urban area of 112.70 km². Hence, we determined that three droneports or depots would be sufficient to fulfill the city's delivery demand. We consider this because drones need to follow the airways and probably will need to fly a considerable distance to achieve a point compared to free flight.

While certain studies propose the distribution of droneports [24, 40], they rely on e-commerce data unavailable for the Brazilian

Table 4: Comparision of ground delivery with end-to-end drone delivery

City	Real driving distance (km)	Drone delivery distance (km)	DSR - real driving to Google (%)	DSR - real driving to drone (%)	Real driving time (min)	Drone delivery time (RDS) (min)	Drone delivery time (MDS) (min)
SORRISO	8.36 ± 5.62	1.89 ± 2.01	21.59 ± 26.90	69.18 ± 29.84	13.84 ± 9.58	2.83 ± 3.26	1.42 ± 1.51
CERQUILHO	4.77 ± 2.71	1.65 ± 1.16	25.67 ± 29.48	57.84 ± 29.20	7.69 ± 5.02	2.67 ± 2.11	1.24 ± 0.87
TIETÊ	6.30 ± 4.25	1.90 ± 1.71	16.02 ± 40.85	61.85 ± 30.60	10.51 ± 7.02	3.02 ± 2.80	1.42 ± 0.87
MARINGÁ	7.86 ± 4.20	4.07 ± 2.23	34.01 ± 22.54	44.28 ± 22.56	13.51 ± 7.64	7.33 ± 4.63	3.05 ± 1.28
CONSELHEIRO LAFAIETE	5.66 ± 3.34	1.69 ± 1.31	30.02 ± 27.61	62.96 ± 27.57	10.96 ± 7.51	3.24 ± 2.93	1.26 ± 0.98
COLATINA	8.34 ± 5.45	1.66 ± 1.72	28.01 ± 30.57	75.04 ± 23.80	15.12 ± 12.05	2.77 ± 3.24	1.24 ± 1.29

DSR - Distance Shortening Rate; RDS - Real Delivery Speed; MDS - Maximum Delivery Speed



(a) Flow of vehicles **(b) K-means** **(c) Algorithm 1**

Figure 2: Maringá results overview

Table 5: Last-mile delivery results

Route	Distance (km)			Last-mile Delivery by Drone (min)	Last-mile Delivery by Motorcycle (min)
	Average	EGC	Average + EGC	Average + EGC	
Source to Droneport/Depot	3.34 ± 1.67	4.70 ± 1.61	3.27 ± 1.46	6.16 ± 3.81	2.45 ± 1.09
Droneport/Depot to Destination	3.82 ± 1.87	4.13 ± 1.80	3.45 ± 1.58	2.59 ± 1.19	6.35 ± 3.77
Total	7.16 ± 2.06	8.84 ± 1.89	6.73 ± 1.72	8.75 ± 3.61	8.80 ± 3.65

cities examined in this research. Additionally, none of these studies consider a real delivery dataset within an IoD scenario where dedicated airways are present, resembling terrestrial routes. We employed the K-means algorithm to partition the Maringá graph into three sections [23]. The resulting segmentation can be observed in Figure 2b. We analyzed the vehicular flow on each road segment to identify the suitable location for the depot or droneport. Specifically, we examined the flow of vehicles for each delivery within the Maringá dataset, considering the shortest route between the origin and destination points. This approach enabled us to identify roads that potentially experience higher traffic levels, as illustrated in Figure 2a.

Algorithm 1 outlines the process of distributing points designated as droneports or depots. Each node possesses two attributes: *flow*, representing the frequency of a node appearing in all routes within the Aiqfome dataset, and *egc*, denoting the eigenvector centrality [4] that signifies the influence power of a node based on its neighboring nodes. On lineS 1-2 of the algorithm, the mean and standard deviation of the *flow* attribute is calculated across all nodes. Subsequently, in lines 5 to 8, nodes with a *flow* greater than the mean and less than the mean plus the standard deviation are added to the set T. Finally, on line 9, the node with the highest *egc* value is appended to the set of nodes that will serve as droneports or depots. Table 5 presents the results of Algorithm 1. The displayed distance is the sum of the distance from the departure point to the depot/droneport plus the distance from the depot/droneport to the destination. We compare the analysis using only the point closest to the mean and the point with the highest *egc* and we verify that our method that uses the metrics together produces the best result.

