Feasibility and opportunity study of an optimized flows and storages pooling in city logistics

Parisa Dolatineghabadi

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Présentée par

Parisa DOLATINEGHABADI

Thèse dirigée par **Marie-Laure ESPINOUSE, Professeur, UGA**, et codirigée par **Karine EVRARD SAMUEL, Professeur, INP Grenoble**

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Étude de faisabilité et d'opportunité d'une mutualisation optimisée des flux et des entreposages dans le cadre de la logistique urbaine

Feasibility and opportunity Study of an optimized flows and storages pooling in city logistics

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devant le jury composé de :

Madame Marie-Laure ESPINOUSE
Professeur, Communauté Université Grenoble Alpes, Directrice de thèse
Monsieur Bernard GRABOT
Professeur, École Nationale d'Ingénieurs de Tarbes, Rapporteur
Monsieur Bruno DURAND
Maître de Conférences, Université Paris Nanterre, Rapporteur
Madame Gülgün ALPAN
Maître de Conférences, Grenoble INP, Examinatrice
Madame Valérie BOTTA-GENOULAZ
Professeur, INSA-Lyon, Présidente
Madame Karine EVRARD SAMUEL
Professeur, Grenoble INP, Invitée, Co-directrice de thèse

Abstract

City logistics, considered as the last step of supply chain management, aims to optimally plan, manage and control the freight movements within a logistical network in urban areas. Freight transportation causes significant negative impacts on the quality of living in urban areas in terms of congestion, emissions and space consumption. Collaboration has been introduced to alleviate these negative impacts; however, collaboration in city logistics projects is challenging, since additional efforts of planning and control of collaboration are significant. In recent years, pooling has emerged as a collaborative strategy that leads towards systematic collaboration between stakeholders involved while they are well-informed about the processes and have direct influence on decision making.

The aim of this thesis is to study possible forms of pooling in the context of city logistics in order to analyze conditions for an efficient pooling implementation. To this end, we have conducted a comprehensive literature review on city logistics in order to analyse and classify its different aspects. Surveying the literature also conducted to identify a lack of systematic analysis on pooling in city logistics. In order to overcome this research gap, we have proposed a general stepwise framework that aids to identify all necessary steps toward an efficient pooling implementation. Furthermore, we have introduced a novel concept, called 'typology of flow', to analyse different possibilities of logistics pooling at a first step and to identify potential constraints before pooling implementation at a second step. We have quantified the impacts of these constraints on the efficiency of pooling using a real case raised from the literature. At the end, we have used our proposed framework, novel concept of typology of flow and results obtained from our experimental analysis in order to classify important factors for city logistics pooling viability in long term.

Keywords. City Logistics, Collaboration, Pooling, Planning Framework, Typology of Flows, Scenarios assessment.

Résumé

La logistique urbaine, considérée comme la dernière étape de la supply chain, recouvre toute prestation concourant à une gestion optimisée des flux de marchandises en milieu urbain. Le transport de marchandises a des effets négatifs importants dans les zones urbaines en termes de congestion, d'émissions nocives et de consommation d'espace. Pour atténuer ces effets, une collaboration entre les différents acteurs de la logistique urbaine a souvent été initiée dans de nombreuses villes. La collaboration dans les projets de logistique urbaine est difficile, elle nécessite de réunir de nombreuse parties prenantes dont les intérêts sont souvent divergents. Ces dernières années, la mutualisation logistique est apparue comme une stratégie qui mène à une collaboration systématique entre acteurs. Cependant, elle a peu été étudiée dans le contexte urbain. L'objectif de cette thèse est de proposer une réflexion sur la conception d'une logistique urbaine innovante grâce à la mutualisation. Pour cela, nous avons effectué un état de l'art systématique afin d'identifier les différents champs de la logistique urbaine. Selon les résultats de cette revue de la littérature, nous avons constaté une absence d'analyse sur les aspects opérationnels de la mutualisation. Afin de remédier à ce manque, nous avons proposé un cadre général qui aide à identifier toutes les mesures nécessaires en vue d'une mutualisation efficace. Nous avons développé un nouveau concept, appelé « typologie des flux » permettant d'analyser différentes possibilités de mutualisation en logistique urbaine et ensuite d'identifier les contraintes potentielles liées à la mutualisation. Nous avons quantifié les effets de ces contraintes sur l'efficacité de la mutualisation utilisant un cas réel issu de la littérature. Enfin, nous avons mobilisé notre typologie des flux et les résultats de notre analyses expérimentales afin de classifier les facteurs clés permettant d'aborder la viabilité de la mutualisation à long terme.

Mots-clés. Logistique urbaine, Collaboration, Mutualisation, Cadre de planification, Typologie de flux, Évaluation de scénarios.

