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M.Sc. Thesis

BUSINESS ANALYSIS OF THE DRONE'S LAST MILE DELIVERY ENVIRONMENT

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I. Politecnico di Torino. Management Engineering Department.

To my family,

that showed me that education path.

To all my friends,

that made that path much more enjoyable.

To Polito and Politécnica,

for providing me such a remarkable international experience.

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“Don’t like to write,

but love having written”

(Douglas Adams)

ABSTRACT

A good transportation from the last hub to the final customer receives the name of last mile delivery. Last mile is currently the least efficient component of the delivery chain, presenting high costs besides the small distances incurred. The major challenges of last mile delivery as it is today are related to an increase of labor costs and the wastes inherent to the current model of attended home delivery. In addition to that, customer requirements are getting more rigid as they expect not only precise and costless deliveries, but also fast ones.

In that scenario, drone technology emerges as a potential problem solver. The introduction of drones performing the last mile delivery can improve its efficiency by increasing the asset usage, reducing the work force demanded and performing deliveries within a short lead time, among others. However, the introduction of this technology still faces some barriers, mainly related to its legalization, public acceptance and other issues related to the technology itself, such as its range and interaction with the final customer.

In addition, the introduction of this technology does not only affect some operational components of the delivery chain, but also how the business entities within this environment perform their roles and interact with each other. Because of that, a study of the concept of business model and how it can be applied to the last mile delivery context was necessary. To develop suitable business models, a defined framework was used and a general classification of the drone usage potentialities on the specific context was made. As result, four business models involving different business entities, with the common factor that they all used the drone technology to perform the last mile delivery, were developed and analyzed, presenting not only how the actors interacted between each other but also the context in which each model could be applied. The four business models discusses were (i) centralized distribution center, (ii) multiple departure centers, (iii) departure centers with centralized warehouse and (iv) centralized warehouse with mobile transshipment model

Finally, a mixed-integer linear programming model was developed, introducing mathematical formulations that could present analyze more quantitatively the models discussed.

Key words: (i) last mile delivery; (ii) drone technology; (iii) business model; (iv) mixed-integer linear programming

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AHD	Attended Home Delivery
B2B	Business to Business
B2C	Business to Commerce
BE	Business Entity
CAGR	Compounded Annual Growth Rate
LP	Linear Programming
MILP	Mixed-Integer Linear Programming
UAV	Unnamed Aerial Vehicle

CONTENTS

1 Introduction

1.1 Motivation

This session exposes the main reasons that have lead the author to realize this work.

1.1.1 Growth of last mile delivery

On the consumer's perspective, shopping online presents many advantages when compared to the "traditional" in-person way. Those benefits include, among others (Ehmke and Mattfeld, 2012):

(i) Greater product choice and possibility to obtain goods not commercialized locally.

(ii) Time and money savings due to better opportunities for product's price and quality comparison and no longer need for the buyer to drive to the physical store.

Those advantages, added to the internet diffusion, resulted on an explosion of online sales: from 2010 to 2016, the compounded annual growth rate (CAGR) of B2C e-commerce sales was 23% (Ecommerce Foundation, 2016). This recent boom of online retail challenged the logistic capacity of many companies, from retailers to logistics operators (Winkenbach and Janjevic, 2017).

According to the McKinsey report (2016), the growth of e-commerce is the main responsible for the evolution of deliveries' volume. On mature markets, volume can even double on the next 10 years (reaching approximately 25 billion of parcels delivered per year in the US, the biggest market); while in emerging countries this growth figure can be much higher.

In order to face this scenario, it is important to study how the emergence of innovations - that can act on both technology and business model - on the last mile delivery will influence its whole environment.

1.1.2 High costs: the main challenge of last mile delivery

In logistics, “last mile” is defined as the transportation of goods from the last hub to its final destination - what may go from rural houses to huge urban offices buildings. In other words, it “encompass any movement of freight or products between a distribution center and the point at which the end consumer will receive it” (Lopez, 2017).

The most usual last mile delivery method used is the one in which the parcel is delivered to the customer at his home, personally, which receives the name of attended home delivery (AHD). The AHD is really inefficient and inflexible, as the customer must wait for the parcel to arrive and, from the delivery company perspective, there is a risk that the receiver is not home, making it necessary to perform a second delivery trial (Zhang and Lee, 2016).

As result, despite the fact that this logistic segment usually represents a small fraction of the whole distance incurred within the transportation (especially when there is aerial movement involved), it represents up to 50% of the total delivery cost (McKinsey, 2016). The last mile delivery then becomes a key process for both retailers and logistics operators in order to get competitive advantage, and the drone technology emerges as one possible solution for the cost reduction on last mile delivery.

1.1.3 Development of drone technology

The drone is a relatively new technology. However, this does not affect the fact that it has already been explored in multiple situations and still presents many potentialities. Sales of drones are expected to surpass US$12 bi in 2021 (CAGR of 7.6% from 2016), and this growth will occur mainly on commercial drones (Business Insider, 2017).

The McKinsey’s study (2016) presents some growth estimations about the use of drones on the logistics sector on the near future, related to (i) the technology development, (ii) the increase of customer acceptance and (iii) the raise of labor costs (improving the opportunity costs of investing on drone technology). It estimates that “autonomous vehicles including drones will deliver close to 100 percent of X2C and 80 percent of all items” (McKinsey, 2016).

Those optimistic predictions over the use of drones in the future are determinant factors to believe that this technology can assume a role on the last mile delivery, making it necessary to develop a business study of it.

> *“One day seeing an Amazon drone will be as common as seeing a mail truck.” – Jeff Bezos, CEO, Amazon (Wattles, 2015)*

1.1.4 Search for competitive advantages

Competition between business on the modern economy and the search for competitive advantages motivate the emergence of efficient innovations. The source of competitive advantage may not come just from the productivity maximization of each company, but “also in the efficiency of the logistics system supporting the entire network (…) using an effective and efficient customize logistics chain, able to supply new high value and added services” (Caroli et al. 2010). In the last mile delivery, currently regarded as one of the “most expensive, least efficient and most polluting sections of the entire supply chain” (Gevaers et al., 2010), this would not be different.

With that in mind, drone technology emerges as an innovation that could be useful to suppress some challenges of last mile delivery, promoting a more efficient delivery environment and not restricting itself to one company or another.

1.2 Objective

The e-commerce expansion is a phenomenon that has promoted a search for more economically efficient ways to deliver products, especially on the final and least efficient part of the route (the last mile). This search has recently found the drone technology as one of its possible solutions.

To verify the viability of the inclusion of drones on the last mile delivery context, this work focus analyzing the last mile delivery environment, verifying how the drone technology could fit to it, and then proposing new models in which the use of drones may be fitted. The creation and comparison between business models is an important first step for drones to become widely used on the last mile delivery, as business models innovations (BMI) often outperform process and product ones (BCG, 2009).

In addition, the highlight of this work is involving multiple actors of the last mile delivery, from the consolidation center to the method on which the receiver will get the good ordered. This aggregation is fundamental to provide an overview about this specific environment.

Finally, the development of a mixed-integer linear programming (MILP) optimization model is an interesting approach since it can quickly provide optimal cost solutions for the last mile deliveries (Almeder et al, 2009). This allows not only to verify quantitatively the economic viability and the requirements' attendance of the business models discussed, but also to compare the results among them.

In conclusion, aiming to do an overall analysis of the drone's last mile delivery environment, this work has mainly three objectives:

- Realize an extensive research over the last mile delivery context and expose how drone technology could fit to it trying to reduce its main issues.
- Develop and present an analysis of possible last mile logistics' business models that include drones as last mile transportation vehicle.
- Determine a mathematical model to optimize solutions of the discussed business models using mixed-integer linear programming (MILP).

1.3 Drawbacks

This session presents some of the main disadvantages and drawbacks of using drones as last mile delivery vehicle. Other specifications of the drone technology will be presented on the chapter 3.

1.3.1 Regularization

The main restriction for the development of drone's last mile delivery is related to the legal area.

In order to avoid trespassing over privates' properties and guarantee safety to the people on ground, rigid rules have been stated against the use of drones (Donahoe, 2015; Gounley, 2015), especially on the USA (Ames, 2015). Those rules refer to which areas drones can be used and the ratio between number of drones and its operators (Stanford, 2016). However, some regulations have started to advance on a way to permit commercial delivery drones (Stanford, 2016), particularly on rural areas (McKinsey, 2016).

Jeff Bezos, CEO of Amazon, company that have already performed some experiments with delivery drones, stated that "[drone] technology is not going to be the long pole. The long pole is going to be regulatory" (D'Onfro, 2014).

1.3.2 Public acceptance

Many innovations that start to influence relevantly on people's daily life naturally tend to face an initial avoidance. This would not be different on the last mile delivery.

The AHD, besides inefficient, is a "comfortable" delivery method from the customer's perspective. It involves a "simple" procedure on which one person gives other a product that had been ordered.

On the other hand, reception is much more complex with drones. It involves an autonomous flying vehicle performing a delivery, as it will be exposed along the next chapters. This complexity naturally promotes some public rejection. In addition, people are still unsecure with the use autonomous vehicles. For those reasons, drone's delivery may face some troubles related to public acceptance.

However, researches (McKinsey, 2016; Temando, 2016) have showed that public acceptance has already started to shift, especially among the younger customers, which represent the “future” perception over that technology.

1.4 Work Structure

The first chapter presented a general overview of the work, with its main motivations and objectives. The next chapters will include the following:

Chapter 2 - Literature: presents an initial revision over the concepts and theories used on the study. It exposes (i) a deeper perspective of the last mile delivery context, including a general characterization of it, (ii) the concept of business model, how it applies to this work and a brief introduction of the framework used and finally (iii) a brief definition of linear programming (LP) and how it can be applied to last mile delivery.

Chapter 3 - Use of drones on last mile delivery: exposes possibilities of applications of drones on the last mile delivery and the actors involved on it.

Chapter 4 - Characterization of the use of drones on last mile delivery: classify the potentialities of the use of drones on the last mile delivery

Chapter 5 - Methodology: presents the tools and methods used on the development of this work, including the framework used on the development of the new business models and the basis for a the mixed-integer linear programming (MILP) model deployment.

Chapter 6 - Results: exposes the obtained results and its applications, including the proposed business models and the mathematical MILP model to find cost optimal solutions.

Chapter 7 - Conclusion: concludes this work and suggests future studies.

Chapter 8 - References: lists the bibliographic references used along this work.

2 Literature

In this chapter, the author presents the references used with the objective of constructing a solid theoretical basis for the analysis of the drone's last mile delivery environment that will allow the development of business models and the construction of a simulation model.

2.1 Last mile delivery

This session exposes a deeper look over the last mile delivery, presenting the main challenges involved on it as well as its main characteristics.

2.1.1 Challenges

This sub session presents the main challenges involved on the last mile delivery, which are related to both its requirements and costs.

2.1.1.1 Requirements

The requirements of the last mile delivery can be either market-related - demands made by the customers -, or connected to its environment - associated to its externalities.

2.1.1.1.1 Market

From a costumer perspective, exigencies on the delivery experience are getting more rigid, intensifying the urgency for a more efficient logistic, mainly at the most critical level: the last mile. Among others, the customers most discussed delivery issues are (Visser et al., 2014):

(i) Good not being delivered
(ii) High charge
(iii) Long order lead time
(iv) Obligation to stay at home

On that scenario, customers expect not only high speed and low costs, but also certainty of delivery (day and even time-slot), since time spent waiting the parcel to arrive is highly undesired.

The McKinsey report (2016) presented a research over some customers' requirements on what concerns delivery options, which main results are presented on the next figures.

Figure 2.1 - Share of customers choosing different delivery options

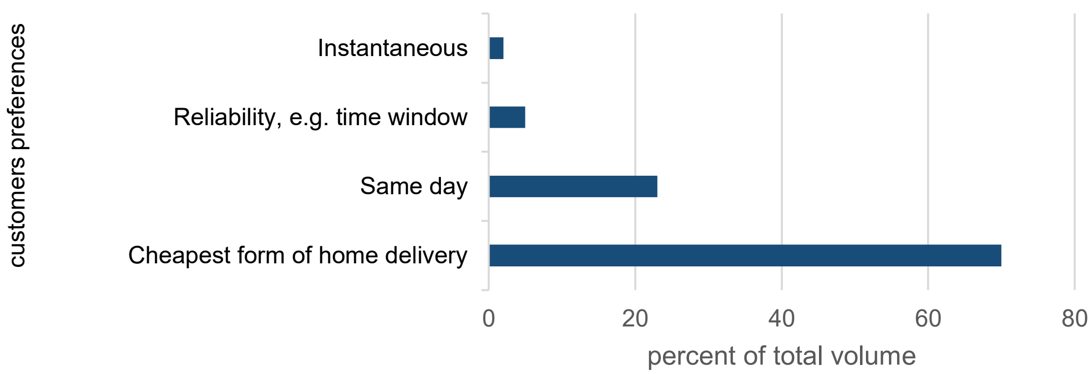
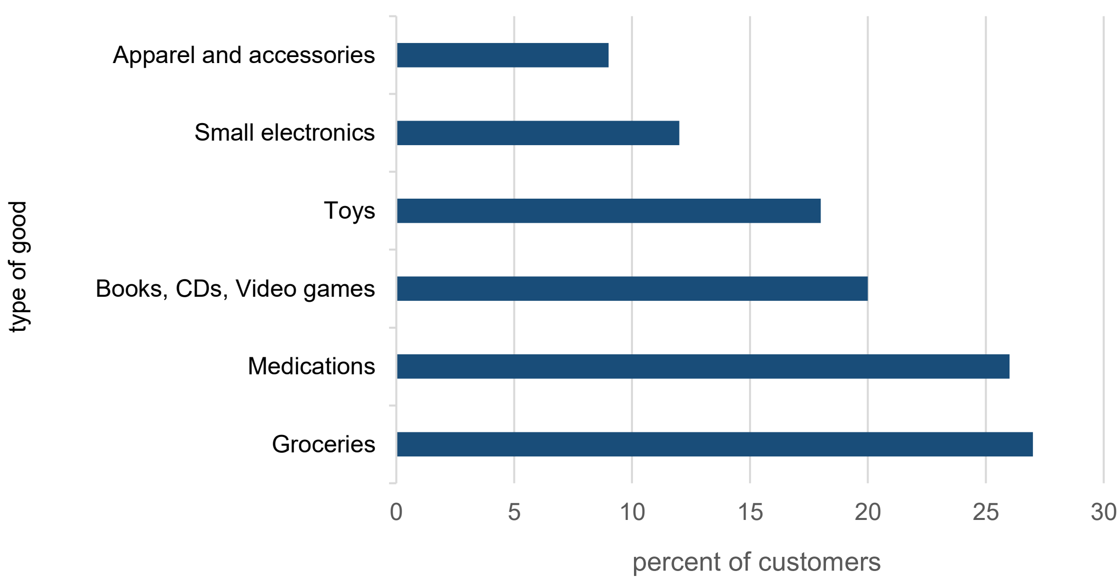


Figure 2.2 – Share of customers who did not buy an item online due to long delivery times



Source: adapted from McKinsey report (2016)

It is possible to establish, from this data and the report, three interesting conclusions related to customers' preferences:

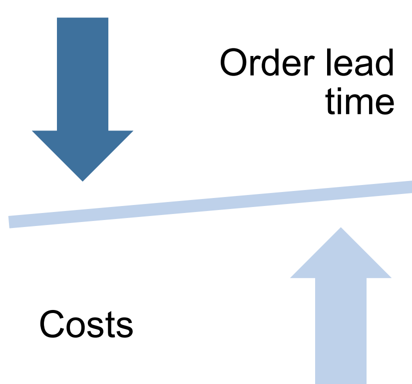
(i) Besides the fact that a huge majority of customers prefer the cheapest delivery method, over 20% would agree to pay a little more (up to 3 euros) for same day or instantaneous delivery, and this number is even higher between the younger people, suggesting an increase of this figure on the next years.

(ii) In some product categories (such as groceries and medications), more than 25% of the customers decided not to purchase a product online due to long order lead time.

