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UPC BARCELONATECH

Methodology for the optimal design of Urban Consolidation Centers in Urban Areas

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Abstract

The objective of this project is to develop a study on the feasibility of implementing last mile freight consolidation centres (UCC) in the inner city, taking the city of Barcelona as an example. The project includes a study of the current market and the options that can be developed in a large city, followed by a study of the characteristics of the market and the type of commerce in Barcelona. Consequently, a methodology is developed to study how to calculate the ideal value of consolidation centres in each city according to the typology of each district and the typology of its commerce, as well as the possible location of the UCCs. This study is carried out by analysing the estimated costs of each of the proposals according to the type of vehicle or operational centre and the characteristics of the market.

Finally, the document carries out a cost-benefit study among all the actors involved in the logistics chain to study the viability of the project on an economic and social level. In this way, an ideal optimisation of the impact on each of the agents involved is achieved in order to know and ensure the viability (or not) of the implementation of this type of consolidation logistics centres.

ACKNOWLEDGEMENTS

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1 Introduction

Urban Consolidation Centers (UCC) are logistics facilities aimed to consolidate parcels before being distributed to the final customers. This consolidation allows carriers to operate the distribution network in two different supply chains: the access distribution network between distribution centers and UCC, and the local distribution network from UCC to final customers. These networks may be operated by differentiated fleets, adapted to the desired specifications of each environment. The potential cost savings due to the consolidation of freight trips in the local network are achieved at the expense of the operating cost incurred at the UCC. Generally, logistic service providers (LSP) experience cost savings when carrying the parcels to be distributed to the final customers through UCCs. These LSP only incur the operational cost of the access distribution network (from Distribution Centers to UCC). Then, the facility operator, a new agent of the system, will take over all logistic processes to distribute parcels from the UCC to the final customers. UCC operator sorts and consolidates the shipments of many companies and delivers them usually in environmentally friendly vehicles and according to an agreed level of service with final receivers.

Nevertheless, the main question raised is how these processes are economically balanced with revenue streams. There was a wide list of UCC initiatives that are no longer in service because the UCC manager went bankrupt, or the local authority did not continue subsidizing the service through the urban facility. Therefore, the analysis of the business model and the economic conditions to be met are strategic to ensure the financial sustainability of these freight measure. Hence, the aim of this document is to present and justify a financial model for deploying a network of UCC, in the particular case of Barcelona, Spain.

In the following lines, we are going to compare two delivery strategies:

- Strategy A. This strategy will refer to the conventional distribution scheme where carriers distribute parcels directly to receivers from the distribution centers located out of the city.
- Strategy B. This strategy implies the operation of an urban logistic facility called Urban Consolidation Center or Consolidation Facility (CF). Collaborative carriers send parcels at these facilities, where they are unloaded, consolidated, classified and loaded into a new vehicle fleet operated by the consolidation facility manager. These new fleet will distribute parcels to the final customers.

The document is structured in the following way. Firstly, agents involved and their relations are presented. From the relations between stakeholders, potential revenue streams to balance the new cost incurred by agents in the new distribution scheme are presented in Section 3. In Section 4, a detailed description of the freight distribution system in Barcelona is introduced. The modeling approach to estimate logistic costs and the optimal number of consolidation facilities is then described in Section 5, based on the continuous approximation. Finally, Section 6 proposes a new network of Consolidation facilities in Barcelona, complemented by Section 7 where its profitability and financial sustainability is analyzed. A cost-benefit analysis is done, by firstly selecting the location and then displaying the final costs and benefits in the matrices Stakeholder-Effect matrices derived from a multi-actor cost benefit analysis (MACBA). A sensitivity analysis is done before giving the conclusions.

2 Freight Distribution market. Consolidation Facilities, Agents involved and new policies

Urban Consolidation Center (UCC) concept is associated with the installation, operation and management of a huge freight transport facility to logistic service providers near big cities. Such business facilities seem to be capable of resulting in major modifications in the last mile delivery and distribution system of the area where they are settled in. In most of the cases, it is proven to be a very important junction where the urban and interurban parts of the transport chain are interconnected (Figure 2.1). It constitutes a freight transport node of great significance, as this is the place where several freight operations such as handling of cargo, loading / unloading, warehousing and added value services are developed. The prevailing effect on the surrounding cities is usually proven through the fact that the collaboration and type of partnerships amongst freight transport stakeholders is determined and fully directed in compliance with the UCC's operational, business and economic scope and objectives.

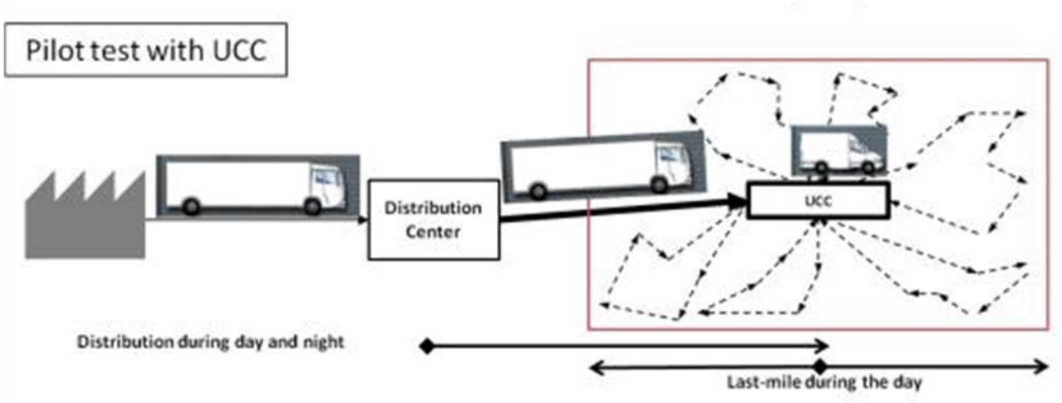


Figure 2.1 Distribution scheme using Urban Consolidation Centers. Source: Nathanail et al. (2013)

Nevertheless, the UCC has embraced several urban facility implementations with heterogeneous objectives: public distribution depot, central goods sorting point, urban transhipment centre, shared-user urban transhipment depot, freight platforms, cooperative delivery system consolidation centre (specific, e.g. retail, construction), urban distribution centre, city logistics (or city logistic) schemes, pick-up drop-off location or offsite logistics support concept. This ambiguity is a proof that the UCC concept has mutated over the years. Nevertheless, according to Browne et al. (2005), a UCC can be generally described by any facility that connects long-haul transport with deliveries to stores and offices, among other destinations, located in urban areas.

In Allen et al (2014), the different implementations of UCC are mainly classified in 3 typologies.

- UCCs serving all or part of an urban area: They are mainly utilized for distributing retail products; although office products, and occasionally food deliveries can also be served through the UCC. They are mainly operated by a public or neutral company.
- UCCs serving large sites with a single landlord: this UCC type is linked to a big freight demand attractor such as hospitals, commercial malls, transport terminals, etc. Retail products and HORECA supply chain are typical supplied through UCCs associated to the demand attractor pole.
- Special project UCCs: These are UCCs that are used for consolidating construction materials for major building projects including housing, office blocks, hospitals or Olympic Games.

One fundamental feature is the type of ownership of the UCC, the underlying business model for the management and operation of the UCC, as well as the allocation of delivery costs and benefits/profits to engaged stakeholders. The following ownership schemes and operating business models are usually encountered in practice (Browne et al., 2005):

- UCC privately owned and operated by a single party, either directly or by subcontracting: three cases appear in practice: i) single-site with one landlord, where retailers are benefited from special handling for using the UCC (e.g., shopping mall-UCC in York), ii) single-site "demanding" landlord, where the retailers are required to use a common UCC (e.g., Stockholm and Heathrow construction UCC) and iii) "Dutch System", where carriers and shippers are kind of obliged to use the UCC.
- Private joint ventures, led by the carrier industry without involvement of any public institution: this category refers to carriers who must cooperate to run a UCC, as they cannot afford to act individually. They tend to look for neutral solutions, like starting up a joint company (e.g., Kassel UCC).
- Private Public Partnerships (PPP): the establishment of a UCC whose owners derive from both private and public sector. Stakeholders could be local authorities, commercial actors, logistics operators etc. This kind of ownership is extensively used in Italy (Browne et al., 2005), and may appear in two forms, either the start-up of a new company (e.g., Siena) or the establishment of agreement with an existing one (e.g., Padova).
- Publicly owned UCC: these are initiatives owned by public authorities and operated by private actors selected by tender (e.g., La Rochelle).

These enormous business facilities seem to cause the emerging of respective needs, such as the major initial investments that must be made. Investments are especially required during the first phases of its development, in order for the construction works to be funded, the purchasing of equipment to be processed and for the development of high value services to be promoted. These investments, necessary for the UCC's viability and sustainability, are usually provided by public and state funding, as well as some private initiatives. In addition, during the operation phase, the supporting role of the regional stakeholders (retailers, public authorities and society) is considered to be of crucial importance for the UCC's successful business operation.

UCCs is not a new concept since they were implemented in 1940s in USA and in early 1970s in Europe (Allen et al., 2014; Paddeu, 2017). Table 2.1 presents the number of UCC initiatives launched in the 1970-2010 period. UK, Germany, Italy and the Netherlands are the countries that have explored the potentialities of UCC in a high number of sites.

Despite the potential benefits that UCC initiatives can provide and the large number of UCCs ventures all around the world, the implementation in practice commonly fails (Browne et al., 2005; Nordtømme et al., 2015). Indeed, most of the UCCs initiated in Germany and Italy are now closed (Allen et al., 2014). From a list of 82 initiatives of UCCs properly reported in 17 European countries, 62 UCCs were still in service in 2019, 20 UCCs are closed (13 UCCs because of financial reasons, and 7 UCCs because of the end of their purpose as Special Project).

Country	Unknown	1970–1975	1976–1990	1991–1995	1996–2000	2001–2005	2006–2010	Total
Austria	–	–	–	–	1	–	–	1
Belgium	–	–	–	–	1	–	–	1
Canada	–	–	1	–	–	–	–	1
Finland	–	–	–	–	–	1	–	1
France	–	1	–	5	–	3	2	11
Germany	–	–	–	8	6	–	–	14
Italy	–	–	–	–	1	5	8	14
Japan	1	–	1	–	–	2	–	4
Monaco	–	–	1	–	–	–	–	1
The Netherlands	–	–	2	3	1	1	7	14
Portugal	–	–	–	–	1	–	–	1
Slovenia	–	–	–	–	–	–	1	1
Spain	–	–	–	–	–	1	2	3
Sweden	–	–	–	–	2	2	1	5
Switzerland	–	–	–	2	1	–	–	3
UK	–	4	4	1	4	4	21	38
USA	–	1	–	–	–	–	–	1
Total	1	6	9	19	18	19	42	114

Table 2.1 Number of UCCs in the 1970-2010 period.

In the following figure, which shows the data in the table above, it can be seen that over the years there has been a growing interest in the implementation of consolidation facilities technologies in the different countries listed in the table, with a very considerable increase in the most recent period (2006-2010). This is due to the large increase in demand for these services due to the growing awareness of ecological factors, the efforts of large countries to reduce traffic in their main cities, as well as the boom of the internet and platforms such as Amazon, which require a much more recurrent express delivery service than in previous years. This means that at a logistical level, the different delivery companies are seeking greater proximity of their logistics centres to end customers, seeking to have warehousing platforms very close to the centre of cities or even inside.

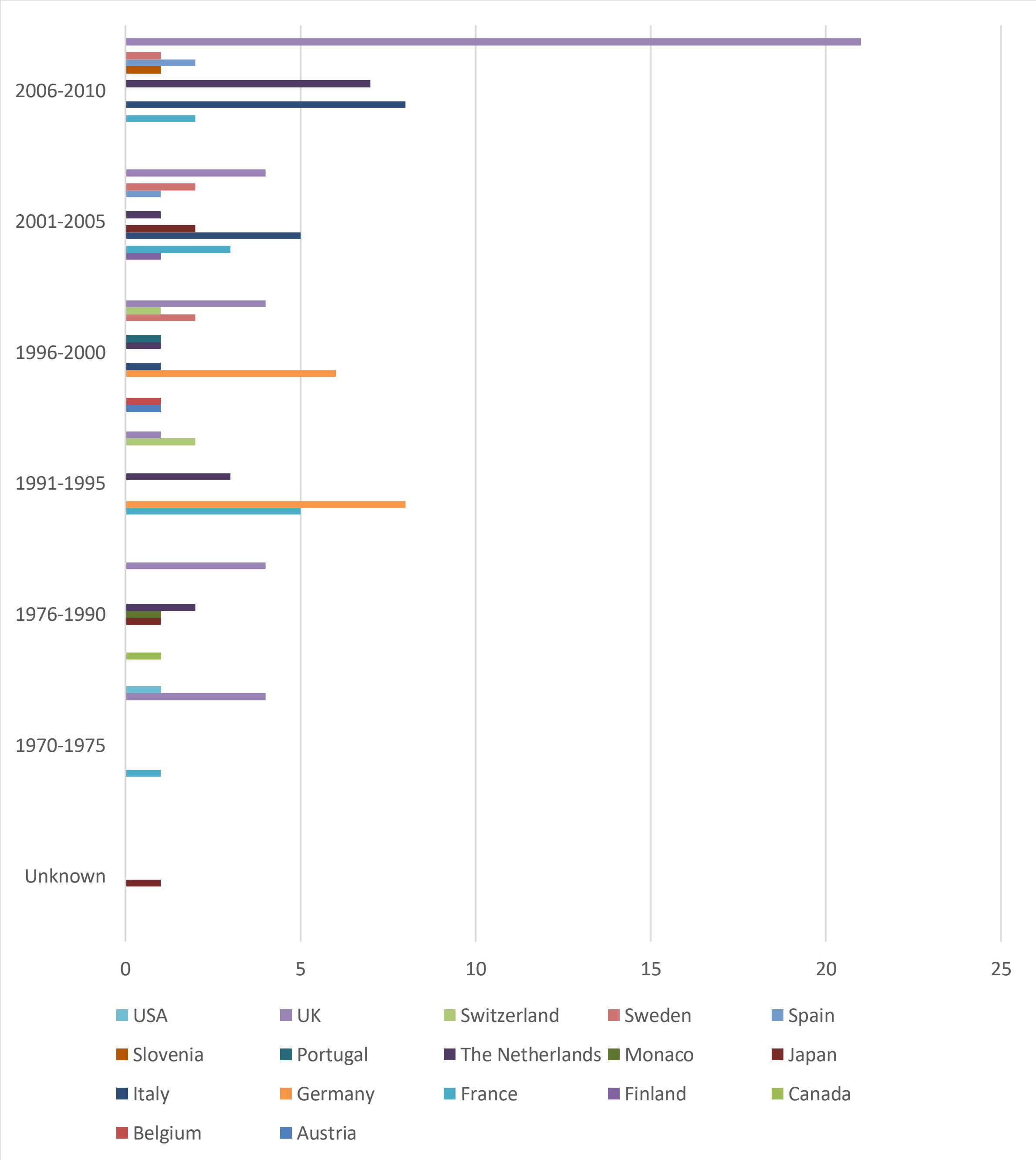


Figure 2.2 Evolution of UCC along the years in developed countries

Other reasons behind these failures are the lacking of recognition that the delivery involves other aspects than transport related aspects such as administration and commercial (Dablanc, 2005). Instead, UCC promotion needs to include a business perspective, not only transportation issues, and taking into account financing, commercial concerns, and management (Benjelloun et al., 2010; Nordtømme et al., 2015, Björklund, M., Johansson, 2017).

For these reasons, the UCC concept has evolved in the last years, including different facility roles and more economic designs of urban facilities. Today, it is preferable to talk about Consolidation Facilities, including Urban Stage Areas, Local Logistics Spaces, etc. and other small and low-cost centres. Figure 2.3 defines different levels depending on the size of the area to be covered by the logistics centre, although any facilities covering an urban area could be considered as a UCC. For this project, we can define Urban Consolidation Centres as integrated centres within cities or densely populated regions, which have an area of influence to carry out the so-called last mile distribution in a fast, efficient, optimal and ecological way, facilitating the correct circulation of people and vehicles and without hindering the daily activities of the city's inhabitants.

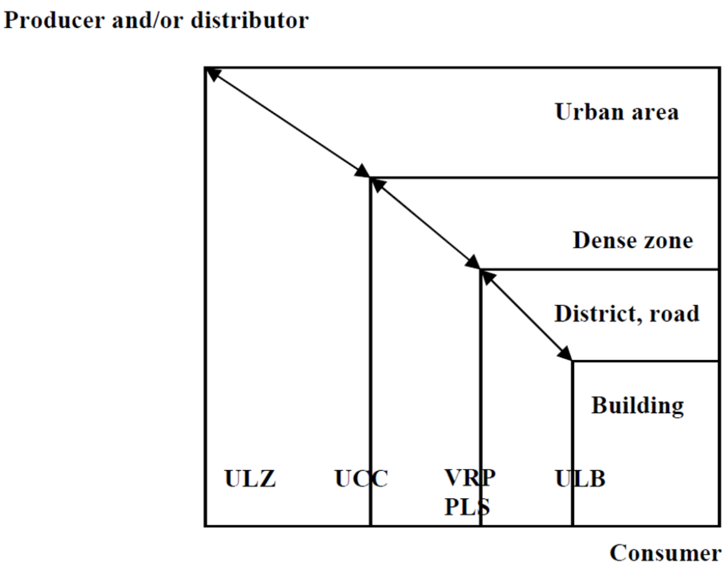


Figure 2.3 Characterization of UCCs (Adapted from Boudouin, 2006)

One of the main problems that we find in the city and that is intended to be solved with the option of implementing UCCs in the cities, is the constant entry and exit of trucks supplying goods for all types of shops and services, such as bars, restaurants and hotels.

The entry of heavy goods vehicles into the city, apart from the greenhouse gas emissions they produce, which are much higher than those of conventional cars due to their size and weight, causes an increase in traffic and the difficulty of circulation, as they are slower vehicles with limited mobility. Moreover, the loading and unloading operations of these vehicles are usually carried out in front of the shops where they provide their services, and in many cases, they occupy part of the traffic lanes, parking spaces or even part of the pavements, bus lanes or bicycle lanes. The consequence is an increase in the traffic-related problems suffered by both people and freight. Deliveries in cities as densely populated as Barcelona, tend to be distributed evenly throughout the city. This also leads to an increase in traffic around the delivery points, and not only on the roads where these vehicles circulate, as well as being operations that in many cases take several minutes.

For these mentioned reasons, the main objective of the CFs and UCCs is to optimise last-mile deliveries and reduce the number of medium and large freight vehicles circulating within the city, as well as the number of kilometres they have to travel, by delivering only to the corresponding logistics centres without having to go shop by shop. A good example is the one shown in the Figure 2.4.

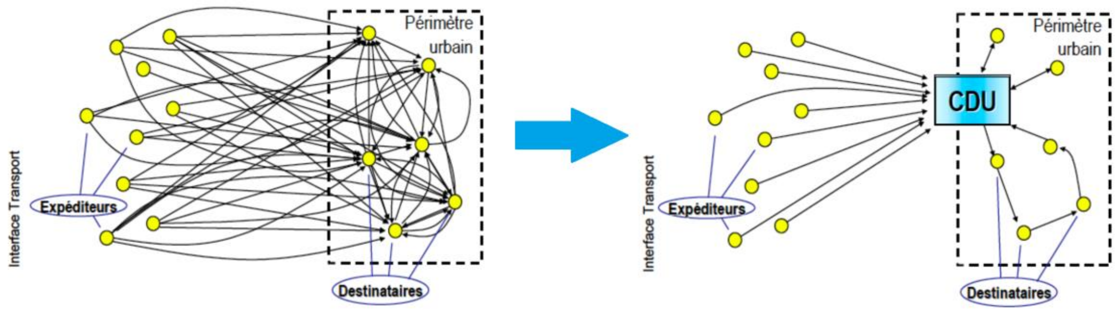


Figure 2.4 Transport flows before and after the implementation of an UCC. Source: Bruxelles Mobilité, 2012

2.1 Agents Involved

The presence of a CF or UCC represents a pivotal change in the logistics system of a city. CF measure is often accompanied by other policies such as banning the entrance of trucks and vans into the area the consolidation center serves or setting up time windows where trucks are taxed or have free entrance. These measures imply changes in the relations between existing agents. We will first enumerate the agents considered in the present work.

2.1.1 CF Operator

This agent oversees the operation of the consolidation facility. It may be a neutral carrier although the facility can also be run by a private company or one of the carriers that are actually serving the zone of study. This agent will try to obtain profits by consolidating the shipments from other carriers and may offer other additional services to customers, such as storage, scheduled deliveries or even group purchasing.

2.1.2 Carriers/Suppliers

For the sake of simplicity, no distinction is made between carriers and suppliers. They are treated as companies that send freight to the center by charging a fare. The reason that justifies it is twofold. Firstly, both kinds of companies tend to hire autonomous drivers to send them the load and secondly, the sectors in which suppliers deliver directly by their own means, such as food industry, restaurants and bars, are excluded from this study.

By using the Consolidation Facility (CF), carriers avoid the time spent for the stops and deliveries, as well as a fleet reduction and capacity expansion (the use of less vehicles but of bigger capacity) given that they avoid the peddling part of the transport. Nevertheless, they face a crucial commercial drawback. Shippers use their drivers very often as commercial agents who take orders and collect feedback and promote their products to retailers. With the presence of an intermediate agent, they lose this advantage. This is one of the main reasons why CFs and UCCs are rejected by conventional carriers.

2.1.3 Retailers

Retailers are the agent who receives the loads. There is a high heterogeneity in their nature in addition to the difficulties of numerically assessing their new benefits and costs due to the CF and UCC. They may reject the new policy due to the loss of direct physical contact with their suppliers, but may see a deal of opportunities in CFs for the additional services and for having more control on the disturbance caused by the arrival of shipments.

2.1.4 Government (Authorities)

Authorities are often the agents that foster the implementation of the UCC solution. They aim to reduce externalities such as noise, pollution and congestion. They may give one-time subventions for constructing the facility or structural subventions in case the operating costs are higher than the operating revenues. It may be interested on minimizing the subvention by incorporating the biggest number of agents in the project. Government has therefore a pivotal role in the CF success.

2.1.5 Non-users

They are the main reason why a CF project is generally undertaken. Non-users are subjected to the externalities caused by urban logistics. They role in the model is to receive the reduction of this externalities. Government should take advantage of the project benefits and let non-users know about them, since subventions come from taxpayers, which most of them are non-users.

2.2 Costs and benefits of UCCs

2.2.1 Overview

The following Figure 2.5 summarizes the chain of effects that the presence of a CF-UCC causes in case of poorly loaded vehicles on direct deliveries replaced by better loaded vehicles for UCC.

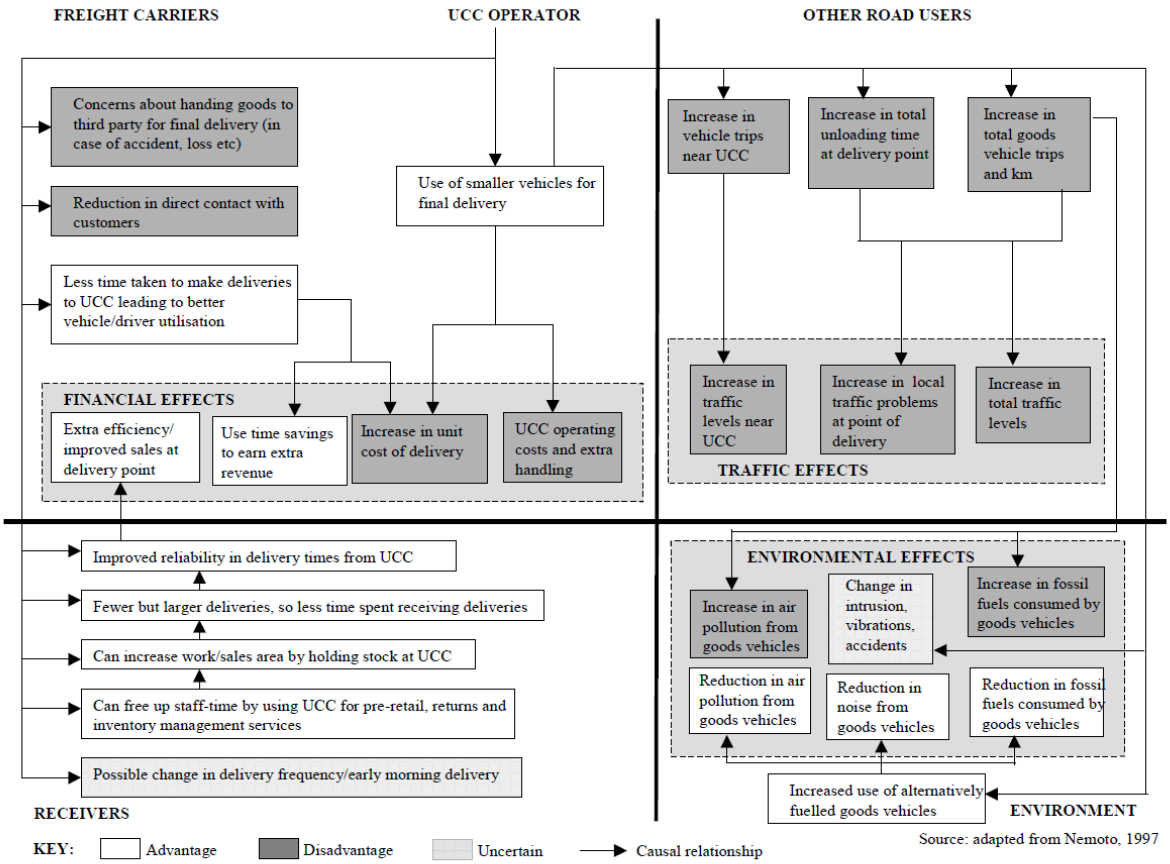


Figure 2.5 **Cost and benefits associated to UCCs (Alen et al., 2014)**

UCC operators tend to use smaller vehicles for final deliveries in order to do the peddling more fluidly due to physical characteristics of the delivery zone (adapted from Browne, 2005). This causes some drawbacks such as an increase in the unit cost of deliver and UCC operating costs and extra handling, to be compensated by a higher load factor in vehicles.

Besides the physical logistics aspects, the inclusion of an intermediate agent involves risks and difficulties on information in the preexisting chain links. This may concern risk of accidents and losses due to this new third-party agent as well as a loss of direct contact between agents. On the other hand, suppliers take less time to make deliveries since they have to make only one stop. They improve the utilization of their vehicles and may reduce their fleets. These time savings cause extra revenues. Other additional benefits are the free-up of staff-time in case of UCC offers additional services such as inventory management.

The use of smaller vehicles in addition to the adoption of alternative fueled goods vehicles reduces local emissions, noise and air pollution. Moreover, these vehicles may induce indirect effects on retailers, by improving the quality of life and the adequacy for consumers to spend time walking on the streets and do shopping.

2.2.2 Cost and benefits included in the present appraisal

One of the main difficulties that arise when appraising a CF or UCC project is the quantification of impacts, costs and benefits. The first difficulty is the lack of data from agents that do not want to share their information, such as carriers, or because they even do not know or consider it. This is the case of retailers, who may not monitor their stocks levels or gather information from customers and shipments.

Secondly, the high number of agents make the collection of information difficult. Carriers often hire autonomous drivers who deliver the loads for them. These small companies (median of 1 worker) increase even more the complexity of data collection. For retailers, an extensive survey campaign is required especially when the use of UCC is voluntary.

Thirdly, some impacts have a qualitative nature. How can we quantify that streets become more pleasant to promenade and buy? Which percent of the buy increase is due to the reduction of noise and vehicles? Appraisals will therefore in this case give a lower bound of the benefits. Finally, these benefits need to be allocated between the parties involved. This should be a simple process, but the difficulties enumerated above and the strong dependence on the nature of the center complicates it. The UCC breakeven point with regard to the current scenario will mainly depend on the number of retailers and carriers implied. This will also have an impact on subsidies and taxes. The costs and benefits included in the present appraisal are summarized in Table 2.2.

Agent	Benefits	Costs
UCC Operator	Profit making company (from fares) Subsidies	Overhead and operating costs
Carriers	Less trips Less vehicles Better use of time resources (drivers and vehicles)	Operating Costs
Receivers	None	None
Authorities	Taxes from UCC	Less taxes from previous situation
Non-users	Reduction of air pollution, accidents, climate change.	Taxes for subventions

Table 2.2 Cost and benefits per agent

For the sake of simplicity, no distinction is made between different grades of administration in terms of local authority, regional and national government. In the same line, non-users' agent is generally specified.

Trucks will arrive at the UCC from 6AM to 10 AM or even during the night, before retailer's opening time and partially avoiding peak hour congestion. Commodities will be unloaded, quickly ungrouped and grouped in shipments to be delivered in the same time windows that current carriers do. In this way, retailers will not see any difference between the previous and the new situation. A fare for the service can be charged to the shipper, the retailer or both and all agents will see their surplus increased if the demand is enough to cover the additional costs the terminal imposes. The potential fare structures or cash flows between agents are examined in the next Section.

3 Fare structures

The introduction of a Consolidation Facility (CF) or Urban Consolidation Center (UCC) radically changes the cost structure of existing distribution agents. Carriers avoid the peddling part of the distribution trip and may use bigger vehicles to deliver to the new distribution center, reducing the number of trips. This reduces their costs drastically, increasing carrier's profits if UCC delivers for them. On the other hand, the UCC operator has costs to be covered. There are many different approaches to reach equilibrium between agents. These depend on the final demand and the costs of the UCC.