Algorithm 1: Depots/Droneports distribution

```
Input  : graphs
Output : nodes
nodes ← {}
for (G in graphs) do
    α ← average(G.nodes.flow)
    β ← ste(G.nodes.flow)
    T ← {}
    for (n in G.nodes) do
        if (n.flow > α ∧ n.flow < α + β) then
            T ← T ∪ n
    nodes ← nodes ∪ max(T.egc)
return nodes
```

3.4.2 Last-mile Delivery. Table 5 presents the results of delivery times for the last-mile delivery performed by drones or motorcycles, taking into account the previously determined locations of the depots or droneports. For this analysis, we assume that the section carried out by motorcycles maintains the average speed of real deliveries (see Table 2) In contrast, the segment carried out by drones operates at a speed of 80 km/h. The time required for the drone's ascent and descent is calculated as 0.005 min. In this calculation, we consider that the drone ascends to a maximum altitude of 200 m. The results show that the average delivery time for drones last-mile delivery is 2.59 ± 1.19 min, while a delivery conducted solely by the drone at maximum speed takes approximately 3.05 ± 1.67 min. Although the mean delivery time is slightly lower for the mixed-delivery approach, the difference is not significant when considering the standard deviation. The results are similar when last-mile delivery is done by motorcycles.

Therefore, it is evident that for a city like Maringá, which is considered medium-sized in Brazil, the mixed-delivery approach with last-mile delivery does not provide significant time advantages. However, it is essential to consider other factors that may influence the decision-making process. For instance, the analysis of the Maringá delivery dataset reveals instances where the delivery distances exceed the reference drone's autonomy of 12 km. In such cases, last-mile delivery can be beneficial as the maximum distances traveled by the drones remain within the threshold.

In last-mile delivery carried out by drones, motorcycles can transport multiple orders to depots in a single trip, thereby reducing the overall travel time. On the other hand, in last-mile delivery conducted by motorcycles, drones cannot consolidate packages for efficiency during the initial leg, whereas motorcycles can deliver multiple packages in a single route. Although this second method is not extensively discussed in the literature, it is reasonable to assume that in urban areas with a high housing density, drones may face challenges in finding suitable locations for package delivery, thereby hindering the feasibility of last-mile delivery by drones.

4 DRONE DELIVERY GUIDELINES FOR IOD

This section introduces a guideline for drone delivery in the IoD context. Additionally, we conducted a case study in the city of Maringá to assess the effectiveness of the proposed guideline.

4.1 Guidelines Overview

Figure 3 provides an overview of the drone delivery guide in the context of the IoD. The yellow boxes represent essential factors for decision-making, while the blue boxes represent examples of data that can be utilized. The initial step in determining the most favorable delivery type involves gathering environmental data, including airway information, depot and droneport locations. Collecting drone-specific data such as autonomy, speed, and payload capacity is also crucial. Another requirement is selecting the factor to consider when choosing routes, such as time, cost, or CO_2 emissions. Different priorities can yield different solutions; for instance, the fastest delivery may not always be the most cost-effective or environmentally friendly option. Additionally, the delivery decision necessitates knowledge of the delivery origin and destination, along with weather conditions.

4.2 Study Case

Aiming to verify the effectiveness of our proposed guideline, we applied it to design an IoD drone decision system for the city of Maringá. The step-by-step process is presented as follows.

- **IoD Environment**: We consider airways overlapping the roads for the urban area of Maringá (area of Figure 2). The airways form a graph where the intersections are the nodes, and the connections are the edges. We also consider the depots created by Algorithm 1, as shown in Figure 2c.
- **Drone's Specifications**: We consider the drone's specifications in Table 3.
- **Parameters**: Our goal was to opt for the fastest delivery method. We do not consider cost or other elements such as sustainability.
- **Mission Data**: We simulate all deliveries for Maringá available in the Aiqfome dataset.
- **Weather Information**: We consider only good conditions in this decision process.