(iii) The customers do not present high interest on moving themselves to get a parcel, so home delivery may dominate the last mile delivery market.

Summing up, according to Davis and Mentzer (2006) (apud Boyer et al. 2009), the challenge between the last mile delivery companies and the market preference is to deal with the trade-off between "order lead time and cost".

Figure 2.3 – Main tradeoff to be solved by today's last mile logistics companies



Source: made by the author

Those preferences meet the main principle of using drones on last mile delivery. The idea of using this type of vehicle is to shorten the order lead time of home deliveries as they act on a dedicated route and would not gain economy of scale by delivering on lockers that involve customer's movement. On the other hand, the main obstacle to its use is the cost per delivery, what will determine whether it is a cheap form of home delivery, the major customer preference. This issue may be especially relevant on market segments that fast delivery is not a major requirement and customers would not be willing to pay for same-day or even instantaneous delivery, such as electronic devices, cosmetics and apparel (McKinsey, 2016).

2.1.1.1.2 Environment

Last mile delivery is relevant not only on the logistics' context, but also on a more extended society perspective.

Last mile delivery presents not only economic issues, but it also face high social and environmental costs, related to both traffic and pollution caused by its fragmentation and the low range of use of cargo load compartments of the transportation vehicles (usually small trucks) (Iwan et al. 2016).

While logistics providers and e-retailers try to develop more economically efficient ways to perform the delivery, the growth of e-commerce is associated to an increase of traffic in urban areas (related to a higher number of vehicles in circulation and parking issues) and, consequently, an increase of noise and air pollution (mainly due to higher CO_2 emissions).

With that in mind, and since those issues are related to the inefficiency on the last mile delivery process (Winkenbach and Janjevic 2017; Shcau et al. 2016), it is important to think of innovations that present a "healthier" and sustainable method of last mile delivery as a "society requirement".

In this scenario, the use of drones may represent a way to reduce those negative externalities. The substitution of trucks and vans for drones promotes a reduction on the number of vehicles in circulation on the cities, lowering traffic and pollution levels. On the other hand, the use of drones may represent a safety issue for the population and the high use of batteries demanded by this technology is not an adequate way to surpass this sustainability issue.

2.1.1.2 Cost

This sub session presents the main reasons that lead the last mile delivery to be the cost dominant segment of the logistic chain.

2.1.1.2.1 Labor costs

As it was presented on the previous chapter, last mile delivery represents an extremely cost inefficient segment of the delivery. The main reason that explains this issue is the fact that the today method is labor-intensive, and “labor costs tends to dominate the travel cost per mile for consumer direct deliveries” (Boyer et al., 2009). The labor costs are the main reason why incumbents, which are the companies that present significant labor cost disadvantages, are struggling (McKinsey, 2016). The last mile delivery situations that are mainly related to that high contribution of labor costs are (McKinsey 2016; de Souza et al. 2014):

(i) Location of delivery points, usually highly spread over access-restricted areas - usually urban centers - and away from the larger distributions centers, which are usually located on the cities’ outskirts. This scenario results on an inefficient load usage of vehicles and, consequently, an excess of labor force responsible for the delivery.

(ii) Restricted time windows available for the delivery to occur (mainly because the customer must personally receive their packages), what contributes to a poorly labor force’s usage.

The drone technology may represent an interesting last mile delivery solution in this scenario of increasing labor costs, as they may reduce the number of employees needed for the delivery, since one person may be responsible for multiple drones. On the other hand, for that advantage to confirm, it is necessary to do an extended comparison research over salary between drivers and drone controllers and how the drones would effectively reduce the total labor force demanded.

2.1.1.2.2 Waste

In addition and related to labor costs, the huge amount of waste is another issue responsible for high costs on last mile delivery. The reduction of waste-in-process (WIT) is the main goal of Just-in-Time (JIT), a cost-effective philosophy that has already been applied to innumerous firms and industries, including city logistics. An increase on the utilization of firm's assets at a higher possible level is the main responsible for waste reduction, what promotes simultaneously productivity's maximization and maintenance of customers' level of satisfaction (Ohno, 1988).

On terms of last mile delivery, situations that can be considered waste are listed next (Bhusiri et al. 2014):

- From a distributor's perspective:
    - Wrong or untimely delivery
    - Dissatisfaction of the receiver
    - Damage of goods
    - Underutilization of resources (such as vehicle or manpower)
- From a receiver's perspective:
    - Additional expenses incurred due to delivery process inefficiencies, such as inventory, labor, holding and opportunities costs

Those wastes are very often observed on attended home delivery (AHD) due to factors that were observed on the previous sessions. It is possible to highlight wastes related to repeated delivery and non-deliverables, which represent 12% and 2% of total deliveries, respectively (Visser et al. 2014). Going further, even the main concept of AHD can be seen as waste from both the customer and the distributer points of view, since there is no effective need for the customer to physically receive the good. Finally, even using man force to perform a work that could be realized by autonomous technology fits on the category of waste. The list of wastes could go on, including, among others, wastes related to the traffic situations or time spent waiting the receiver.

In addition, this necessity to keep the last mile delivery efficient and attend the services levels demands a complex mechanism that increases the work - and costs - of the sector (de Souza et al. 2014), what usually promotes a generation of unnecessary efforts and can also be considered waste.

In that scenario, the “emergence of drones as a transportation alternative to trucks is of particular relevance when considering last-mile deliveries in large cities, where the use of traditional truck-based methods (…) is becoming increasingly restrictive” (Tavana et al. 2017). The use of drones on last mile delivery can be seen as a JIT tool and may reduce significantly the waste on that process, promoting, among other solutions:

(i) Reduction - or even clearance - of failed deliveries
(ii) Better use of resources due to the existence of no time restrictions to realize the delivery
(iii) Vehicles usage at full capacity
(iv) Use of autonomous technology to substitute man force.

2.1.2 Classification

In order to have a deeper look over the last mile delivery, making it possible to have some insights about possible roles that drones may develop, an analysis on the variables that act over it was made.

The variables that influence the last mile delivery is a thematic that has been widely explored on the literature (Boyer at al. 2004; Gevaers et al. 2014; Hayashi et al. 2014; among others). Winkenbach and Janjevic (2017) verified that they could be grouped into five categories, which are presented on the next table.

Table 2.1 – Last mile delivery variables grouped

Order and place of payment		
	Place of order placement	
		Online
		Offline
	Moment of payment	
		On purchase
		On delivery
	Means of payment	
		Credit/Debit Card
		Online wallet
		Cash
Warehousing and order preparation		
	Governance of warehousing activities	
		E-retailer
		3PL
	Order preparation technology	
		Manual
		Semi-automatic
		Automatic
	Place of order preparation	
		(Sub)regional hub
		Metropolitan/urban hub
		Local hub
Customer service performance		
	Order lead time	
		Deferred delivery
		Next-day delivery
		Same-day delivery
	Delivery time window	
		None
		1 day
		Few hours
		Scheduled delivery
	Services at delivery	
		None
		Value-added services
		Instant returns
Distribution		
	Route organization	
		Combined
		Dedicated
	Intermediary transhipment	
		None
		Urban depot
		Mobile warehouse
		Urban transhipment point
	Mode and vehicles used for feeder transport	
		Truck/LCV
		Personal vehicle
		Tramway
		Barge
	Mode and vehicles used for last-mile transport	
		Truck/LCV
		Personal vehicle
		Carcocycle/bicycle
		Walker/trolley
	Governance for feeder transport	
		E-retailer
		Parcel/postal operator
		Pick-up point operator
		Courier network
		Crowd-shipping network
	Governance for intermediary transhipment point	
		E-retailer
		Parcel/postal operator
		Last-mile specialist
	Governance of last mile transport	
		E-retailer
		Parcel/postal operator
		Pick-up point operator
		Courier network
		Crowd-shipping network
		Last-mile specialist
Product exchange		
	Place of product exchange	
		Home/near-home/workplace
		Automatic locker
		Urban pick-up center
	Means of product exchange	
		Attended
		Unattended

Source: adapted from Winkenbach and Janjevic (2017)

In addition to this classification, it is interesting to discuss the environment in which those deliveries are made, since this is a factor that influence directly the type of delivery used.

Consumer density on the delivery area is an important factor on the last mile delivery because it is not only related to the number of goods to be delivered but also to the length of the route and the traffic.

In general, the higher the population density, the higher the efficiency of the delivery routes. This happens once customers are located near to each other it becomes easier for the planner to develop a shorter route that meets all customers, even including the traffic delay. On the other hand, since there are more people traveling within those high density areas, it is a less safer environment for packages left unattended when it is not possible to deliver directly to the person or in other safer manner (Boyer et al. 2009).

Finally, to complete an overview about last mile delivery, it is useful to discuss methods of which the final customer can effectively receive his delivery, as this is an important issue of the drone application on last mile delivery.

Allen et al. (2007) presented some key solutions for the customer’s reception method other than the usual attended home delivery (AHD) that presents many disadvantages as it was observed. The main solution are:

(i) Reception boxes: boxes are fixed on a wall outside the customer’s home or any other delivery place. They are accessed by a key or electronic code, which is owned by both the responsible for that specific delivery and the box owner. Can be used by basically any type of good if the temperature is controlled, but presents some issues on apartments, where there are many people living on the same building and there may be not available room for the boxes of all residents.

(ii) Delivery boxes: similar to reception boxes, but instead of demanding each household to “own” its box, those belong to the company that is responsible for the last mile delivery. Those boxes are filled with goods at the distribution hub and then are temporally attached to the customer's home via a locking device. The customer receives the code to open the box and, after collecting the good, the box is recollected by the company.

(iii) Controlled access systems: a partnership between the customer and the delivery company, on which there is a possibility for the delivery company to enter on the customer's home by using a kind of "universal" key and then leave the delivery on a safe place where the customer will later find.

(iv) Locker-banks (Iwan et al., 2016): this method is composed by locked boxes located at attended places (like supermarkets and shopping centers). The customer decide on which locker he wants to receive his delivery and the company deliveries on the chosen one, on a way that only the delivery company and the customer have the code to open the locker. This method is sort of a "half-way" between the "customer do the last mile" and a home delivery, since he can choose places where he usually go.

(v) Collection points: the delivery is left on lockers inside determined "stores" - the collection points -, and then the customer notified, being able to go there and get his package. It can work automatically, with a system that only allows the final customer to open the locker, or manually, with attendants. In this method, the customer is responsible for the last mile of the delivery.

The next table presents a comparison between those methods and the AHD.

Table 2.2 – Comparison between delivery reception methods

	Attended delivery	Reception box / Delivery box	Controlled access sytem	Locker-bank	Collection point
Who covers last mile?	Delivery company	Delivery company	Delivery company	Customer	Customer
Customer present on delivery?	Yes	No	No	No	No
Types of products	Any	Packages, groceries	Packages, groceries	Packages, groceries	Packages
Failed deliveries	High	Virtually none	Virtually none	Virtually none	Virtually none
Delivery window	Fixed delivery hours	Delivery company operating hours	Delivery company operating hours	Delivery company operating hours	Collection Points operating hours
When goods can be colected	When at-home/office	24h	24h	Locker-bank host operating hours	Collection Points operating hours
Retrieval time for customer	None	Very short	Very short	Short to Long	Short to Long
Drop-off time	Long	Short	Short	Very short	Very short
Initial investment	Low	High	Medium	Medium	Low/Medium
Delivery cost	High	Low	Low	Lowest	Lowest
Possible operational problems	High failed deliveries and poor vehicle utilization	Large need of box necessary	Concern about safety	Customer has to travel to collect	Customer has to travel to collect
Potential reduction of transportation vehicles	-	Some reduction	Some reduction	High reduction	Highest reduction

Source: adapted from Iwan et al. (2016)

In terms of cost reduction, Punakivi et al. (2001) concluded that home delivery solutions that presented secure unattended reception were the most cost efficient based on a simulation on the metropolitan area of Helsinki that achieved up to a 60% cost reduction when comparing to attended deliveries.

On the next chapter, it is going to be presented how that classification and analysis of the last mile delivery can be applied to the drone's context.

2.2 Business model

2.2.1 General concept of business model and the innovations influence on it

Business model is an expression of the way - which, how and when the activities are performed - that a determined company create value to its customer, analyzing business economic potentialities to sell its products (Afuah, 2004). It express not only how the company is organized and the relationships between stakeholders of the business environment are established, but also its financial consequences (Saebi and Foss, 2015). In addition, the business model concept is not exclusive to one or another business segment and can be applied to multiple situations, inclusive to last mile delivery. This topic is going to be deeply studied on the next session.

The business model is composed by four components, which are presented next:

- Value proposition: determine the way that company define its competitive advantages on the market.
- Value chain: composed by key resources, key processes and key partners (Zenezini et al. 2017).
- Cost structure: determine how processes and partners will work on production, allocating resources.
- Revenue: determine the way that a business will earn money by selling its products, adding value to the costs and, by doing so, becoming profitable.

Further, as this work studies the introduction of a technological innovation, it is interesting to understand how this phenomenon affect the business model of a determined company or environment.

The work of Schumpeter (1934) has introduced innovation as an important responsible for economic growth. However, at the same time that technological innovation may promote growth due to a market requirement match (Bond & Houston, 2003), such as a new product that solves a market necessity, an innovation that modifies the interaction between business entities, usually presents better results than a solely technological innovation that is not followed by business model change (BCG, 2009). Further, the importance of a joint work between technological and business models innovations come from the fact that growth and business model redesign opportunities are created by the introduction of structural changes such as the introduction of new disruptive technologies, on a way that the “role of business model design becomes particularly salient because different business models may define different value propositions for technologies and the ways to capture value” (Wei et al. 2014).

With respect to the introduction of drone technology to the last mile delivery context, besides representing “simply” an introduction of a known type of vehicle on the delivery chain and not presenting a huge technological disruption, may modify how the actors of the delivery chain interact. Attending new customer’s requirements - such as faster deliveries - may demand an actor’s roles reorganization in order to satisfy the technology potentialities. For instance, the location of drone’s departure centers and even the storage control may become more relevant on this scenario. In addition, the autonomous drone control itself may require that new actors become introduced, what would certainly modify the revenue and information flow.

2.2.2 Concept of business model applied to last mile delivery

In order to define an overall structure of a last mile delivery business model, this sub session first presents the business structure of the main actors involved on the last mile delivery. Finally, it shows a framework that contributes to the development of business models on the city logistics' context.

2.2.2.1 Main actors of last mile delivery

Besides the fact that the concept of business models applied to the delivery environment is not well defined, there is a common agreement about its objectives (Timmers, 1998, 2003; Afuah & Tucci, 2001; Magretta, 2002), which can be summarized as the following (Madlberger and Sester, 2005):

- Determine the flow architecture of products, services and information.
- Determine how value is generated to the customer.
- Determine how revenue is sourced to the business.

On the last few years, the last mile delivery environment has become more fragmented due to an emergence of new entrants. At the same time, companies are becoming more collaborative and building on last mile partnerships to achieve higher levels of efficiency - either through physical internet (PI) or alliances (PWC, 2016). Those two phenomenon have built a more complex network between actors of last mile delivery.

For that reason it is important to present each actor of the last mile delivery and to determine how, in that specific context, they meet their respective objectives. All the actors involved on last mile delivery could be grouped into three big groups, which are described next.

2.2.2.1.1 Merchants

Merchants are the retailers or the suppliers, who are responsible for the products and the direct management of the customers. Their business models often go much further than the delivery - involving elements such as product quality and advertising channels.

However, last mile delivery can be seen as the connection between the customer order and the physical delivery (Esper et al. 2003), becoming a key factor for the business viability and a source of competitive advantage (Madlberger, 2004; Bain, 2012). That is true mainly because fast and precise deliveries means value to the customer (McKinsey, 2016), what is especially important on the least efficient segment of the delivery.