Given that the appraisal has been calculated with an average volume and weight for shipments, equal for all of them, a specific fare structure to each carrier is not possible. Instead, the fare will account for a percentage of the difference in carriers cost due to the presence of the CF or UCC. Fares per tour, shipment, volume and weight are calculated straightforwardly.

One alternative solution for the fare structure would be that the UCC operator charges a fare to retailers and force carriers to reduce their current tariffs (Alternative 1 in Figure 3.1). Given that the current economic context is detrimental to retailers, receivers will be reluctant to increase the economic charges or increase the complexity of transport bills, since UCC does not cause any logistic cost saving. Therefore, this option is excluded.

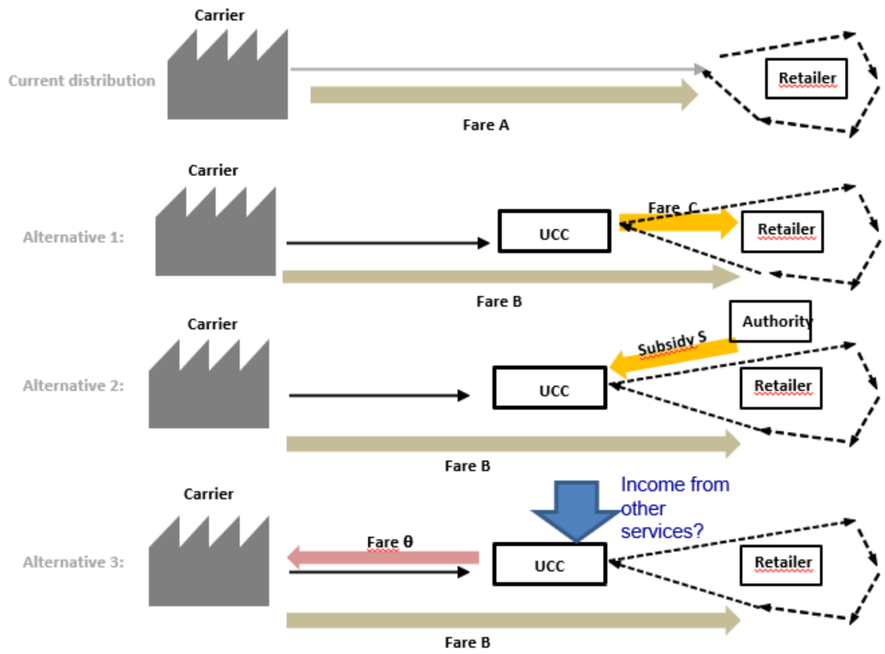


Figure 3.1 Cash flows between agents

Another option (alternative 2 in Figure 3.1) is that a subsidy S may be assigned to the UCC operator which compensates losses until a zero-deficit level. This subsidy will be provided by the local authority. In reality, local authorities have limited budgets. It is rare that they take part actively in the distribution market, promoting the creation of logistic facilities by tenders, when this market is supposed to be led by private companies.

Finally, the approach suggested in this study is to charge a fare θ_{CF} to the carrier in order to reduce its surplus. This fare will be paid to the UCC operator, to compensate the new cost that this player will incur. This solution becomes efficient when costs savings due to scale economies present in the

UCC distribution are capable of covering the entire costs of the UCC, both fixed and variable. This approach does not need any regulation from the local authority, and carriers and CF operator can sign private agreements to define the liabilities and duties of each stakeholder.

The introduction of the Urban Consolidation Center could be considered as a natural monopoly of a delimited geographical extension. Since it is common in UCC projects to close the access of trucks to the delivery area, this hypothesis is coherent. The UCC operator or the public regulator has therefore freedom to set the most adequate fare, but it may guarantee that the desired effects of the measure will be achieved.

4 Methodology of the study

The study presented in this project was made possible thanks to the use of open data from Barcelona City Council and other geographic information platforms and published data. In order to characterise the city of Barcelona, we have used the data published on the aforementioned website of the city council on commerce located on the ground floor throughout the city. The database presents the information of each of the commerce, with its coordinates, its professional activity, the typology of this activity, the neighbourhood and district where it is located, its current state or the exact address of the establishment. All this information refers to the year 2019 but has been taken as a reference for the study.

For the graphic study, the free Geographic Information Systems (GIS) software QGIS has been used. With it, and thanks to the multiple options for editing data files, shapefiles, point clouds and others, it has been possible to generate the map of Barcelona with the characterisation of each of its neighbourhoods and districts. In this way, each of the commerce has been geolocated and it has been possible to study the density of commerce from different points of view, as well as other characteristics of the city such as its population density for each neighbourhood.

After all this, and thanks to the software, once the study that will be developed in the following points has been carried out, it has been possible to distribute the different Consolidation Facilities on a map.

It is also important to know this information in order to have a global vision of how commerce is distributed throughout the city of Barcelona. For example, as shown in the figure 4.1, the density of commerce in l'Eixample is different from that in the area of Les Corts - Pedralbes.

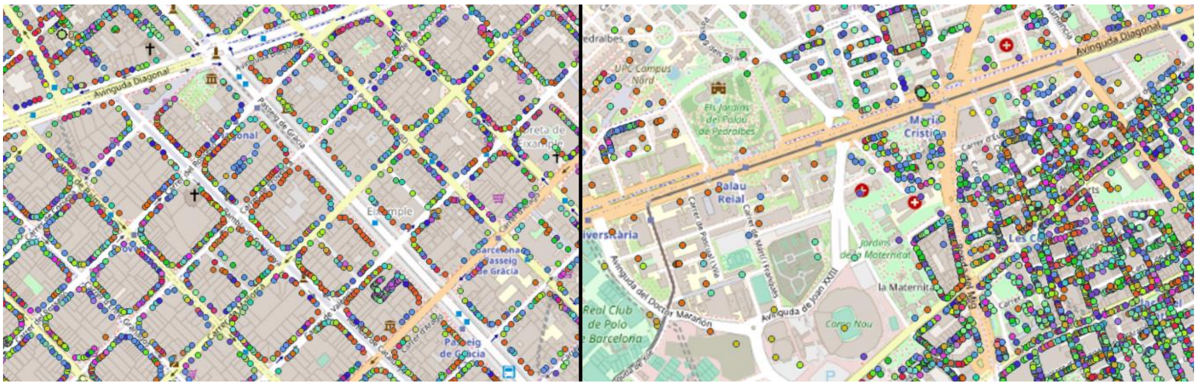


Figure 4.1 Example of the distribution of the commerces in l'Eixample (left) and Les Corts (right)

Previous studies carried out in various areas of Barcelona or in other parts of Europe have also been taken into account, above all to use as a reference the values of fixed and variable costs for the facilities, the agents involved in the whole logistics system and the pros and cons of the measures applied and how they can be improved. It is for this reason that indicative values are taken in each of the points of this study, based on the mistakes made in previous proposals for the creation of UCCs that had to be closed and on the values of percentage rates and distribution of payments in successful cases around the world.

5 Freight Distribution in Barcelona. Market characteristics

Barcelona is a city with a multitude of different types of retailers and commerce. Depending on the area and its characteristics, different commercial premises may predominate, focused on the target of potential customers or on the general typology characteristic of the neighbourhood. In order to define the correct distribution of consolidation facilities, the volume of freight needed in each neighbourhood must be considered. It depends on the necessary storage space, the ideal type of vehicle and the location of the consolidation facilities.

5.1.1 Demand

The study carried out to characterise the demand based on the census of commerce published by Barcelona City Council in 2019. It defines the characteristics and location of more than 80,000 premises in the city, including data such as their location and the type of products they sell. This information is summarized in Table 5.1.

District	Food	Horeca	Personal apparel	Housing	Leisure	Public/Private Services	Automotive and repairs	Other	Total
Ciutat Vella	901	1647	1174	230	416	259	19	3520	**8166**
Eixample	1631	3114	1908	934	740	1060	381	6146	**15914**
Sants-Montjuïc	771	1043	542	270	238	457	215	4698	**8234**
Les Corts	294	513	322	141	117	402	76	1774	**3639**
Sarrià-Sant Gervasi	682	879	925	423	192	835	142	3640	**7718**
Gràcia	747	737	740	313	267	514	159	4007	**7484**
Horta - Guinardó	606	515	427	217	135	381	167	4066	**6514**
Nou Barris	726	598	459	227	146	400	173	3864	**6593**
Sant Andreu	539	671	524	266	162	421	200	3376	**6159**
Sant Martí	953	1440	810	351	268	652	259	5401	**10134**
Total	**7850**	**11157**	**7831**	**3372**	**2681**	**5381**	**1791**	**40492**	**80555**
Weekly operations	15.00	12.00	11.00	19.00	18.00	8.00	8.00	8.00	
Average demand (m3)	0.1	0.125	0.1	0.5	0.1	0.1	0.25	0.1	
Loading/Unloading time (min)	17.00	12.00	10.00	13.00	12.00	4.00	4.00	4.00	

Table 5.1 Distribution of premises in the districts of Barcelona. Weekly operations, demand and service time.

In order to categorise the shops, they have been divided into eight groups, according to the type of products they offer:

- Food: Supermarkets, food and similar.
- Automotive and repairs: Workshops or sale of products for vehicles.

- Housing: Real estate activities or domestic products.
- Horeca: Bars, restaurants and similar.
- Leisure: Leisure and cultural facilities, shops selling leisure products.
- Personal apparel: Daily non-food use like clothes, cleaning or personal equipment.
- Public and private services: insurance, education, financial, health care.
- Other: All other products.

The distribution of the premises per each district is represented as a percentage as follows:

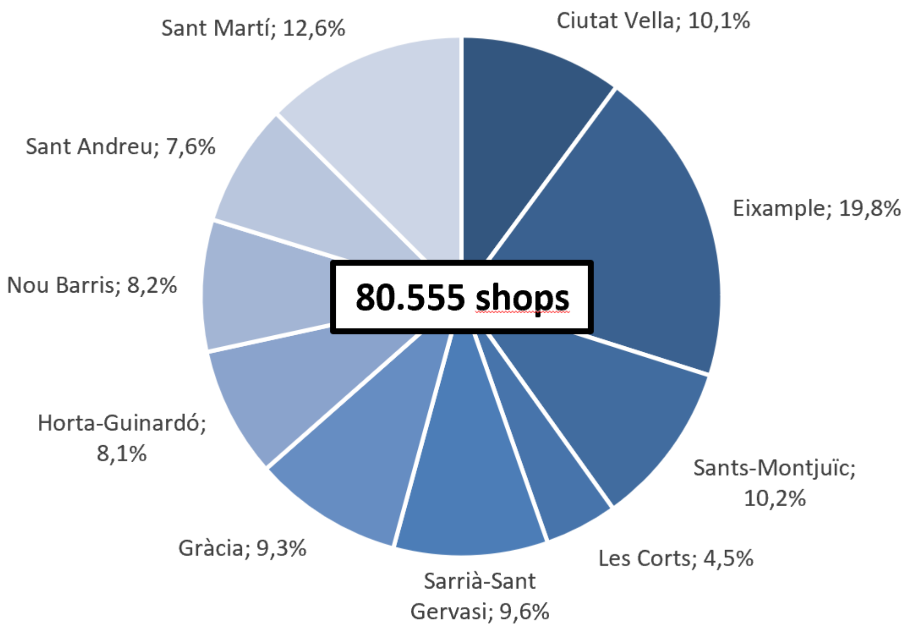


Figure 5.1 Percentual distribution of premises per district in Barcelona

In addition, the coordinates of each of the retail shops in the database of the city council have been used to create a GIS map. This product is also a deliverable of the current study. Based on this GIS, the distribution of the number of shops according to the district of the city can be mapped in Figure 5.. It can also be calculated the density of retailers per district (Figure 5.), the number of vehicles spots or logistic operations per district (Figure 5.) or the volume generated in each district (Figure 5.)

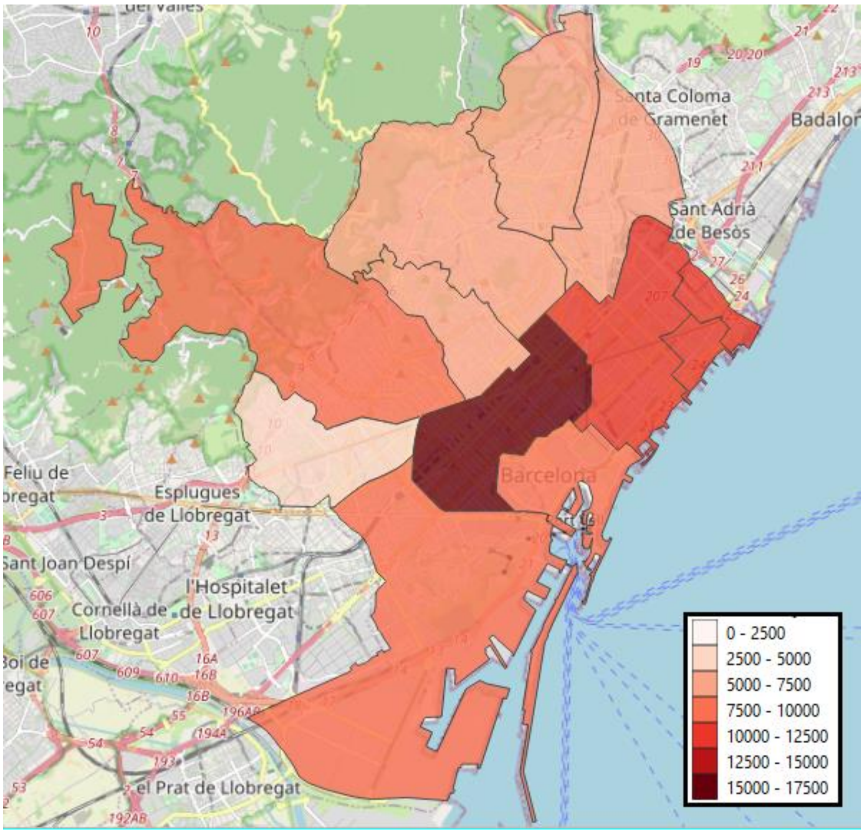


Figure 5.2 Total amount of commerce per district

With these values, the aim was to calculate the demand in each neighbourhood in order to be able to size the number and dimensions of the consolidation facilities needed in each area of Barcelona. However, the volume of daily products of each type and their characteristics had to be taken into account in order to have a more accurate view of the needs of each commerce. A similar study was carried out in 2016 by BCNecologia, for the creation of a consolidation facility in the old Abaceria market in the Gràcia district. The needs of each of the categories were sized according to the daily and weekly quantity of freight to be received and the volumetric dimensions of each of parcels.

After analysing the volumes required for each type of commerce and its dimensions, as well as the necessary characteristics of the delivery vehicle, the commerce categories for food, catering, automotive and repairs, and housing were discarded, leaving four types of commerce that the consolidation facilities will have to cover. As an example, a large tonnage truck is needed to deliver to supermarkets, as well as having to maintain certain temperature and humidity characteristics for many of their products.

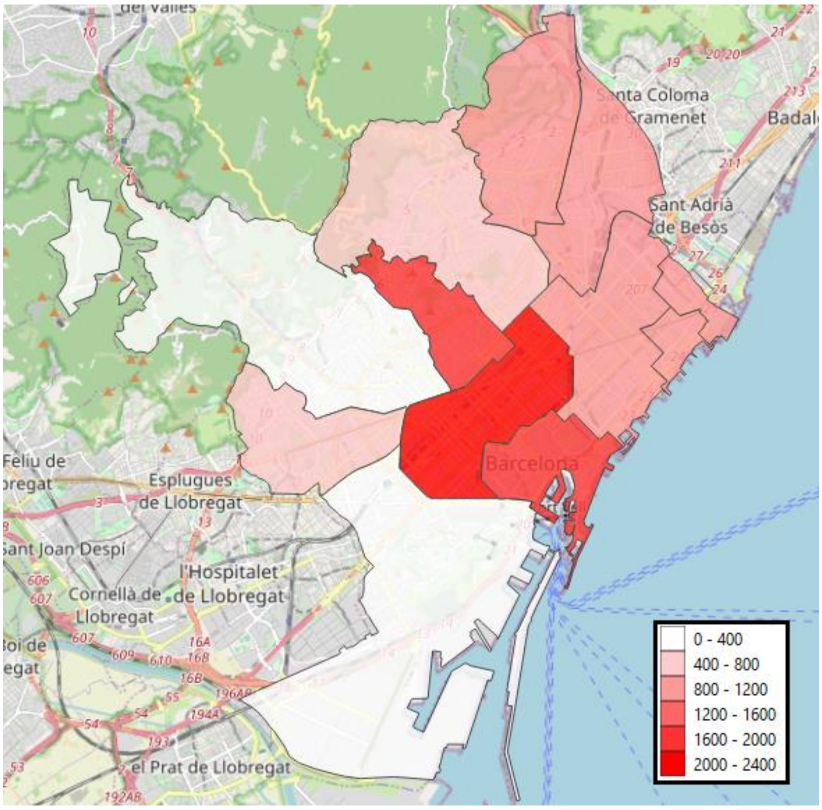


Figure 5.3 Density of receivers per district (rec/km2)

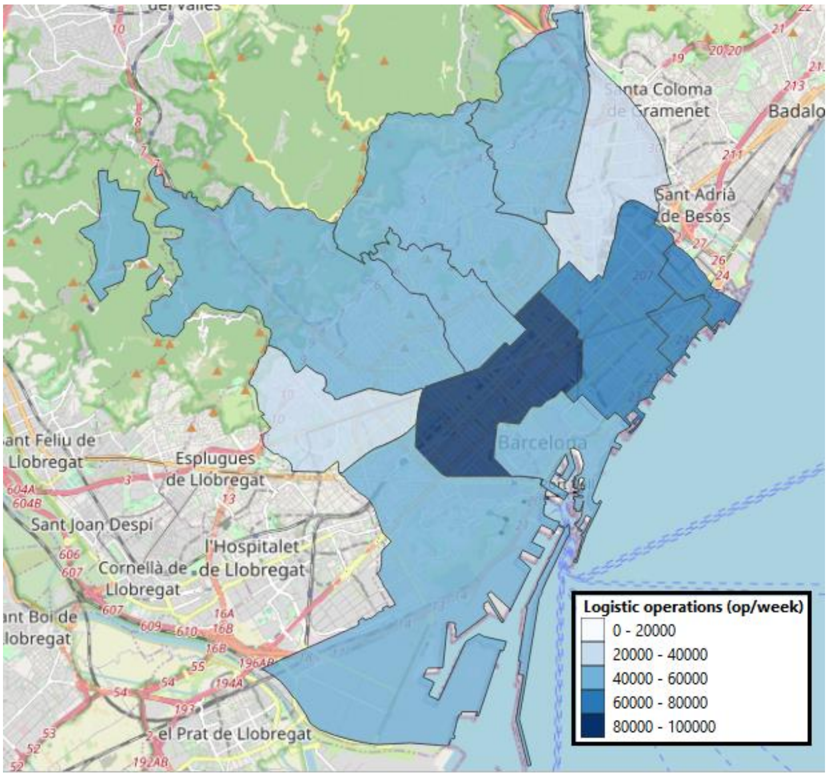


Figure 5.4 Logistic operations per day in each district (m3/day)

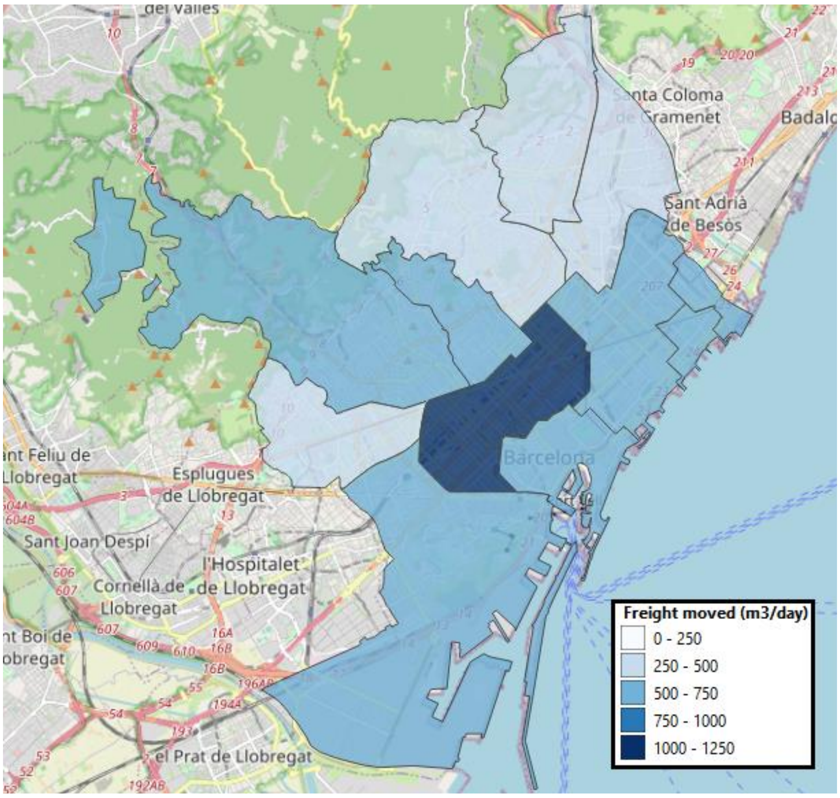


Figure 5.5 Volume of freight moved per day in each district (m3/day)

5.1.2 Carriers

No particular carrier data has been available for the appraisal of this project. Nevertheless, we considered the freight survey carried out in the framework of STRAIGHTSOL project (Johansen et al, 2014). The only data accessible was in a question in the descriptive analysis about which carriers did visit each retailer. This question was split in three spaces in which shopkeepers answered the most significant ones. The aggregated responses were grouped and listed in Table 5.2.

Carrier	Company share	Market share for for-hire carriers
#1	70%	21%
#2		19%
#3		10%
#4		10%
#5		10%
#6		10%
#7		5%
#8		5%
#9		5%
#10		5%
Autonomous	30%	Excluded from analysis

Table 5.2 **Demand served by carriers**

5.1.3 Potential Consolidation facilities and vehicles

The organisation of service logistics can be organised in multiple ways. This section shows different infrastructure possibilities to act as a Consolidation Facility or UCC as well as different methodologies for last mile delivery.

5.1.3.1 Logistics Facilities

The characteristics of the places to be used as a Consolidation Facility are fundamental for the definition of the correct functionality and day-to-day operations. The selection of one design among multiple centre typologies should be taken according to the logistics and urban planning of each neighbourhood or area of influence covered by the Consolidation Facility. Each area may present many different operational problems, such as lack of space, lack of land owned by the municipality, the type of vehicle to be used in each area according to the traffic conditions (pedestrian streets or not, steep or not, etc.).

- **Municipal markets**

The city of Barcelona has a large network of municipal markets, which meet the needs of the citizens of all districts and neighbourhoods in a fairly equitable and balanced way. In addition, pedestrianisation and the creation of super blocks around the markets are being promoted in order to make the neighbourhood where they are located more dynamic. It is for this reason that locating Consolidation Facilities in municipal markets or adjacent locations ensures an even distribution throughout the city according to the number of inhabitants in each area. This does not necessarily have to be the optimal location in terms of commercial needs, as population density does not have to be directly related to commerce density.

In order to deploy the Consolidation Facilities in the municipal markets, the situation of each market should be analysed. It could occupy the space of some of the stands, or stands that are not currently in use, as well as creating new facilities by reusing spaces or creating them outside the market. Another option, if there is a car park or warehouse with vehicle access, is to install them in the basement, in such a way as to create a space close to the entrance and exit where to receive, organise, and carry out deliveries, without disturbing the correct functioning of the market.

Figure 5.6 Sant Antoni market, Barcelona. Source: Expansion.com

- **BSM, SABA or similar car parks**

Barcelona has a fairly extensive network of public-private car parks. The best known are the private car parks managed by the company SABA and the public concession parking lots of the company BSM (Barcelona Serveis Municipals). In addition, there are many supermarkets, large shops and shopping centres with large car parks. In all the cases mentioned above, it is unlikely to find one that has full capacity, except for large events or important festivities in the city.

For this reason, using part of some strategically located car parks as a Consolidation Facility would be a good option, as there are many of them distributed throughout the city.

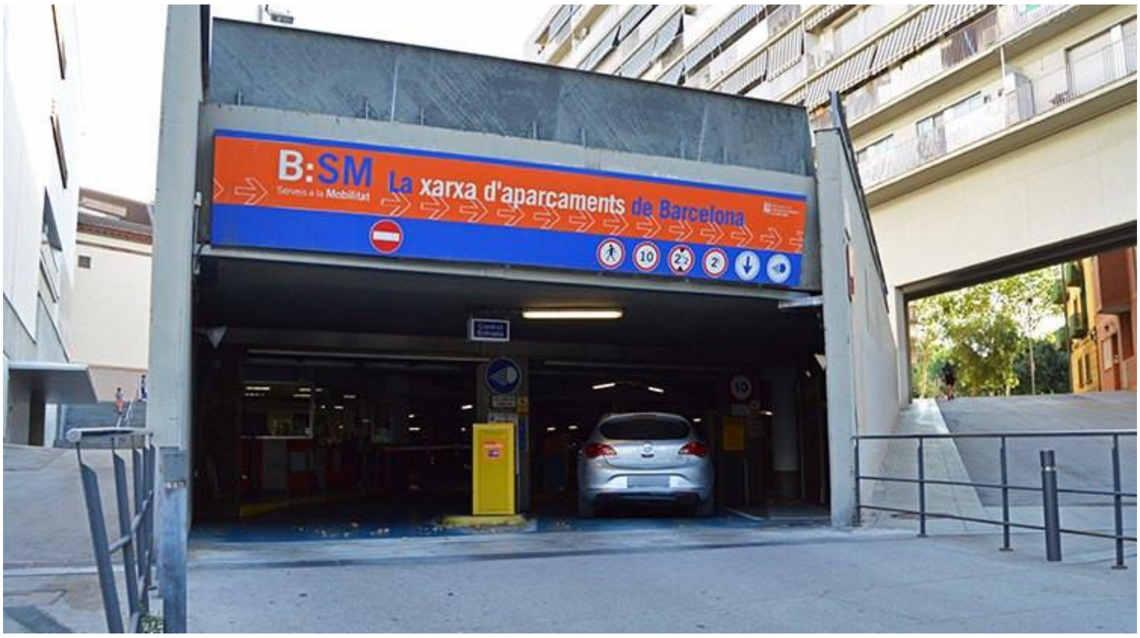


Figure 5.7 Example of parking BSM. Source: Parclick.es

The operation of this service could be managed by locating the Consolidation Facilities in areas close to the entrance and exit lanes, to avoid long driving distances inside the car park. Its management could depend on the company that manages the car park itself, as well as on a private company or the city council "renting" the space for community use. This factor would return an economic profit to the owners of the parking company.

It should be noted that some of the problems that could be encountered are the problems of the car park and the Consolidation facility being able to function correctly and the constant entry and exit of delivery vehicles. The vertical gauge and the slope of the entrance and exit lanes of the car park could also be a problem, as in some cases they are very steep, while others, such as the one in the image above, are (at least the first floor) at street level, which would facilitate the operation of the logistics centre.

- **Lockers**

This system has been implemented in many parts of the world and in our country for some years now. It consists of metal closets or cabinets with boxes of different sizes where the customer can receive their orders without having to be at home. An order reference code is entered, sent in advance by the company that sends the product, and makes it easier to pick it up at any time you want. Some of the companies that use them, and which are most commonly seen in Spain are Amazon, DHL and the public postal service (Correos). They are generally located at key points in cities, such as train or metro stations, or central public places.

This is a very useful system for small deliveries, but could lead to space problems with large deliveries, as well as being less optimised in terms of operations, as they have to be collected order by order. Its use as a possible Consolidation facility could be a mix between the current lockers, where the carrier would collect all the necessary consignments in the same box or in several boxes, and workers who would organise them to optimise the routes. Even so, its use should be limited to small consignments for multiple points, due to the space restrictions mentioned above.

Figure 5.8 Example of an Amazon Locker. Source: computerhoy.com

- **Green Points**

In Barcelona there are many recycling collection and green points, as well as being used by gardeners working for the city council. There are different formats in the city, depending on their function and use. There are some located in the areas furthest from the city centre, occupy several square metres and deal with larger waste. On the other hand, in all neighbourhoods and generally located in parks, there are prefabricated modules where they collect all types of waste that cannot be disposed of in the containers that are usually found in the streets.

The use of these spaces as a Consolidation facility would be a good option, as it is easy to place the prefabricated modules in various places without taking up much space, as well as being cheap to build and maintain and not having a great visual effect.

As in the case of the car parks, part of the large facilities mentioned above could be used as a Consolidation facility. The problem with these facilities is that they are located on the outskirts of the city and would therefore only cover a small area. For this reason, the ideal solution for use as a Consolidation facility would be to install the prefabricated modules as annexes to the existing ones in parks or in new strategic locations, considering that they should be located at points of easy entry and exit of vehicles for last mile delivery and close to key streets for the circulation in each neighbourhood. Several people would work in the Consolidation facility to organise deliveries and optimise routes to ensure that delivery is as optimal and fast as possible.

Figure 5.9 Example of a Green Point in Barcelona. Source: Ajuntament de Barcelona

5.1.3.2 Vehicles

There are multiple vehicles that could be used in last mile deliveries. The use of environmentally friendly vehicles, such as bicycles or electric motorised vehicles, would always be considered. This is an important point to take into account for the correct functioning of the consolidation facilities, as it is necessary to identify the problems that could arise in the delivery depending on the vehicle. Some of these problems may arise from the geography of the place, whether it be the slopes of the streets, the location of the delivery points and their ease of parking, the number of vehicles circulating in the villages or the weight of the consignments.