The decision-making process for choosing the delivery method is based on the scheme illustrated in Figure 4. Firstly, we calculate the distance between the departure and destination points. To ensure the feasibility of using drones, the mission distance (calculated as twice the distance between the points) should be within the range of the drone's autonomy. If it is possible to complete the entire delivery using drones, we compare the estimated delivery time for both drone and motorcycle deliveries, considering the airways in the IoD scenario. If the full delivery cannot be accomplished with drones, we assess whether a mixed delivery approach or solely using motorcycles would be more advantageous, considering the estimated delivery times for each option. In the case of mixed delivery, only the last-mile delivery by drones is considered. Also,

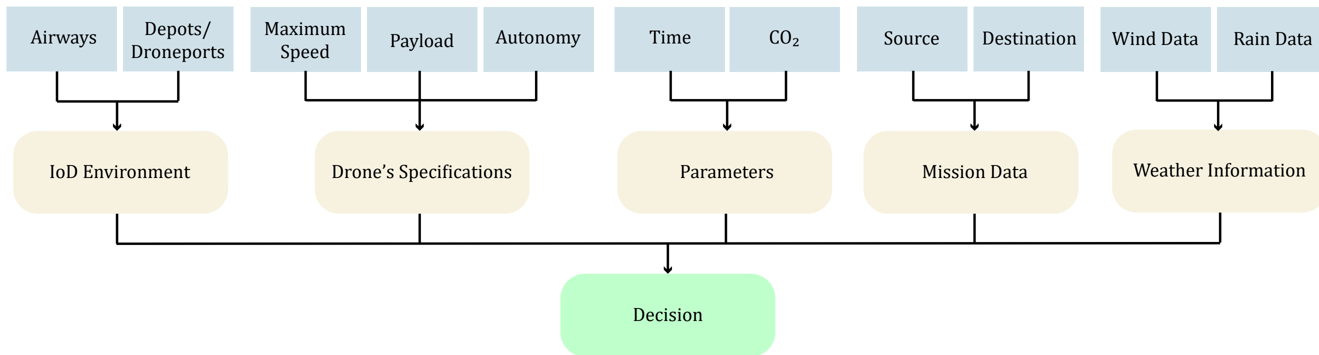


Figure 3: Drone Delivery Guidelines for IoD

Table 6: Summary of results for distance and time for Maringá

	Single delivery strategy			Multi delivery strategy			
	Motorcycle	**Drones**	**Mixed**	**Motorcycle**	**Drone**	**Mixed**	**All**
Distance (km)	7.86 ± 4.20	4.07 ± 2.23	6.73 ± 1.72	4.73 ± 2.24	3.09 ± 1.43	7.70 ± 1.76	**4.51 ± 2.62**
Time (min)	13.51 ± 7.64	7.33 ± 4.63	8.75 ± 3.61	9.84 ± 4.31	5.81 ± 3.43	9.51 ± 3.48	**6.99 ± 3.86**

the distance estimation for motorcycle delivery is determined based on the Aiqfome dataset using Google distance.

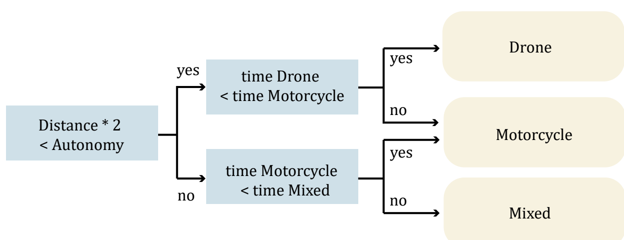


Figure 4: Drone Delivery Decision System for Maringá

Using the system of Figure 4, we determine the most time-efficient delivery method based on the distance. The results indicate that out of the 1459 trips, 19 should be conducted by motorcycles, 997 by drones, and 443 through mixed delivery. Table 6 displays the results regarding time and distance, and compares them with those obtained when using a single delivery method for all trips. It is evident that with the decision system, the overall average total delivery time is reduced compared to using only one delivery method for all trips. Furthermore, this method ensures that all deliveries assigned to drones are feasible, as the maximum autonomy limit of 12 km (round trip) is considered.

5 CONCLUSIONS

This study presents a comprehensive guideline for designing drone delivery decision systems. Specifically, our contribution lies in providing a systematic approach that facilitates the development of drone delivery decision systems. The proposed method considers why, where, and when to use drone delivery. Our approach covers the definition of the Internet of Drones and is validated using real-world data. Additionally, we design an algorithm for distributing points that can serve as depots or droneports. We applied our method to a case study, and our results show that employing our guideline in decision systems decreases the delivery time by 49% compared to real delivery time.

For future research, we aim to explore additional parameters such as cost and sustainability in our analysis. Furthermore, we intend to investigate the distribution of points throughout the city, considering factors like the projected usage of drones and incorporating data on food delivery.

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