In addition, “excellence in logistics enables the strategic progress of these firms and plays an important role for overall company performance in terms of profitability and growth” (Sandberg et al. 2011). In those “flow-oriented” companies, where logistics plays a decisive role on the outperformance of competitors and on the overall strategy, it is possible to discuss a “logistics-based business model” (Sandberg et al. 2011), which can be seen as a “blueprint” of a company’s overall strategy (Osterwalder et al., 2005; Magretta, 2002).

In that scenario, last mile delivery performs a decisive role for a merchant company not only because it represents huge part of the costs and time consumption, but also because it means the interface between the company and its final customer.

However, besides its importance, merchants companies are often not responsible for providing the logistics services of their products, mainly because this usually does not integrate its core business and competencies (Bain, 2012). As result, this task is usually outsourced, what can be viewed as a “make or buy decision”.

2.2.2.1.2 Logistics providers

The shift on the corporation’s perspective of logistics from a mandatory cost to an enhancer of the company’s product offering and a source of competitive advantage (Mentzer et al. 2014) opened path for a significant growth of logistics providers (Bain, 2012).

The logistics providers are responsible for the organization of the whole delivery chain, which goes from the moment when the product leaves its production center - usually an industry - to the final customer. This path can include warehouses, consolidation and distribution centers and means of transportation - from planes to drones. The main logistics providers and a brief description of each one are exposed next:

(i) Warehouse operator: responsible for the storage of products and usually represents the first step of the delivery. After production, products are usually taken to big warehouses where they wait until an order requesting is sent. After that, product is carried to a vehicle that will be responsible for its subsequent transportation.

(ii) Urban Consolidation Center (UCC) operator: UCCs work similarly to warehouses, differing specially in three characteristics: (i) its size - smaller than warehouses; (ii) its location - closer or even in city centers - and; (iii) the period of time that products are storage - shorter than in warehouses, presenting higher product turnover. They usually storage products coming from warehouses either because they have ran out of this product or even because a final customer close to its area has ordered it. In other words, UCCs can work as a small warehouse - if the product is intended to be storage until a purchase order is made - or as a transshipment point on the delivery chain - if the purchase has already occurred. The main idea of UCC is (i) to promote cheaper deliveries by consolidating products of different companies that should be delivered within its respective area, avoiding a poor load usage of vehicles and (ii) to reduce the order lead time, representing a storage place closer to the final customer. Finally, UCCs may also be responsible for the transportation of products.

(iii) Express courier/parcel operator: main responsible for products' movement, either from warehouses to UCCs, UCCs to final customers or any other trip. They (i) operate delivery's vehicles, (ii) are often responsible for the integration between the parts of the delivery chain, presenting information about the product - such as which products are carrying and real time position – and (iii) may also provide an intermediary storage of the products, similarly to UCCs.

(iv) City freight carrier / Last mile specialist: perform the same activities as the express courier/parcel operators, but working specifically on the last mile of the delivery, this is, from the last hub to the final customer. As result, they are responsible for the product actual delivery to the final customer, performing any additional service, such as the usage of reception methods presented on the previous session. In other words, they represent the interface between delivery and customer.

The merchants - or other logistics providers -, to perform those activities, often hire logistics providers, whose value proposition rests in three key pillars (Bain, 2012):

(i) Optimizing logistics costs for customers
(ii) Shortening the length of the order completion cycle
(iii) Reducing the number of fixed assets

The major challenge for logistics providers is the alignment of the “corporate strategy with the right organizational model and matching that strategy to targeted customer segments” (Bain, 2012). In other words, under a resource-based view (RBV), leading logistics providers are the ones that obtain competitive advantage by the excel at understanding the key customers’ needs and purchasing behaviors, presenting logistics and supply chain management capabilities that simultaneously fit those needs and are both valuable and difficult to imitate (Sandberg et al. 2011; Ketchen and Giunipero, 2004; Barney and Clark, 2007; Olavarrieta and Ellinger, 1997).

Those challenges and values are basically the same on the last mile delivery environment, but can be observed with an even stronger intensity due to the importance of this logistic segment.

2.2.2.1.3 Support

Supportive actors do not act directly on either the production, storage or transportation of goods. On the other hand, they are essential for those activities to occur.

Many actors other the merchant and logistics providers are necessary to sustain not only the last mile delivery, but also all the delivery chain, providing the structure to the flow of products and information. For instance, both the lands used for warehousing and consolidation and the vehicles used for transportation may be owned by third parties. Similarly, ICT specialized companies might perform communication tasks and even local governments can provide subsides to the logistics providers as a “reward” for the reduction of negative externalities.

2.2.2.2 A last mile business model framework

The session 2.1 focused on describing typologies of different last mile delivery on a high and aggregated level, while this session so far has presented the main actors involved on the delivery context. However, since this work intend to discuss an innovative implementation of this sector, it is fundamental to use a “universal” framework.

Zenezini et al. (2017) developed a city logistics framework that compared its systems to business ecosystems assuming that both are composed by multiple stakeholders interrelated decision-processes (Tian et al. 2008), on a way that firms are “simultaneously influenced by their internal capabilities and by their complex interactions with the rest of the ecosystem” (Iansiti and Levien, 2004).

On this scenario, Business Entities (BEs) play roles - functions in a network of companies - reacting to and modifying its environment (Pohlen and Farris, 1992). On the context of city logistics, the existing BEs and the corresponding roles that may be performed by them are presented on the next table.

Table 2.3 – Business entities and corresponding roles that they may assume on the city logistics context

Roles	BE	Express courier	City freight carrier	Green delivery operator	UCC operator	Supplier	Large retailer	Local retailer	Local administrator	ICT platform operator	Real state developer
Receiver					X		X	X	X		
Goods consolidation and logistics services	User	X				X	X	X	X		X
	Provider	X	X	X	X						
City delivery services	User	X				X	X	X			
	Provider		X	X	X	X	X				
Network coordination		X			X				X	X	X

Source: Zenezini et al. 2017

Furthermore, it is important to mention that in a city logistics environment, BEs can share roles or even perform two or more roles, but all the roles must be performed (Zenezini et al. 2017).

A deeper look over this framework and how it can be applied to drone's last mile context will be made on the methodology chapter.

2.2.2.3 Innovation on the last mile delivery

As it was previously discussed, the introduction of technological innovations usually are followed by a business model modification. However, there is still little literature regards the effects of a business model innovation or technological introduction on an environment, and not only in how it affects a single company. This deficit is even stronger when last mile delivery is discussed, what may be justified by the lack of innovative dynamics of this market.

In face of this barrier in order to study the drone role on the last mile delivery and how would they affect its whole environment, the framework presented on the previous sub session will be only used. This framework is able to cover this work demands since it can adequately expose an environmental dynamics change and due to the fact that the introduction of drones would not disruptively affect the last mile delivery organization.

2.3 Mixed-Integer Linear Programming (MILP)

2.3.1 Definition of linear programming (LP) and the simplex algorithm

LP is a "tool for solving optimization problems" (Winston et al. 2003). In a more broad perspective, for a problem to be considered a LP problem it must have four main components (Winston et al. 2003):

1. Decision Variables (x_i): can have their values modified in order to optimize the objective function.

2. Objective Function: linear function that should be optimized (by maximizing or minimizing its value) through the change of the decision variables' values.
3. Constraints: set of linear equations or linear inequalities that constraint the values that the decision variables can assume. Constrains can also be related to the type of decision variable, restricting it to be, for instance, a binary variable (assuming only 0 or 1 values) or an integer variable (assuming only integers values). The LP problem receives the name of mixed integer linear programming (MILP) when it mixes integer or binary variables with non-integer ones, and can be considered a specific type of LP.
4. Sign restriction: associated to each decision variable, it specifies whether it can assume only nonnegative values ($x_i \geq 0$) or if it is unrestricted in sign (urs).

Now that the components of a LP problem were exposed, it is important to find a way to discover their solution, what means discovering the decision variables values that not only optimize the objective function but also satisfy all constraints and sign restrictions.

In 1947, George Dantzig developed the *simplex algorithm*, an efficient method to solve LP problems. The application of this method consists on the iterative working with matrixes, what become exhaustive on problems with many constraints and/or decision variables (Winston et al. 2003).

Fortunately, today many software - such as excel's solver - manage to solve LP problems on a very efficient way. Those tools make it possible to simulate multiple versions of the same problem, making modifications on some constraints, the objective function and/or even including (or excluding) decision variables.

2.3.2 Application on last mile delivery

Modelling is a useful method to solve problems which tests on a real life system would be inviable (mainly due to high costs). It consists on abstracting, analyzing and optimizing a real world problem on a way that the solution could go back and finally be applied (Borshchev and Filippov, 2004). Modelling a problem into a LP form is a method that has many applications, from financial portfolio decisions to logistics (Winston et al. 2003).

The Vehicle Routing Problem (VRP) is a combinatorial optimization problem that helps define the best set of routes and assets' usage attending a determined set of customers and their requirements. It has been deeply studied on the literature and presents many variants since Dantzig and Ramser (1959) first proposed it (Boyer et al. 2009).

Further, the methodology chapter exposes a detailed description of how the VRP could be applied to the drone's last mile logistics context. Moreover, on the results chapter, a mathematical formulation of the general problem and specific treatments for each of the business models discussed will be presented.

3 Use of drones on last mile delivery

This chapter presents an overview about how drone technology is already being applied and could be further used on the last mile delivery context, providing hints for the development of business models. It first introduces some drone specifications, then it presents the way that this type of delivery operationally works and exposes the situations where drone are seen to be more suitable. Finally, it synthetizes the main advantages and drawbacks of using delivery drones.

3.1 Drone’s last mile delivery specifications

This session presents some technical specifications of the drones used as delivery vehicles in order to introduce some of its use possibilities and constraints.

3.1.1 Automation

Drone refers to any unpiloted aircraft or spacecraft, and usually receives the name Unmanned Aerial Vehicle (UAV) (Howell, 2015). They can be fitted on all automation levels of the US SAE standard J3016, that goes from “no automation” to “full automation” (Schreurs and Steuwer, 2015). One of the main advantages of using autonomous vehicles (AV) is to “liberate humans from stress and dangers of driving” (Mitrea and Kyamakya, 2016) and, on the last mile delivery context, an eventual cost reduction as it was presented on the previous chapter.

On the drone’s last mile delivery context, drones should, considering a nomenclature accepted in Germany, present high automation, what means there is “no need for continuous monitoring of the system by the human” (Schreurs and Steuwer, 2015). This level of automation permits that a single person controls multiple drones simultaneously (Wang, 2016). Besides there is some regulatory laws that restrict to a one-to-one relation between drone and controller, it is reasonable to assume that each controller can be responsible from eight to twelve drones (Stanford, 2016).

3.1.2 Type of load

Drones that have already been tested on last mile deliveries managed to carry up to 5 pounds (roughly 2,26kg). Even though this sounds like a small weight, Amazon affirms that over 80% of their packages fit on this restriction (Wang, 2016), what make this type of delivery interesting from an economical perspective.

3.1.3 Other specifications

The American companies Amazon and Matternet are some among others that have already experienced using drones as delivery vehicle. Besides the difference on their “looks”, as it is possible to see on the figures 3.1 and 3.2, both are electric, weighting around 20kg, with batteries that allow them to travel on around 100m high up to 20km from 40km/h to 80km/h carrying about 2kg packages (McCollon, 2017 and Ong, 2017).

Figure 3.1 – Amazon Prime Air delivery drone model

Source: Amazon (2015)

Figure 3.2 – Matternet delivery drone model

Source: Slashgear (2017)

3.2 How it works

This session exposes the working of a drone delivery from an operational perspective.

3.2.1 Departure and route

The main idea of using drones as a vehicle to realize last mile deliveries concerns on the reduction of order lead time - time required from purchase until the good is finally delivered -, since this is one of the main requirement of customers, as it was observed on the first chapter. Companies such as Amazon, Matternet and Flirtey have already presented drone's last mile delivery solutions, and the shortening of lead time is the main element that they all present as its differential. For instance, Amazon promises to make deliveries in under 30 minutes.

In that scenario, it is essential that both departure speed - time spent between the finalization of the order and the departure of the vehicle to its destination - and the route performed by the drone are optimized. The following steps characterize a basic operational working of a drone delivery, which will be further detailed on this chapter and the next one:

(i) The corresponding distribution/consolidation center - where the drones are kept and the goods storage - receives and processes an order.
(ii) It internally selects and picks the good ordered.
(iii) The drone collects the good and takes it to the customer autonomously using a GPS system.
(iv) The drone leaves the good in the customer’s place and finally comes back to its origin, autonomously.

This process may seem quite inefficient, since both route density (number of drop offs - or stops - made in a delivery route, what often receives the name of “milk-run”) and drop-size (number of goods dropped at each stop) are equal to one (Wang, 2016). In other words, the drone carries and deliveries only one good during its whole trip.

On the other hand, studies (Benjamin, 1990; Chang and Chou, 2012; Chang et al. 2009; Storhagen and Hellberg, 1987) discussed that often small-but-frequent deliveries - as it happens on the drone case - attends the Just-In-Time (JIT) principles more than large-but-once deliveries. In that context, the main reasons why this “distortion” may occur are (Tavana et al. 2017):

(i) High economies of labor costs
(ii) The average speed of the drone, that besides being compared to the trucks ones, are made on a “straight line” to the customer
(iii) The “hard-to-reach areas effect” - when there is deficient road infrastructure the difficult that truck access - almost do not affect the drone deliveries

3.2.2 Reception

One of the major concerns over drone delivery relates to the drone-customer interaction, this is, the good reception.

All three companies analyzed (Amazon, Matternet and Flirtey) presented similar solutions to the reception, which consisted basically on the drone possessing an image-recognition mechanism that allowed it to verify, within the location of the delivery - based on GPS connection -, the exact point to leave the good. The “image” to be recognized could be something similar to a "banner" of the company logo placed on the floor, as it happens on the Amazon case. This type of delivery method, in this work, will be named as "free box", and can be either "fixed" on the customers' house or workplace or placed by him after making the order.

This solution presents some problems, such as

(i) Cases that delivery should be made to houses that do not present landing areas or buildings that do not present a specific area for each resident to get its deliver.
(ii) All potential customers must possess and position the "free box".
(iii) Safety issues on leaving the goods unattended, what is especially true in urban centers, as it was presented on the previous chapter.
(iv) Might present some trouble due to climate scenarios, such as nighty, windy and rainy situations, that can affect the image's recognition.
(v) Different companies performing drone deliveries may possess distinct "free boxes", forcing the customer to own more than one tool or demanding its standardization.

It is important to state that, considering that drones make just one delivery per trip, it does not make sense using reception methods that involve the customer realizing the last mile of the delivery. This happens not only because there is close to zero cost reduction, but also because customers prefer direct delivery to their home (McKinsey, 2016).

On the scenario of unattended deliveries, which presents some advantages as it was observed on the previous chapter, besides the "free box", the use of both customer specific reception boxes and delivery boxes are suitable, beyond the "free box", which can be used for both attended or unattended. Possible solutions to each method are described next:

- Customer specific reception box: in buildings or houses with small available landing area it is possible to construct a platform on the roof, where the box(es) may be installed (it is possible to think that each apartment can have a specific box or maybe there could be a limited number of boxes for each building). The box would contain an image or symbol that would be recognized by the drone, which would have a mechanism that allows its interaction with the box, making it possible for it to open the specific box, leave the delivery and then lock it. After that, the final customer, who would have the access to the box, would be able to go there and open it.

- Delivery box: work similarly to the reception one. However, in this case, the drone would carry the box containing the product, and then land by identifying the place to land due to some sign (similarly to the “free box”). After that, the drone leaves the box on the marked place. Then, the customer, who has the access code of the box, open it and collects the good, leaving the box only to be posteriorly recollected.

Those methods presents some of the same restrictions of the “free box”, but solves the safety issue.

In addition, it is possible to think of efficient ways to do the recollection in the case of delivery boxes on the drone’s delivery situation, such as:

(i) A truck that is responsible for the boxes recollection on a following day

(ii) The drone itself recollects the box on the situation where they are leaving a product on the same customer or on a close one. In this way, the “go back” journey would not be considered as waste.

Punakivi et al. (2001) compared the two solutions presented previously out of a drone context, and the main advantages and disadvantages of each solution are presented on the next table.