- **Electric Vans**

The use of small vans for last mile delivery can be useful, especially for longer routes, for transporting a higher volume of freight or for areas of the city with steeper slopes. Promoting the use of electric vehicles instead of vehicles that use fossil fuels is a much better measure for the environment, in addition to the fact that these vehicles are much smaller than those generally used in deliveries and which are to be replaced with this project. On the other hand, their handicap is the difficulty they may encounter in loading and unloading procedures depending on the point of collection or delivery.

Figure 5.10 Example of electric van. Source: noticias.coches.com

- **eCargoBikes**

Last mile delivery is ideally done using conventional or preferably electric bicycles or tricycles, to make it easier for the carrier to drive. The vehicles called eCargoBikes have boxes at the front or rear where the goods are placed.

The great benefits of this type of vehicle is the use of a completely sustainable vehicle, which takes up little space and is very easy to load and unload, as it is easy to access the necessary places. In fact, as they are considered non-motorized vehicles (the engine only assists the pedalling activity of riders), they can run along the sidewalk (in the case of Barcelona, sidewalks longer than 5 metres, or according to the regulations of each municipality) and even along the opposite way of streets. It helps to reduce the need of detours and the distance covered between two consecutive points. On the other hand, its great disadvantage is that the volume that can be transported is smaller than for vans, so the routes are more limited. There are different models and designs, but according to Navarro et al (2016), they are able to move up to 180 kg. Its volumetric capacity is around 1.2 m^3.

Figure 5.11 Example of eCargoBike. Source: Lomosa movilidad

- **Autonomous Delivery Device, ADD**

The Autonomous Delivery Device (ADD) is a type of autonomous vehicle that is specifically designed to carry freight from one point to another. These are robots that are similar in shape to vans but much smaller, which drive autonomously along pre-designed routes. They are charged by a battery like electric vehicles. Their main advantage is that they do not take up much space, so they do not cause traffic problems, as well as being sustainable vehicles. We can differentiate between two types of ADD:

- Single delivery ADD: This is a robot that allows a product to be picked up and delivered along a route with a single pick-up point and a single delivery point. This product has been designed and tested by several companies as a solution for urgent deliveries of freight, such as the test carried out by Domino's Pizza this year in Houston, USA. Its dimensions are very small, and its freight compartments are opened using a code.
- Multi-delivery ADD: This is the same concept as the previous one, but larger and with several compartments for different packages. Each of these spaces is unlocked with a separate code to ensure that deliveries are made correctly.

Another use case for unmanned vehicles is drones. Companies such as Amazon have already started testing in semirural areas. They allow individual deliveries, with the advantage that they are not affected by human actions or vehicles around them.

The main problem with these vehicles is the lack of legislation and regulation for their use and circulation in most countries in the world, which is why it is necessary for administrations to legislate this type of delivery, together with the companies involved, to ensure the future of autonomous home deliveries.

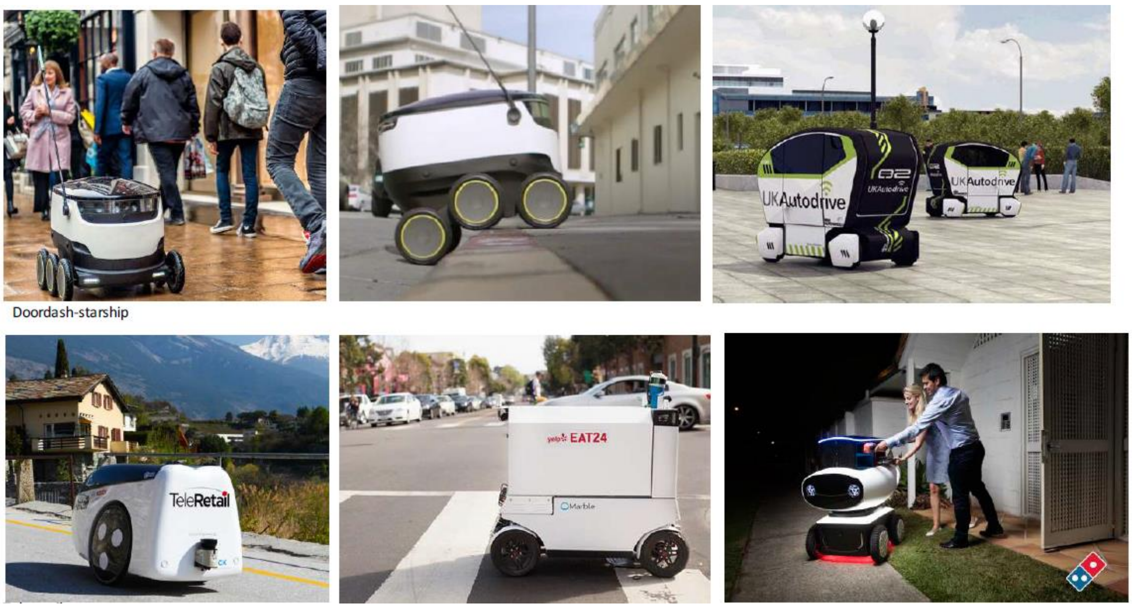


Figure 5.12 Examples of Autonomous Delivery Devices

6 Cost Estimation Models

6.1 Introduction

In this section cost model used will be defined. The followed methodology is based mainly on Estrada and Roca-Riu (2017). Cost functions are issued from Daganzo's Continuous Approximation method. Traditional operations research models often require a large amount of data that is not often available. CA method addresses the numerical solution of the problem by replacing variables values by its average values. We will solve the routing model by ignoring the exact locations of retailers to be visited and using instead a density of demand over the zone of interest.

6.2 Vehicle cost data

Vehicle cost data is considered from Generalitat de Catalunya (2015). The *Observatori de Costos del transport de mercaderies per carretera a Catalunya* (Freight Road Transport Cost Observatory in Catalonia), which is updated on six-month or yearly basis. Costs are estimated by splitting them in fixed (per hour) and variable (per kilometer) and will define the costs for current carriers operation and future carriers operation. Particularities for the UCC Operator will be specified.

6.2.1 Fixed costs (cost per hour)

It is the set of costs consisting of the expenses, that starting from the hypothesis that labour regulation is obeyed and, under the conditions of a demand-volatile market and fares being not guaranteed due to a transport supply excess, they are virtually fixed for companies in the short term (on a yearly basis). These costs tend to depend more on waiting time or time used to give service rather than on the kilometers run.

6.2.1.1 Personnel

Only the personnel that drives the vehicle forms this entry. Personnel expenses are calculated, when possible, in accordance with collective agreements of road freight transport in each province. In our case, costs are calculated for the Barcelona province. These costs are calculated for 2250 working hours, loosely larger than what it is stipulated in the collective agreement. About 1.2 drivers per truck should be needed to work that amount of time. These costs include wages, extra salaries and seniority (an average value of 10 years is considered).

6.2.1.2 Financial expenses

This entry comprises the interests paid for the acquisition of new vehicles. It should not be considered when a company is purchasing them with its own resources. Given that the market share of self-employed drivers is significant and that companies actually employ these drivers in order to palliate and reduce the capacity of their fleets, this entry will be included in all vehicles for the current scenario. To calculate the financial expenses, the formula of the compound interest with French system of fixed installments:

$$Interests = V\left[n\frac{r(1+r)^n}{(1+r)^n-1}-1\right]$$

V: Total value of the vehicle

n: Loan amortization period (taken as 5 years)

r: Long-term interest rate

Finally, interests are distributed over the period that the vehicle is being used:

$$Financial\ costs = \frac{Interests}{Useful\ live}$$

UCC vehicles will be paid monthly in eight years for viability reasons, at an annual 9% interest rate.

6.2.1.3 Insurance

Insurances considered are third party, given that the most part of sector works with this kind of insurances. Compulsory insurance, civil responsibility, damages and compensation, and shipments insurance are considered.

6.2.1.4 Overhead costs

All costs not directly imputable to the operation of the vehicle are included in this entry:

- Organization: fleet management cost and transport plans elaboration.
- Administration: accounting, non-drivers employees, paperwork, etc.
- Commercial: marketing, trademark image, creation and launching of new products.
- Information to customers, tracking, etc.

Tax burden such as taxes over mechanic vehicles, vehicle inspection test, tax over economic activities (IAE) and driver cards are also included.

6.2.1.5 Allowance

Allowances are often calculated in function of annual average kilometers and standard trips characteristics during the yearly operating period (about 250 days). Given that the frame of this project is urban freight transport, local or regional allowance is used.

6.2.2 Variable costs (costs per kilometer)

6.2.2.1 Fuel

It comprises the expenses related to consummation of fuel. To calculate this cost, the price without taxes was considered, in addition to discounts of 2% when fuel is bought on fuel pump and 5% if it is bought on depot. The estimation of average cost per type of vehicle was done by considering: the average fuel consumption, the six-month average of fuel price and the average number of kilometers run per year and per type of vehicle.

6.2.2.2 Tires

For the determination of the tire cost, tire characteristics, their average price and average yearly kilometers run were taken into consideration.

6.2.2.3 Maintenance and repairs

It comprises the cost of small repairs done in vehicle repair shops or our repair shop, labor, materials and derived expenses from common repairs as well as accidental repairs. Given the impossibility of splitting both concepts, a constant quantity along the useful life of the vehicle was inferred.

6.2.3 Unit cost values per vehicle

Table 6.1 shows the values used for the economic evaluation of the project, considering all the stated in the last two sections. The average cost for current carriers is issued from a weighted average of the vehicles found in the area.

	Van. Capacity C=9m3. Internal combustion engine *a			Small Van. Capacity C=2m3. Internal combustion engine *b			Electric Cargo bike. Capacity C=1.2m3. Electric engine assisted *c			ADD Electric Van. Capacity C=1.2m3 *d		
Temporal-based cost	**Euros**	**Euros/ h**	**%**	**Euros**	**Euros/ h**	**%**	**Euros**	**Euros/ h**	**%**	**Euros**	**Euros/ h**	**%**
Driver salary	44288	19.68	66.96	42,222	18.77	68.9%	27,768	14.28	91.5%	0	0.00	0.00
Depreciation	2811	1.25	4.25	1,951	0.87	3.2%	1,500	0.772	4.9%	**5,853**	**0.87**	**47.21**
Financial costs	328	0.15	0.50	228	0.10	0.4%			0.0%	228	0.10	1.84
Insurance	1972	0.88	2.98	2,070	0.92	3.4%			0.0%	2,070	0.92	16.70
Company overhead	2328	1.03	3.52	2,170	0.96	3.5%	950	0.49	3.1%	2,170	0.96	17.50
Meals	5076	2.26	7.67	5,076	2.26	8.3%			0.0%	0	0.00	0.00
Temporal-based cost	**56,803**	**25.25**	**85.88**	**53,717**	**23.87**	87.7%	**30,218**	**15.54**	**99.6%**	**10,321**	**2.85**	**83.25**
Distance-based cost	**Euros**	**Euros/ km**	**%**	**Euros**	**Euros/ km**	**%**	**Euros**	**Euros/ km**	**%**	**Euros**	**Euros/ km**	**%**
Fuel /Electricity	5336	0.152	8.07	4,395	0.13	7.2%	60	0.01	0.2%	277	0.014	2.24
Wheels	267	0.008	0.40	212	0.01	0.3%	0	0.00	0.0%	120	0.006	0.97
Maintenance	3736	0.107	5.65	2,953	0.08	4.8%	74	0.01	0.2%	1,680	0.084	13.55
Tolls	0	0.00	0.00	0	0.00	0.0%			0.0%	0	0.000	0.00
Distance-based cost	**9,339**	**0.267**	**14.12**	**7,560**	**0.22**	**0.12**	**134**	**0.015**	**0.4%**	**2,077**	**0.104**	**16.75**
Total annual cost	**66,142**		**100,0**	**61,277**		**100,0**	**30,352**		**100,0**	**12,398**		**100,0**

*a. It is considered that this vehicle works 2250 hours in a year and runs 35000km per year. The average fuel consumption is 17 liters/100km

*b. It is considered that this vehicle works 2250 hours in a year and runs 35000km per year. The average fuel consumption is 13 liters/100km

*c. This vehicle has been considered to present a purchasing cost of 7500 EUROS, to be depreciated along a lifetime of 5 years. It is considered that this vehicle works 243 days per year, 8 hours. It runs 9000km per year.

*d. This vehicle has been considered to present a depreciation price three times higher than a small van. It is considered that this vehicle works 2250 hours in a year and runs 20000km per year. To be conservative, we assume that the electric consumption is 0.165 KWh/km (equivalent to a passenger car). The estimation of the electricity price in Spain is p= 0.084 Euros/KWh for 2017

Table 6.1 Vehicle unit cost and main characteristics

Overhead and financial costs are not considered for the electric cargobike since they are owned by the CF operator.

The results of the table are shown in the following image:

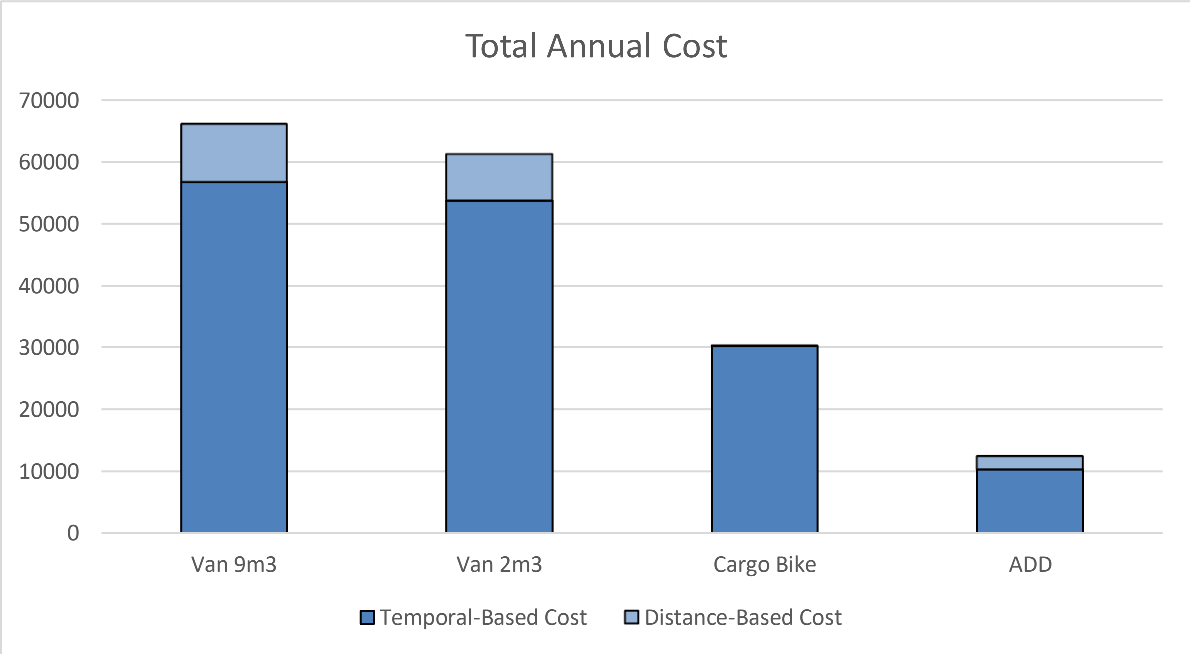


Figure 6.1 Total Annual Cost per type of vehicle

As can be seen, the temporal-based costs are reduced a lot from vans to cargo bikes and especially for the ADD case. The cost related with distance, which includes the use of fuel, maintenance and everything related with the proper operation of the vehicle, is close to zero for the case of cargo bikes, which needs a low value for maintenance and no fuel, while the values for the vans are so much higher. For ADDs, this cost is reduced with the data we have, but is a value that can be changed along the time while the new features and innovations in this type of vehicles will be implemented.

6.3 Terminal costs

6.3.1 Introduction and in-terminal zones

A Consolidation Facility or Urban Consolidation Center is basically a urban depot located in or close to the delivery zone. Its function is to receive, ungroup, stock freight and prepare the orders and group those orders for specific customers. Its size has to be proportional to the flow of commodities to be treated, but it also needs additional spaces to make operations possible such as loading and unloading docks, offices and special chambers to properly stock certain types of commodity.

Given the lack of information about the three potential layouts (markets, green points or devoted facilities) and starting from the hypothesis that there is no limit of space available for the UCC, only one calculation about the operating surface needed will be done. The different zones that a UCC must have are:

Loading docks

A loading dock or Loading/Unloading area is a recessed bay in a building or a platform in a facility where trucks are loaded and unloaded. Loading docks may be exterior, flush with the building envelope, or fully enclosed. They are part of the UCC's service or utility infrastructure, typically providing direct access to staging areas, storage rooms, and freight elevators. They may account for 25-30 percent of the final surface.

Warehouses that handle palletized freight use a dock leveler, so items can be easily loaded and unloaded using power moving equipment (e.g. a forklift). When a truck backs into such a loading dock, the bumpers on the loading dock and the bumpers on the trailer come into contact and create a gap; also, the warehouse floor and the trailer deck may not be horizontally aligned. A dock leveler bridges the gap between a truck and a warehouse to accommodate a forklift. Where it is not practical to install permanent concrete loading docks, or for temporary situations, then it is common to use a mobile version of the loading dock often called a yard ramp.

Despite loading docks may take different layouts, the most common option is the one where trucks load and unload from the back and perpendicularly to the facility. The dimensioning variables are the maximum number of trucks that may operate in peak hours, the length and width of the vehicles and the height of the dock. In our case, two different kinds of vehicles may arrive to the platform: light and medium trucks, which may use elevated docks and vans which may be loaded and unloaded through procedures at ground level.

Operating surface

The operating surface may be organized differently in function of the layout of the building/facility and the disposition of the streets and docks. In general terms, subzones may be assigned according to the particular operations. Incoming freight must be firstly identified check, prior to its ungrouping and order consolidation. Then, freight is brought to the order grouping area. In our case this will follow a cross-docking scheme, and commodities will be stacked at the ground level over palettes or containers to be loaded easily.

Corridors

Corridors that may be used by both workers and mobile equipment should have enough width to let them pass with safety. In case only one forklift passes at a time, the corridor should measure at least the forklift width plus one meter. If two forklifts are going to pass, the width must be at least one meter and forty centimeters plus the width of the two machines.

Offices

Two different offices should be considered: one of the administrative services and a second for the overhead management. Both rooms must be placed close together. The estimated surface for each one should be about 10-15 square meters for the administration and between 15 and 20 sq. meters for the management, given that meetings may take place.

Services

This will include toilets, shower and a locker room.

6.3.2 Surface calculation

The first surface to be calculated is the stock surface. To proceed, we will consider the number of the retailers present in each district, including personal apparel (clothes), leisure, public and private service offices and others. We excluded from the analysis restaurants, food industry, supermarkets, public works and building construction industry, and automotive repair services (row #2 in Table 6.2). From a recent study from BCNecologia (2016), we consider the number of weekly operations of each type of receivers: 11 op/week in personal purchases, 18 op/week in leisure, 8 op/week public and private service, and 8 del/week in others receivers. From these ratios, the number of logistic operations in each District has been evaluated in a week time horizon (row #2 of Table 6.2.). These figures summarize the total number of deliveries made by the conventional carrier fleets in a weekly basis. From this data, we have calculated the corresponding number of parcels to be distributed in a daily basis by the 10 most important for-hire carriers in the area. To do so, we have considered that the service is only provided 6 days per week and these 10 carriers represent the 70% of the total shipments in each district. The rest 30% will be made by autonomous drivers, that will be initially out of the scope of the analysis. Finally, the number of parcels per day and their corresponding volumes are presented in rows #4 and #5 of Table 6.2 respectively, considering an average volume of 0.1 m3/parcel. Row#6 accounts for the fleet size needed to carry these parcels from distribution centers to each district by conventional carriers, whose capacity is $C=9m^3$.

	Ciutat Vella	Eixam-ple	Sants-Montjuïc	Les Corts	Sarrià-Sant Gervasi	Gràcia	Horta - Guinardó	Nou Barris	Sant Andreu	Sant Martí
Area of service (km2)	3.43	6.93	18.34	4.88	10.06	3.56	6.36	5.18	5.62	8.53
Retail shops and departments (shops)	5369	9854	5935	2615	5592	5528	5009	4869	4483	7131
Logistic operations per week in each District (op/week)	50634	91956	51486	23056	49431	49114	42703	41789	39056	62158
Receivers to be visited per day in each District (op/day)	5907.3	10728.2	6006.7	2689.9	5767.0	5730.0	4982.0	4875.4	4556.5	7251.8
Freight moved in each District (m3/day)	590.7	1072.8	600.7	269.0	576.7	573.0	498.2	487.5	455.7	725.2
Conventional vans needed to access the district per day (veh/day)	100	120	90	32	76	76	64	64	64	100

Table 6.2 Freight activity inputs

At this point, we would conceptualize a Consolidation facility Design to be able to serve 3000 parcels per day. It is equivalent to assume that the UCC will be able to manage 300 m3/day. This volume is converted into surface with the use of a pallet unit. A pallet-like surface per order is considered as enough to group orders to be delivered. Freight is not going to be stocked, that is to say, all the commodities that arrive at the UCC are going to be delivered the same day. Despite of that, the terminal will be sized with a bigger surface. Assuming an average volume per pallet of 1.3 m3/pallet, the demand consisting of 3000 parcels has been considered that gives a surface of about 230 m^2. This area is reduced a 25% to assume that only the 75% of the pallets to be distributed among the whole day will be at the same time in the UCC, given a final cross docking area of 170 m2.

The internal organization of the consolidation facility is mainly composed of two cross-docking areas, each one of surface equal to the calculated above. Incoming shipments are received and left on designated palette square areas and in the second, outcoming shipments and specific truck loads are created according to the demanded orders. In addition to this, a small stocking area accounting 20%

of the cross-docking surface is set up to stock shipments that do not need to be sent the same day. Corridors account for about 25% of the cross-docking surface. The total surface of the terminal is estimated in Table 6.3.

Zone	m²
Cross-docking	340
Stock	68
Corridors	85
Office	35
Services	15
Total surface	543

Table 6.3 Final surfaces of the terminal

To represent these surfaces in a percentual way, the following figure illustrates the division of the total surface for each logistic facility. Is obvious that the cross docking represents more than the 60% of the space of the terminal, while it is the area where all the products are stored, and shipments are distributed to optimize the best route.

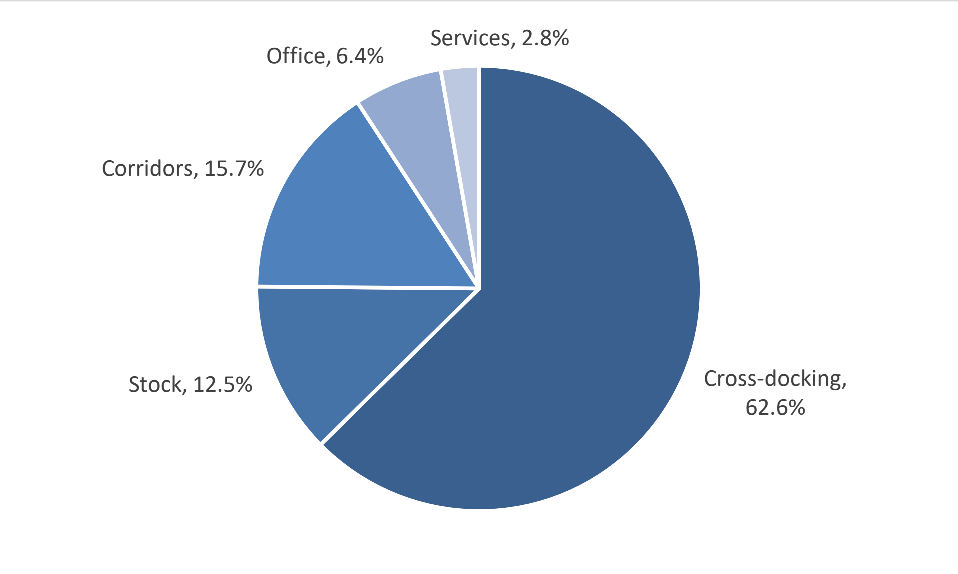


Figure 6.2 Surfaces of the terminal

It is important to remark that, as can be seen in the following figure, which represents the graphics of the freight activity inputs, in general, the percentages between the different variables are similar in each of the data, except for the percentage value of the surface area occupied by each district of the city. This is due to the great difference in the number of spaces and their use within Barcelona. L'Eixample, for example, is a very densely populated neighborhood with a high percentage of commerce and the daily transfer of freight, while Sarrià - Sant Gervasi or Sants - Montjuïc have a lot of green space, which in terms of surface area is counted but where there are practically no inhabitants and much less commerce.

For the reason commented in the previous paragraph, Sants-Montjuïc represents the 25% of the surface of Barcelona, but it represents only the 10% of retail shops, of logistic operations per week or the 11% of vans needed per day. On the other hand, the districts of Ciutat Vella or Gràcia represents only the 5% of the surface of Barcelona each, but both represents around the 10% of the other inputs related with the fright distribution logistics in the city.

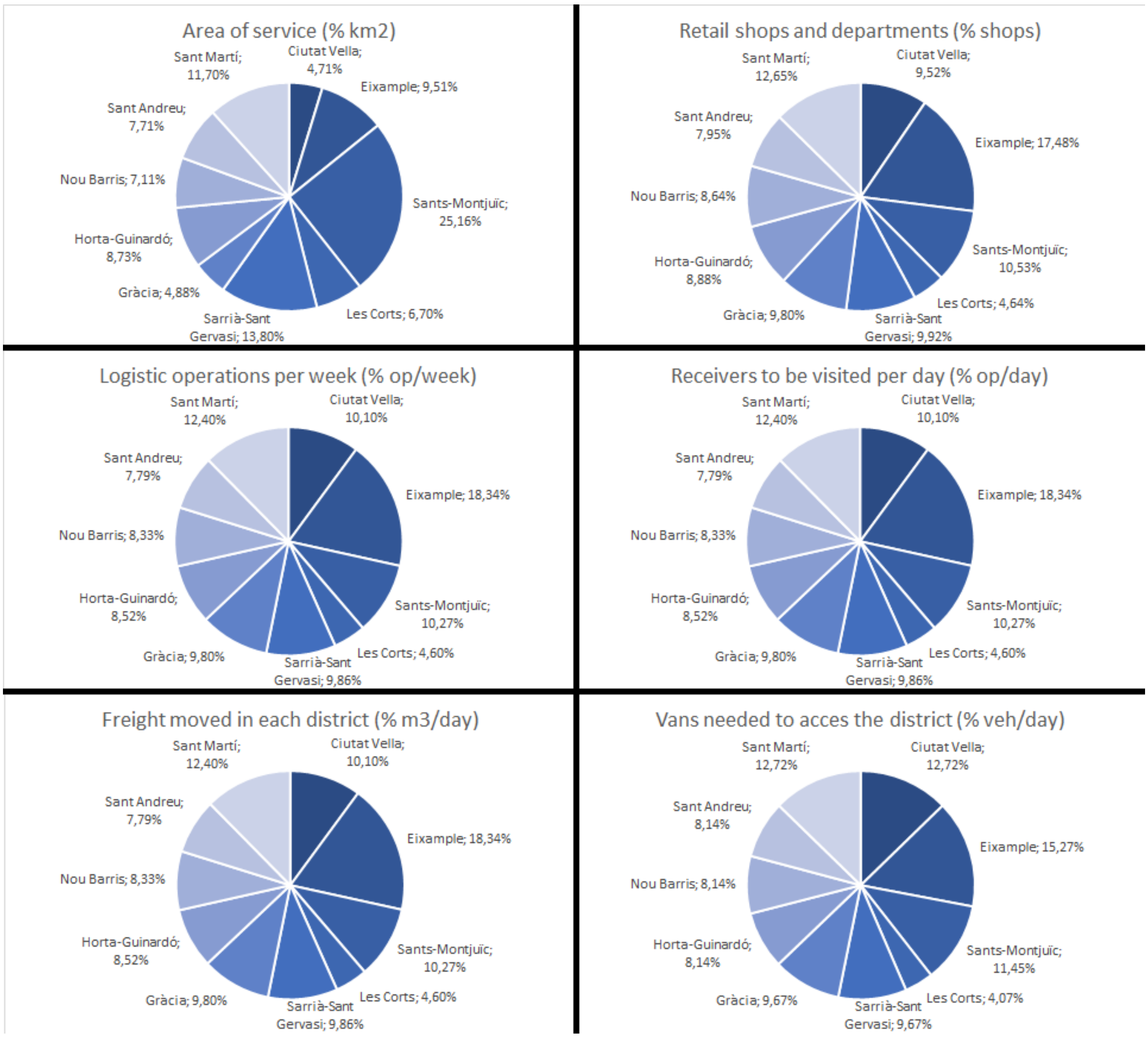


Figure 6.3 Freight activity inputs per district

6.3.3 Fixed terminal costs

Terminal costs are calculated based on the resources needed in a pilot test held in Psg. Lluís Companys, Barcelona during the year 2013-15. The UCC was in fact a micro-depot, that consisted of three adapted containers for offices, services and stocking area. The cross-docking operations were performed in the exterior area, protected by one shelter from the weather. The renting cost of the containers, the depreciation cost of the shelter (55,000 euros) the water, electricity and wi-fi services, as well as the wage of one person responsible for receiving the parcels represented a total cost of 6878 Euros per month (see Navarro et al, 2016). This cost was calculated assuming that the Municipality allocated the public space for free.

Entry	Coefficient[1]
Monthly investment	6878 EUR/month
Facility cost, Ω	275.12 EUR/day

Table 6.4 Terminal costs

As it was justified in Section 4, the deployment of a UCC network can be performed taking advantage from the current location of green waste material points scattered over the region.

6.4 Externalities

6.4.1 Air pollution

Air pollution costs will be based only on costs related to the negative effects caused by NO_X emissions and PM on the human health. The corresponding emission factors are calculated from EEA (2019), supposing that:

- The fleet typology of conventional carriers in Strategy A corresponds to Light Commercial Vehicles Diesel N1-II Euro 6 a/b/c DPF (<3.5 Tonnes). These vehicles cruise at an average speed of v=15 km/h when delivering within the city. When the vehicle is using major arterials, roadways and urban highways connecting the city and the distribution centers, the fleet will travel at an average speed of v= 55km/h.
- In strategy B, the fleet typology of conventional carriers to move the freight from Distribution centers to the UCC is the same as before (Commercial Vehicles Diesel Light Commercial Vehicles Diesel N1-II Euro 6 a/b/c DPF, <3.5 Tonnes), travelling at v= 55 km/h.
- The fleet typology of the CF manager, under Strategy B, Scenario A, to move the freight UCC to final receivers corresponds to Diesel Large-SUV-Executive car, Euro 6 a/b/c, DPF. These vehicles travel at speed v= 15 km/h.
- The fleet typology of the CF manager, under Strategy B, Scenario B or C, to move the freight UCC to final receivers corresponds to e-cargobikes (electric-assisted vehicles) or Autonomous Delivery Devices (electric vehicles). Therefore, we do not consider exhaust emissions of these vehicles. The PM emissions derived from the brakes or the friction between wheel tires and pavement is not addressed in this study.

The emission factor corresponding to these pollutants, as well as, the monetary values recommended by CE Delft (2018) in Spain are given in Table 6.5.

[1] Values adapated from DUGAM project (Distribució Urbana de Mercaderies en Àrees Metropolitanes)

Entry	Cruising Speed	**NOx Emission factor** (g NOx/veh-km)	**NOx Monetary value** (EUR/kg of NOx)	**PM Emission factor** (g PM/veh-km)	**PM Monetary value** (EUR/kg of PM)	**Aggregated pollutant Proxy** (EUR/veh-km)
Large-SUV-Executive Euro 6 a/b/c, DPF	15	0.8700	14.8	0.0032	354	0.014001
Light Commercial Vehicles Diesel N1-II Euro 6 a/b/c	15	0.2793	14.8	0.00217	354	0.0049
Light Commercial Vehicles Diesel N1-II Euro 6 a/b/c	55	0.2202	14.8	0.00104	354	0.003626

Table 6.5 **Pollutant emission and cost**

6.4.2 Environment – Climate Change

Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. Carbon dioxide is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle--both by adding more CO_2 to the atmosphere and by influencing the ability of natural sinks, like forests, to remove CO_2 from the atmosphere. While CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution.

Road transport contributes about one-fifth of the EU's total emissions of carbon dioxide (CO_2), the main greenhouse gas. CO_2emissions are in fact equivalent CO_2emissions composed by all other gases besides CO2 that expelled to the atmosphere foster the greenhouse effect. These additional gases are N_2O and CH_4, the impact of the first one is 298 times larger than CO_2's while the second it is 25 times larger. Despite the magnitude of these conversion factors, the quantity emitted is very small. Therefore, only a small part of the final equivalent CO_2 emissions is composed by these gases.

The value of CC improvement per ton of CO_2 saved is issued from the CE DELFT 2018 study (148 € /Tm CO_2 and 3700 EUR/Tm CH4). This is one way of monetizing the impact of CO_2 in the environment. In a parallel scenario, climate change externalities would be also assessed through the use of the CO_2 stock market price, that is in the region of 8€/Tm CO_2.

The emission factor corresponding to these pollutants, as well as, the monetary values recommended by CE Delft (2018) in Spain are given in Table 6.5.

Entry	Cruising Speed	CO2 Emission factor (g CO2/veh-km)	CO2 Monetary value (EUR/kg of CO2)	CH4 Emission factor (g CH4/veh-km)	CH4 Monetary value (EUR/kg of CH4)	Aggregated pollutant Proxy (EUR/veh-km)
Large-SUV-Executive Euro 6 a/b/c, DPF	15	311.05	0.148	0.0000075	3.7 (GWP=25)	0.0463
Light Commercial Vehicles Diesel N1-II Euro 6 a/b/c	15	318.38	0.148	0.0000075	3.7 (GWP=25)	0.04712031
Light Commercial Vehicles Diesel N1-II Euro 6 a/b/c	55	198.49	0.148	0.0000075	3.7 (GWP=25)	0.02937718

Table 6.6 **CO2 eq emission and cost**

6.5 Taxes

Besides taxes already included in vehicle unit costs, corporate taxes will be applied to the CF operator for those years in which this agent has positive profits. Corporate taxes account for 35% of companies' gross profits. In addition to corporate tax, oil taxes for the carriers and the UCC operator are also considered. This tax accounts for 35% of the price with added value tax excluded.

6.6 Subsidies

This entry consists of a transfer of capital from the public government to the CF Operator in case of yearly operating losses. This objective is to avoid lose for this agent, that is reaching a zero profit level for that year. Subsidies will be considered in scenarios, only if the CF operator does not reach a profitable business.

6.7 Methodology for estimating the number of Consolidation facilities

The deployment of Urban Consolidation Centers or any other consolidation facility before serving the final customer implies an additional transhipment in the freight system. From now on, the freight system in the urban area will be classified into inbound routes from Distribution center to the UCC (out of the city), and the outbound routes from UCCs to the final customers. This division implies two fleet typologies to be used in each leg of the distribution and therefore, the adaptation of its characteristics to the requirements. Generally, the fleet running inbound routes presents higher vehicle capacity due to the consolidation of shipments. On the other hand, the outbound routes are operated by smaller vehicles due to the vehicle size or temporal constraints imposed by local authorities and receivers.

The following section summarizes the modelling approach used to estimate the optimal number of urban logistic facilities in a given area based on continuous approximation technique. The formulas presented are derived from a more extensive analysis presented in Daganzo (2005).

6.7.1 Route modelling in the system with transshipment

Let's assume an urban region of area A with a spatial demand density of points to be visited equal to δ (customers/km2-day). The objective of this methodological development is to find out the number of urban terminals, where freight will be loaded into vehicles operating outbound routes to visit final customers. However, the estimation of the number of terminals K will be developed by means of the service area associated at each terminal, I_i, i.e. $A = \sum_{i=1}^{K} I_i$.

6.7.1.1 Outbound routes

The vehicles assigned to outbound routes operate the final leg of the supply chain, distributing freight from UCCs to the final customer. The vehicle capacity is assumed to be v_O (kg/tour) and the cruising speed in the urban area is s_O (km/h). Every customer is supposed to demand a parcel of weight u_O $(\frac{kg}{customer})$. Due to different constraints, we assume that the vehicle can only visit $n_{s,O}$ customers. Under this situation, the total cost of the outbound routes per unit of parcel in a given day of service is defined by Equation (5.1).

$$z_O\left(\frac{EUR}{kg - day}\right) = \alpha_0 + \alpha_1\left(\frac{1}{n_{s,O}u_O}\right) + \alpha_2\left(\frac{1}{u_O}\right) \quad (5.1)$$

In the previous formula, we consider the following cost parameters:

- Parameter $\alpha_0 = c_h + c_i T$ accounts for the handling and fixed pipeline inventory cost per shipment unit. The unit handling cost is referred by c_h and will capture the extra packaging or classification work load per unit of parcel that the transhipment requires at the UCC. On the other hand, $c_i T$ is the multiplication of the holding cost per unit of parcel (c_i) and the total travel time of the tour (T). Since the time headway between two consecutive dispatchments is fixed (one shipment per day) we do not consider holding cost of the freight. The high value of the holding cost has already forced that the service will be provided each day. Therefore, we assume that this parameter is $\alpha_0 = c_h$.
- Parameter $\alpha_1 = 2r_i\left(c_d + \frac{c_t}{s_O}\right) + c_s$ accounts for the transportation cost per outbound route (or dispatchment). We assume that the urban terminal is located at the center of the service area, and therefore, the distributing vehicle must run r_i units of distance from the UCC. This distance r_i depends on the number of UCCs. Therefore, the vehicle must overcome r_i units of distance in service area I_i on average to visit the first customer. When all customers will be served, the vehicle will also run r_i. Units of distance to return back to the UCC. This distance is multiplied by the corresponding unit distance cost c_d (EUR/veh-km) to estimate the costs related to the motion (first term of parameter α_1) and the unit temporal cost of vehicles c_t(EUR/veh-h). The latter is divided by the cruising speed to prorate this cost per the total distance run in one hour of service. The second term of parameter α_1 is the unit stopping cost, and corresponds to the last visit of the UCC once the tour is completed. If we assume a UCC distribution following a diamond pattern, the expected distance to be run to access each distribution area is $E(r_i) = \frac{\sqrt{2I_i}}{6}$.
- The term $\alpha_2 = k\delta^{-1/2}\left(c_d + \frac{c_t}{s_O}\right) + c_s$ accounts for the transportation cost caused by a new customer in the tour. The parameter k is a constant that depend on the distance metric chosen and the shape of the street network, while δ is the spatial density of points to be visited by the outbound routes in the city. The distance between two consecutive customers in the area o service, $k\delta^{-1/2}$, is then multiplied by the total cost of vehicles per unit of distance. Again, we include the stopping cost associated to the visit at each customer location.

The total number of customers that can be visited within the same tour, $n_{s,O}$, is constrained by physical and temporal constraints. If we assume that each customer demands u_i units of products every day, an average waiting time per stop or customer τ_i and a maximal delivery time in the city H_{max}, the number of customers is given by Equation (5.2).

$$n_{s,O} = \min\left\{\frac{v_o}{u_i}; \frac{H_{max}}{\frac{k\delta^{-1/2}}{s} + \tau_i}\right\} \tag{5.2}$$

When the temporal constraint is not tight, the temporal length of the tour is lower than H_{max} and vehicles must depart from UCCs at the maximal capacity. Under these circumstances, the shipment size, that is, the total amount of freight carried by the vehicle within the tour is $v_O = v_{O,max}$. Therefore, vehicles must depart from UCCs full. When the temporal constraint is tight, vehicles must return back to the UCC, even if they have parcels on the truck to be distributed. In that case $v_O < v_{O,max}$ so that, the shipment size is defined by the total number of deliveries that it can perform within H_{max}. Indeed, the denominator of the second term, $\frac{k\delta^{-1/2}}{s} + \tau_i$ is the required time between two consecutive deliveries.

Therefore, the unit transport cost of outbound routes (Equation 5.1) can be reformulated by Equation (5.3).

$$z_O = \begin{cases} c_h + \left(\dfrac{\frac{\sqrt{2I_i}}{3}(c_d + c_t/s) + c_s}{v_{o,max}}\right) + \left(\dfrac{k\delta^{-1/2}(c_d + c_t/s) + c_s}{u_i}\right) & if\ v_O = v_{O,max} \\ c_h + \left(\dfrac{\frac{\sqrt{2I_i}}{3}(c_d + c_t/s) + c_s}{\frac{u_i H_{max}}{\frac{k\delta^{-1/2}}{s}+\tau_i}}\right) + \left(\dfrac{k\delta^{-1/2}(c_d' + c_t'/s) + c_s'}{u_i}\right) & if\ v_O = \dfrac{u_i H_{max}}{\frac{k\delta^{-1/2}}{s} + \tau_i} < v_{O,max} \end{cases} \tag{5.3}$$

6.7.1.2 Inbound routes.

The inbound routes will be operated by vehicles of capacity $v_{max,I}$. Due to the small number of UCC, we should consider that the route of vehicles will be always constrained by the physical capacity (amount of freight to be delivered) and not by the temporal constraints. These vehicles depart from the distribution center and visit as many Urban Consolidation Centers as they can in the urban area, before returning back to the distribution center. In a single tour, the vehicle can only visit $n_{s,I}$ customers. The total cost of the inbound routes per unit of parcel in a given day of service is defined by Equation (5.4).

$$z_I\left(\frac{EUR}{kg - day}\right) = \alpha_0' + \alpha_1'\left(\frac{1}{n_{s,I}u_{max,I}}\right) + \alpha_2'\left(\frac{1}{u_{max,I}}\right) \tag{5.4}$$

In the previous formula, we consider the following cost parameters:

- Parameter $\alpha_0' = c_h'$ accounts for the handling per shipment unit. The unit handling cost is referred by c_h and will capture the extra packaging or classification work load per unit of parcel that the transhipment requires at the distribution center. Again, we do not consider unit inventory cost, since the headways between shipments are given and vehicles can depart at full capacity from the distribution center.
- Parameter $\alpha_{1'} = 2\rho\left(c_d' + \frac{c_t'}{s_I}\right) + c_s'$ accounts for the transportation cost per inbound route (or dispatchment). We assume that the urban terminal is located ρ units of distance far from

the distribution center. Therefore, the vehicle must overcome 2ρ units of distance just to access to and egress from the service area $I_i$to complete the tour. The former is multiplied by the corresponding unit distance cost $c_d{}'$ and temporal cost c_t' to estimate the costs related to the motion (first term of parameter α_1). The temporal cost has been prorated by the vehicle pace (inverse of the cruising speed). The second term of parameter $\alpha_1{}'$ is the unit stopping cost, and corresponds to the last visit of the distribution center when the tour is completed.

- The term $\alpha_2{}' = k\delta_T{}^{-\frac{1}{2}}\left(c_d{}' + \frac{c_t{}'}{s_O}\right) + c_s{}'$ accounts for the transportation cost caused by a new terminal in the tour. The parameter *k* is a constant that depend on the distance metric chosen and the shape of the street network, while δ_T is the spatial density of terminals in the city. This variable can be approximated by the root square of the inverse of the area served by the terminal i, i.e. $\delta_{T,i} = \frac{1}{I_i}$.

Hence, Equation (5.4) can be revisited to finally formulate the unit cost of inbound routes per unit of freight by Equation (2).

$$z_I\left(\frac{EUR}{kg - day}\right) = c_h{}' + \left(\frac{2\rho(c_d{}' + c_t{}'/s) + c_s{}'}{v_{max,I}}\right) + \left(\frac{kI_i{}^{1/2}(c_d{}' + c_t{}'/s) + c_s{}'}{\lambda_i I_i}\right) \qquad (5.5)$$

6.7.1.3 Terminal cost

Finally, we can consider an additional term that accounts for the terminal cost, that is, the facility cost that the logistic operator will incur when deploying the UCCs in the city. This cost is captured in Equation (5.6), where c_r^t(EUR/kg-day) is the rent cost of the UCC per unit of parcel, and $\Omega\left(\frac{EUR}{day}\right)$ a fixed facility cost. The second term of Equation (5.6) is prorated by all items served by a UCC, i.e. the total demand density rate ($u_i\delta_i$, items per unit of area and time) times the service area of the UCC.

$$z_T\left(\frac{EUR}{kg - day}\right) = c_r^t + \left(\frac{\Omega}{u_i\delta_i I_i}\right) \qquad (5.6)$$

6.7.2 Optimization

Therefore, the total logistic cost of distribution with transhipment at UCCs is finally given by Equation (5.7), as the sum of inbound, terminal and outbound costs.

$$z\left(\frac{EUR}{kg-day}\right) = z_I\left(\frac{EUR}{kg-day}\right) + z_T\left(\frac{EUR}{kg-day}\right) + z_O\left(\frac{EUR}{kg-day}\right) =$$

$$= c_h{}' + \left(\frac{2\rho(c_d{}' + c_t{}'/s) + c_s{}'}{v_{max,I}}\right) + \left(\frac{kI_i{}^{1/2}(c_d{}' + c_t{}'/s) + c_s{}'}{\lambda_i I_i}\right) + c_r^t + \left(\frac{\Omega}{\lambda_i I_i}\right) + c_h$$

$$+ \begin{cases} \left(\frac{\frac{\sqrt{2I_i}}{3}(c_d + c_t/s) + c_s}{v_{o,max}}\right) + \left(\frac{k\delta^{-1/2}(c_d + c_t/s) + c_s}{u_i}\right) & if\ v_O = v_{O,max} \\ \left(\frac{\frac{\sqrt{2I_i}}{3}(c_d + c_t/s) + c_s}{\frac{u_i H_{max}}{\frac{k\delta^{-1/2}}{s} + \tau_i}}\right) + \left(\frac{k\delta^{-1/2}(c_d{}' + c_t{}'/s) + c_s{}'}{u_i}\right) & if\ v_O = \frac{u_i H_{max}}{\frac{k\delta^{-1/2}}{s} + \tau_i} < v_{O,max} \end{cases} \qquad (5.7)$$

The total cost of distribution per item is convex, so that we can identify the minimal number of urban consolidation facilities that minimize the expression in the domain of analysis. Taking derivatives with regard to I_i, we can obtain the optimal area of service of each UCC and therefore, the estimation of how many UCCs facilities would be needed to cover the region of area A. This can be done easily by the estimation of the value of Equation (5.7) in different parts of the city. This is only valid if we assume that all terms of this equation are only dependent to the city attributes evaluated at each service area associated to UCCi. In this sense, this statement is true if the all UCC will present the same capital cost to be constructed, not depending on the total flow captured through each facility. Equation (5.8) provides the optimal value of the area of service of terminal i ($I_i *$) depending on the kind of the dominant constraint. The optimal value must be calculated numerically, calculating the root of these arrays.

$$\frac{dz}{dI_i} = 0 \Rightarrow \frac{k\frac{\sqrt{2}}{6}(c_d + c_t/s)}{v_{o,max}} I_i *^{3/2} - \left(\frac{k(c_d{}' + c_t{}'/s)}{2\lambda_i} I_i *^{1/2}\right) - \left(\frac{c_s{}'}{\lambda_i} + \frac{c_r^o}{\lambda_i}\right) = 0 \;\; if \; v_o = v_{o,max}$$

$$\frac{dz}{dI_i} = 0 \Rightarrow \frac{k\frac{\sqrt{2}}{6}(c_d + c_t/s)}{\frac{u_i H_{max}}{\frac{k\delta^{-1/2}}{s} + \tau_i}} I_i *^{3/2} - \left(\frac{k(c_d{}' + c_t{}'/s)}{2\lambda_i} I_i *^{1/2}\right) - \left(\frac{c_s{}'}{\lambda_i} + \frac{c_r^o}{\lambda_i}\right) = 0 \;\; if \; v_o = \frac{u_i H_{max}}{\frac{k\delta^{-1/2}}{s} + \tau_i} < v_{o,max} \qquad (5.8)$$

6.8 Methodology for estimating the Cost incurred by each agent

In this section, the cost variation due to the consolidation facilities is estimated. Formulas are developed to assess the temporal and distance costs difference between regular distribution and the distribution through a Urban Consolidation Center (UCC).

6.8.1 Assumptions

In the following text, formulas accounting for the operational cost of *M* carriers are now used to compare two alternative logistic Strategies: (*A*) independent carriers performing last-mile delivery in a regular distribution, and (*B*) a last-mile delivery system with collaboration among carriers and freight consolidation through a Consolidation Facility (*UCC* or *uSA*).

We consider that *M* carriers have to visit *N* receivers located in a compact zone of a city of area *I,* corresponding to the service area of one Consolidation Facility. This area I has been calculated by means of the methodology presented in Section 5.7. Receivers are uniformly distributed within the area *I.* The vehicles depart from a depot located at distance ρ from the center of the service area. Let δ be the spatial density of receivers in the area of study *I*. We assume that receivers are uniformly distributed over the region of service, so that $\delta = N/I$ is considered constant in all area of service. We assume that the average parcel volume to be served in regular distribution is *y*. The carriers will use a homogeneous fleet of volume capacity *C*. The vehicle capacity *C* is defined as the total volume of parcels that one vehicle can carry whereas *C/y* is the expected maximal number of receivers that one tour is able to visit. Vehicle tours are designed within the time horizon *H.* It captures the available time period in which receivers admit the deliveries during the day. We will refer as line-haul distance to the distance from the distribution center to the central point of the urban distribution area. On the other side, local distance is the distance covered during the delivery of parcels within the cluster of receivers. Given the density of streets in urban areas and for the simplicity of the evaluations, we use the L_1 metric to determine distances in the service area.

We assume that each carrier *i=1,..,M* gives service to a subset of N_i customers, with $N = \sum_{i=1,..,M} N_i$. Indeed, the variable $\phi_i = N_i/N$ denotes the market share of each carrier *i* (*i*=1,..,*M*) considering the total distribution of parcels in the area of service. The market share can be different among carriers. Therefore, the customer density of each company is denoted by $\delta_i = N_i/A$, *i = 1,..,M.* Note that δ_i is smaller than the overall demand density in the region $\delta = N/A$.

In Strategy A, the same vehicles owned by the carrier perform the long-haul and the local distribution, visiting the corresponding N_i receivers location in different routes (see Figure 6. a).

In the collaborating strategy (strategy *B*), the consolidation facility is located inside the delivering area. Moreover, we consider that carriers still use vehicles with the same capacity in the line-haul distribution (from distribution center to the urban consolidation facility, see Figure 6. b). However, the *CF* operator may use a different fleet of smaller capacity in the last mile distribution network with regard to the carrier's fleet. These vehicles will be shipped from the Consolidation Facility to visit all receiver's locations (see Figure 6. c). Indeed, we consider the capacity of those vehicles used by *CF* operator in the last mile network to be $C_{CF} = k_C C$, where $k_c \in \mathbb{R}^+$, ($k_C \leq 1$), that will fit better the vehicle size regulations of the city and the physical layout of existing streets. In several real implementations, *CF* operator chose electric vehicles or even electric cargo-bikes to perform the deliveries in the last mile network.

Strategies *A* and *B* will be compared in terms of transportation costs, the externalities caused by the distribution system to the citizens and the net benefit of the *CF* operator (only for strategy *B*). Throughout the document, the superscripts *A*, *B* and *CF* refer to the estimation of variables or parameters for independent carriers (strategy *A*), collaborating carriers through a consolidation facility (strategy *B*) and the *CF* operator respectively.

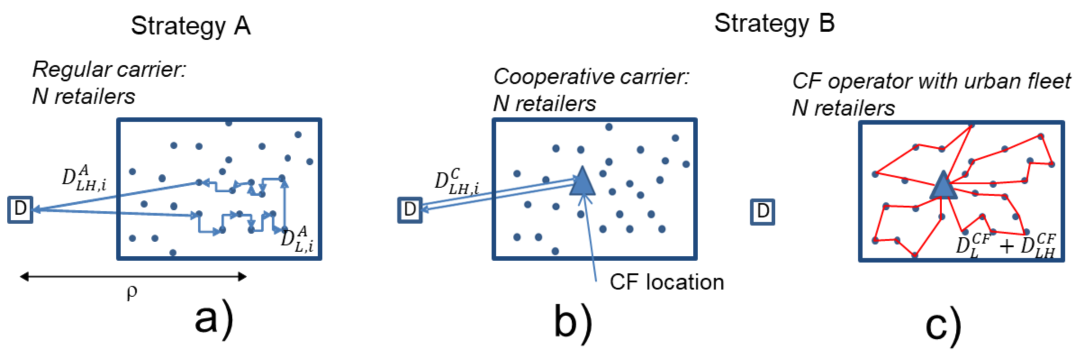


Figure 6.4 Distribution scheme in Strategy A and B

6.8.2 Strategy A

The total cost of the *M* carriers (Z_C^A) in strategy *A* is the sum of the costs of each individual carrier ($Z_{C,i}$) (see Equation 5.9). The estimation of the local and line-haul distance presented in Equations (5.10)-(5.11) depends on the relative market share of each specific carrier *i*, ϕ_i (*i=1,..M*) and the maximal number of receivers that one vehicle can serve in one tour, $\psi_i^A = min\left\{\frac{C}{y}; \frac{H-\beta/v_L}{\frac{2\delta_i^{-1/2}}{\sqrt{3}v_L}+\tau}\right\}$. Here, the time horizon *H* has been considered as the maximal time period in which regular carrier's vehicles are allowed to run within the city boundary. Note that in the estimation of local and line-haul distance, the number of tours is defined by $\left[\frac{N\phi_i}{\psi_i^A}\right]^+$, where $[x]^+$ is a mathematical operator that gives the lowest integer value greater than or equal to x. Equation (5.12)captures the total distribution time required by the fleet to complete the deliveries to every receiver. Moreover, the cost of the emissions produced by the whole freight fleet (Z_{ext}^A) is addressed in Equation (5.13). Considering *E* different types of pollutants, the cost associated to the emission of pollutant *j(j=1,..E)* is estimated as the product of the total distance covered in each part of the route (line-haul versus local) and the emission factor of pollutant *j* corresponding to the vehicle used (amount of pollutant *j /unit of distance)*, $f_j(v)$. This factor depends on the cruising speed of vehicle *v* in each part of the route. The parameter $\$_j$determines the monetary cost of the impact of an amount of pollutant *j* on the society and the environment. This approach is consistent to the methodology presented in EMEP-EEA (2019). The numerical values for the distance, temporal and emission parameters are defined in Table 6.1, Table 6.5 and Table 6.6.

$$Z_C^A = \sum_{i=1}^{M} Z_{C,i}^A = c_d\ (D_L^A + D_{LH}^A) + c_t\ T^A \tag{5.9}$$

$$D_L^A = \sum_{i=1}^{M} D_{L,i}^A = \frac{2}{\sqrt{3}}(IN)^{1/2}\sum_{i=1}^{M}\phi_i^{1/2} + \beta\sum_{i=1}^{M}\left[\frac{N\phi_i}{\psi_i^A}\right]^+ \tag{5.10}$$

$$D_{LH}^A = \sum_{i=1}^{M} D_{LH,i}^A = 2\sum_{i=1}^{M}\rho_i\left[\frac{N\phi_i}{\psi_i^A}\right]^+ \tag{5.11}$$

$$T_A = \left({D_L^A}/{v_L} + {D_{LH}^A}/{v_{LH}}\right) + \tau N \tag{5.12}$$

$$Z_{ext}^A = \sum_{i=1}^{M}\left(D_{L,i}^A\sum_{j=1}^{E} f_j\ (v_L)\$_j + D_{LH,i}^A\sum_{j=1}^{E} f_j\ (v_{LH})\$_j\right) \tag{5.13}$$

6.8.3 Strategy B

In this Strategy, we assume that all carriers are going to distribute the parcels through the Consolidation Facility. The total costs are divided into two distribution components: the costs that traditional carriers undergo to distribute goods to the consolidation strategy (Z_C^B, Equation 5.14), and the costs of the *CF* operator for last-mile distribution (Z_{CF}, see Equation 5.15). The term Z_C^B includes: the transportation cost associated to the link distribution center-*CF* covered with regular carrier vehicles (Z_{DT}^B), and the price that the carriers pay to the *CF* operator for using the *CF* (Z_θ^B). It is assumed that each carrier *i* (*i*=1,..,*M*) has to pay a fare $\theta(i)$ to the *CF* operator for each parcel to be distributed through the *CF*.

The cost analysis for the *CF* operator considers the cost concerning the distance covered, the travel time and a new term Ω that captures the investment cost to build and maintain the consolidation facility itself. The parameter Ω is expressed in monetary units per unit of service time. Since the consolidation facility is not conceived to be a storage warehouse and parcels are shipped on the same day, the inventory cost of freight is neglected. We assume that the cruising speed of the fleet used by *CF* operator is equal to v_L. In addition to that, those environmental-friendly vehicles may be exempted to obey the temporal access restriction imposed by local governments in local distribution. Therefore, the maximum distribution time horizon for *CF* operator's vehicles is supposed to be H^{CF} ($H^{CF} \geq H$). Here, we have also supposed specific unit cost $\left(c_d^{CF}, c_t^{CF}\right)$ from Table 6.1 and emissions factors $f_j^{CF}(v_{CF})$ (only for vans,Table 6.5 and Table 6.6) as fleets can be adapted to the urban environment.

$$Z_C^B = \sum_{i=1}^{M} Z_{DT,i}^B + \sum_{i=1}^{M} Z_{\theta,i}^B = \sum_{i=1}^{M} \left(c_d\ D_{LH,i}^B + c_t\ T_i^B\right) + \sum_{i=1}^{M} \theta_{CF} N_i \tag{5.14}$$

$$Z_{CF} = \left(c_d^{CF}\left(D_L^{CF} + D_{LH}^{CF}\right) + c_t^{CF} T^{CF}\right) + \Omega \tag{5.15}$$

$$Z_{ext}^B = \sum_{i=1}^{M} \left(\left(D_{LH,i}^B\right) \sum_{j=1}^{E} f_j\ \ (v_{LH}) \$_j) + \left(D_L^{CF} + D_{LH}^{CF}\right) \sum_{j=1}^{E} f_j^{CF}(v_L)\, \$_j) \right) \tag{5.16}$$

The total distance in the line-haul distribution and the total travel time incurred by all carriers visiting the consolidation facility are estimated through Equations (5.17)-(5.18). In that case, the number of receivers that one carrier's vehicle tour is able to serve is estimated by $\psi^B = \left\{\frac{C}{y}\right\}$. As vehicles do not perform local deliveries, we have only to satisfy $(H - \tau') \geq 0$. In this constraint, we only subtract the amount of transport activities spent inside the city. If this constraint is not guaranteed, there is not enough time to perform the line-haul distribution from the distribution center to the consolidation facility.

In Equation (5.18), we consider that each vehicle spends a total time τ' due to the unloading operations of all parcels to be routed through *CF*.

On the other hand, the corresponding estimations of the distance- and temporal-based variables for the vehicles of the *CF* operator are presented in Equations (5.19)-(5.20). Here, the local distance formula is affected by a detour extra distance β^{CF}.