Table 3.1 – Comparison between unattended delivery reception

	Customer specific reception box	Delivery box	
Operational cost	Medium	Medium-High	Both are similar, but delivery boxes must be picked after the delivery.
Initial investment	Very high	Medium	All the potential customers must own reception boxes (eventual partnerships with real estate companies e retailers).
Utilization rate	Low	High	Delivery boxes can be flexibly used by different customers.
Customer value	High	Medium	Perception of independence from logistics service providers.

Source: adapted from Punakivi et al. (2001).

It is important to notice that there is no literature related to an analysis of distinctive delivery methods on the drone's situation. For that reason, the decision of the best reception - or even recollection - method involves many components that run away from the scope of this work. Because of that, those methods will be simplified and named as "delivery box" in this study.

On the other hand, for attended delivery, the scenario changes. In order to avoid the above issues related to the reception method mainly on urban centers and avoid that the customer should wait during long hours for its package, there may be a system in which the customer set a time (with an hour interval, for instance) where he will be at home. Then, due to the fact that drones are much less affected by traffic unpredictability, it can inform the exact time when it will arrive, making it possible for the customer to go outside and pick the product directly from the drone, without any reception method. To avoid wrong deliveries there should be a communication between customer and drone to confirm that he is the one that should receive that specific order (a Bluetooth communication between the customer cell phone and the drone, for instance). The attended delivery with drones can be seen as interesting solution to the customers' complaint having to stay home during long hours waiting for their goods arrival.

However, that attended delivery presents some issues too, such as (i) customer and other pedestrian safety (since the drone may fly very close to them), (ii) eventual need to a higher number of controllers since it involves a more complex and less autonomous flight and (iii) subject to repeated deliveries in case the customer does not show up.

3.3 Where it can be used

This work intends to present a general perspective over the use of drones on last mile deliveries, avoiding any restriction of country or demographic situation. On the other hand, it is inevitable to discuss its potentialities under specific situations, mainly on rural areas.

As it was discussed in the previous session, drone delivery presents an issue concerning the reception of goods in buildings and houses that present small “landing areas” - something close to $2m^2$ for a usual drone (McKinsey, 2016). As result, most of the tests were made in rural areas, where is (i) easier to find suitable landing sites, (ii) may represent an area of difficult access for trucks and vans (McKinsey, 2016) and (iii) present less safety issues for unattended deliveries (Boyer et al. 2009).

The McKinsey report (2016) states that in rural areas “it is extremely costly to offer delivery within a specified time window or on the same day with any kind of driving vehicle due to the large distances that need to be covered to be in the right place at the right time”, meaning huge route inefficiencies (Boyer et al. 2009). The drone delivery then emerges as potential solution, as they may be the only feasible solution for same day delivery in some areas.

This rural market may seem small for the work and investment involved on the development of a delivery drone delivery infrastructure - that goes way beyond “buying drones” -, but, accordingly to McKinsey (2016), this market may represent 13% of the deliveries, what equals roughly to a half billion items delivered by 2015. That is surely not a negligible segment.

3.4 Consolidation of benefits and drawbacks of using drones on last mile delivery

As it was observed on the previous sub sessions and the previous chapter, a solution for last mile delivery is very demanding. At the same time that customers' requirements are more demanding, in a way that reliable and fast delivery become key success' factor, those customers do not intend to pay or "travel" for the delivery. In addition, the increase in labor costs and the waste inherent to the attended home delivery (AHD) makes an efficient last mile delivery necessary for economic viability of companies, leading to a necessity of complex planning over the last leg of the delivery (Ehmke and Mattfeld, 2012). Finally, the society is affected every day by the environmental costs resulted from the last mile delivery's inefficiencies.

In this scenario, possible main advantages related to the use of drones as last mile delivery' vehicle are:

(i) Reduction of labor-force needed
(ii) Reduction of urban traffic and pollution
(iii) Shortening of order lead time
(iv) Better use of available resources due to weaker time window restrictions
(v) Attendance to areas in which other types of vehicles performed poorly

On the other hand, it is important to discuss some drawbacks that may emerge from the introduction of this innovation on the last mile delivery context, such as:

(i) Effectiveness of cost reduction, especially on overly populated areas or on market segments where shorter order lead times are not required
(ii) Safety issues related to drones flying over urban areas
(iii) Safety and operational issues related to the reception methods, especially in urban centers
(iv) Effectiveness of the ecological footprint's reduction

4 Characterization of the use of drones on last mile delivery

This chapter uses the information presented previously in order to classify all the potential scenarios that involve the drone technology on the last mile delivery context. Performing this review over possible practical implementation of drones in last mile will support the development of specific business models on the results chapter.

The table 2.1 - which presents some variables to define the last mile delivery - will be used as guidance to define variables involved on the drone's last mile delivery. However, since this work is related to an introduction of an innovative last mile delivery method, it will be necessary to make some adjustments and go further than the classification model presented.

Each variable - and others introduced - presented on the table 2.1 was classified according to its potentialities and viabilities as whether it can or cannot be applied to the drone's last mile delivery context, influencing the last mile delivery business model. The variables that could be applied are exposed along the next sub sessions

4.1 Purchase

The variables present on this session are related to the purchase and payment methods of a retailer's product that will be subsequently delivered to the final customer.

Table 4.1 – Purchase and payment variables on drone's last mile delivery

Purchase and payment	
Place of order placement	Online
	Offline
Moment of payment	On purchase
Means of payment	Card (credit or debit)
	Online wallet
	Cash

Source: created by the author

4.1.1 Place of order placement

Besides the fact that a huge majority of deliveries are made due to e-commerce sales, as it was presented on the first chapter, there is no restriction of it when drones are introduced. In that case, the purchase can be done in either an online website or a physical store - since the product is delivered on a subsequent moment, obviously.

4.1.2 Moment of payment

One of the main advantages of using drones on the last mile delivery is the possibility to make unattended deliveries and one of its main drawbacks is public acceptance. In that scenario, it does not make sense to develop a technology that allows the consumer to pay “to the drone” on the moment that the good is delivered, since this would restrict its use to attended deliveries and would face even more public rejection due to its complexity. Those two reasons restrict the moment of payment to the purchase on this work analysis.

4.1.3 Means of payment

Adopting the same idea of sub session 3.2.1.1.1, cash payments are usually exception on the good deliveries context, but drone technology does not introduce any restriction to payments methods, just that they should be done on the moment of the purchase. On the other hand, the mean of payment influence the revenue flow, defining how e to who the purchase fee will be directed - such as credit card fees.

4.2 Warehousing and order preparation

The variables presented on this session are related to the order preparation and the warehouse facilities operation. However, since this works focus on the last mile delivery, those components will not be deeply studied. In addition, as it will be further explored on the next chapter, some assumptions related to warehouse operation on the last mile delivery environment will be made.

Table 4.2 – Warehousing and order preparation on drone's last mile delivery

Warehousing and order preparation	
Place of order preparation	(Sub) regional hub
	Local hub
	Urban hub
Governance of warehousing activities	Retailer
	Warehouse operator
	UCC operator
Order preparation technology	Manual
	(Semi) automatic

Source: created by the author

4.2.1 Place of order preparation

As it was observed previously on this chapter, drones present a restriction concerning their range, on a way that they must departure from an area close to the final customer. However, the place of order preparation is not necessarily the last one before the good goes in direction to the customer - there may be transshipment points -, what could permit existence of (sub)reginal hubs of order preparation other than the place where the drone departure.

On the other hand, one of the main goals of drone's last mile delivery is the reduction of the order lead time, what goes against the existence of regional hubs, that are located far from the final customer. That tradeoff will be further studied on the results chapter.

4.2.2 Governance of warehousing activities

Retailers (especially large ones), warehouse operators and in some scenarios even Urban Consolidation Centers (UCC) operators can perform the warehousing activities, which includes product storage, order processing, product selection and its introduction on the vehicle that will lead it to the next stop, among other activities that will not be studied on this work.

4.2.3 Order preparation technology

Besides the fact that the automation level of the order preparation can influence on the order lead time, its particularity runs away from the scope of this work and in that case will not be further considered.

4.3 Customer service performance

This session presents the variables related to the “outputs” of the drone’s last mile delivery. In other words, the variables that are “perceived” by the final customer.

Table 4.3 – Customer service performance on drone’s last mile delivery

Customer service performance	
Order lead time	Same-day delivery
	Instantaneous
Delivery time window	None
	Scheduled delivery
Services at delivery	None

Source: created by the author

4.3.1 Order lead time

The main concept of using drones on last mile delivery is the possibility to shorten the order lead time. Due to that, only instantaneous and same-day deliveries will be considered. In addition, drone’s deliveries attempt to clear the number of failed deliveries, and, as result, no deferred deliveries will be taken into account.

4.3.2 Delivery time window

Besides the fact that drones present a huge time precision - since they are not subject to many unpredictability, such as traffic -, it does not make much sense to discuss time windows in unattended deliveries. On the other hand, it is possible to deliver within a short scheduled delivery time window, such as instantaneous and attended deliveries (on situations where there is no adequate reception method as it was previously discussed), or even on some specific situations such as a delivery to risk areas that should only receive within some hours of the day.

4.3.3 Services at delivery

Up until now there is no additional service offered by drones, and the development of a value-added technology can be very expensive, but may emerge on the future, such as the possibility for the customer to return the product (on that scenario, the drone would do the opposite of the delivery and pick the good on the customer house). However, those features run off the scope of this study and will not be considered.

4.4 Distribution

This session presents the variables related to the whole distribution method of the product, from intermediary storages to the final customer, going through different vehicles and consolidation centers. In addition, this session introduce not only “how” the product travels but also “who” may be responsible for its movement and storage at each phase.

Table 4.4 – Distribution on drone's last mile delivery

Distribution	
Route organization	Dedicated
	Combined
Mode and vehicles used for feeder transport	Truck/LCV
	Tramway
	Barge
Governance for feeder transport	Retailer
	Courier network
	Express courier / Parcel operator
	UCC operator
Intermediary transshipment	None
	Urban depot
	Urban transshipment point
	Mobile warehouse
Governance for intermediary transshipment point	Retailer
	Express courier / Parcel operator
	City freight carrier / Last mile specialist
	UCC operator
Mode and vehicles used for last mile transport	Drone
Governance of last mile transport	Retailer
	Courier network
	City freight carrier / Last mile specialist
	UCC operator
Network operator	Courier network
	Express courier / Parcel operator
	UCC operator
	ICT platform operator

Source: created by the author

4.4.1 Route organization

There is no technology yet that permits the drone to carry more than one good per trip. In that condition, it is not viable to make a combined route. However, on a multimodal transportation, it is possible to mix both combined and dedicated route organizations.

4.4.2 Mode and vehicles used for feeder transport

On a drone's last mile delivery situation there can be some modes and vehicle used for feeder transport, such as trains, barges, trucks and light commercial vehicles (LCV). It is not going to be considered the possibility of drone due to its capacity (one good per trip), what would make this process extremely inefficient and economically inviable. In addition, it will not be considered the possibility of personal vehicles, which would fit on a crowd-shipping network, what is not adequate to the drone's context, as it will be presented next.

4.4.3 Governance for feeder transport

The feeder transport represents the good transportation from the warehouse to an intermediary transshipment point, route that may not be necessary depending on the location of the warehouse. Multiple Business Entities (BEs) can perform its governance.

4.4.4 Intermediary transshipment

On a drone's last mile delivery situation there can be some types of intermediary transshipment that connects one route to another, that is: urban depots, mobile warehouse, urban transshipment points or even none.

4.4.5 Governance for intermediary transshipment point

The intermediary transshipment point represents the consolidation point from which the goods are directed to the final customer or other intermediary transshipment point. Multiple BEs can perform its governance. There may exist some situations on which the intermediary transshipment is not necessary.

4.4.6 Mode and vehicles used for last-mile delivery

Obviously only drones will be considered for this process, since this is the main actor of this work.

4.4.7 Governance of last mile transport

The last mile transport represents the good transportation from the last transshipment point to the final customer. Besides the fact that crowd-shipping networks and pick-up point operator are BEs often present on the context of last mile delivery, they would hardly work with drones. The former due to its complexity and hard viability to fit on the drone context - especially when thinking about the drone control technology - and the latter one because it obviously does not make sense to have pick-up points on a drone’s last mile delivery environment. Even though, other multiple BEs can perform that function.

4.4.8 Network operator

As it was discussed on the previous chapter, network coordination is extremely relevant on a drone’s last mile delivery context, presenting updates over the current situation of orders, goods and vehicles. Because of that, the company responsible for the coordination of the network of drones assumes an important role on the business model of the last mile delivery. Multiple BEs can assume that role.

4.5 Product exchange

This session presents the variables that represent the interface between the delivery company and the final customer. In other words, the moment when the product is finally delivered.

Table 4.5 – Product exchange on drone's last mile delivery

Product exchange	
Place of product exchange	Home / Workplace
Means of product exchange	Unattended delivery box
	Unattended "free box"
	Attended - scheduled
Governance of reception method	Retailer
	City freight carrier / Last mile specialist
	UCC operator
	Local administration

Source: created by the author

4.5.1 Place of product exchange

As it was discussed previously on this chapter, one of the main advantages about using drones on last mile delivery is that there are no huge differences between delivering on the home/workplace of the customers and other pick-up centers, and because customers appreciate home deliveries, that will be the only option considered.

4.5.2 Means of product exchange

As it was discussed previously on this chapter, one of the main advantages of using drones on last mile delivery is the possibility to make unattended delivery, avoiding the risk of failed deliveries, which can be expensive. However, as it was seen on the session 3.2.2, the reception method of drone deliveries is one of the main barriers for this technology development. Since the objective of this work is not the development of technical ideas, and as it was presented previously on this chapter, it will be only considered unattended receptions made by either “delivery box” - customer-specific or not - or “free box”.

On the other hand, attended deliveries might be suitable for this environment, on a situation where the customer schedule the exact time where he is at home, on a way that the drone deliveries the product on a restrict time window or even instantaneously.

4.5.3 Governance of reception method

Since the reception method becomes a relevant variable on the context of drone's last mile delivery, the company that "owns" it starts to assume an important role on the last mile delivery business model. Multiple BEs can assume that role.

5 Methodology

This chapter gather all the information provided previously and defines how it is going to be used in order to reach the two goals of this work:

(i) Definition of possible last mile delivery business models that use the drone technology.

(ii) Application of a mixed-integer linear programming (MILP) solution on the models proposed.

This chapter first details the framework used and then, based on the general classification of the previous chapter, exposes the main assumption used on the models development and how that classification fits on the framework.

After that, an overview of the MILP problem is shown, exposing also the main assumptions made to perform the mathematical formulation.

5.1 Business Models

As it was presented on the section 1.2, one of the main objectives of this work is develop and present a comparison over business models on last mile logistics that include the use of drones.

This session first details the framework that was used in order to make that development and comparison possible. After that, the main assumptions made for this work are made. Finally, the framework is further studied with the exposition of how the drone’s last mile environment fits to it.

In other words, the tools necessary for the development of drone’s last mile delivery business models will be exposed along this session.

5.1.1 Framework

As it was presented on the literature chapter, Zenezini et al. (2017) developed a framework that can be used to describe business models on a city logistics context.

That framework sustains itself on the concept that business entities (BEs) use resources to perform essential roles to a correct performance of its respective environment, while interacting with others BEs.

On a deeper definition, role is composed by activities performed, decisions made and metrics used by a BE, creating a scenario in which BEs can perform different roles and the same role can be performed by different BEs (Tian et al. 2008). In other words, BEs perform activities based on decisions, which are made based on a metric analysis. Those components are responsible for building a business model at the same time that this business model is responsible for the determination of the partnership model within BEs and may even influence the decisions taken by each one (Zenezini et al. 2017).

The table 4.1 presents the components of this business model framework when applied to the city logistics context, exposing the definition and the properties of each one.