In addition to this, the number of receivers visited in each tour is now compute by $\psi^{CF} = min\left\{\frac{k_c C}{u}; \frac{\left(H^{CF} - \tau^{CF}\right) - \beta_{CF}/v_L}{\frac{2(\delta)^{-1/2}}{\sqrt{3}v_L} + \tau'}\right\}$. We consider that the time horizon available for the local distribution performed by *CF* operator's fleet is affected by the time consumed by regular carriers in the link just between the distribution center - *CF* and the unloading operation time. This assumption allows a proper comparison of strategy *A* and *B* in the same time period *H* and it takes into account the transshipment operations at the consolidation facility.

$$D_{LH}^B = \sum_{i=1}^{M} D_{LH,i}^B = \sum_{i=1}^{M} 2(\rho_i) \left[\frac{N\phi_i}{\psi_i^B}\right]^+ \tag{5.17}$$

$$T^B = \sum_{i=1}^{M} T_i^B = \left(\frac{D_{LH}^B}{v_{LH}}\right) + \tau' \sum_{i=1}^{M} \left[\frac{N\phi_i}{\psi_i^B}\right]^+ \tag{5.18}$$

$$D_L^{CF} = \frac{2}{\sqrt{3}}(AN)^{1/2} + \beta^{CF}\left[\frac{N}{\psi^{CF}}\right]^+ \tag{5.19}$$

$$T^{CF} = \frac{D_L^{CF}}{v_L} + \tau^{CF} N \tag{5.20}$$

7 Consolidation Facility network design

7.1 Number of UCC per district and location

The optimization procedure derived in Section 5.7. has been carried out with the input parameters considered in Section 5.3 and 5.4. Figure 7.1 depicts the optimal service area in Scenario 1 (vans) in the situation when the capacity constraint of the CF operator's fleet is not considered. On the contrary, Figure 7.2 shows the results in the same Scenario when this capacity constraint is addressed.

It can be noticed that the limitation of capacity of the local distribution vehicles tends to reduce the area of service, and therefore, to increase the number of CF in the district. The tighter the constraint is, the more vehicles are requested. As expected, as we increase the density of retailers to be visited, the area of service of a single Consolidation facility is reduced. The reason is twofold:

- There are more parcels to be distributed and the vehicle capacity constraints are binding
- The facility (fixed) cost is prorated to a high number of customers in the same area. If the creation of a new facility is justified for the same number of customers, this condition is achieved for smaller areas as the demand density increases.

Moreover, Figure 7.3 and Figure 7.4 present the optimal area of a Consolidation Facility when the capacity constraint is activated in Scenario 2 and 3 respectively. The tendency in these Scenarios is similar to the corresponding in Scenario 1. Nevertheless, Scenario 2 presents the lowest values of service areas and therefore, the most restricted designs of Consolidation Facilities. Hence, we opt for calculating the number of Consolidation Facilities by the value obtained in Scenario 2.

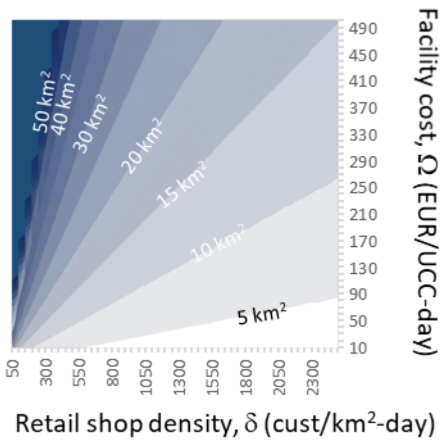


Figure 7.1 Optimal area served by each UCC as a function of retail density and facility cost. Scenario 1-Vans (no constraint)

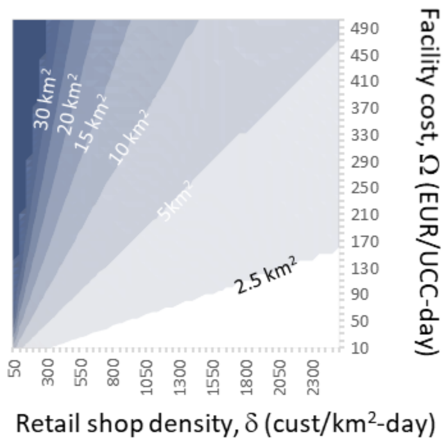


Figure 7.2 Optimal area served by each UCC as a function of retail density and facility cost. Scenario 1-Vans (Constraint)

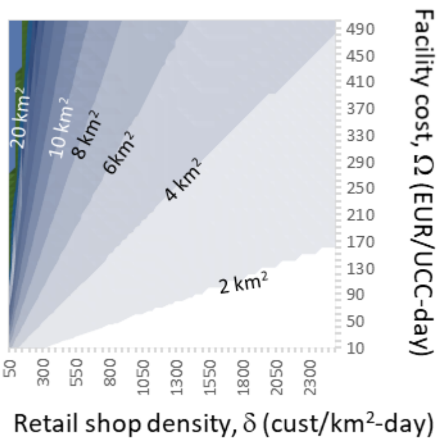


Figure 7.3 **Optimal area served by each UCC as a function of retail density and facility cost. Scenario 2-eCargobikes (no constraint)**

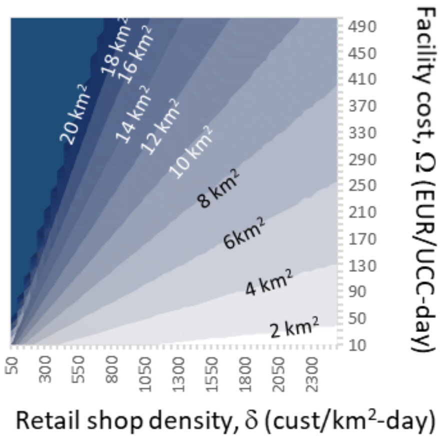


Figure 7.4 **Optimal area served by each UCC as a function of retail density and facility cost. Scenario 3-ADD (no constraint)**

Finally, using the input parameters corresponding to scenario 2 and the optimization procedure developed in 5.7, the area of service and the number of Consolidation Facilities for each district in Barcelona is presented in Table 7.1 Number of UCC. Generally, each district needs 2 Consolidation facilities, except for the case of l'Eixample and Sants-Montjuïc. In l'Eixample, the high number of retailers to be served forces the system to increase the number of facilities to 3 units. In the case of Sants-Montjuïc, the number of facilities has been also increased to 3 units, due to the huge area embraced by the district. In order to cover the most peripheral points in the district with low cruising speed vehicles (ecargobikes), we need to have more CF units in the district. Finally, Les Corts district can be served by just one Consoldiation Facility, because the premises and retail shops are highly concentrated in a given area.

	Ciutat Vella	Eixam-ple	Sants-Montjuïc	Les Corts	Sarrià-Sant Gervasi	Gràcia	Horta - Guinardó	Nou Barris	Sant Andreu	Sant Martí
District Area (km2)	3.43	6.93	18.34	4.88	10.06	3.56	6.36	5.18	5.62	8.53
Optimal area of UCC, I* (km2)	**2.80**	**3.00**	**8.46**	**5.98**	**5.82**	**2.92**	**4.73**	**4.19**	**4.62**	**4.48**
Optimal number of UCC	1.23	2.31	2.17	0.82	1.73	1.22	1.34	1.24	1.22	1.91
Optimal number of UCC (rounded)	**2**	**3**	**3**	**1**	**2**	**2**	**2**	**2**	**2**	**2**

Table 7.1 **Number of UCC**

With these results, different options have been considered to distribute the corresponding area to each of the 21 consolidation facilities for the city of Barcelona. It was considered appropriate to define the zones by districts, as shown in the table above, although in reality, the supply area may include parts of neighbouring districts, depending on the ease of access and the location of the logistics centres within each district.

As can be seen in the following figure, the distribution of UCCs per district with respect to their surface is not homogeneous. Except for Eixample, which is the densest district of Barcelona when we talk about commerce and services, the other neighbourhoods of the city have more surface in square meters than the optimal number of logistic facilities needed per district.

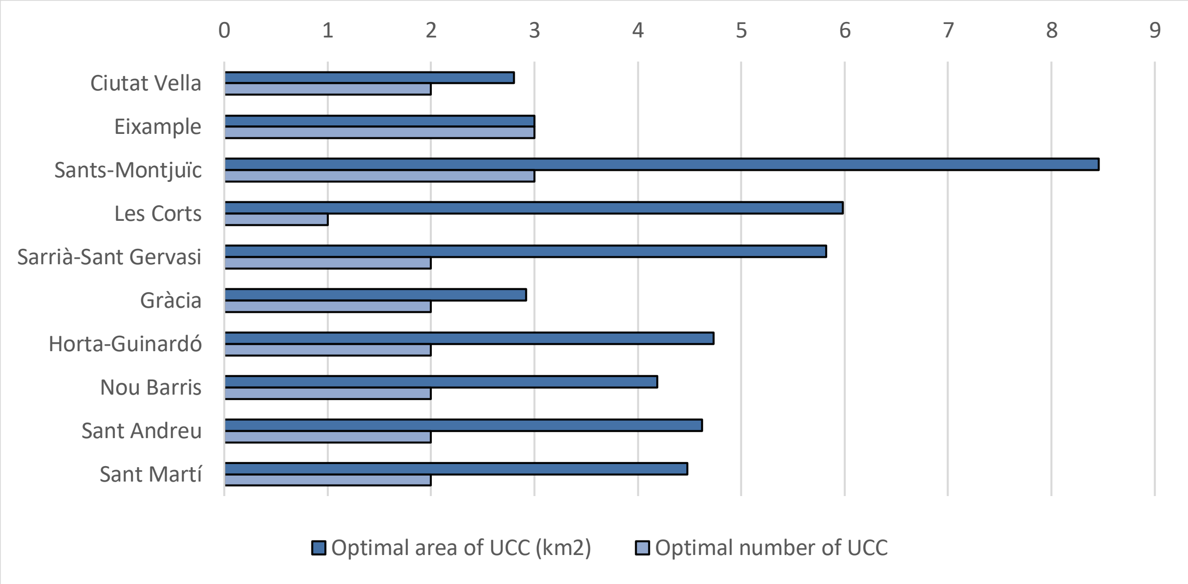
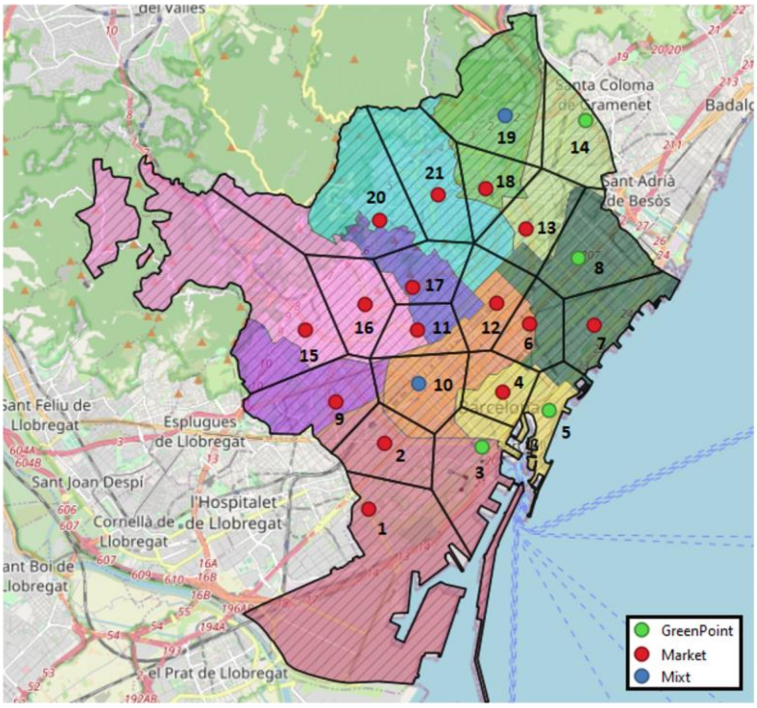


Figure 7.5 Optimal area and number of UCC

In Section 4, different options have been considered for being potential locations for freight consolidation centres, among green points and municipal markets. These public facilities are optimally distributed throughout the city, according to the density of commerce and population. In addition, they are large spaces (parks for the green points, or large squares or pedestrianised areas for many of the municipal markets) where prefabricated modules can be located as consolidation facilities, or to use a small part of the markets' warehouse as a logistics point. Last but not least, these are points with easy access for vehicles, whether vans, eCargoBikes or ADDs, as they are already set up for the arrival of freight or cleaning vehicles.

Finally, in order to present the results and represent the service surfaces of each of the consolidation facilities, it has been considered convenient to make the distribution using Voronoi polygons, considering as nodes the green points or municipal markets, distributed and chosen according to their location and characteristics.

The final location of the 21 Consolidation facilities in Barcelona is shown in Figure 7..



1. Mercat de La Marina
2. Mercat d'Hostafrancs
3. Punt Verd del Poble Sec
4. Mercat de Santa Caterina
5. Punt Verd de La Barceloneta
6. Mercat dels Encants
7. Mercat del Poblenou
8. Punt Verd de Sant Martí de Provençals
9. Mercat de Les Corts
10. Mercat/Punt Verd del Ninot
11. Mercat de l'Abaceria
12. Mercat de la Sagrada Familia
13. Mercat de Felip II
14. Punt Verd de Sant Andreu
15. Mercat de Sarrià
16. Mercat de Sant Gervasi
17. Mercat de Lesseps
18. Mercat de la Mercè
19. Mercat de Montserrat/Punt Verd Roquetas
20. Mercat de Vall d'Hebron
21. Mercat d'Horta

Figure 7.6 Location of the Consolidation Facilities

As can be seen, and as mentioned above, the polygons are not homogeneous with the shape of the districts of Barcelona, but this does not make the distribution less optimal, but on the contrary. For example, in the Eixample District we find a logistics centre located further East almost on the border with the Sant Martí district, so it would not make sense to limit its zone of influence or service area to the Eixample area, if the most optimal shape is the one presented. A similar situation also applies to the Sarrià - Sant Gervasi area and the north of Les Corts (Pedralbes neighbourhood). These two areas have similar commerce characteristics, with very low density or concentrated in small areas, as they are residential neighbourhoods, so they use the same consolidation facility. Logically, depending on the point chosen, other possible locations close to the chosen ones could be considered, as there are unforeseen events or situations that may occur in the future.

8 Cost-Benefit Analysis

8.1 Scenario results

The estimation of the impacts of the new distribution scheme on different stakeholders is undertaken in this Section. Different scenarios are analyzed to assess the final viability of the terminal under different fleet typology and the fare charged to carriers.

In all these scenarios carriers are obliged to stop at the Consolidation Facility and unload their shipments. For this reason, it is considered that 70% of the retailers (demand) will be served through the terminal by 10 logistic service providers. The other 30% of the receivers will be served by autonomous or small size carriers in a conventional fashion. To guarantee stability to this situation, neither carrier costs nor retailers' should increase.

The three different scenarios regarding the vehicle technology adopted by the CF operator are:

- Scenario 1. Vans.
- Scenario 2. Electric cargobikes
- Scenario 3. Autonomous Delivery Devices

8.1.1 Analysis of distance, routing time and cost

Table 8.1, Table 8.2 and Table 8.3 present the results obtained for Scenario 1,2 and 3 respectively. In all Scenarios, Strategy B is able to reduce the total logistic costs incurred by all agents and externalities; therefore, it is a more sustainable and efficient measure to distribute freight in urban areas. When the CF operator chooses vans to perform the last mile distribution, the total cost reduction of Strategy B ranges between 19 -26% in the Barcelona districts. Nevertheless, in Scenario 2 (ecargobikes), the potentialities of Consolidation Facilities are increased and the cost reduction reaches 36-45%. Finally, the Scenario 3 based on ADD obtains an overwhelming cost reduction of 72-78%.

The total distance run by the all vehicles (owned by carriers and CF operator) presents uneven results. There are districts in Barcelona where the total distance run by vehicles in Strategy B is around 5% larger than the corresponding value in Strategy A. Although this increment, Strategy B is more convenient in terms of cost because the routes are operated by vehicles of lower distance cost.

Finally, the reduction of the CO_2 eq monetization achieves 27-47% in the Scenario where the final distribution is operated by vans (Scenario 1). It is worth to mention that the cost of air pollutants (NO_x and PM) in Strategy B is higher than in Strategy A in all districts except for Eixample. The increment ranges between 8-25%. This tendency is not visible in Scenarios 2 and 3, where the urban fleet owned by CF operator is electric or non-motorized. In those cases, the reduction of CO_2 eq gases and local pollutants is within 35-55%.

		Ciutat Vella	Eix-ample	Sants-Mont.	Les Corts	Sarrià-Sant Gerv.	Gràcia	Horta – Guin.	Nou Barris	Sant Andreu	Sant Martí
	Number of UCC	2	3	3	1	2	2	2	2	2	2
STRATEGY A (business as usual)	Distance run by commercial fleet (km/day)	2254.9	2645.0	1591.5	1926.2	2187.3	1854.8	1595.8	1562.2	1564.2	2441.7
	Time of vehicles (hours/day)	383.8	452.9	226.8	308.1	339.0	321.9	256.7	254.5	250.4	397.0
	Transportation cost, ZT, (EUR/day)	10292.2	12142.9	6151.7	8294.3	9142.6	8624.2	6907.5	6843.1	6740.4	10677.0
	External cost, ZCo2 (EUR/day)	106.3	124.6	75.0	90.8	103.1	87.4	75.2	73.6	73.7	115.1
	External cost, ZL (EUR/day)	11.1	13.0	7.8	9.4	10.7	9.1	7.8	7.7	7.7	12.0
	Total cost, ZTOT (EUR/day)	**10409.5**	**12280.5**	**6234.5**	**8394.5**	**9256.4**	**8720.7**	**6990.5**	**6924.4**	**6821.8**	**10804.0**
STRATEGY B (through UCC)	Distance run by trucks (km/day)	2000.0	1600.0	1200.0	1280.0	1520.0	1520.0	1280.0	1280.0	1280.0	2000.0
	Time of trucks (h/day)	48.9	39.1	29.3	31.3	37.1	37.1	31.3	31.3	31.3	48.9
	Distance run by the CF fleet, (km/day)	342.6	394.5	387.1	443.5	478.2	288.6	337.8	299.9	294.5	537.1
	Time of CF fleet (h/day)	254.1	298.7	151.0	207.0	226.8	212.3	171.2	168.7	165.4	267.7
	Transportation cost incurred by carrier without fare (EUR/day)	1767.8	1414.2	1060.7	1131.4	1343.5	1343.5	1131.4	1131.4	1131.4	1767.8
	Logistic cost incurred by CF operator (EUR/day)	6415.0	7489.3	3963.5	5310.7	5792.1	5406.1	4433.9	4366.1	4285.9	6780.0
	External cost, ZCo2 (EUR/day)	74.6	65.3	53.2	58.1	66.8	58.0	53.2	51.5	51.2	83.6
	External cost, ZL (EUR/day)	12.0	11.3	9.8	10.8	12.2	9.6	9.4	8.8	8.8	14.8
	Total cost, ZTOT (EUR/day)	**8269.5**	**8980.1**	**5087.1**	**6511.1**	**7214.7**	**6817.2**	**5627.9**	**5557.9**	**5477.3**	**8646.2**

Table 8.1 Distance, time and cost incurred in Scenario 1

		Ciutat Vella	Eix-ample	Sants-Mont.	Les Corts	Sarrià-Sant Gerv.	Gràcia	Horta – Guin.	Nou Barris	Sant Andreu	Sant Martí
	Number of UCC	2	3	3	1	2	2	2	2	2	2
STRATEGY A (business as usual)	Distance run by commercial fleet (km/day)	2254.9	2645.0	1671.7	2006.4	2187.3	1854.8	1836.4	1722.6	1564.2	2521.9
	Time of vehicles (hours/day)	392.3	463.8	241.3	323.1	346.4	330.4	299.1	266.9	259.9	413.2
	Transportation cost, ZT, (EUR/day)	10506.7	12416.4	6539.9	8694.8	9330.1	8838.6	8043.2	7197.9	6979.6	11107.4
	External cost, ZCo2 (EUR/day)	106.3	124.6	78.8	94.5	103.1	87.4	86.5	81.2	73.7	118.8
	External cost, ZL (EUR/day)	11.1	13.0	8.2	9.8	10.7	9.1	9.0	8.4	7.7	12.4
	Total cost, ZTOT (EUR/day)	**10624.0**	**12554.0**	**6626.8**	**8799.2**	**9443.9**	**8935.1**	**8138.8**	**7287.6**	**7061.0**	**11238.6**
STRATEGY B (through UCC)	Distance run by trucks (km/day)	2000.0	1600.0	1200.0	1280.0	1520.0	1520.0	1280.0	1280.0	1280.0	2000.0
	Time of trucks (h/day)	48.9	39.1	29.3	31.3	37.1	37.1	31.3	31.3	31.3	48.9
	Distance run by the CF fleet, (km/day)	516.0	588.9	556.8	651.3	703.1	424.9	494.1	440.1	429.5	799.1
	Timeof Cf fleet (h/day)	282.9	331.3	180.9	242.5	260.5	235.6	217.3	192.7	188.7	311.8
	Transportation cost incurred by carrier without fare (EUR/day)	1767.8	1414.2	1060.7	1131.4	1343.5	1343.5	1131.4	1131.4	1131.4	1767.8
	Logistic cost incurred by CF operator (EUR/day)	4678.8	5431.5	3094.6	4053.5	4333.1	3942.5	3659.3	3276.0	3213.6	5131.7
	External cost, ZCo2 (EUR/day)	58.8	47.0	35.3	37.6	44.7	44.7	37.6	37.6	37.6	58.8
	External cost, ZL (EUR/day)	7.3	5.8	4.4	4.6	5.5	5.5	4.6	4.6	4.6	7.3
	Total cost, ZTOT (EUR/day)	**6512.6**	**6898.5**	**4194.8**	**5227.1**	**5726.8**	**5336.2**	**4833.0**	**4449.7**	**4387.2**	**6965.6**

Table 8.2 Distance, time and cost incurred in Scenario 2

		Ciutat Vella	Eix-ample	Sants-Montj.	Les Corts	Sarrià-Sant Gerv.	Gràcia	Horta – Guin.	Nou Barris	Sant Andreu	Sant Martí
	Number of UCC	2	3	3	1	2	2	2	2	2	2
STRATEGY A (business as usual)	Distance run by commercial fleet (km/day)	2254.9	2645.0	1671.7	1926.2	2347.7	2015.2	1836.4	1722.6	1724.6	2521.9
	Time of vehicles (hours/day)	398.6	471.9	251.1	318.7	366.8	340.6	279.5	273.9	269.9	424.4
	Transportation cost, ZT, (EUR/day)	10667.7	12621.6	6787.2	8562.0	9889.6	9137.7	7548.9	7376.4	7276.5	11389.2
	External cost, ZCo2 (EUR/day)	106.3	124.6	78.8	90.8	110.6	95.0	86.5	81.2	81.3	118.8
	External cost, ZL (EUR/day)	11.1	13.0	8.2	9.4	11.5	9.9	9.0	8.4	8.5	12.4
	Total cost, ZTOT (EUR/day)	**10785.0**	**12759.2**	**6874.1**	**8662.2**	**10011.7**	**9242.5**	**7644.4**	**7466.0**	**7366.2**	**11520.4**
STRATEGY B (through UCC)	Distance run by trucks (km/day)	2000.0	1600.0	1200.0	1280.0	1520.0	1520.0	1280.0	1280.0	1280.0	2000.0
	Time of trucks (h/day)	48.9	39.1	29.3	31.3	37.1	37.1	31.3	31.3	31.3	48.9
	Distance run by the CF fleet, (km/day)	516.0	588.9	556.8	651.3	703.1	424.9	494.1	440.1	429.5	799.1
	Time of Cf fleet (h/day)	295.8	346.0	194.8	249.6	282.8	246.8	210.4	203.7	199.4	331.8
	Transportation cost incurred by carrier without fare (EUR/day)	1767.8	1414.2	1060.7	1131.4	1343.5	1343.5	1131.4	1131.4	1131.4	1767.8
	Logistic cost incurred by CF operator (EUR/day)	1171.6	1322.2	888.1	1054.1	1154.0	1022.5	926.0	901.2	888.0	1303.7
	External cost, ZCo2 (EUR/day)	58.8	47.0	35.3	37.6	44.7	44.7	37.6	37.6	37.6	58.8
	External cost, ZL (EUR/day)	7.3	5.8	4.4	4.6	5.5	5.5	4.6	4.6	4.6	7.3
	Total cost, ZTOT (EUR/day)	3005.4	2789.2	1988.4	2227.7	2547.7	2416.2	2099.6	2074.9	2061.6	3137.5

Table 8.3 Distance, time and cost incurred in Scenario 3

As a resume of the calculations shown in the previous tables, is possible to do a comparison between the different scenarios and strategies for each of the districts of Barcelona, as can be seen in the following figure:

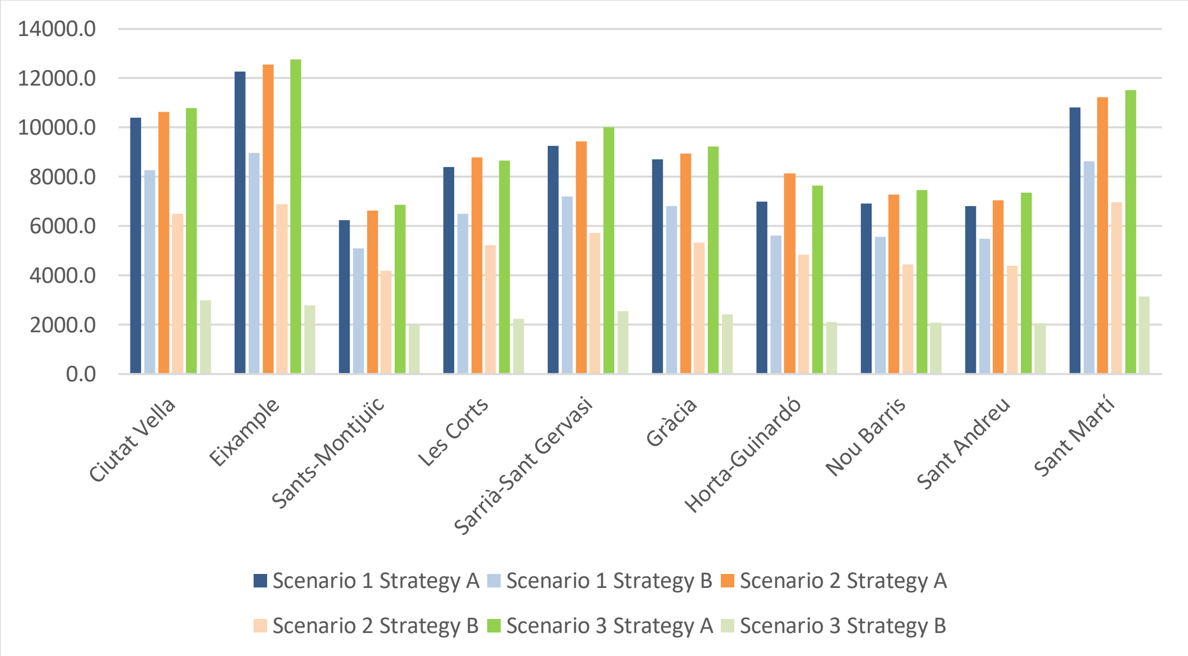


Figure 8.1 Total cost for each district comparing the different strategies and scenarios (€/day)

As can be seen, the third scenario with the strategy proposed in this project, of implementing consolidation facilities throughout the city, significantly reduces the total cost of all the other proposals, in terms of distance, time and economic cost. Furthermore, it can be seen how, in all scenarios, the proposed strategy of UCCs improves the strategy currently used at the cost level, this being a global financial calculation adding up the costs and benefits of all the actors. In the following sections, the costs and benefits of the individual actors will be analysed to see if the proposal to implement last mile delivery centres is economically feasible for all actors, and if in this way, all would be willing to accept such a proposal that changes the current urban logistics paradigm.

8.2 Profitability analysis

In this section, we propose a list of metrics and KPIS to analyze the profitability that will experience each stakeholder involved in the distribution when Consolidation Facilities (CF) will be used. We also provide a criterion to establish the fare to be paid by carriers to CF operators to compensate for the new logistic cost to be incurred.

8.2.1 KPIS

The metrics of analysis are based on the previous variables that characterize the transportation, emission, and facility costs as well as the logistic performance of the distribution routes.

- **Global profitability**. The assessment of the total cost savings in the system will be performed by means of the Δ_T variable, in EUR/day units. It is defined in Equation (7.1), as the difference between the total cost incurred by all stakeholders between Strategy A and B. This variable should be positive for ensuring that the total effect of the new distribution scheme based UCC on the society is convenient.

$$\Delta_T = \left[\sum_{i=1}^{M}\left(Z_{c,i}^A - Z_{c,i}^B\right)\right] - Z_{CF} + \left(Z_{ext}^A - Z_{ext}^B\right) \geq 0 \qquad (7.1)$$

- **Carrier's profitability**.
  - Δ_C variable. This variable, defined in Equation (7.2), accounts for the total cost difference incurred by the carrier between Strategy A and B in EUR/day units, including the fares to be paid to CF operator. Carriers will experience a profitable business when operating through UCC if the Δ_2 variable is higher than 0. This metric should be defined for each carrier *i*=1,..,M involved in the distribution and therefore, it depends on its market split. Therefore, we will calculate this metric Δ_2 for the worst and best company.

$$\Delta_{2i} = \left(Z_{c,i}^A - Z_{c,i}^B\right) \geq 0 \qquad \forall i \qquad (7.2)$$

  - $\eta_{C,i}$ ratio. It is calculated as the quotient between the cost incurred by one carrier i=1,..,M in Strategy A and the cost experienced when shifting to Strategy B (Equation 7.3). The cost in strategy B also takes into account the fare expenses to be distributed to the CF operator. This ratio should be lower than 1 to ensure an economic sustainable strategy for carriers.

$$\eta_{C,i} = \frac{c_d\left(D_{LH,i}^C\right) + c_t\left(T_i^C\right) + \theta_{CF}N_i}{c_d\left(D_{L,i}^A + D_{LH,i}^A\right) + c_t\ T_i^A} \leq 1 \quad \forall i \qquad (7.3)$$

  - δ_{Ci} variable. This variable defines the difference of the unit carrier transport cost per parcel between Strategies A and B (see in Equation 7.4). The unit costs in Strategy A and B are calculated as the quotient between the total transport cost incurred by the carrier in each strategy and the total number of receivers served, i.e. $z_{c,i}^A = Z_{c,i}^A/\left(N\phi_i\right)$ and $z_{c,i}^B = Z_{DT,i}^B/\left(N\phi_i\right)$. It is worth to mention that this unit cost per parcel must not take into account the fares to be paid by the carrier to CF operator. It only consists of transportation expenses. This variable will be used to determine the most suitable fare, in comparison to corresponding unit cost experienced by CF operator.

$$\delta_{Ci} = \left(z_{c,i}^A - z_{c,i}^B\right) \geq 0 \qquad \forall i \qquad (7.4)$$

- **Consolidation facility operator's profitability.**
  - Δ_{CF} variable. This variable accounts for the profit that the CF operator will experience in Strategy B running the local distribution (Equation 7.5). It considers as a potential income from the fares paid by different carriers i=1,...,M as well as the potential subsidy S from local authorities. On the other hand, this variable considers the operating cost to distribute parcels and the fixed cost of the consolidation facility (Ω). This variable should be higher than 0 to justify the involvement of the CF operator in the new distribution scheme.

$$\Delta_{CF} = \left(\sum_{i=1}^{M} \theta_{CF} N_i\right) + S \quad - c_d^{CF}(D_L^{CF} + D_{LH}^{CF}) - c_t^{CF} T^{CF} - \Omega \geq 0 \tag{7.5}$$

- z^{CF} variable. This variable defines the unit CF operator cost per parcel (see Equation 7.6). This variable will be used to determine the most suitable fare, in comparison to corresponding unit cost experienced by CF operator.

$$z^{CF} = \left(c_d^{CF}(D_L^{CF} + D_{LH}^{CF}) - c_t^{CF} T^{CF} - \Omega\right)/N \tag{7.6}$$

- **Externalities.**
  - Δ_{ext} variable. This variable captures the difference of the externality cost (Air pollution and greenhouse gases effect) between Strategy A and B (Equation 7.7).

$$\Delta_{ext} = Z_{ext}^{A} - Z_{ext}^{B} \tag{7.7}$$

  - η_{ext} ratio. It is defined by the quotient of the monetary cost of the emissions in Strategy B and in Strategy A . It should be lower than 1 ($\eta_{ext} \leq 1$) to represent a suitable situation that would improve the air quality of the city.

$$\eta_{ext} = \frac{\sum_{i=1}^{M}\left((D_{LH,i}^{B})\varepsilon(v_{LH}) \quad + (D_L^{CF} + D_{LH}^{CF})\varepsilon^{CF}(v_L)\right)}{\sum_{i=1}^{M}\left(D_{L,i}^{A}\varepsilon(v_L) + D_{LH,i}^{A}\varepsilon(v_{LH})\right)} \leq 1 \tag{7.8}$$

8.2.2 Fare definition

The fare θ_{CF} to be paid by the carriers to the receivers should satisfy two conditions: i) it should be higher than the average transport cost per parcel that the CF operator incurs and ii) it should be lower than the transportation cost saving per parcel that collaborating carrier will experience when it moves from Strategy A to Strategy B. These two conditions are summarized in Equation (7.9).

$$z^{CF} \leq \theta_{CF} \leq \delta_{Ci} \tag{7.9}$$

In fact, the difference M_C=($\delta_{Ci} - z^{CF}$) is the total cost savings per parcel in the system incurred by the carrier and CF operator. The determination of this fare within the previous domain determines the allocation of the benefits among collaborating stakeholders. If we set the fare equal to δ_{Ci}, it implies that all the benefits of Strategy B are allocated to CF operator through the fare θ_{CF}, and the worst collaborating carriers do not foresee any cost variation when passing from Strategy A to Strategy B. If we set the fare equal to the lower boundary (z^{CF}), the situation represents that the CF operator's profit is 0. The incomes of CF operator coming from the fare θ_{CF} are equal to the costs that this agent will incur. Under this situation, the collaborating carrier will experience the highest profitability of its participation in this initiative.

Hence, the CF fare is one of the service drivers that the CF operator must define with the carriers involved in the distribution. The fare, if satisfies Equation (7.9), can be calculated by $\theta_{CF} = z^{CF} + pM_C$, where $M_C = (\delta_{Ci} - z^{CF})$ and *p* is the fraction of the total cost saving per parcel (or fare margin) that is internalized by the CF operator. The complementary part, $(1-p)(\delta_{Ci} - z^{CF})$, is the real cost saving per parcel of the carrier, including the fare paid. In this study we have assumed that the CF operator only internalizes the 25% of the fare margin M_C =($\delta_{Ci} - z^{CF}$), while the rest part will be internalized by the carrier as cost savings.

Therefore, in this study, the final fare will be defined by $\boldsymbol{\theta_{CF} = z^{CF} + 0.25(\delta_{Ci} - z^{CF})}$.

8.2.3 Profitability results in Scenarios

In Section 7.1, we have analyzed that the sum of total cost incurred by all agents and emissions monetization in Strategy B were lower than the corresponding values of Strategy A in all districts. It is corroborated by the results of Δ_T metric obtained in Table 8.4, Table 8.5 and Table 8.6, that summarize the values corresponding to the profitability KPIs in Scenario 1, 2 and 3 respectively.

Nevertheless, it does not guarantee that each particular stakeholder will be benefited by the new distributions scheme. Thus, a further analysis per agent is needed:

The carrier agent experiences cost savings in all districts and Scenarios. In Scenario 1, this metric ranges between Δ_C 56-435 EUR/day. This fact is also identified by the $\eta_{C,i}$ ratio, that highlights that the carrier cost in Strategy B is equivalent to 0.77-0.85 times the cost in Strategy A. The δ_{Ci} metric varies within 2.32-3.00 EUR/parcel. It indicates that the carrier would afford a maximal CF fare equivalent to this figure and Strategy B would still be suitable for this agent. On the other hand, the CF operator experiences a unit logistic cost per parcel ranging in the domain z^{CF} (1.78;2.17). Since this figure is lower than the δ_{Ci} metric, it means that there is a feasible CF fare that compensates the cost incurred by the CF operator and makes Strategy B still competitive for the carrier. This fare, in the Scenario 1, has resulted to range between **θ (1.91;2.35) EUR/parcel.** The total cash flows between carriers and the CF operator is shown in the last row of Table 8.4.

In Scenario 2, the δ_{Ci} metric is quite similar to Scenario 1, and varies within 2.49-3.08 EUR/parcel. Nevertheless, the most outstanding achievement is the reduction of z^{CF}, in comparison to Scenario 1. This metric z^{CF} is now within 1.34-1.48 EUR/parcel. As a result of this, the CF fare to compensate the CF operator can be significantly shortened to **θ (1.63;1.92) EUR/parcel. This fact allows that the** carrier reduces the cost incurred by 27-36% ($\eta_{C,i}$ =0.64-0.73), including the fare to be paid to the carrier.

This tendency is even more noticeable in Scenario 3 with ADD. If the CF fare is set around **$\theta = 1$** EUR/parcel, both carrier and CF operator profitability is ensured. The cost incurred by the carrier is even reduced by 50%, in comparison to Strategy A.

	Ciutat Vella	Eix-ample	Sants-Mont.	Les Corts	Sarrià-Sant Gerv.	Gràcia	Horta – Guin.	Nou Barris	Sant Andreu	Sant Martí
Total cost savings, Δ_T (EUR/day)	2140.00	3300.39	1147.38	1883.45	2041.73	1903.51	1362.62	1366.51	1344.48	2157.78
Carrier cost savings, $\min \Delta_C$, (EUR/day)	87.4	138.9	56.9	77.3	114.7	78.2	62.0	60.5	60.6	97.8
Carrier cost savings, $\max \Delta_C$ (EUR/day)	296.4	435.1	134.8	235.9	256.3	276.5	171.1	174.7	174.5	284.7
Carrier cost ratio, $\min \eta_{C,i}$	0.84	0.78	0.83	0.81	0.77	0.82	0.83	0.83	0.83	0.83
Carrier cost ratio, $\max \eta_{C,i}$	0.85	0.82	0.88	0.85	0.85	0.84	0.87	0.87	0.87	0.86
Carrier trans. unit cost in Strategy A, $z^A_{c,i}$ (EUR/parcel)	3.49	3.40	3.07	3.08	3.17	3.01	2.77	2.81	2.96	2.94
Carrier trans. unit cost in Strategy B, $z^B_{c,i}$ (EUR/parcel)	0.60	0.40	0.53	0.42	0.47	0.47	0.45	0.46	0.50	0.49
Carrier trans. unit cost difference, δ_{Ci} (EUR/parcel)	2.89	3.00	2.54	2.66	2.70	2.54	2.32	2.34	2.46	2.46
CF profit, Δ_{CF}, (EUR/day)	527.19	809.70	281.27	445.61	493.83	467.16	335.55	338.61	316.21	507.99
Unit cost incurred by CF operator in Strategy B, z^{CF} (EUR/parcel)	2.17	2.09	1.98	1.97	2.01	1.89	1.78	1.79	1.88	1.87
Emission cost savings, Δ_{ext} (EUR/day)	30.64	61.00	19.85	31.21	34.78	28.92	20.40	20.94	21.37	28.63
Emission cost reduction ratio, η_{ext}	0.74	0.56	0.76	0.69	0.69	0.70	0.75	0.74	0.74	0.77
Fare, θ (EUR/parcel)	**2.35**	**2.32**	**2.12**	**2.14**	**2.18**	**2.05**	**1.91**	**1.93**	**2.02**	**2.01**
Fare Cash flows (EUR/Day)	6942.2	8299.0	4244.7	5756.3	6286.0	5873.2	4769.4	4704.7	4602.1	7288.0

Table 8.4 Profitability results in Scenario 1

	Ciutat Vella	Eix-ample	Sants-Mont.	Les Corts	Sarrià-Sant Gerv.	Gràcia	Horta – Guin.	Nou Barris	Sant Andreu	Sant Martí
Total cost savings, Δ_T (EUR/day)	4111.46	5655.53	2432.00	3572.11	3717.08	3598.94	3305.80	2837.89	2673.76	4273.06
Carrier cost savings, $\min \Delta_C$, (EUR/day)	166.6	234.0	109.0	144.0	185.7	145.4	144.2	114.5	114.6	181.1
Carrier cost savings, $\max \Delta_C$ (EUR/day)	582.5	776.2	324.5	482.2	488.0	514.4	490.2	355.9	355.4	593.5
Carrier cost ratio, $\min \eta_{C,i}$	0.70	0.64	0.70	0.68	0.64	0.68	0.65	0.69	0.70	0.70
Carrier cost ratio, $\max \eta_{C,i}$	0.71	0.68	0.74	0.71	0.73	0.71	0.68	0.74	0.74	0.72
Carrier trans. unit cost in Strategy A, $z_{c,i}^A$ (EUR/parcel)	3.56	3.47	3.27	3.23	3.24	3.09	3.23	2.95	3.06	3.06
Carrier trans. unit cost in Strategy B, $z_{c,i}^B$ (EUR/parcel)	0.60	0.40	0.53	0.42	0.47	0.47	0.45	0.46	0.50	0.49
Carrier trans. unit cost difference, δ_{Ci} (EUR/parcel)	2.96	3.08	2.74	2.81	2.77	2.62	2.77	2.49	2.57	2.58
CF profit, Δ_{CF}, (EUR/day)	990.98	1363.07	589.56	869.00	885.94	899.34	550.49	697.40	659.48	1032.26
Unit cost incurred by CF operator in Strategy B, z^{CF} (EUR/parcel)	1.58	1.52	1.55	1.51	1.50	1.38	1.47	1.34	1.41	1.42
Emission cost savings, Δ_{ext} (EUR/day)	51.30	84.80	47.37	62.13	63.63	46.33	53.29	47.37	39.13	65.19
Emission cost reduction ratio, η_{ext}	0.56	0.38	0.46	0.40	0.44	0.52	0.44	0.47	0.52	0.50
Fare,θ (EUR/parcel)	**1.92**	**1.90**	**1.84**	**1.83**	**1.81**	**1.69**	**1.69**	**1.63**	**1.70**	**1.70**
Fare Cash flows (EUR/Day)	**5669.8**	**6794.5**	**3684.1**	**4922.5**	**5219.1**	**4841.8**	**4209.8**	**3973.4**	**3873.1**	**6164.0**

Table 8.5 Profitability results in Scenario 2

	Ciutat Vella	Eix-ample	Sants-Mont.	Les Corts	Sarrià-Sant Gerv.	Gràcia	Horta – Guin.	Nou Barris	Sant Andreu	Sant Martí
Total cost savings, Δ_T (EUR/day)	7779.57	9969.96	4885.76	6434.44	7464.00	6826.32	5544.79	5391.11	5304.65	8382.94
Carrier cost savings, $\min \Delta_C$, (EUR/day)	306.8	399.1	206.2	260.5	325.1	293.9	219.7	214.4	211.2	340.7
Carrier cost savings, $\max \Delta_C$ (EUR/day)	1120.0	1407.2	677.2	881.7	1006.1	967.5	763.4	729.6	716.0	1191.2
Carrier cost ratio, $\min \eta_{C,i}$	0.46	0.39	0.46	0.43	0.40	0.41	0.44	0.44	0.44	0.45
Carrier cost ratio, $\max \eta_{C,i}$	0.46	0.43	0.47	0.46	0.46	0.46	0.47	0.47	0.48	0.46
Carrier trans. unit cost in Strategy A, $z^A_{c,i}$ (EUR/parcel)	3.61	3.53	3.39	3.18	3.43	3.19	3.03	3.03	3.19	3.14
Carrier trans. unit cost in Strategy B, $z^B_{c,i}$ (EUR/parcel)	0.60	0.40	0.53	0.42	0.47	0.47	0.45	0.46	0.50	0.49
Carrier trans. unit cost difference, δ_{Ci} (EUR/parcel)	3.01	3.13	2.86	2.76	2.96	2.72	2.58	2.56	2.70	2.65
CF profit, Δ_{CF}, (EUR/day)	1929.07	2468.45	1214.27	1581.97	1844.77	1692.67	1370.71	1334.13	1314.22	2079.28
Unit cost incurred by CF operator in Strategy B, z^{CF} (EUR/parcel)	0.40	0.37	0.44	0.39	0.40	0.36	0.37	0.37	0.39	0.36
Emission cost savings, Δ_{ext} (EUR/day)	51.30	84.80	47.37	57.96	71.97	54.67	53.29	47.37	47.47	65.19
Emission cost reduction ratio, η_{ext}	0.56	0.38	0.46	0.42	0.41	0.48	0.44	0.47	0.47	0.50
Fare,θ (EUR/parcel)	**1.05**	**1.06**	**1.05**	**0.98**	**1.04**	**0.95**	**0.92**	**0.92**	**0.97**	**0.93**
Fare Cash flows (EUR/Day)	3100.7	3790.6	2102.3	2636.1	2998.8	2715.1	2296.7	2235.4	2202.2	3382.9

Table 8.6 **Profitability results in Scenario 3**

A summary of the results of the three scenarios can be seen in the following figure:

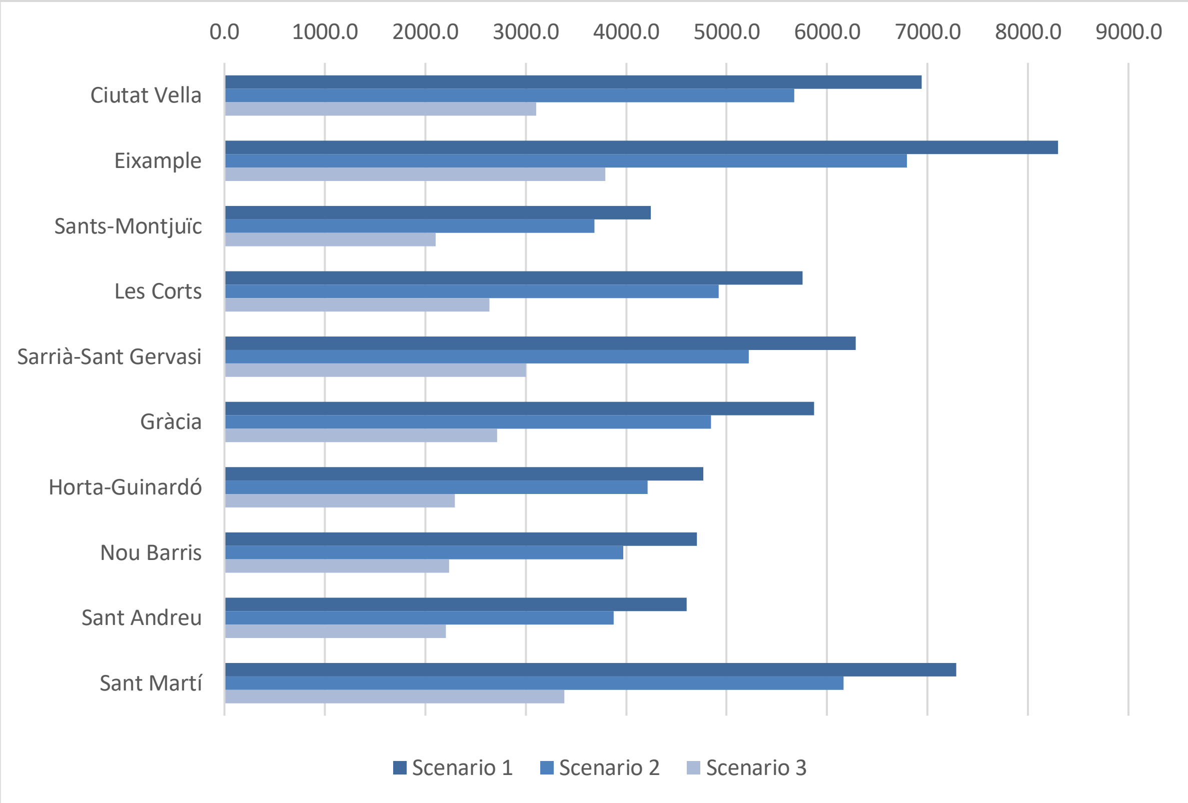


Figure 8.2 Profitability results: Fare cash flows (€/day)

As can be seen, in all cases the fare cash flows are reduced from scenario 1 to scenario 3, as the measures are increasingly more sustainable or involve fewer energy resources or fewer people for their full implementation. In addition, the third scenario, with the use of ADDs, allows in all districts a higher profit for the Carrier and the CF operator, and therefore a higher success rate for the consolidation facility.

8.2.4 Profitability summary. Multi-actor cost benefit analysis (MACBA)

The Scenarios analyzed above can be also compared through the use of a Stakeholder-Effect matrix for a given district, performing a multi-actor cost-benefit analysis. Each cell of this matrix quantifies the monetization of effect x (in rows) on the agent y (in columns), as a difference between Strategy B and A. Therefore, if the cell is positive, it means that this effect causes a net income or a cost saving when switching from Strategy A to B. On the contrary, a negative value represents an increment of cost or a decrement of profit for a given effect and agent. The sum of all cells of a given column "j" determines the total benefits or profit generated by Strategy B to the agent "j" with regard to Strategy A. In addition, the sum of all cells in the same row "i" accounts for the total monetized impact of effect "i" in the whole system, integrated by all stakeholders involved. It is worth mentioning that the impact of cash flows between agents and taxes are cancelled in the overall analysis of a given row associated to a given effect. Finally, the sum of all cells in the matrix gives the net profit of the Strategy B with regard to Strategy A, and would be equivalent to the Δ_T metric analyzed in the previous subsection.

The following Table 8., Table 8.8 and Table 8. represent the Stakeholder-Effect matrix in Eixample District for Scenario 1, 2 and 3 respectively. The matrices corresponding to other districts can be built similarly, using the data available in Section 7.2.3. Since all operating scenarios give the CF operator positive profits, subventions are not needed.

The overall effect of Fees (the fares paid by carriers to CF Operator) in all Scenarios is cancelled. It should be highlighted that Fares are only needed to compensate the CF operator expenses, but they do not affect the total system profitability (sum of all cells or equivalently, Δ_T metric). The effect of Petrol taxes is also cancelled in the whole system, although the taxes supported by carriers and CF operator in Strategy B are lower than the corresponding value in Strategy A. The distance-based cost as well as the cost of the driver wages and meals are encompassed in the effect named Distribution Cost. On the other hand, the vehicle depreciation, maintenance and vehicle financial cost are considered within the effect Vehicles. The effect called Personnel refers to the staff needed in the Consolidation facility to receive parcels to be classified and distributed with the urban fleet.

The results presented in the Stakeholder-effect matrix summarize the tendencies explained before. Scenario 3 is the most profitable for all agents involved and requires the lowest level of compensations by means of fares between carriers and CF operator. It also produces positive environmental effects with regard to Scenario 1, although they are the same in Scenario 2. Since it presents the lowest temporal-based cost (inexistence of drivers), the system is able to maximize the cost savings in Strategy B. Scenario 2 based on ecargobikes is the second best in terms of the profitability of the system, carrier and CF operator. Finally, the utilization of ICE vans in the last mile distribution by the CF operator produces the weakest profitable results, but still positive.

			SUM	Agent			
			3,295.83 €	Carriers	UCC Operator	Government	Non-Users
Effects			Subtotal	2,459.14 €	794.02 €	-18.33 €	61.00 €
Operation		Fees	0.00 €	-8,298.98 €	8,298.98 €		
		Taxes	0.00 €	29.45 €	-11.12 €	-18.33 €	
		Distribution Costs	2,991.18 €	9,358.83 €	-6,367.65 €		
		Personnel	-135.00 €		-135.00 €		
		Subsidies	0.00 €		0.00 €	0.00 €	
Assets	Invest.	Vehicles	518.65 €	1,369.84 €	-851.19 €		
		Terminal Fixed Costs	-140.00 €		-140.00 €		
Ext. Eff.	Air Pollution		1.64 €				1.64 €
	Climate Change		59.36 €				59.36 €

Table 8.7 SE Matrix for Scenario 1 (Vans) in Eixample District

			SUM	Agent			
			5,655.53 €	Carriers	UCC Operator	Government	Non-Users
Effects			Subtotal	4,237.12 €	1,346.47 €	-12.85 €	84.80 €
Operation		Fees	0.00 €	-6,794.53 €	6,794.53 €		
		Taxes	0.00 €	29.45 €	-16.60 €	-12.85 €	
		Distribution Costs	5,469.57 €	9,596.50 €	-4,126.93 €		
		Personnel	-135.00 €		-135.00 €		
		Subsidies	0.00 €		0.00 €	0.00 €	
Assets	Invest.	Vehicles	376.17 €	1,405.69 €	-1,029.53 €		
		Terminal Fixed Costs	-140.00 €		-140.00 €		
Ext. Eff.	Air Pollution		7.17 €				7.17 €
	Climate Change		77.63 €				77.63 €

Table 8.8 SE Matrix for Scenario 2 (eCargobikes) in Eixample District

			SUM	Agent			
			9,969.87 €	Carriers	UCC Operator	Government	Non-Users
Effects			Subtotal	7,446.16 €	2,451.77 €	-12.85 €	84.80 €
Operation		Fees	0.00 €	-3,790.63 €	3,790.63 €		
		Taxes	0.00 €	29.45 €	-16.60 €	-12.85 €	
		Distribution Costs	8,924.70 €	9,774.76 €	-850.06 €		
		Personnel	-135.00 €		-135.00 €		
		Subsidies	0.00 €		0.00 €	0.00 €	
Assets	Invest.	Vehicles	1,235.38 €	1,432.58 €	-197.20 €		
		Terminal Fixed Costs	-140.00 €		-140.00 €		
Ext. Eff.	Air Pollution		7.17 €				7.17 €
	Climate Change		77.63 €				77.63 €

Table 8.9 SE Matrix for Scenario 3 (ADD) in Eixample District

In the following figures, the results of the SE Matrix are shown, comparing the economic results obtained by each of the agents involved in the logistics chain, as well as the comparison between the different scenarios.

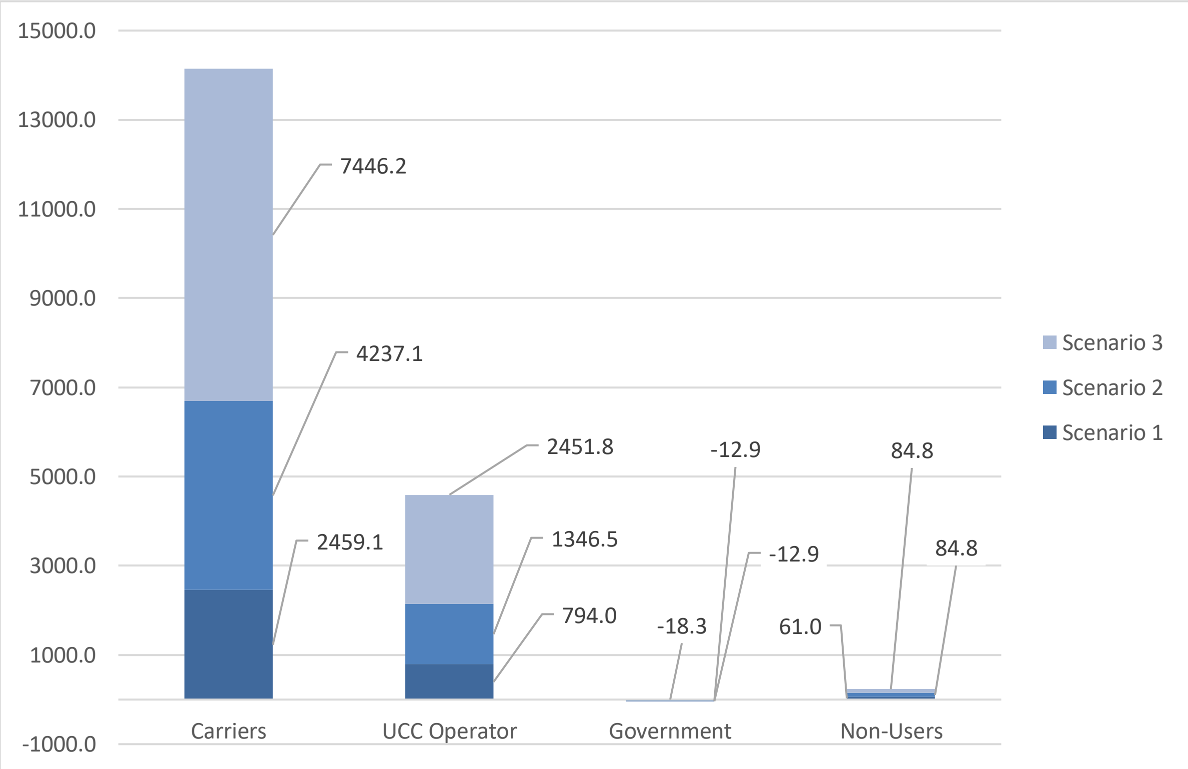


Figure 8.3 Results of SE Matrix for each agent

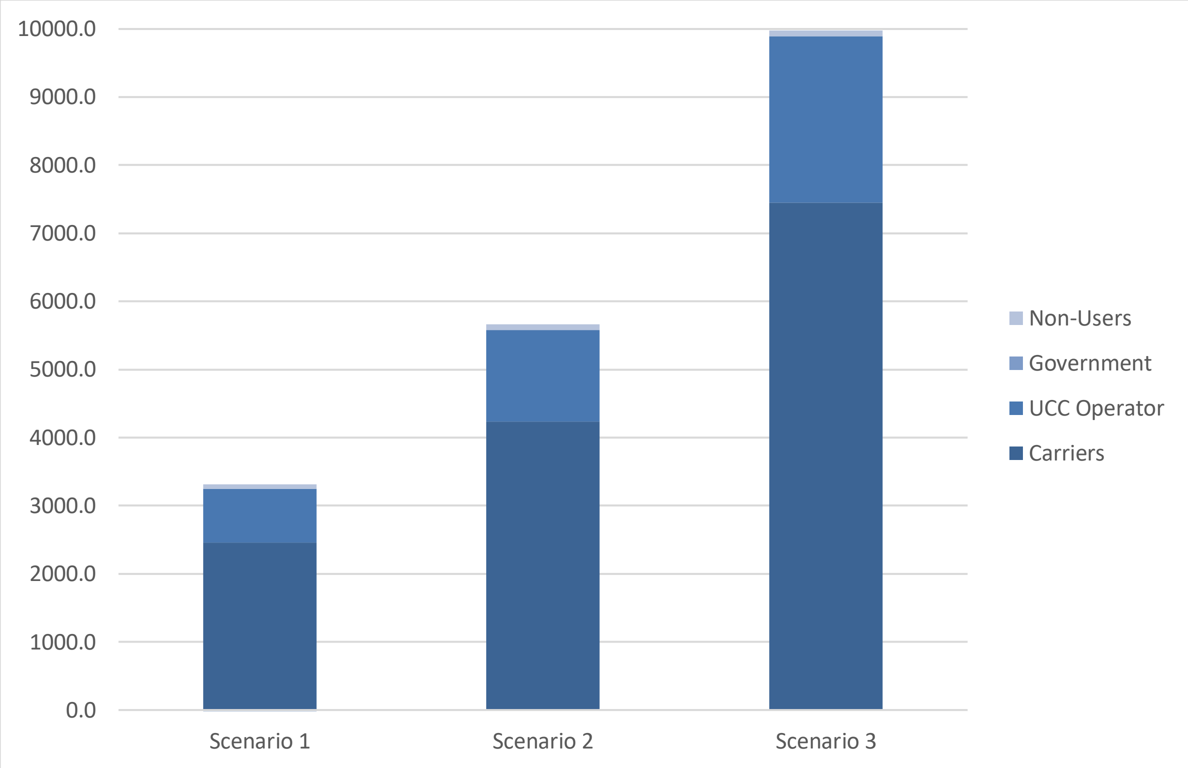


Figure 8.4 Results of SE Matrix for each scenario analyzed

As can be seen, the only agent to lose money is the government of the city council, but it is a really little cost related with taxes which can be considered as zero thanks to the difference with the amount of money received by the other agents, and including the non-users of the logistics chain.