Table 5.1 – City logistic business model framework

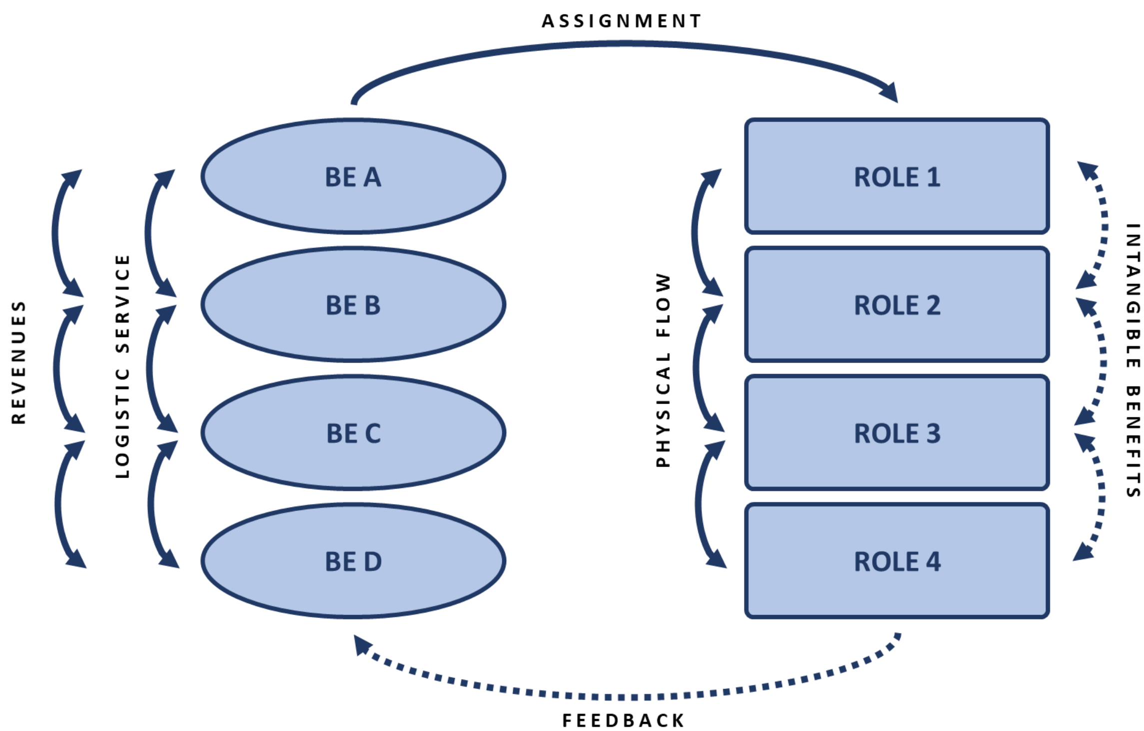
Component	Definition	Properties
Resources	owned by the business entities and necessary for the roles to be performed	Owner Unit Cost
Activities	taks that use resources and are unique to the correspondent role	Resource consumption
Decision	subject to parameters, constraints and variables, can be operative or strategic	Business object Value
Metrics	measure a determined business object and influence on the decision of the BE	Objective Decision variable Constraints
Value exchanges	BE and its roles represent a value network of exchanging goods, services, revenues, informatio and intangible benefits (Allee, 2008)	Provider/Receiver Type

ROLE of the BE

Source: Zenezini et al. 2017

Finally, with respect to interaction between BEs and how roles are connected, Zenezini et al. (2017) affirmed that "goods and services flow between BEs in return for revenues. (…) Then, the value exchanges of money, goods and services, as well as the intangible benefits (e.g. value proposition) are dependent on the role assignment, and are thus created (or co-created) and exchanged during the actual execution of the roles". This complex interaction BEs and roles can be seen in a simpler form on the next figure.

Figure 4.5.1 – The relations between BE and their roles on the city logistics context



Source: Zenezini et al. 2017

In conclusion, it is possible to define a business model of a BE as both (Zenezini et al. 2017):

(i) The set of roles that the BE specifically performs

(ii) The relationship of this BE to other in terms of value exchange

It is interesting to notice that this definition allows the existence of some overlaps of business models, what is natural on an environment with multiple participants. However, this work tries to focus not only on the business model of each BE, but also on how they are connected to each other. In that way, it presents a more general overview of the environment.

In conclusion, the framework used to develop possible business models using drone technology can be synthetized as:

(i) BEs are responsible for performing determined roles
(ii) Those roles are composed by activities, decisions and metrics
(iii) Each activity demands resources to occur
(iv) BEs are interconnected, realizing activities with its own and others BEs' resources.

5.1.2 Assumptions over the business models development

This sub session exposes the main assumptions made on this work in order to adapt to the drone's last mile delivery context, presenting a more focused analysis.

5.1.2.1 Warehousing

With respect to the warehousing activities, is going to be assumed that, on the moment of the purchase, the product ordered is already storage in a warehouse close to the city (outskirts, for instance) or even on it. In that case, if the product is produced in somewhere far from the final customer (other country, for instance), the warehouse is responsible for its stock maintenance according to demand prediction and product turnover. As it was presented on the previous chapter, its governance can be either made by a specific warehouse operator, the retailer itself or, on situations where the product present high turnover, even an UCC can be responsible for product's storage before the order.

This assumption was made mainly because (i) this work focus on the last mile of delivery and (iii) drones' deliveries intend to shorten the order lead time, becoming senseless to store products that are supposed to be delivered by that technology far from the final customer.

5.1.2.2 Vehicles

As it was presented on the previous chapter, drones are obviously the only type of vehicle used on the last mile delivery, but for feeder transportation more options were presented, such as trucks, trains and barges. However, those two latter ones are not going to be considered due to its complexity and to the fact that they are usually present on long-distance travels and provide slower services when compared to other methods - specially barges -, what goes against the main principle of the use of drones on last mile deliveries. In that case, only trucks will be responsible for the feeder transportation.

5.1.2.3 Reception method on unattended deliveries

As it has already been discussed previously, the reception method on drone's unattended deliveries possibly represents the major barrier for the success of this innovation in some situations, and there is still no discussion over possible solutions. Because of that absence of alternatives and considering that there is no intention to realize a technical analysis of this problem, it is going to be assumed that (i) on lowly density populated areas, the "free box" will be used and (ii) on highly density populated areas a "reception box" will be used. In both cases, the method should have been distributed previously and each one present a specific cost and demand a specific period to realize the delivery.

5.1.3 Application of framework on a drone's last mile delivery environment

This sub session intends to realize a deep analysis of the drone's last mile delivery environment based on the framework presented, approaching the components from table 4.1. It firsts introduces the Business Entities (BEs) and resources of the drone's last mile delivery. After that, roles are studied by exposing its main activities. Finally, all those components are gathered, presenting how resources, BEs and roles are interconnected.

In other words, it aims to show how BEs can use their resources to perform specific activities while interacting with other BEs. The development of this lower level perspective over the drone's last mile delivery context will be essential to the construction of suitable business models.

5.1.3.1 Business entities (BEs)

Many BEs may perform roles on the drone's last mile delivery context. The main ones are listed next:

- Customer
- Retailer (local or large)
- Supplier
- Express courier / parcel operator
- City freight carrier / Last mile specialist
- Urban Consolidation Centers (UCC) operator
- Warehouse operator
- ICT platform operator
- Local administration

In addition, there are some business that can be considered peripheral to the last mile delivery context, and even though they are not going to be deeply studied, they are presented next:

- Payment processing company (such as credit card, online payment, smart phone application)
- Insurer companies
- Real state developer
- Vehicles renter
- Warehouse management system company

5.1.3.2 Resources

This session lists not only the main resources other than the financial ones, but it also presents how BEs relate to them. This relation will serve as basis for the development of business models on the next chapter.

As it was observed previously, resources are any intangible or tangible good that is necessary for a correct performance of the roles. Every resource presents as properties a BE that owns it, and in the end of this session it is presented a table that synthesizes the relationships.

The main resources on the drone's last mile delivery are listed next:

(i) Employer (consolidation, transportation and control) - Employers are an important resource on the last mile delivery context. They are necessary in multiple fronts of this business, such as the trucks driving, the organization of orders and drone control, among other activities that should be performed by persons.

(ii) Transportation vehicle - Another intuitive resource presents on the last mile delivery context are the transportation vehicles, responsible for the carriage of the products from one place to another, such as from a warehouse to intermediary transshipment or to final customers. In this work, only drone will be considered to make the last mile transport, while trucks will be analyzed for the other routes. The vehicles can be owned by multiple BEs, inclusive rental companies that are exclusively responsible for lending vehicles.

(iii) Consolidation center and warehouse - The consolidation center and warehouses can be seen as an integration of innumerous resources, that can go from the building itself where the products are stored to the pallet machines that organize the orders made by the customers.

(iv) Land - The land is considered as a distinguish resource from the consolidation center since it is usually owned by different BEs. The lands can go from small location on huge urban centers to large areas in a rural zone.

(v) Reception tool - As it was observed previously, the drone’s last mile delivery demands an innovative reception method. This method can be a delivery box or even a “free box”, as it was defined previously. Different BEs can own those resources.

(vi) Information and Communications Technology (ICT) platform - The ICT are the resources responsible for the whole integration between business entities, what can go from a communication platform to inform demand of certain products to a drone’s control center.

(vii) Subsides - Subsides are usually tax reduction provided by the local administration to companies that promote the increase of positive externalities or reduction of negative ones. On this work context, companies that guarantee the reduction of traffic and pollution, for instance, can be awarded with subsides. Besides the fact that subsides are used financial resources, a separation was made in order to provide a better understanding.

The table 4.2 presents the synthesis of the correspondence between the resources and the owners presented. Further, on this chapter, it is going to be presented how those resources perform their respective roles.

Table 5.2 – Synthesis of resources and corresponding owners

Resources	Customer	Large retailer	Local retailer	Supplier	Express courier / parcel operator	City freight carrier / Last mile specialist	UCC operator	Warehouse operator	ICT platform operator	Local administration
Employer		X	X	X	X	X	X	X	X	
Transportation vehicle		X				X	X			
Consolidation center and WH		X			X	X	X	X		X
Land		X				X	X	X		X
Reception method						X	X			
ICT platform					X	X	X		X	X
Subsides										X

Source: created by the author

5.1.3.3 Roles

As it was observed previously, roles are composed by (i) activities, (ii) decisions and (iii) metrics performed by BEs. This sub session lists not only the main activities, decisions and metrics of the drone's last mile delivery, but also presents how BEs relate to them. This correlation will serve as basis for the development of business models on the next chapter.

As it was presented on the literature chapter, the roles that are performed on the context of city logistics are the following:

- Receiver
- Good consolidation and logistics services

- User of good consolidation and logistics services
- Delivery services
- User of delivery services
- Network consolidation

This sub session separates the roles in “macro activities” in order to provide a more detailed view of the working structure of the drone’s last mile delivery. It is important to note that, besides the fact the all roles must be performed, not necessarily all activities should do.

The main decision and metrics of each macro activity are also described next.

(i) Receiver

a. Customer reception - as drone’s last mile delivery presents only the final customers as possible receiver, this is the only BE involved on this activity, which is composed by basically any eventual preparation for the delivery - such as positioning the “free box” - followed by the customer picking the product. The customer’s decisions are related to what kind of product wanted, the order lead-time desired and the willingness to pay for the delivery. Those components can be seen as the customers’ requirements and are essential for the development of the whole structure of the delivery chain. In that work, it will be studied the scenario in which the customer purchases small products - within the requirements presented previously - and order lead-times under 24 hours.

(ii) Provider of goods consolidation and logistics services

a. Product selection and organization - activities performed within a good consolidation center can be synthetized on a way that its input is an order - such as a product’s purchase -, and its output is the introduction of the good on a delivery vehicle. The main decisions related to the provider of those types of services are related to which type of product to attend - in this context, only small and light products, such as electronic devices or groceries - and how fast should they prepare the order - related to its customer requirement.

b. Reduction of negative externalities - one of the main outputs of the consolidation centers is the possibility to reduce the number of transportation vehicles, what may result on less traffic and less air pollution. For that reason, the reduction of negative externalities can be seen as another activity performed by those BEs. The main decision related to it is how and how much will the center contribute to the reduction of those externalities.

(iii) User of goods consolidation and logistics services

a. Outsourcing of consolidation services - the use of goods consolidation and logistics services is related basically to the outsource of those activities. In other words, companies - such as retailers - hire third ones to develop those activities for them, mainly because they believe that this will provide better competitive advantages. The main decision variable is whether to outsource or not this activity (similar to a “make or buy” decision), and then to whom it must be outsourced, what is related mainly to the cost of it and how well the consolidation center would fit to the rest of the activities (such as the geographical proximity to the customers).

b. Subsides - in order to obtain the reduction of negative externalities, such as reduction on traffic and air pollution, the local government may provide subsides - like tax reduction - for companies to develop their consolidation and logistics activities. Those subsides are obviously related to the degree of reduction of those externalities.

(iv) Provider of delivery services

a. Intermediary delivery - the intermediary delivery is a non-essential activity for the last mile delivery environment. This activity is related to the transportation of a product from the consolidation center on the outskirt of the city to an intermediary transshipment point inner the urban area. In this work, it will be considered that only trucks may perform this kind of delivery, for reasons that have already been presented on the previous chapter. The main decision related to the provider of this type of service are related to the quantity of assets necessary for the performance of this activity, based on type of product and how fast should they deliver the order in order to satisfy the requirements of the customer.

b. Last mile delivery - This activity can be seen as the great differential of this work. The drone delivery is related to the transportation of a good to its final customer. It involves basically picking the product from the exit place - that can be a consolidation center within the urban area or a warehouse on the outskirts -, going to the customer’s house or work place and coming back. Besides the fact that this procedure has a certain level of autonomously as it was described on the previous chapter, this activity demands also some degree of vigilance. The main decision related to this activity is the number of assets that should be provided - for instance, the number of drones that should be used - to satisfy the customer’s requirements.

c. Reception - Because the reception on the drone’s context is something considerably innovative, it was considered as a distinct activity. It is related to the reception methods described previously, that consists on the drone detecting the delivery tool - either the box or the “free” - and leaving the product on it. The obvious main decision related to that activity is choosing among the two options of reception method described, considering mainly the safety and the cost, based on the customer requirements. This decision is affected by the location of delivery - urban or rural area - and the perception of the user, related to both its usability and safety. In any case, its owner should have installed the reception method previously, although this procedure will not be considered on this work.

   d. Reduction of negative externalities - The same principle as the one presented previously.

(v) User of delivery services

   a. Outsourcing of intermediary transshipment – the outsource of intermediary transshipment consists on hiring a company to realize that specific task that was described previously. The decision is related not only to which company use, but also to either use an intermediary transshipment or not. The metrics used to this decision are obviously the cost and the quality of the service – related mainly to the lead time -, considering the customer requirements.
   b. Outsourcing of last mile delivery - This activity can be seen as quite the same as the previous one, modifying only the fact the it is essential and the customer is the final receiver of the product.
   c. Outsourcing of reception method - This outsource consists on hiring a company to be responsible exclusively for the reception method, this is, providing and maintaining the reception tools to the final customer. The decision is related basically to which specialized company to hire based on the method used - what is also related to the type of customers attended - and cost.
   d. Subsides - The same principle as the one presented previously.

(vi) Network coordination

   a. Data analysis and real time solutions - Network coordination on the delivery context is related to the exchange of real time information between parties, such as new orders and real time location of goods. In a delivery context which time-efficiency is an extremely valuable variable, it is essential that the infra structure that provides the exchange of information within the BEs is well developed, making it possible to reduce wastes. The main decision of this activity is related to the use of assets based on the customer's requirements and the cost of collecting, analyzing and providing information.

The way that Business Entities (BEs) and roles - divided into activities - are interconnected on the drone's last mile delivery context is presented on the next table, exposing each activity and the possible responsible for it.