8.2.5 *Profitability sensitivity analysis*

The purpose of this analysis is to analyze the variation in the profitability of stakeholders with regard to the parameters that may present more uncertainty in the reality. Undoubtedly, these parameters are:

- The number of receivers and retail shops (N) that will finally participate in the new distribution scheme through Urban Consolidation facilities.
- The cost of the consolidation facility, including investment and operation (Ω).

In order to simplify this analysis, we will focus our attention on the parameter M_C. As it was defined previously, M_C is the difference between the cost savings experienced by carriers when switching from Strategy A to B, and the cost incurred by the CF operator (See Section 7.2.2.). This meaning is the total economic margin per parcel that is saved in the new Strategy B with regard to Strategy A. Therefore, the fare can be calculated by $\theta_{CF} = z^{CF} + p \cdot M_C$ where p is the fraction of this margin passed to the CF operator by means of the fare. The other part, $(1-p) \cdot M_C$, is the economic incentive (Cost saving per parcel including) of the carrier to take part in the new distribution system. If $M_C < 0$, it means that there is not any fare that would satisfy Equation (7.9)

Figure 8.1-Figure 8.10 depict the M_C variable in all districts under the 3 Scenarios considered (a-Vans, b-ecargobikes, c-ADD). In all Districts, Scenario 1 presents an unfeasible region where the cost savings experienced by the carriers are not sufficient to cover the cost per parcel incurred by CF operator. This infeasible domain (in black) is generally defined by a number of receivers lower than N< 300 shops and facility cost higher than Ω>100 EUR/day. It can be also noticed that in Scenario 1 there is a short margin to establish a feasible CF fare. In the vast domain under analysis, although the service is profitable for all stakeholders, this margin is lower than 1 EURO /parcel. It means that carriers and

receivers are going to negotiate about how this 1 EURO/parcel margin is split among them by means of fare.

In Scenario 2, the infeasible region (black) is significantly reduced and can be avoided if we deploy low cost Consolidation Facilities, whose unit cost is Ω<160 EUR/day. In that case, we achieve a maximal fare margin of 2 EUROS/parcel, fact that should foster the participation of carriers and CF operators in the new distribution scheme.

Finally, Scenario 3 presents the best results, with fare margins that can arise to 4 EUR/parcel. In this Scenario 3, even if the number of receivers is low, carriers and CF operators can always set an agreed fare that will ensure a profitable business for all of them.

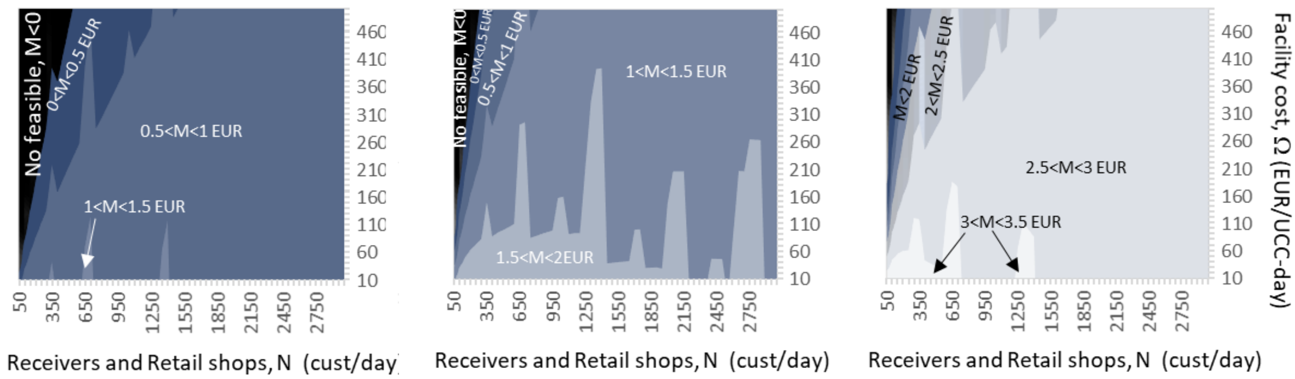


Figure 8.1 Sensitivity analysis in Ciutat Vella District, a) Vans, b) eCargobikes c) ADD

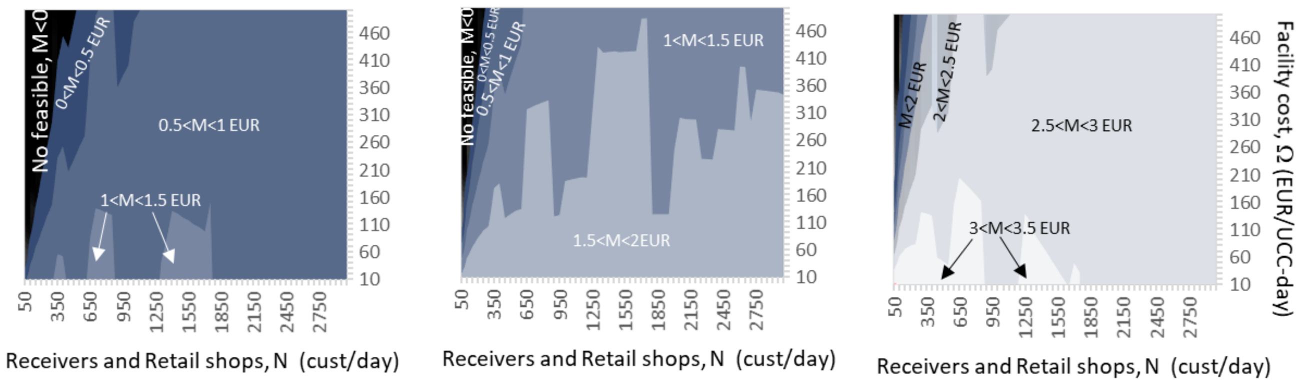


Figure 8.2 Sensitivity analysis in Eixample District, a) Vans, b) eCargobikes c) ADD

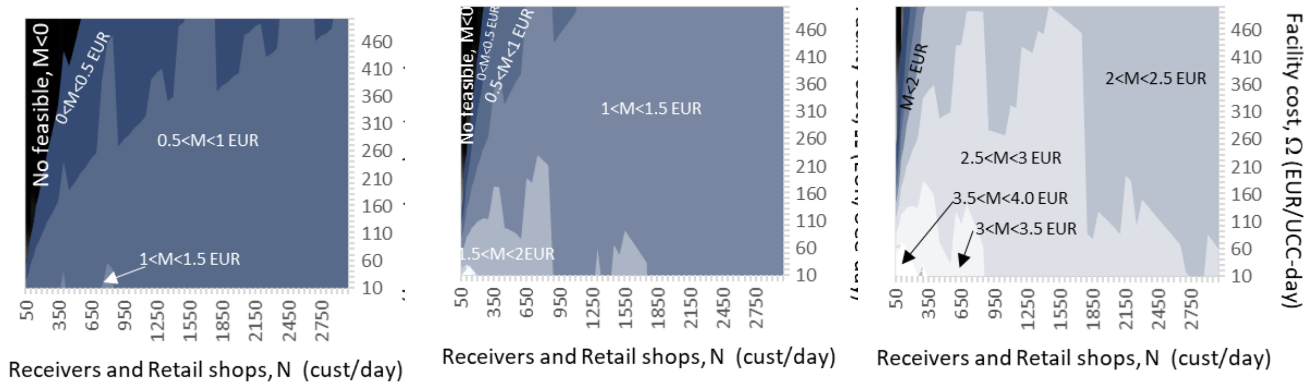


Figure 8.3 Sensitivity analysis in Sants-Montjuic District, a) Vans, b) eCargobikes c) ADD

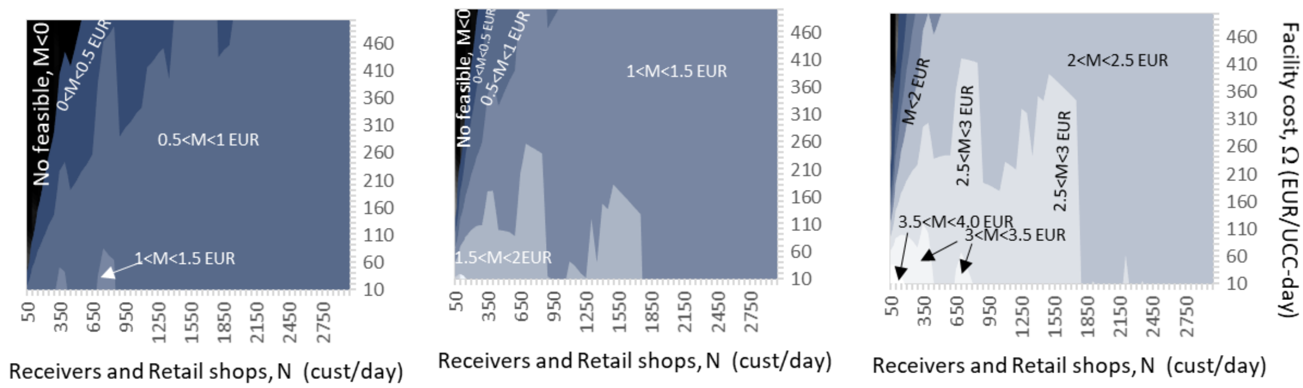


Figure 8.4 Sensitivity analysis in Les Corts District, a) Vans, b) eCargobikes c) ADD

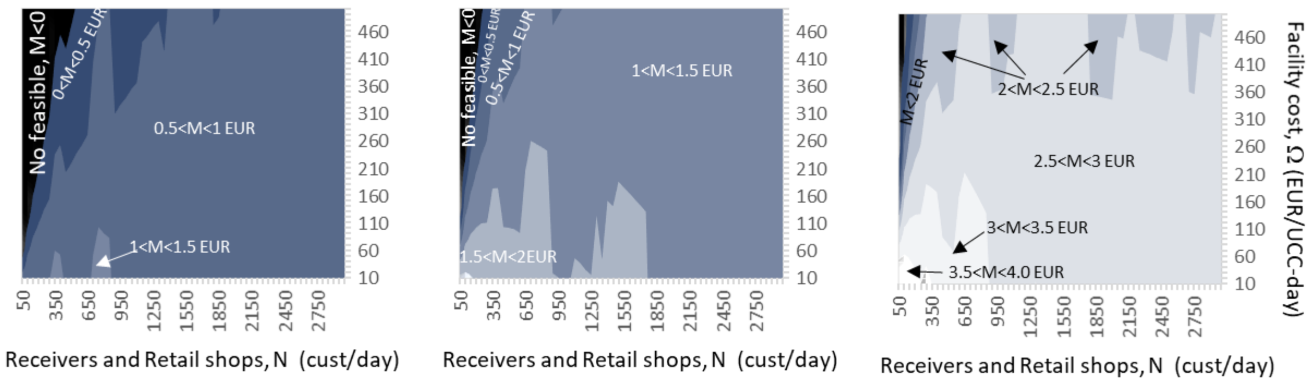


Figure 8.5 Sensitivity analysis in Sarrià-Sant Gervasi District, a) Vans, b) eCargobikes c) ADD

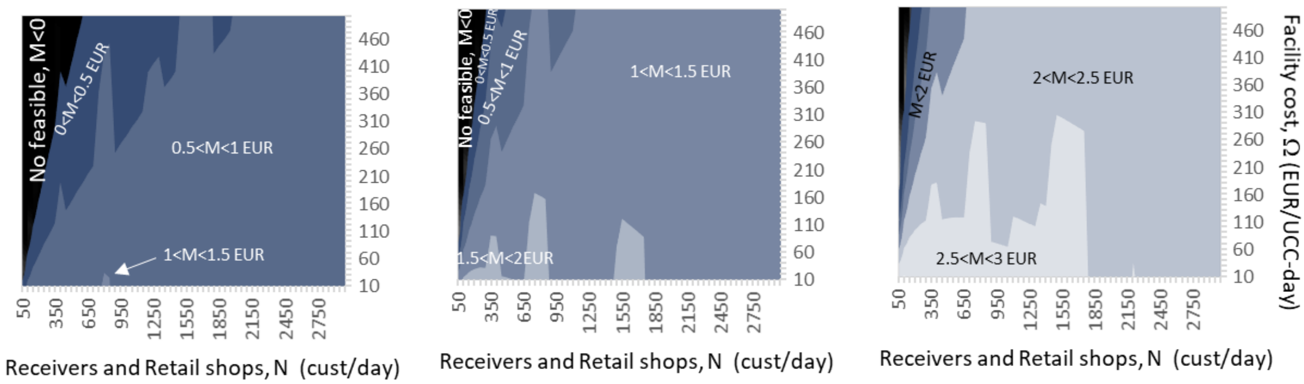


Figure 8.6 Sensitivity analysis in Gràcia District, a) Vans, b) eCargobikes c) ADD

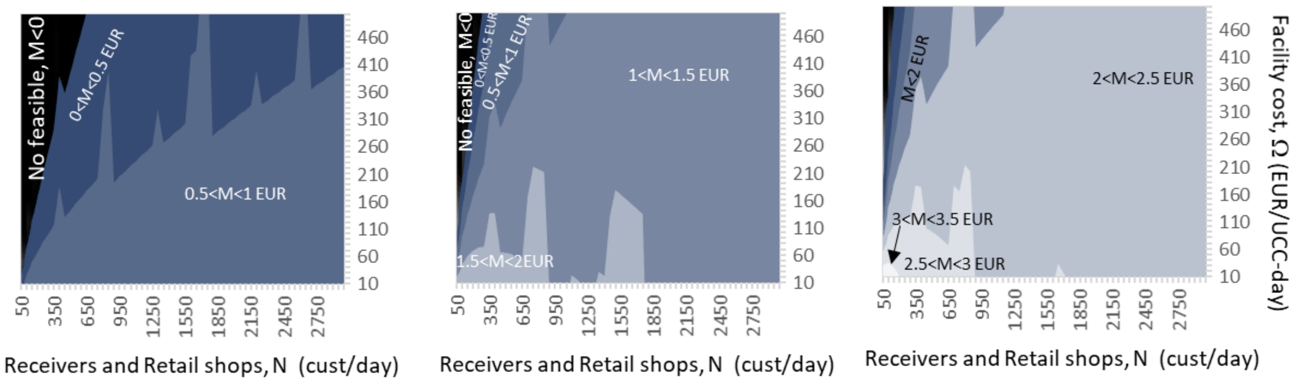


Figure 8.7 Sensitivity analysis in Horta-Guinardó District, a) Vans, b) eCargobikes c) ADD

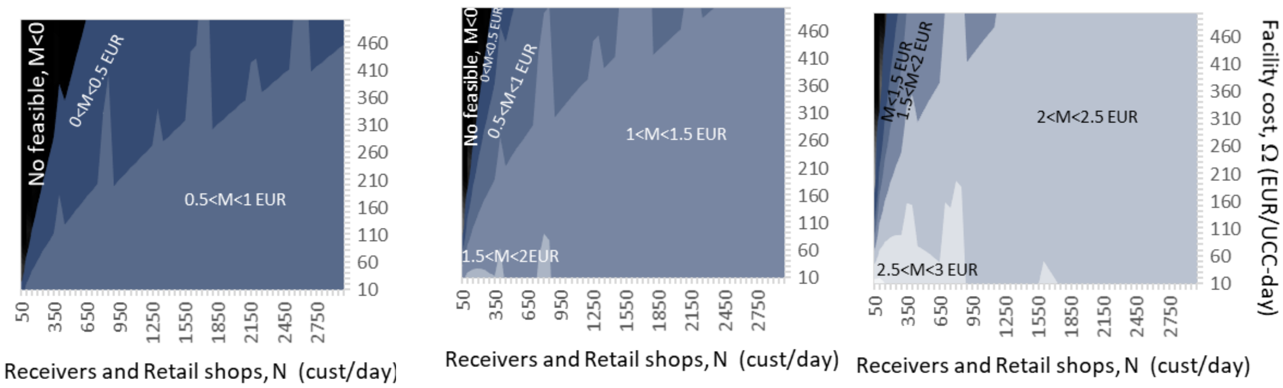


Figure 8.8 Sensitivity analysis in Nou Barris District, a) Vans, b) eCargobikes c) ADD

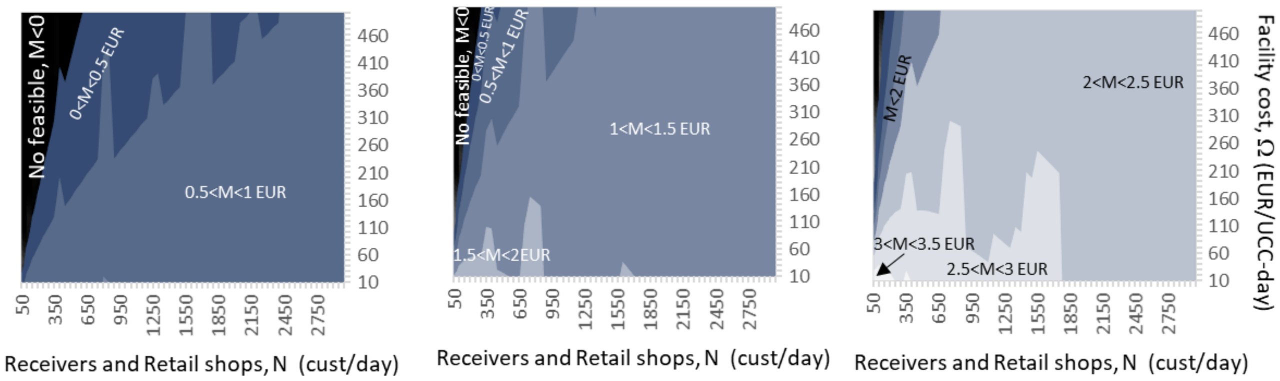


Figure 8.9 Sensitivity analysis in Sant Andreu District, a) Vans, b) eCargobikes c) ADD

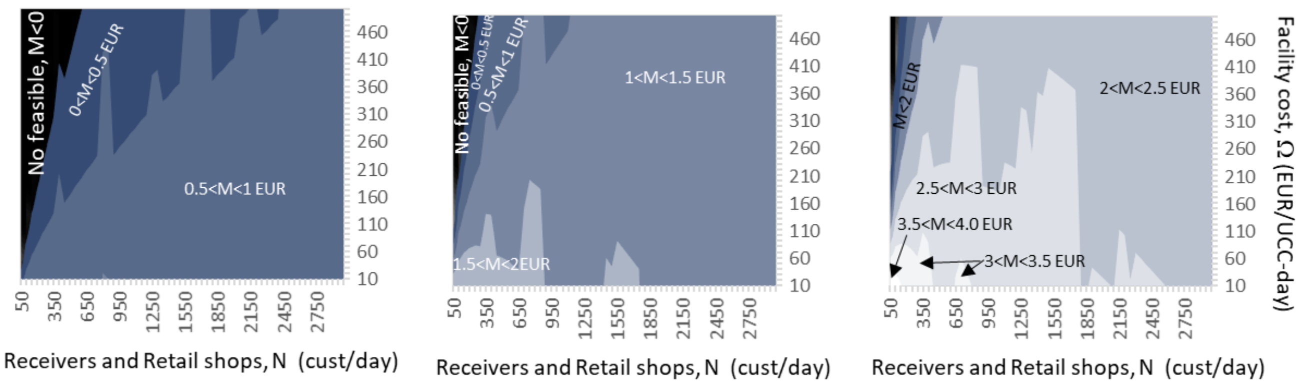


Figure 8.10 Sensitivity analysis in Sant Martí District, a) Vans, b) eCargobikes c) ADD

9 The future of last mile logistics

The study of UCCs as a solution to reduce pollution in urban areas is only a first attempt to achieve, with a better optimisation and use of available resources, a better understanding between the actors present in a logistics system.

For many years, the main European and world cities have been developing multiple initiatives to reduce pollution in urban areas. According to a study by the Spanish Association of Commercial Coding (AECOC): “Within urban mobility, the weight of freight distribution has been increasing and will continue to do so in the coming years. In 2019, its weight on the total traffic in the centre of Madrid was 38%, and it is estimated that in 2025 this percentage will already be 47%”[2].

As can be seen, this is a very high percentage of pollution in cities, which is why city councils have decided to take action. Some of the initiatives to improve the quality of life in major cities have been the reduction of loading and unloading spaces, reduction of on-street parking, the pedestrianisation of many streets or the creation of restricted access zones in some areas of the cities. Central London's Toll, Barcelona's Low Emission Zone or the Madrid Central project are some of the examples of these initiatives.

This section therefore proposes, based on the technologies that are being created and tested by various companies around the world, a global analysis of how last mile delivery can be addressed through the implementation of consolidation facilities within cities.

The first point to take into account is the regulation of each of the countries and cities involved. At present, few of them have a specific regulation for urban distribution centres such as the one presented in this project, or if they do, it is very poor at a conceptual level and leaves many hypotheses up in the air.

Regulation influences the fees to be paid by the different actors in logistics distribution, in order to avoid economic "abuses" by the large logistics companies in the sector, and in this way the creation of a UCC or consolidation centre is more likely to be a successful option. To give an example of this situation, it would be when the CF operator charges 25% while the Carrier charges 75% (calculation made in this document), and, over the years, the carrier decides to increase its percentage to such an extent that the CF operator is not profitable and has to close.

As can be seen in the graph below (Figure 9.1), some of the projects implemented at European level have not been successful, and according to the studies that analyse their creation and development, which can be consulted in the bibliography, in almost all cases this has been due to a problem of economic sustainability due to poor planning of tariffs and percentages for each of the actors involve in the logistics.

[2] Report of AECOC ‘Hacia un modelo sostenible de Distribución Urbana de Mercancías en España’:

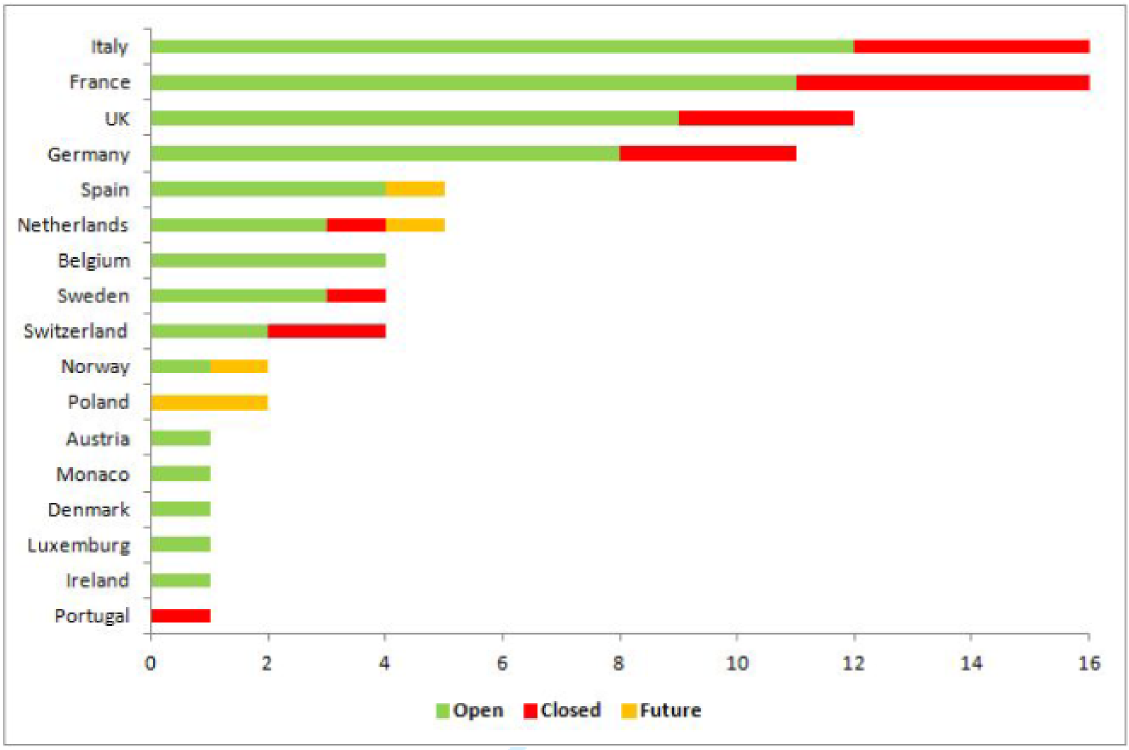


Figure 9.1 **Launch of UCC in Europe**

In addition to fare regulation, in order to develop technologies that can deliver autonomously, such as the ADDs mentioned earlier in this document or drones, European, national and municipal regulation is needed. The implementation of these technologies in the day-to-day life of cities should not be taken as a simple action, as their place of circulation, their actions, the actions to be taken in the event of a failure or accident, among many other factors, must be regulated. Currently, it is widely known that Germany has been one of the first countries to start regulating and legislating the circulation of autonomous vehicles or robots in its country.

In the near future, and taking the German country as an example, this will be the general trend in the most developed countries, so as not to be left behind in the implementation of new technologies that make people's lives easier. Moreover, this factor is also essential for the development of consolidation facilities, since, as has been proven in the document, it is the cheapest option among those studied.

Having dealt with the legal issue, and focusing on the technological factor and the improvement of the optimisation model presented, several options were presented at European and global level as future ideas for consolidating last-mile freight transport.

The first idea, which is based on the system used by Amazon, is the digitalisation of products in order to establish an emarket place in city neighbourhoods in order to compete with Jeff Bezos' company. The aim is for local commerce to have the option of digitising their physical products to convert the spaces into a collection and delivery point, in addition to their current use as a shop. One of the examples of this technology is developed by the Spanish company Grupo Mox, which offers the aforementioned service to its customers. In this way, local commerce can offer its customers the option to shop online and become, as mentioned above, a mere intermediary, to pick up on site or even create a delivery service. In addition, the aforementioned technology can control stock, manage delivery routes or develop an easy-to-access website with a simple purchasing system.

Linked to this previous option, and currently being implemented as a pilot test in some towns near Barcelona (Viladecans or Sant Quirze del Vallès) is the use of these emarkets place as a municipal service for small packages, in a similar idea to the lockers used by companies such as Amazon or Correos. In addition, Sant Adrià del Besós has implemented, also as a pilot project, a virtual currency for payment in local commerce, in an attempt to boost local shops and differentiate themselves from the rest.

Another line of research, which is more focused on delivery, is presented by companies such as TNT in a pilot project carried out in Brussels, Belgium, called Mobile Access Hub. In this test, as shown in Figure 9.2, a large truck left its trailer at a strategic point in the city, from where the last mile delivery vehicles departed with the packages already organised according to the routes to be taken, an action that had been carried out in the warehouse outside the city.

Figure 9.2 Example of Mobile Access Hub. Source: TNT

This solution allows the speed of delivery, as well as great savings in the facilities and logistics of the consolidation facilities or UCCs presented in this project. On the other hand, there is the problem that, once the delivery has been made, the lorry is empty and the freight has to be reloaded at the logistics centre outside the city, which means that a new route has to be done.

A variation of this model, which is currently being studied by some companies, is the use of small buses that depart from UCCs located within the city with the carriers already loaded with packages on their bicycles or scooters. After a first ride, they are dropped off at a strategic location from where they take their last-mile delivery route. In this way, the number of consolidation facilities within the city is reduced, allowing a larger delivery area to be covered.

This option could also be improved by realising the same idea but with ADDs or similar autonomous vehicles, further reducing the expense of this option by reducing the costs of consolidation facilities.

At present, the main handicap of the ADDs or drones developed for delivery is that they can only deliver very small quantities of products on the same route, which is why they are currently only suitable for small deliveries.

Another model that would improve the possibilities and speed of distribution of UCCs is the implementation of an automated system of mechanical arms for the organisation of deliveries. In this way, and having developed an algorithm that works with artificial intelligence, delivery routes for last mile drivers or ADDs would be generated in the most optimal way possible, organising orders by proximity, route difficulty based on geography and many other factors. The option is similar to the cranes used in freight ports to deliver and relocate containers, but scaled down to a small scale for an urban consolidation centre, reducing costs and the surface area required for each logistics centre.

10 Conclusion

UCC are appropriate solutions to reduce the amount of traffic and space used by urban logistics, especially in compact neighborhoods, concentrating a high density of retailers. Despite that, the implementation of this solution is not straightforward, since the current carriers are reluctant to the presence of an intermediary logistic operator. To solve this problem, UCC or consolidation facilities can offer added-value services such as inventory management, storage space or group ordering. The promotion of a UCC or Consolidation Strategies is not a question of transportation cost savings and reduction of vans. Some of the drawbacks of the implementation of UCC are related to the administrative and commercialization activity that carriers need to perform in urban areas.