Table 5.3 – Relation between activities and BEs

		Customer	Large retailer	Local retailer	Supplier	Express courier / parcel operator	City freight carrier / Last mile specialist	UCC operator	Warehouse operator	ICT platform operator	Local administration
Receiver	Customer reception	X									
Provider of goods consolidation and logistics services	Product selection and organization		X			X	X	X	X		
	Reduction of negative externalities		X			X	X	X	X		
User of goods consolidation and logistics services	Outsourcing of consolidation services		X	X	X	X	X				
	Subsides										X
Provider of delivery services	Intermediary delivery		X			X		X			
	Last mile delivery		X				X	X			
	Reception						X	X			
	Reduction of negative externalities		X			X	X	X			
User of delivery services	Outsourcing of intermediary transshipment		X	X	X	X		X			
	Outsourcing of last mile delivery		X	X	X	X		X			
	Outsourcing of reception method		X	X	X	X	X	X			
	Subsides										X
Network coordination	Data analysis and real time solutions					X	X	X		X	X

Source: created by the author

5.2 Mixed-Integer Linear Programming (MILP)

This sub session exposes a general formulation of the “cost optimization for drone’s last mile delivery” problem, presenting a generic overview that could be applied to each scenario of business model developed.

Firstly, an overview of the problem is shown, exposing the type of problem and how it is going to be approached on this work. After that, the assumptions made for this problem are shown. On the results chapter, the problem is mathematically modeled accordingly to the MILP’s exigencies, presenting the variables and parameters inherent to each model and formulating the objective function as well as the constraints.

5.2.1 Overview of the problem

As it was presented on the literature chapter, problems that are composed by the determination of the cheapest set of routes attending to a set of requirements can be seen as a Vehicle Routing Problem (VRP).

On one hand, the VRP problem is exceedingly complex and NP Hard, and that’s why researches mainly focus on the development of heuristic solutions (Braysy and Gendreau, 2005). On the other, fortunately, the problem turns out to be a lot simpler for drone deliveries.

Since each drone can only carry one package at a time, the problem does not have to consider route possibilities, only “straight line” routes: from the place where the good is caught – distribution or consolidation center, for instance – to the final customer, and then all the way back. In this scenario, the drone’s last mile delivery could be considered similar to a multi-trip vehicle routing problem (MTVRP) (Dorling et al. 2017), which can be solved with mixed-integer linear programming (MILP). This type of problem allows the same vehicle to realize multiple trips to make deliveries along the same day, differing from the usual model in which a truck, for instance, departure from a certain spot and only comes back at the end of the day.

The drone’s problem has as objective the minimization of the last mile delivery costs of the whole environment, and not of a specific company under a pre-conceived business model, as it was presented previously. This includes not only the cost of the utilization of drone - including the battery and the “ownership costs” -, but also the cost of the drone’s controllers, the costs of consolidating the products, other transportations routes, among others. Finally, the problem is also subjected to the satisfaction of the delivery constraints, such as the required order lead time.

This problem can be analyzed under a MILP perspective since it is composed by both integer variables - such as the use or not of some assets, like drones - and non-integers ones - related to distance and time.

Finally, it is going to be made multiple simulations for each business model discussed on the next chapter, each one modifying one or more constants presented on the problem.

5.2.2 Assumptions over the MILP

This sub session lists the main assumptions made in order to formulate the drone’s problem.

(i) Drones and trucks (if any) perform only linear routes with constant speed
(ii) Besides the fact that mobile warehouses performing intermediary transshipment are viable on this environment, only fixed ones will be considered on this problem due to its complexity
(iii) Deliveries can be made during all day within the period considered in each simulation
(iv) Trucks will only travel through dedicated routes
(v) Drones and trucks will be individually designated to work exclusively within specific consolidation centers
(vi) Drivers, controllers and the maintenance of consolidation centers will be considered as variable assets and will receive proportionally to time worked

6 Results

This chapter presents the results of this work, applying the methodology exposed previously. Firstly, it will be shown some drone's last mile delivery business models developed using the proposed framework. Finally, it will be developed a mixed-integer linear programming (MILP) solution for each model discussed.

6.1 Business models

This session exposes some business models in which the drone delivery technology would fit. For each model though, it is going to be shown (i) a general overview of it, presenting a brief description of how it would work, (ii) how the interaction between BEs work and (iii) the context for which it could be well fit.

6.1.1 Centralized distribution center model

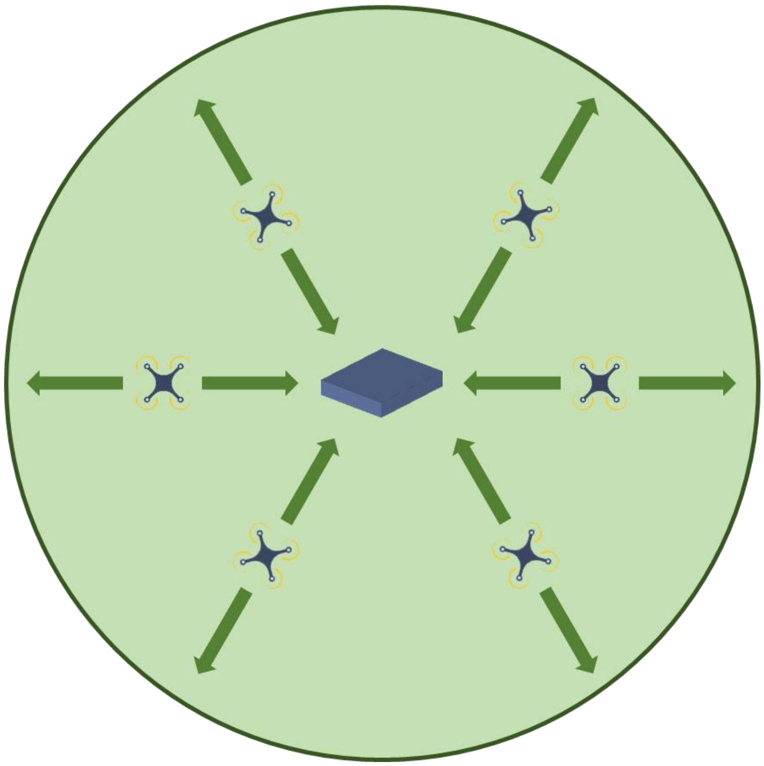
6.1.1.1 Overview

The centralized distribution center model is the simplest one when thinking about drone's last mile delivery as it is the model tested by the companies presented on chapter 3. It consists basically on a huge distribution center that is responsible for the storage of all products whose drone delivery is permitted according to the offering company.

When a customer realize a purchase of one or more products that should be delivered by drone, the distribution center is responsible for preparing the order, that is, picking the product and giving it to a drone in order to realize the delivery. The distribution center is responsible for making a stock and demand control as well, requesting new products in order to avoid both high storage costs and customer dissatisfaction due to a missing of some eventual product.

The main advantage of this model is a high reduction of the order lead time, as the purchased product will be delivered directly to the customer. On the other hand, it is a model whose success depends mainly on the capacity of the distribution center to predict the demand and control its storages, promoting a high product turnover and avoiding stocking issues that may result on high storage costs, missing products or even product loss due to shelf life. In other words, the success of this model depends on a good ICT system that connects the distribution center to its suppliers and customers.

Figure 6.1 – General design of the centralized distribution center model



Source: created by the author

6.1.1.2 Relation between BEs

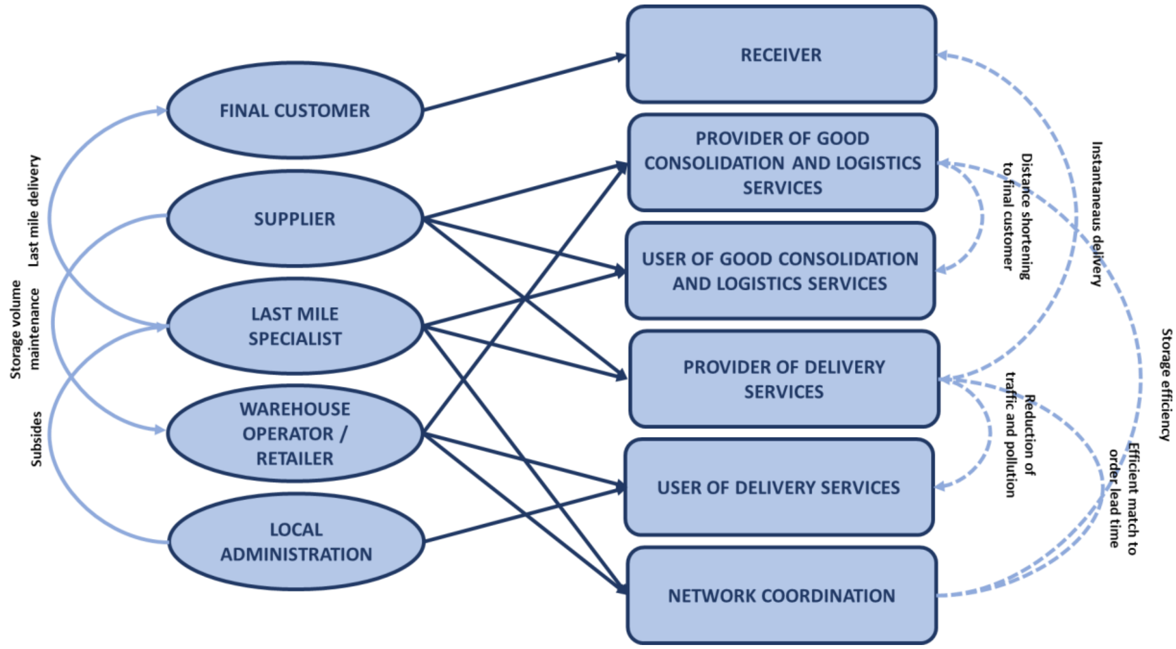
In this model, the warehouse operator (distribution center) is responsible for monitoring its stocks according to the demand forecast, requesting supply to the supplier in order to keep the stock levels at an adequate point, that is, with a correct balance between storage costs and the risk of delaying a delivery due to having ran out of the specific product. There can be multiple responsible for the delivery from the supplier to the warehouse, including eventual intermediary points, but as it was described on the assumptions on the previous chapter, this work focus mainly at the last part of the delivery.

It is interesting to notice that, in this model, the retailer can assume distinctive parts. It can be the responsible for the warehousing, in situations when there is a huge volume of sales within the area, paying the supplier for the goods. It can also outsource this warehousing activity to a specialized company - which would be responsible to deal with the supplier -, in which case the retailer would pay the warehouse operator according to the volume of goods operated, being “financially punished” in case of product absence on the time of the order.

With respect to the order preparation, the final customer would purchase the product online, what would generate an order sent to the retailer and warehouse operator, which would set the order to its delivery. Finally, with respect to the last mile delivery, a last mile specialist company would be responsible for owning the vehicles - and distribute them between the warehouses in which they operate – and operate the drone towards the final customer. The warehouse operator would be responsible for loading the drone with the respective product and informing the last mile delivery specialist company the address of the final customer. The warehouse operator would pay the last mile specialist according to the volume and precision of deliveries made. Finally, the last mile specialist is responsible for the management of the reception method, making sure that the final customer would get his product.

Finally, the local administration may provide subsides to the last mile specialist according to the reduction of traffic and pollution promoted by the substitution of trucks to drones.

Figure 6.2 – Interaction between BEs on the centralized distribution center model



Source: created by the author

6.1.1.3 Where can be applied

This model financial viability depends on some factors, related to its geographical context as well as the products that it intend to cover.

Firstly, since it involves one main distribution center attending a certain population, it is important that the number of customers supplied by it is economically interesting, on a way that the fixed costs of maintaining the distribution center do not become predominant - specially the land costs, since it may occupy a huge area - and promotes a higher turnover of products. Further, it is interesting as well as that it is located on an area of easy access, allowing an effortless and a costless supply, what is a key factor to this model success, as it was described on the previous sub session.

For that reason, the geographical context on which this model would fit most is a suburban or even rural one, with low to medium population density and house predominance. This scenario is interesting because it would permit that a distribution center could be located close to a road - usually presenting lower costs - fueling multiple small cities (assuming that a drone can reach areas up to 20km far from its departure spot, it could fuel an area of over 1.200km^2). Besides that, assuming that a huge majority of customers in this context live in homes with plenty “landing area”, this model would face little trouble related to the reception method, as it was observed previously.

In addition, it is important that the products delivered by this model are required to have a reduced order lead time - due to its emergency use, for instance -, as this is its main advantage and it would expensive to provide this service in situations that it is not required. This model permits that the order lead time becomes even smaller than the time required for the customer to go to a store to purchase the product. Further, it is interesting that the products present an extended expiration period, avoiding losses due to storage, as it was observed previously as one of this model issues.

Because of that, the main products that could be delivered by this model are: (i) personal hygiene items; (ii) non-perishable food; (iii) medications and; (iv) entertainment items (such as books and video games). It would be also able to discuss the delivery of some electronic devices on this model. Besides the fact that those products are not usually required on a one day basis, they are more expensive on a way that the customer may present some willingness to pay an extra fee for the convenience of receiving it on a shorter period, and this fee could make the delivery of this product financially interesting.

Table 6.1 - Application of the centralized distribution center model

	CUSTOMER LOCATION		
PRODUCT	Rural	Suburban	Urban
Non-perishable groceries			
Medications			
Personal hygiene			
Entertainment items			

Source: created by the author

6.1.2 Multiple departures centers

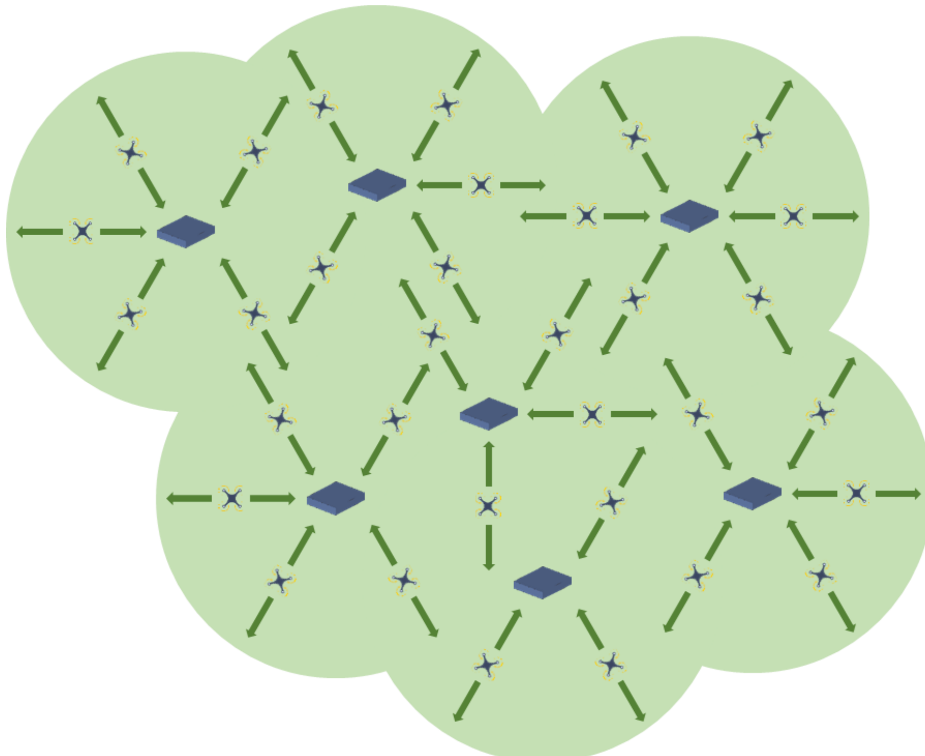
6.1.2.1 Overview

This delivery model is quite similar to previous one on the sense that the product go directly from the place where it was storage before its purchase to the final customer. However, on this model, the centers are smaller and coincide with existing stores. For instance, a huge supermarket or restaurant network can install a drone infrastructure on its bigger units, and then perform food delivery.

On this model, some areas fueled by each center may coincide, or, in other words, the range among drones are overlaid. At the same time that this situation can be seen as an inefficiency of the model, it promotes less worry about storage, since if one store has ran out of some product, other can supply it, not to mention that in this situation the physical stores itself are used to control its products demand and its stock.