The present study has analyzed the impacts of a network of Consolidation Facilities in Barcelona. The promotion of the new distribution scheme should be focused on carriers, the agent that will experience cost savings in the new logistic scheme. Attempts aligned to persuade the participation of retailers are not going to be translated in an increment of the demand consolidated at UCC. It is crucial that the facility conceptualization allows a low cost implementation in the different available relocations, to be more competitive than the regular distribution. The promotion of UCC would be public or private, the CF operator can be a neutral or a profit-company. Nevertheless, the final parcel delivery to the receivers should be made with exclusive vehicles, on behalf of the regular carrier (same branding). Indeed, the CF operator may be conceived as an outsourced company that runs the last mile distribution on behalf of the former carrier. Doing so, the carrier company will not see that the final contact with the receiver is made by another logistic competitor.

The methodology developed to design the network of UCC is based on economic parameters, the potential retailer demand as well as the capacity and temporal constraints of the routes. The model calculates the optimal service area associated to each consolidation facility. Then, the model translates this estimation into a discrete number of consolidation facilities. The implementation in Barcelona resulted in 21 Consolidation Facilities to be scattered over the municipality. Eixample and Sants-Montjuic presented 3 facilities, Les Corts 1 center and the rest of Barcelona districts two units each.

The strategy B, based on the deployment of 21 consolidation facilities, has reduced the total cost of distribution, the utilization time of resources and the transport externalities (air pollution and GHG). The unique metric that has been increased in the new distribution scheme in some Districts is the overall distance run. This is mainly caused by the kilometers run by the local fleet operated by the CF manager. Nevertheless, since this fleet is more economical and environmentally friendly, the total contribution in terms of operating cost and emissions can be notably reduced. The final number of Consolidation Facilities strongly depend on the unit facility cost of these facilities (Ω, EUR/day), the vehicle capacity constraints of the vehicles used in the last mile distribution, and the total demand. On the contrary, the vehicle technology chosen has not a direct impact in the covering area of each consolidation facility.

The present appraisal model has proved the viability of the network of 21 consolidation facilities in Barcelona. A fare calculated as a function of existing carriers cost savings would be imposed to current carriers to compensate the increment of cost incurred by CF operator. Even with the consideration of this fare, the system-, carrier- and CF operator- profitability are ensured in all districts. Three vehicle alternatives have been tested: Diesel vans (EURO VI), electric cargobikes and Autonomous Delivery Devices. The most efficient Scenario is when the last mile distribution network is operated by Autonomous Delivery Devices. In that situation, the total profit margin per parcel is around 4 EUR/parcel. The required fare to guarantee profits for the CF operator is 1 EUR/parcel. The second-best service is when ecargobikes are utilized to distribute parcels to the final retailers from the consolidation facility. In that case, the cost margin is around 2 EUR/parcel, and the required fare to ensure revenue streams for CF operator is 1.70-1.92 EUR/parcel. Finally, the weaker business model is obtained when the fleet owned by the CF operator are diesel vans. The recommended fare will range between 1.91-2.35 EUR/parcel and the cost saving margin is lower than 1 EUR/parcel. In fact, the total profits of the new system to be split between carriers and CF operator are marginal. In this case, the service is not economically feasible when the number of retailers is below 300 shops per district and day, and the facility cost of the UCC is higher than 160 EUR/day. This is equivalent to assume that there is not any fare that compensates the carrier and CF operator at the same time.

Besides the physical advantages of distribution centers, they also entail benefits in terms of externalities. The usage of fewer vehicles reduces the emissions such as CO_2 and NO_x. In the current appraisal, a lower boundary for externalities has been found, since other effects such as noise or space savings have not been included. A total decrease of about 50% in CO_2 emissions in electric or non-motorized fleets has obtained. The emission reduction in Scenario 1 when diesel vans run the service is bounded at 25%.

One of the crucial variables to be defined is the location of the terminal. In this proposal we proposed to take advantage of the existing facilities in the markets, green points (waste materials) or even public/private parkings. Their main differences are their distance and time from the centroid of the delivering zone.

In conclusion, the implementation of a network of Consolidation Facilities in Barcelona is a viable solution to reduce the impacts caused by current urban goods distribution. Nevertheless, this solution has to be deployed taking into consideration the administrative and commercialization actions that carriers wants to continuously perform together with the retailers. The CF operator must address this issue and operate the final distribution network as it was a branch of the carrier.

11 References

- Agència d'Ecologia Urbana de Barcelona (2016), Proposta de Distribució Urbana (CDU) de Mercaderies en el Mercat Municiapl de l'Abaceria (Gràcia).
- Ajuntament de Barcelona (2020), Informe de resultats cens comercial de Barcelona 2019.
- Allen, J., Browne, M., Woodburn, A. and J. Leonardi (2014). A Review of Urban Consolidation Centres in the Supply Chain Based on a Case Study Approach, Supply Chain Forum: An International Journal, 15:4, 100-112, DOI: 10.1080/16258312.2014.11517361.
- Benjelloun, A., Crainic, T.G. and Bigras, Y. (2010), "Towards a taxonomy of City Logistics projects", *Procedia - Social and Behavioral Sciences,* Vol. 2 No. 3, pp. 6217-6228.
- Björklund, M., Johansson, H., (2018), Urban consolidation centre - a literature review, categorisation, and a future research agenda, International Journal of Physical Distribution & Logistics Management, 48(8), 745-764. https://doi.org/10.1108/IJPDLM-01-2017-0050.
- Boudouin, D. (2006). Les espaces logistiques urbains. Guide méthodologique, La documentation française, Paris.
- Browne et al. (2005), Urban Freight Consolidation Centers Final Report, University of Westminster.
- Cambra de Comerç de Barcelona (2008), Microplataformes de distribució urbana, ISBN 84-95.829-43-6.
- Cardenas, I., Borbon-Galvez, Y., Verlinden, T., Van de Voorde, E., Vanelslander, T., & Dewulf, W. (2017). City logistics, urban goods distribution and last mile delivery and collection. Competition and Regulation in Network Industries.
- Castel, A. , Fortuny, A. and M. T. Valdrí (2018), Cap a un model de distribució urbana de mercaderies (DUM) més sostenible a Barcelona: anàlisi dels instruments de planificació i propostes de millora, http://hdl.handle.net/2445/125000.
- Dablanc, L. (2005), "French strategic approach to urban consolidation.", In 1st BESTUFS II Workshop Thematic focus: *Approaches to Urban Consolidation: concepts and experiences*, London. (http://www.bestufs.net/download/Workshops/BESTUFS_II/London_Jan05/BESTUFS_London_Jan05 _Dablanc_INRETS. pdf).
- Daganzo, C.F. (1984a), The length of tours in zones of different shapes, Transportation Research B 18B:12, pp. 135-146.
- Daganzo, C.F. (2005), Logistic Systems Analysis, Springer, ISBN 9783540239147, 296 p.
- CE Delft (2018). Environmental Prices Handbook. Delft, CE Delft, October 2018
- EEA-European Environmental Agency. (2019). Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles. In EMEP/EEA air pollutant emission inventory guidebook 2019.
- Estrada, M., & Roca-Riu, M. (2017). Stakeholder's profitability of carrier-led consolidation strategies in urban goods distribution. *Transportation Research Part E: Logistics and Transportation Review,* 104, 165–188. https://doi.org/10.1016/j.tre.2017.06.009
- Generalitat de Catalunya. 2015. Observatori de costos del transport de mercaderies per carretera a Catalunya, Butlletí de transports 72. Setembre 2015. Barcelona, Catalunya, Espanya. Available from Internet: http://territori.gencat.cat/web/.content/home/01_departament/estadistica/publicacions_estadistiques/territori_i_mobilitat/observatori_del_costos_del_transport_de_mercaderies_per_carretera/butlleti_72_setembre_2015.pdf (in Catalan)
- Gogas, M. and E. Nathanail (2017), Evaluation of Urban Consolidation Centers: A Methodological Framework, Procedia Engineering, Volume 178, Pages 461-471, ISSN 1877-7058.

- Hopkin, J. M. and Simpson, H. F. (1995), Valuation of Road Accidents, TRL Report Number 163, Transport Research Laboratory.
- Janjevic, M. (2015), Urban Freight Consolidation Centres – Trends, Challenges, Solutions, Qalinca Labs, Université Libre de Bruxelles, European Cycle Logistics Conference, San Sebastian.
- Johansson, H., Björklund, M., (2017), Urban consolidation centres: retail stores demands for UCC services, International Journal of Physical Distribution & Logistics Management, 47(7), 646-662.
- Johansen B. G. et al (2014). STRAIGHTSOL Deliverable D5.1 (Demonstration Assessments)
- Kin,B., Verlinde, S., van Lier, T. and C. Macharis (2016), Is there Life After Subsidy for an Urban Consolidation Centre? An Investigation of the Total Costs and Benefits of a Privately-initiated Concept, Transportation Research Procedia, Volume 12, Pages 357-369, ISSN 2352-1465.
- Nathanail, E., Gogas, M. and K. Papoutsis (2013). STRAIGHTSOL Deliverable D2.1 (Urban freight and urban – interurban interfaces Best practices, implications and future needs).

- Navarro, C., Roca-Riu, M., Furió, S., & Estrada, M. (2016). Designing New Models for Energy Efficiency in Urban Freight Transport for Smart Cities and its Application to the Spanish Case. Transportation Research Procedia, 12. https://doi.org/10.1016/j.trpro.2016.02.068

- Nordtømme, M.E., Bjerkan, K.Y. and Sund, A.B. (2015), "Barriers to urban freight policy implementation: The case of urban consolidation center in Oslo", Transport Policy, Vol. 44, pp. 179-186.
- Paddeu, D. (2017), "The Bristol-Bath Urban freight Consolidation Centre from the perspective of its users", Case Studies on Transport Policy, Vol. 5 No. 3, pp. 483-491.
- Railway Project Appraisal Guidelines, European Investment Bank.
- Red Española de Plataformas Logísticas Intermodales para la Mejora de la Competitividad y la Sostenibilidad del Transporte de Mercancías (Proyecto REPLICA)
- Robusté, F. and D. Galván (2005). e-Logistics. UPC Edicions, ISBN 9788483018026.
- Trentini, A., Gonzalez Feliu, J. and N. Malhéné (2015), Developing urban logistics spaces: UCC and PLS in South-Western Europe, halshs-01214749.

Appendix 1. Number of retailers per type of premise

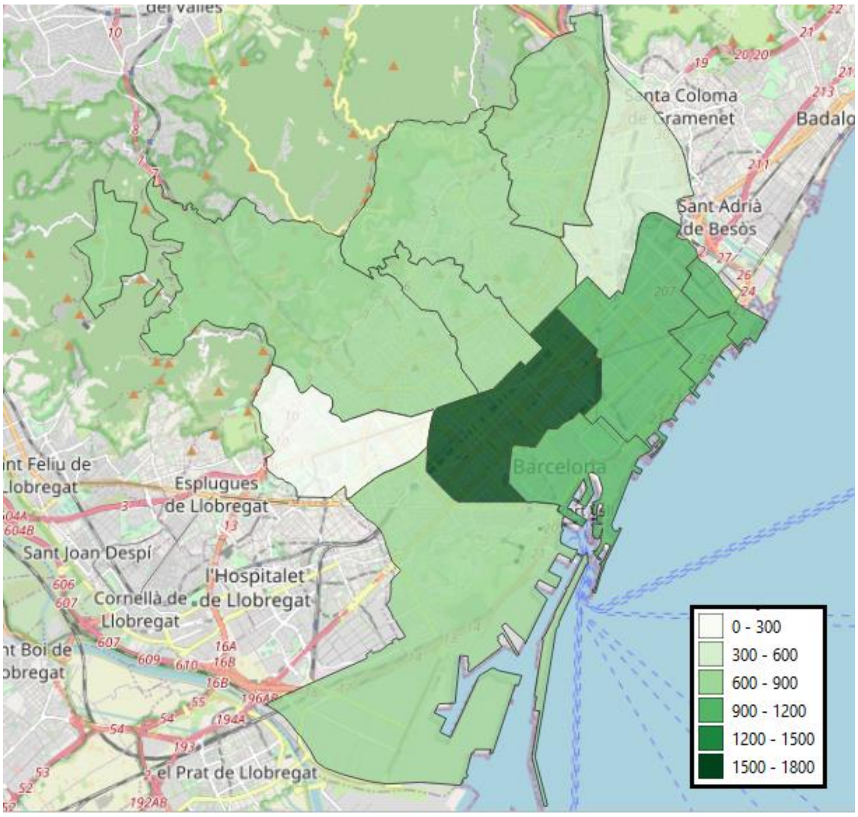


Figure A1.1 Number of supermarkets and grocery stores

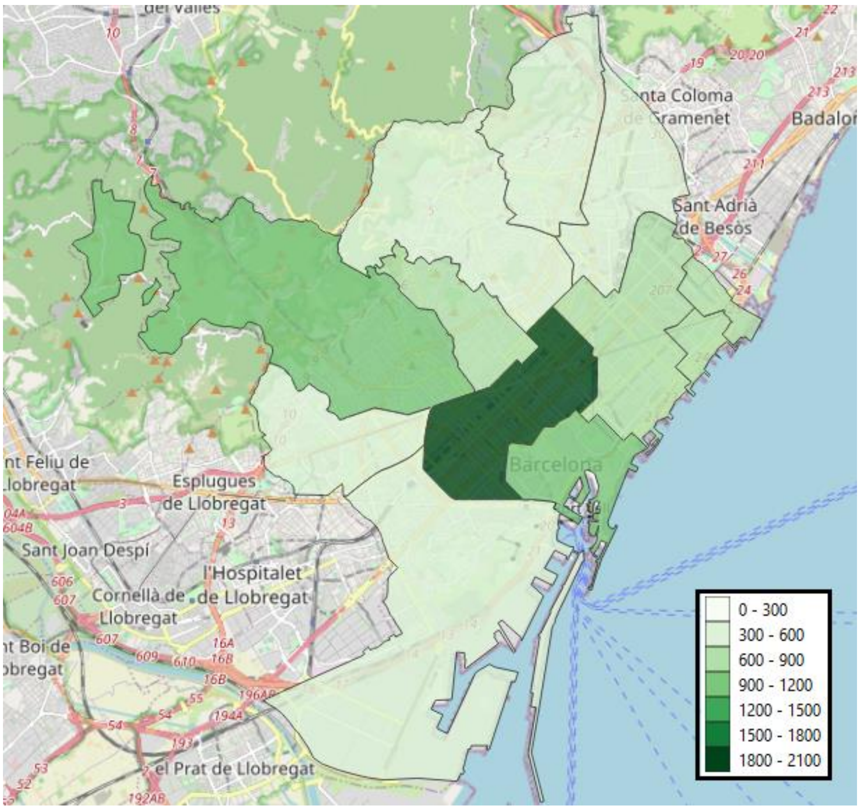


Figure A1.2 Number of personal apparel stores

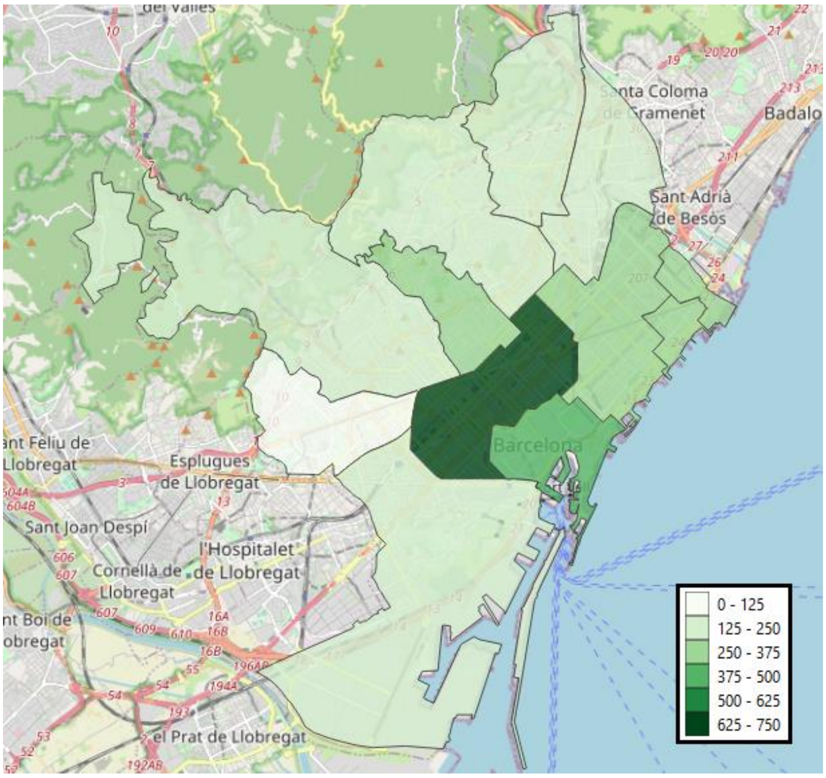


Figure A1.3 Number of leisure activity stores

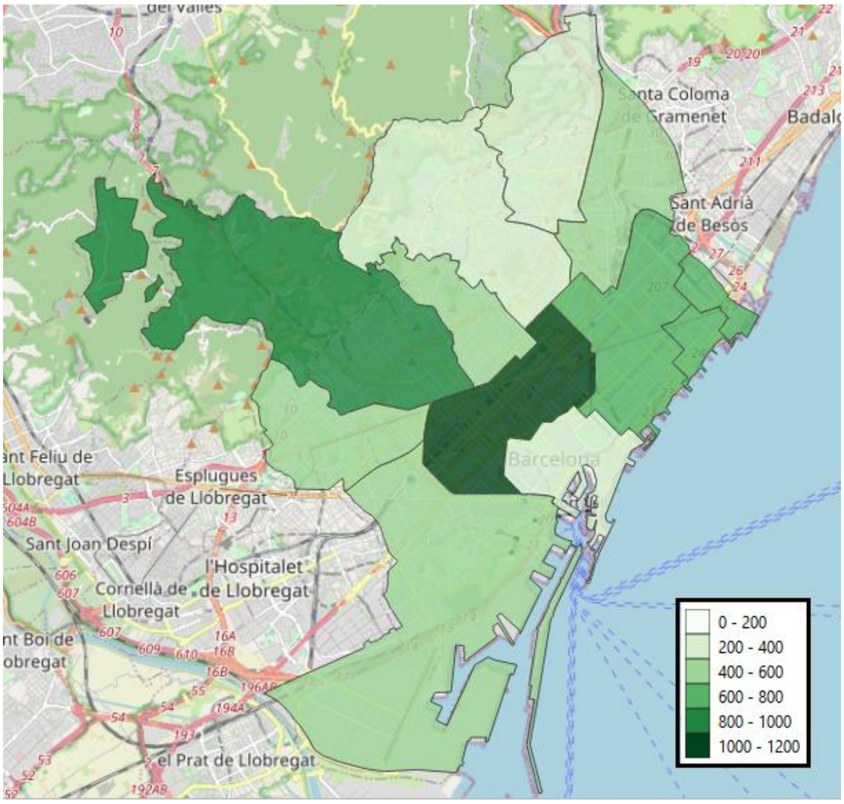


Figure A1.4 Number of public and private offices

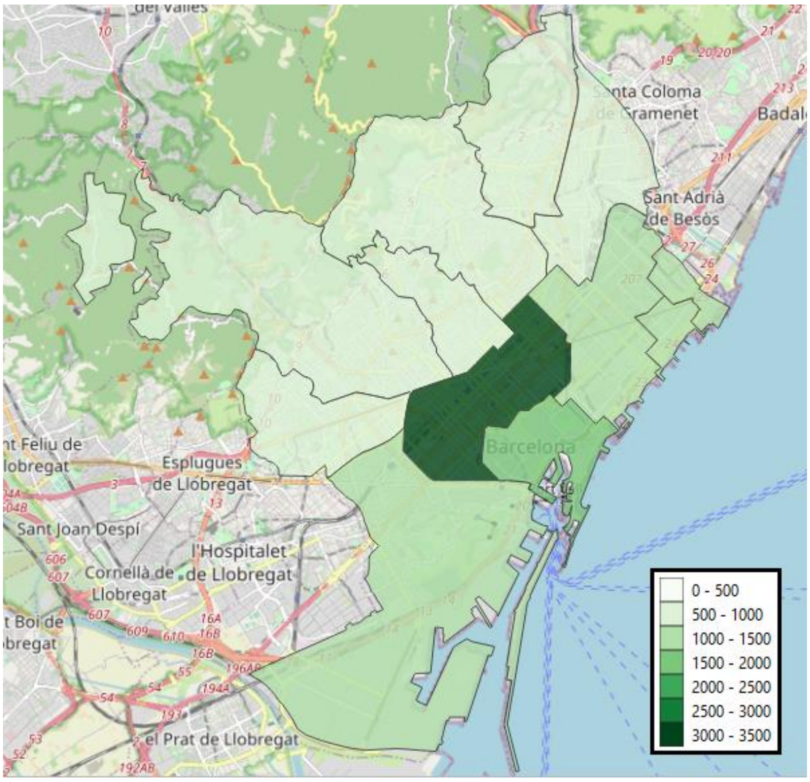


Figure A1.5 Number of Hotels, restaurants and "cafe" stores

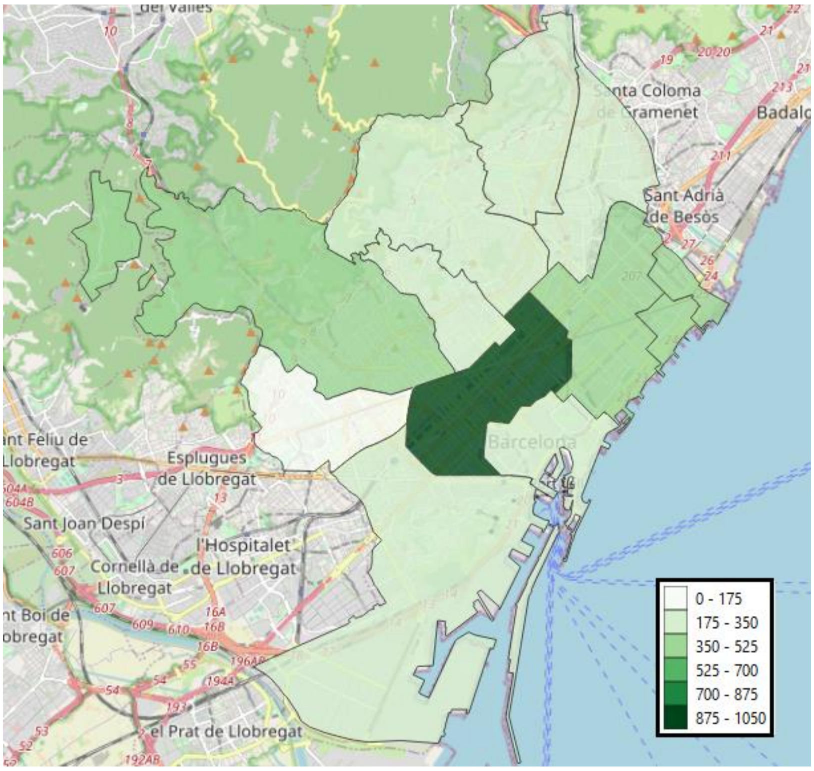


Figure A1.6 Number of household construction and maintenance material stores

Appendix 2. Other graphs and figures

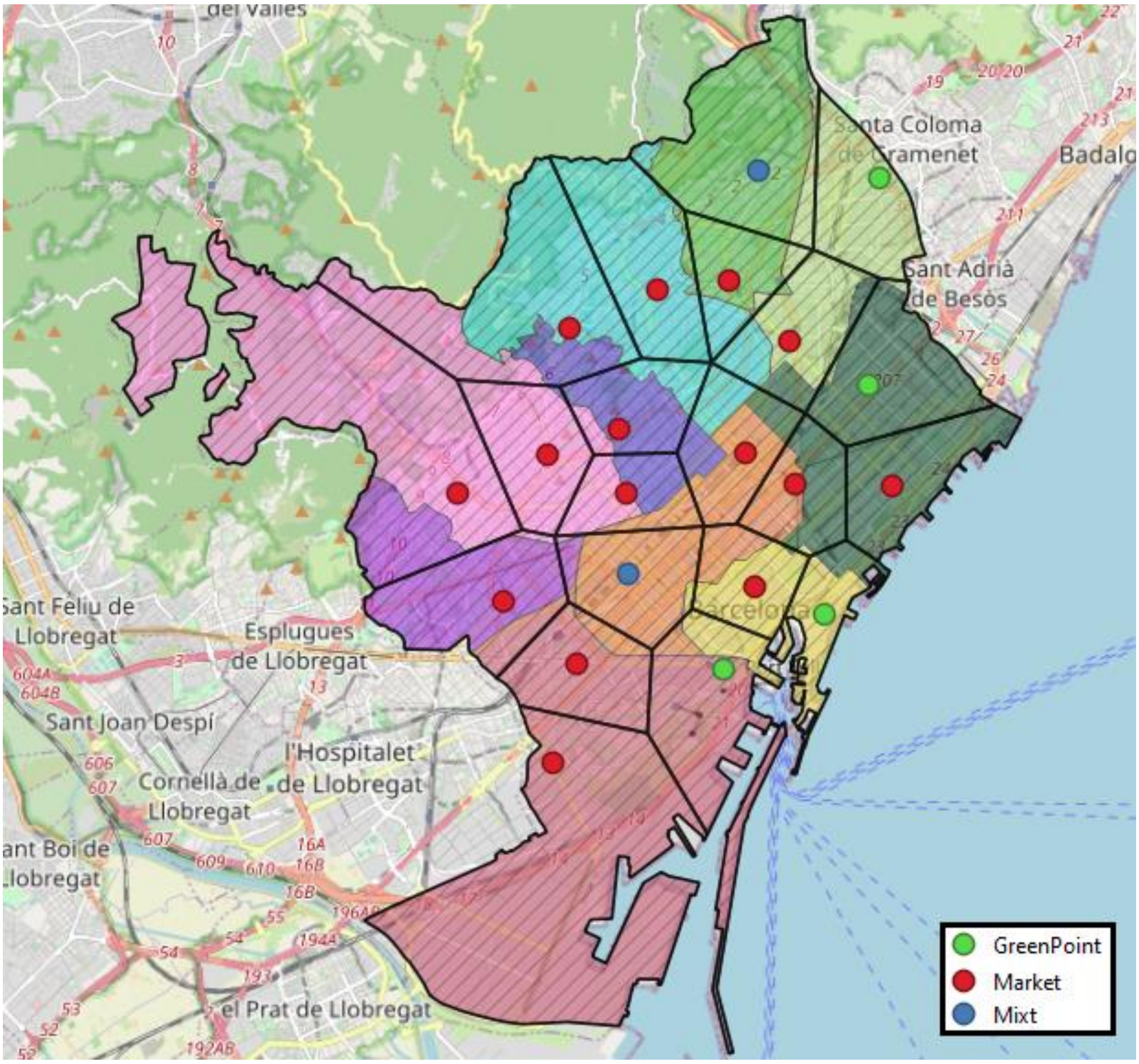


Figure A2.1 Distribution of UCCs along Barcelona

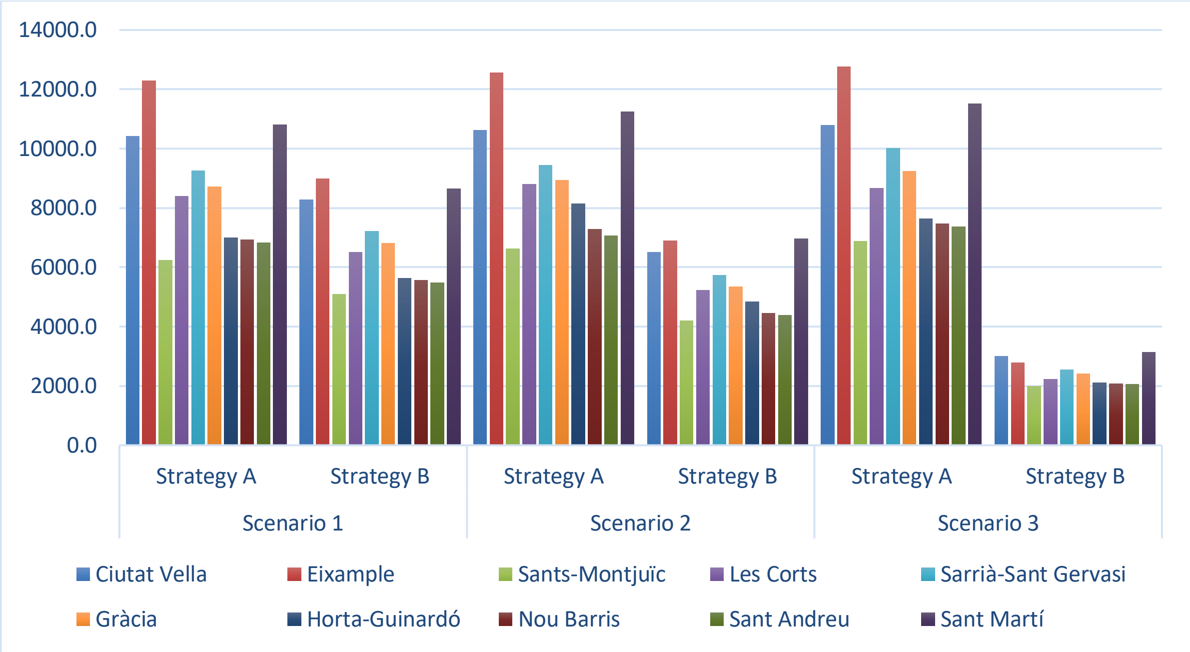


Figure A2.2 **Total cost (€/day).**