The main advantage of this model is, again, the shortening of the order lead time, making it possible to deliver products in lesser time than the locomotion to the store. In addition, there is less worry about storage issues since the departure spot has already the know how about demand and stock and the areas fueled overlaid. Further, this model could unload the weight of some tasks inherent to the stores, such as the payment procedure, what could cause a cost reduction and eventually even the closure of stores in order to avoid cannibalization. On the other hand, the introduction of this complex system on pre-existing store may represent an expensive solution, having to not only install an adequate infrastructure for it, but also hire specialized partners to realize the task.

Figure 6.3 - General design of the multiple departure centers model



Source: created by the author

6.1.2.2 Relation between BEs

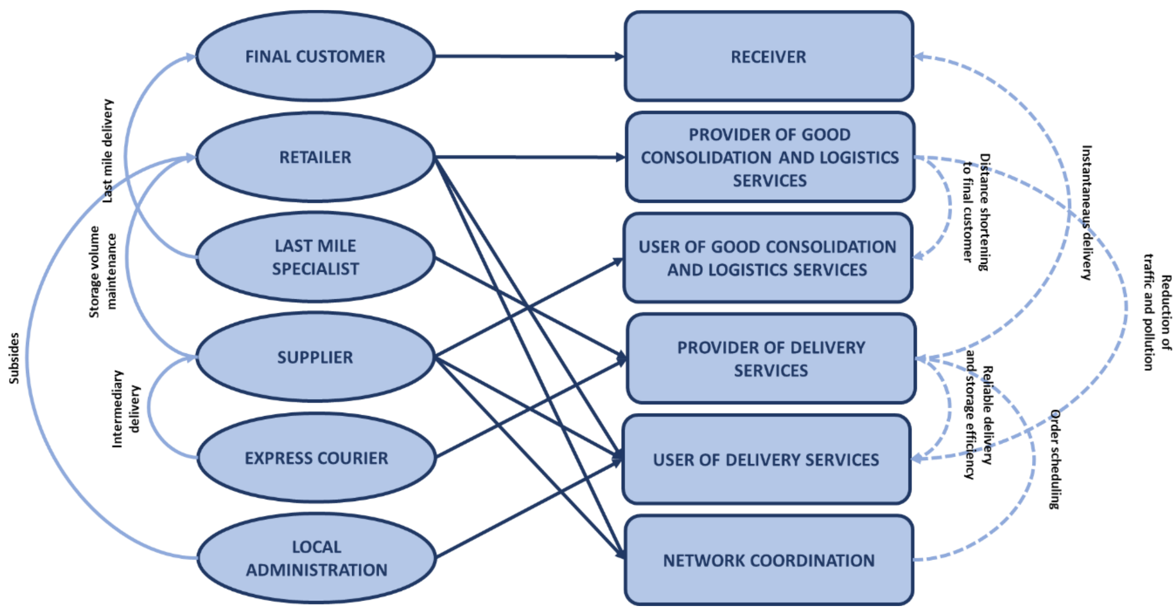
In this model, there is basically nothing innovative on the relation between retailers and suppliers, that is, the retailer is responsible for monitoring its stocks and ordering its supply according to the demand prevision. This model innovation comes specifically on the last mile delivery.

It is interesting to notice, in this model, that retailer and last mile specialist may coincide, what will depend mainly on the retailer volume of sales and investment capability.

After the final customer purchases the product online, the retailer receives an order, which then identifies the closest store that possess the respective product and has the drone delivery infrastructure. The order is finally prepared on the store and the drone carries it to the customer. The last mile specialist (that can be the retailer itself) is responsible not only for delivering the product but also for ensuring that all customers possess the respective reception method, receiving an fee from the retailer according to the deliveries volume and precision.

Finally, the local administration may provide subsides to the last mile specialist according to the reduction of traffic and pollution promoted by the substitution of trucks to drones.

Figure 6.4 – Interaction between BEs on the multiple departure centers model



Source: created by the author

6.1.2.3 Where can be applied

Differently from the previous model, this one could fit on urban centers, since there is no necessity to expand areas - what would promote huge rental costs - and there are no huge supply issues. In that case, this model could be included in any geographical context.

In relation to the products that could be delivered within this model, the ones that require a shorter order lead time are privileged again, such as food (on that case, perishable or not), personal hygiene items, medications and entertainment goods. This model may represent an eventual substitution of the current groceries delivery models performed by supermarkets and restaurants, which goes from bike crowdsourcing to companies vans. On the case of medications, there may be a drone platform installed on some drugstores or even hospitals that would allow de item to be delivered, and the customer may even be willing to pay more for the convenience.

Finally, it is important to discuss the reception method in this model since it involves drone's urban deliveries, what, as it was exposed previously, presents a series of issues related to the reception. On the medicine and groceries situation, it is possible to think in drones performing attended deliveries, as the customers of those products usually want to consume the product immediately. On that case, the winning model (groceries delivery as it is today against drone deliveries) is the one that presents a lower cost, and on the medications situation, it is necessary a deeper study of the increase in revenues due to this offering against its implementation costs.

On the other hand, besides the fact that bookstores may adopt a similar structure, the customers do not "emergentially" desire its products, what may result in situations which the customer wants both a short order lead time and the flexibility to stay out of home. This scenario creates a necessity to develop a reception method on urban areas, increasing the delivery costs that could be hardly compensated by any additional costs to the final customer. In addition, other products, such electronic devices and apparel, would hardly be financially viable since customers do not require a really short order lead time to this products and would not be willing to pay more for this service.

Table 6.2 - Application of the multiple departure centers model

	CUSTOMER LOCATION		
PRODUCT	Rural	Suburban	Urban
Groceries (perishable or not)			
Meals			
Medications			
Personal hygiene			
Entertainment items			

Source: created by the author

6.1.3 Departure centers with centralized warehouse

6.1.3.1 Overview

This model adds a new element to the previous ones: a transshipment point. This is, the product do not necessarily go directly from the place where it was stored to the final customer, being kept on an intermediary hub.

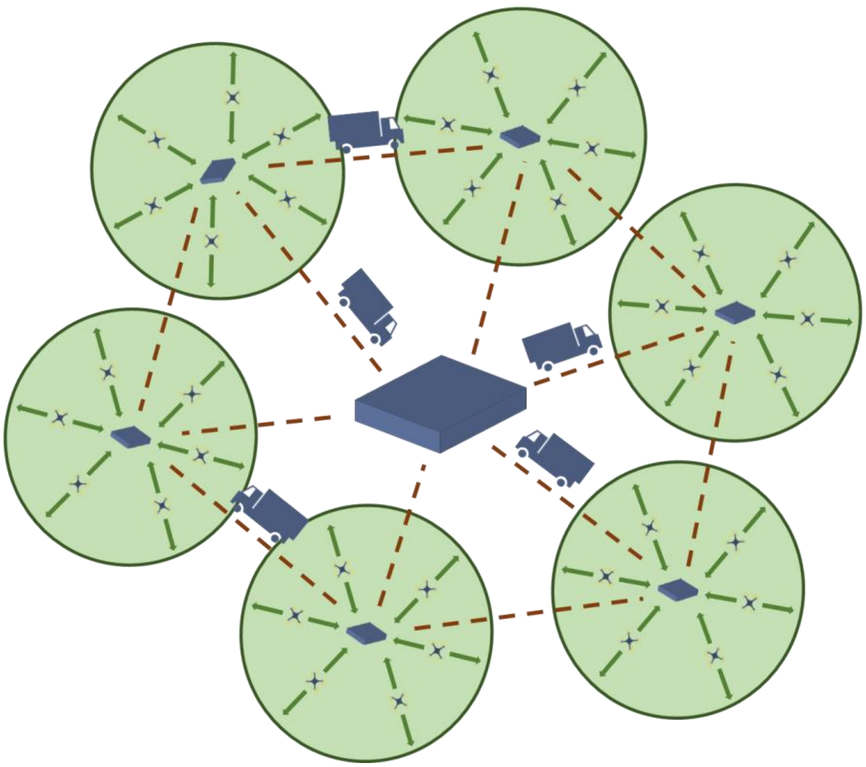
This model foresee a huge consolidation center that is responsible for the supply - by trucks - of some intermediary transshipments hubs, from where the drone would departure to the final customer. In other words, one big consolidation center would be responsible for the product storage as well as the control of stocks, orders and demand (just like the centralized distribution model). And then, at the moment that the final customer realize an order, the center would be responsible for picking the selected product and introduce it in a truck. After that, the truck would carry this package to an intermediary hub - a “departure center” -, where it would be directly moved to a drone responsible for its carriage to the final customer. The distance between departure and consolidation centers can not be too big on a way the would make same day delivery impracticable.

In this model, the truck usage can be seen as much more efficient than the current one, as it can unload multiple packages on the same location, avoiding losses due to multiple stops and huge routes.

The biggest advantage of this model is that it can realize same-day deliveries to an enormous area (for instance, if there are 4 departures centers surrounding one consolidation center, the area fueled by it can reach close to 50.000km^2). Further, this model propose a better truck utilization. On the other hand, it presents some of the same issues as the centralized distribution center model, that is, the necessity that the consolidation center is well attended by its suppliers and a trustworthy demand and stock management system, avoiding losses due to product unavailability or high storage costs. In addition, it is important to find an optimal balance between the order lead time provided to the customer and any additional costs of carrying trucks in excess, being necessary a study of how any revenue increase as consequence of a decrease of lead time provided would increase the costs. Finally, this type of model guarantee same day delivery instead of instantaneous as the previous ones, and because one of the major customer's complaints over delivery was the necessity to stay home waiting for it, this model generates a necessity for unattended deliveries models, what can be a huge issue on drone deliveries as previously studied.

Finally, it is even possible to think of a mix of this model to the centralized one. In that case, the central consolidation center could develop drone deliveries within its area and also supply, by truck, departure centers located outside of the drone's range.

Figure 6.5 - General design of the departure centers with centralized warehouse model



Source: created by the author

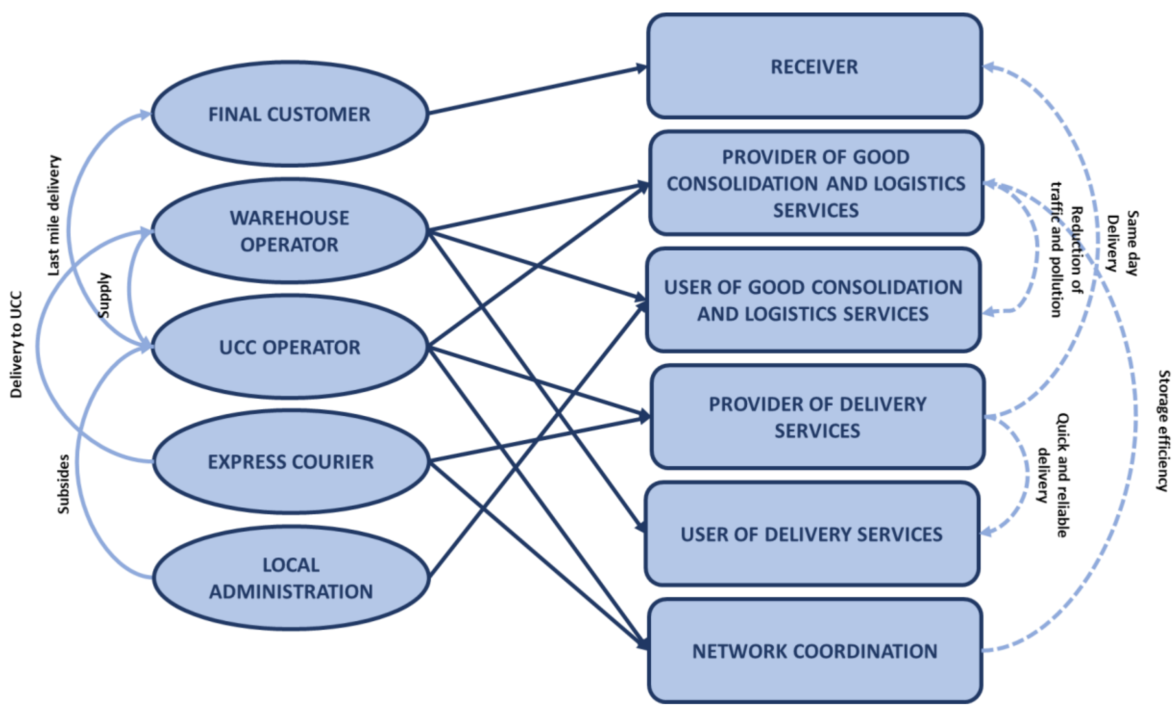
6.1.3.2 Relation between BEs

This method presents a more complex relationship between BEs. Initially, the warehousing is similar to the first model proposed: the warehouse operator (that can also be the retailer) is responsible for keeping its stocks at an adequate level, requiring supply from the supplier, and preparing the order after the customer's purchase, eventually receiving fees from the retailer. However, in this model, a new actor is added: the intermediary transshipment.

Multiple urban consolidation centers (UCCs) can be supplied by the same warehouse, transportation is made by trucks and can be controlled by the warehouse itself or it can outsource that task to an express courier. The UCCs then receives information about the packages and the customers, consolidating them and delivering with drones within the lead time agreed, receiving fees according to the volume and precision of deliveries.

Again, the local administration may provide subsides to the UCCs operator, according to the reduction of traffic and pollution promoted by the substitution of trucks to drones.

Figure 6.6 – Interaction between BEs on the departure centers with centralized warehouse model



Source: created by the author

6.1.3.3 Where can be applied

For the same reasons as the first model, it is interesting that the consolidation center be located within a rural or suburban area. However, due to the distance between departure and consolidation center, it is possible the former one is located within urban area. On the other hand, as it was described on the previous sub session, this model can provide same day - but not instantaneous - deliveries, what may promote a necessity for unattended deliveries, fact that face a huge barrier on urban areas.

With respect to the products attended by this model, obviously the ones that require instantaneous deliveries (such as some groceries or medications) are out of question. In addition, due to the storage issues, perishable goods are also discarded. On the other hand, entertainment goods (such as books, toys and video games) and some electronic devices are usually requested to present a small order lead time, what may privilege them on this model.

In that case, it is important to realize e deep cost study over implementation and maintenance of this method (inclusive the eventual inclusion of an innovative reception method), against the market reaction that may generate revenue increase due to a higher number of purchases or even the willingness to pay a fee per delivery.

Table 6.1 - Application of the departure centers with centralized warehouse model

	CUSTOMER LOCATION		
PRODUCT	Rural	Suburban	Urban
Non-perishable groceries			
Personal hygiene			
Entertainment items			
Small electronic devices			

Source: created by the author

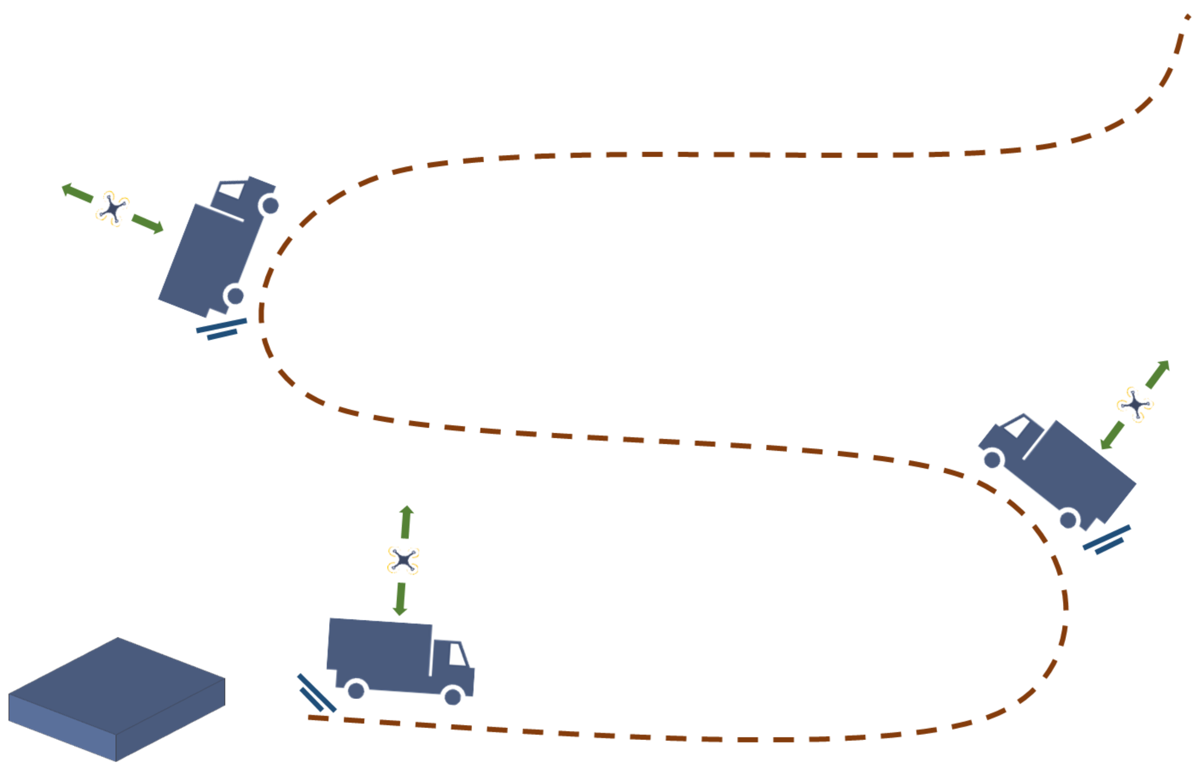
6.1.4 Centralized warehouse with mobile transshipment

6.1.4.1 Overview

The last method proposed can be seen as the most creative and innovative one. It consists of a huge consolidation center from where departure multiple trucks and vans, each one containing some drones. In this method, the truck or van is loaded and while it follows approaches to the final customer, the drones take the respective package and deliver it to him, avoiding any stop of the truck, while the drone returns autonomously to it and preparing to an eventual next delivery.

This method is interesting as it allows fast delivery to isolate or restricted access areas, since the truck do not have to reach the final customer. It allows the truck or van to drive only through good roads and avoids time waste of reaching the customer house and personally delivering the product. On the other hand, it involves a complex mechanism, as the drone must departure from and land on a moving vehicle. In addition, in this model the vehicles may travel long distance in order to reach a considerable population volume that makes it financially viable, and even same day deliveries may become impracticable.

Figure 6.7 - General design of the centralized warehouse with mobile transshipment model



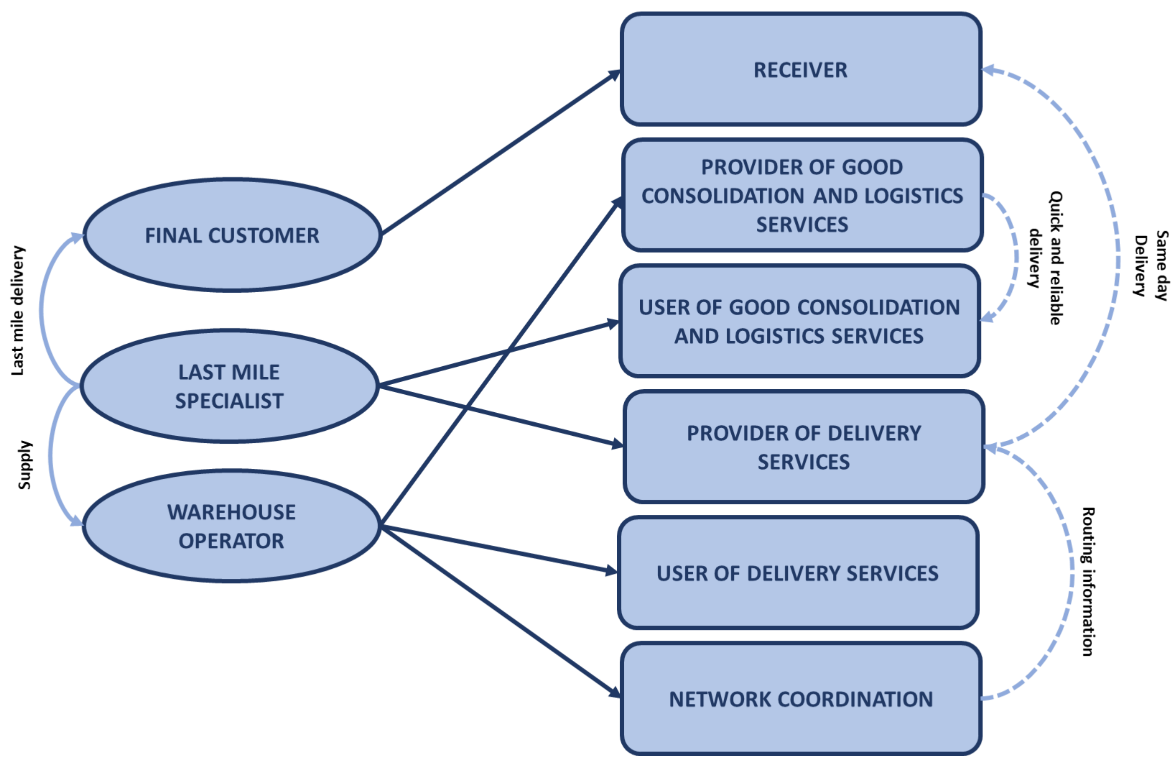
Source: created by the author

6.1.4.2 Relation between BEs

Finally, in this model, despite technically complex, presents a quite simple interaction among BEs. The interaction involving the distribution center and the suppliers is quite the same as the previous ones: the warehouse operator (that can also be the retailer itself) should (i) keep storage levels at a satisfactory point, receiving supply from the suppliers, (ii) prepare the orders after the customer purchase and (iii) inform the last mile delivery specialist over the customers position.

In that case, the last mile specialist is responsible for the control of both the trucks and drones, deciding optimal routes according to the requirements and delivering products within the agreed order lead time, receiving fees accordingly to the volume and precision of deliveries. It is also responsible for any eventual reception method distribution and maintenance.

Figure 6.8 – Interaction between BE on the centralized warehouse with mobile transshipment model



Source: created by the author

6.1.4.3 Where can be applied

As it was described on the previous sub session, this model can reach an enormous area within a same day, making it be adequate to a rural scenario, where the access is restricted and customers may distance considerably one from other.

From a product perspective, this method may attend even same day deliveries, coincide to the ones presented on the previous method. On the other hand, as products are delivered to rural areas, an unattended delivery would not be a huge issue.

Table 6.2 - Application of the centralized warehouse with mobile transshipment model

	CUSTOMER LOCATION		
PRODUCT	Rural	Suburban	Urban
Non-perishable groceries			
Personal hygiene			
Entertainment items			
Small electronic devices			

Source: created by the author

6.2 MILP

This session exposes a general MILP mathematical formulation and then how it can be applied particularly to each business model discussed previously, according to the assumptions made on the previous chapter.

In this work, the problem is approached using time intervals in order to describe how the vehicles are going to behave at each time interval, aiming to minimize the delivery chain cost.

Firstly, all the variables and parameters used are declared and its notation shown. Then, the objective function, the decision variables and the set of constraints is exposed. Finally, the model is discussed for each business model discussed previously on this chapter.

6.2.1 Variables and parameters

This sub session presents all the variables and parameters necessary for the problem, as well as the notation used.

Firstly, the parameters used are described next.

Table 6.3 – Parameters

	Description	Notation
Time of order	Time at which the package k is purchased	TO_k
Route time of drone	Duration of the trip of a drone i from the departure spot f to the final customer	RTd_{fk}
Route time of truck and driver	Time of the trip of a truck from the departure spot f to its destination f'	$RT_{ff'}$
Order lead time	Maximum interval between time of order and the delivery of the product k	OLD_k
Cost/time flying trip	Cost per time that a drone is traveling to realize a delivery - associated to batteries	CTd
Cost/truck and driver driving	Cost per time that a truck and drone is traveling to realize a delivery - associated to salary and fuel	CTt
Cost/time per drone ownership	Cost per time for owning and drone - associated to depreciation or rental	COd
Cost/time per truck ownership	Cost per time for owning a truck - associated to depreciation or rental	COt
Time of simulation	Time that model simulate in real life	TOS
Cost/time per controller	Cost per time that a controller is executing its task, independent of how many drones is operating - related to salary	CC
Truck capacity	Number of packages that a truck can carry	TC
Cost/time per consolidation center	Cost per time of maintaining consolidation center f	CM_f
Drone unload time at final customer	Time for the drone to unload package at final customer	Utd
Truck unload time	Time for the truck and driver to unload package at center f	Utt
Numbers of drones per controller	Number of drones able to be controlled by a single controller	CpD
Preparation time	Time for the order k to be prepared at center f	PT_{kf}

Source: created by the author

As it was described on the literature chapter, decision variables are the ones that are modified in order to optimize the problem solution. In this work, the decision variables are obviously related to either the usage or not at each time the vehicle's usage. In other words, the number of vehicles necessary is the variable that is subject to modification in order to minimize the total cost.

Table 6.4 – Decision variables

	Type	Description	Notation
Drone departure time	Binary	Either the drone i departures or not at time t carrying the package k	DTd_{itk}
Truck and driver departure time	Binary	Either the truck and driver j departures or not at time t carrying the package k	DTt_{jtk}

Source: created by the author

Finally, the auxiliary variables are presented next, presenting the main function to help the understanding of the problem. Theirs variables are all originated from a mathematical relation between the decision variables and parameters.

Table 6.5 - Auxiliary variables

	Description	Notation
Drone usage	Either the drone i is being used or not at time t	d_{it}
Truck and driver usage	Either the truck and driver j is being used or not at time t	v_{jt}
Drone usage at time	Number of drones being used at time t	D_t
Truck and driver usage at time	Number of trucks and drivers being used at time t	T_t
Total number of drones	Number of drones required	TD
Total number of trucks and drivers	Number of trucks and drivers required	TT
Time limit of package delivery	Time limit in which package k can be delivered	TL_k
Drone arrival time	Arrival time at final customer of drone i carrying the package k	AT_{ik}
Truck and driver arrival time	Arrival time at destination f' of truck and driver j carrying package k from f to f'	AT_{jkf}
Drone return time	Return time at departure spot of drone i carrying package k	$RetT_{ik}$
Truck and driver return time	Return time at departure spot of truck and driver j carrying package k	$RetT_{jk}$
Number of controllers	Number of controllers working at inverval time t	C_t
Cost of controllers	Total cost of controllers	TCC
Total cost of drones flying	Total cost of drones due to time flying	TCDF
Total cost of trucks and drivers driving	Total cost of trucks and drivers due to driving	TCTD
Total cost of ownership of drones	Total cost of owning drones	TCOW
Total cost of ownership of trucks	Total cost of owning trucks	TCOT
Total cost of drones	Total cost of drones	TCD
Total cost of trucks and drivers	Total cost of trucks and drivers	TCT

Source: created by the author

6.2.2 Objective function and constraints

As it was presented on literature chapter, the objective function represents the equation whose optimization is desired. In that case, the main objective of this work's model is the cost minimization, which can be described as:

$$\min\ TCT + TCD$$

Equation 6.1 – Objective function

The constraints then can be grouped into three segments:

(i) Vehicles usage
(ii) Time
(iii) Cost

The constraints related to the first group (vehicles usage) are listed next.

(1) $$WTD_{ik} = RetD_{ik} - DTD_{ik}$$

(2) $$WTT_{jk} = RetT_{jk} - DTT_{jk}$$

(3) $$DTD_{ik} = DTD_{ik}^{t} * t$$

(4) $$DTT_{jk} = DTT_{jk}^{t} * t$$

(5) $$RetD_{ik}^{t} = DTD_{ik}^{t-WTD_{ik}}$$

(6) $$RetT_{jk}^{t} = DTT_{jk}^{t-WTT_{jk}}$$

(7) $$d_{ik}^{t} = DTD_{ik}^{t} + d_{i}^{t-1} - RetD_{ik}^{t}$$

(8) $$d_{jk}^{t} = DTT_{jk}^{t} + d_{j}^{t-1} - RetT_{jk}^{t}$$

(9) $$d_{ik}^{1} = 0$$

(10) $$t_{jk}^{1} = 0$$

(11) $$d_{i}^{t} = \sum_{k} d_{ik}^{t}$$

(12) $$t_{j}^{t} = \sum_{k} t_{jk}^{t}$$

(13) $$d_{i}^{t} \leq 1$$

(14) $$t_{j}^{t} \leq 1$$

(15) $$D_{t} = \sum_{t} d_{i}^{t}$$

(16) $$T_{t} = \sum_{t} t_{j}^{t}$$

(17) $$TD \geq D_{t}$$

(18) $$TT \geq T_{t}$$

Equation 6.2 – Set of vehicles usage's constraints

The constraints related to the second group (time) are listed next.

(20) $$TL_k = TO_k + OLT_k$$

(21) $$ATd_{ik} = DTD_{ik} - RTd_k$$

(22) $$ATt_{jk} = DTT_{jk} - RTt_j$$

(23) $$RetD_{ik} = ATd_{ik} + RTd_k + UTd$$

(24) $$RetT_{jk} = ATt_{jk} + RTt_k + UTt$$

(25) $$DTD_{ik} \geq TO_k + PT_k$$

(26) $$DTD_{ik} \geq ATt_{jk}$$

(27) $$DTT_{jk} \geq TO_k + PT_k$$

Equation 6.3 – Set of time's constraints

Finally, the constraints related to the last group (cost) are listed next.

(20) $$C_t \geq {}^{D_t}/_{CC}$$

(21) $$TCC = CC * \sum_t C_t$$

(22) $$TCWD = CWd * \sum_i \sum_k WTD_{ik}$$

(23)** $$TCWT = CWt * \sum_{i}\sum_{k} WTT_{jk}$$

(24) $$TCOD = D * TOS$$

(25) $$TCOT = T * TOS$$

(26) $$TCD = TCOD + TCWD + TCC$$

(27) $$TCT = TCOT + TCWT$$

Equation 6.4 – Set of costs' constraints

7 Conclusion and further studies

This work has provided a general analysis of the drone's last mile delivery environment, focusing mainly on the "business" side.

Firstly, a general overview of the last mile delivery was developed, identifying some risks and opportunities on the inclusion of drones as the vehicle performing that task. The main opportunities are related to the possibility of promoting a efficient delivery method in a more cost-efficient way, reducing wastes associated to poor truck usage and labor costs, reaching its final customer on a shorter order lead time, as well as reducing negative externalities in comparison to the usual attended home delivery method. On the other hand, not only the effectiveness of this efficient increase is uncertain, but there is also the risks associated to the operational and engineering performance of this method.

Then, the main agents of the delivery chain were studied, as well as the framework used to develop business models. While providing efficient logistics options to the final customer begins to represent an important way to differentiate among competitors, it does not integrate the core competencies of e-commerce companies, which still depend on logistic providers. The relation between business entities (Bes) on this environment can be then synthetized as: BEs perform roles – all roles within the logistic sector should be performed, but each one can perform one or more roles -, that are composed by activities, decisions and metrics, interacting with others BEs in exchange of resources and intangibles that might provide competitive advantage.

After that, the drone's environment was deeply studied, identifying its technical and operational restrictions - associated mainly to the reception method and the flying range. Based on that analysis, all the main variables involved on the drone's last mile delivery were listed.

Finally, based on the classification made, business models were developed, identifying the main advantages and disadvantages of each one, as well as the scenario on which each one could be fit and the interactions between agents. It was possible to observe that this technology is viable mainly on rural areas and products which customers require a short order lead time, converging to previous conclusions over its use.

However, the determination whether drones will play a role on the future of last mile deliveries depends mainly on a deeper analysis of costs, understanding how the tradeoffs are going to quantitatively work. This work has developed a MILP mathematical model that can be used as guidance for future quantitative studies.

In other words, in order to provide guidelines for the development of a profitable and efficient drone home delivery service, further research is essential. Analysis and modelling is needed using real data related of customer’s demands and companies’ costs.

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