To

Sohrab, my everything

Maman and Baba, the best parents ever

Ramin, the best supportive brother

Jeiran Nana, my heroine, R.I.P

My grand-parents

All my family members, friends and teachers

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General Introduction

By 2050, around 70% of the world's population will live in cities (Lee, 2014). In this way, economic growth, improvement of urbanization environmental effects, resolving urban unemployment, safe urban freight transport and regional economy development will all be affected more and more by city logistics. City logistics deals with the logistics and transportation activities in urban areas and is spotted as the last stage of supply chain management. Thus, an appropriate and optimal city logistics system will have a great impact on the quality of environment where people live and work (Rao et al., 2015). City logistics issues have been continually studied in different directions since ten years. The most challenging difficulties in city logistics are high number of involved stakeholders and their contradictory objectives, diversity of urban flows, the dynamics nature of the system, negative environmental impacts, tasks dependency, demands increase regarding e-commerce growth, competition leading toward zero delay, regulation leading up to access restriction, concerns to avoid fatality caused by distribution in the cities, different urban geography and complicated relation between all actors and actions.

To cope with these issues, different city logistics' initiatives and measures have been emerged during the last ten years. The main objective of these initiatives is to ensure efficient freight movements in urban area whilst satisfying consumer and business demand and minimizing the externalities (Dablanc, 2009). Additionally, with regard to the importance of freight transportation in cities in order to reach economic development, involved stakeholders have provided new services (Rodrigue 2013, Dablanc and Rodrigue 2017). The required resources in urban areas (such as land, vehicles and personnel) are either scarce or expensive and the implementation of the proposed initiatives needs large investments. Furthermore, collaboration has been introduced as a promising solution (Gonzalez-Feliu and Battaia, 2017).

Collaboration is a very broad and encompassing term, which can take place at different stages: transactional collaboration, informational collaboration and decisional collaboration (Gonzalez-Feliu and Morana 2011). Hence, "pooling" has been proposed as a collaborative strategy to highlight the link between horizontal collaboration and sustainable development in order to achieve the environmental, economic and societal objectives (Moutaoukil et al. 2012). Moreover, pooling in city logistics is interpreted as a systematic collaborative solution where the ultimate goal is to share required resources, either material or immaterial, in order to efficiently perform last mile delivery. In other words, pooling is defined as the mutual and temporary use of resources while all stakeholders have direct influence on decisions making and are well-informed about all processes (Gonzalez-Feliu and Battaia, 2017). In recent years, pooling has been become a debatable subject in city logistics and being studied under different definitions and forms such as delivery system pooling, resources pooling, and information pooling (Gonzalez-Feliu and Morana 2010, Pan 2010, Chanut et al. 2011, Blanquart and Carbone 2010; Senkel eta al. 2013, Durand et al. 2013).

With regard to the current interest in pooling and its contributions for achieving an efficient city logistics system, in this thesis, we study in-depth city logistics pooling and the required conditions for its implementation. To do so, we focus on delivery system pooling and resource pooling in the context of city logistics. In this way, the main research questions of this thesis are as follows:

- How to achieve a successful pooling in a complex city logistics system?
- How pooling can be realized in a city logistics system?
- How to design different forms of pooled distribution network in city logistics?
- What are the potential constraints against pooling implementation?
- How these constraints can affect pooling efficiency?
- How to guarantee a viable pooling in city logistics?

In order to respond to these questions, **chapter 1** of this thesis is dedicated to provide an extensive literature review on city logistics. The aim of this review is to recognise all problems and issues related to city logistics on one hand and to identify implemented measures, proposed initiatives and innovative solutions in this context on the other hand. The results obtained through this review help us to know different aspects of a city logistics system in order to be able to study the possibility of pooling in such a system. **Chapter 2** provides a comprehensive discussion on the interest of pooling integration into the urban freight distribution network. To this end, a general stepwise framework is proposed in which all required steps in order to drive towards a successful pooling implementation is discussed. **Chapter 3** is about operational aspects of pooling. Our proposed framework reveals the importance of system identification in city logistics for a successful pooling implementation. The reason is that pooling causes inevitable changes in the city logistics system, which is often a conglomerate of sub-systems, more or less interconnected, with rather independent functioning. Hence, an overall understanding of the system with regard to the functionality of each sub-system is crucial. To do so, we discuss more deeply about the city logistics system to describe its main elements by introducing the concept “Typology of Flow”. This concept helps us to recognize possible delivery system pooling strategies through combination of innovative solutions in the context of city logistics. Furthermore, it leads us towards the identification of potential constraints before pooling; we identify two groups of constraints, policy-oriented constraints and compatibility constraints. In **chapter 4**, we propose a mathematical approach in order to evaluate impacts of these constraints on resource pooling efficiency. Several operational key performance indicators are also proposed in order to quantify pooling impacts, both advantageous and disruptive ones. In **chapter 5**, we define six scenarios according to the identified constraints and test them on a real case study raised from the literature. C**hapter 6** is devoted to a discussion on viability of pooling in city logistics. High number of failed projects in city logistics justify the importance of this kind of discussion for any initiative including pooling. At the end, we provide an overall discussion about pooling and its benefits and contribution to the city logistics system and main perspectives for the future researches. Overall structure of this thesis is presented in figure I.1.

Finally, the Support from Academic Research Communities (ARC8), Auvergne-Rhône-Alpes, France for funding this thesis is gratefully acknowledged.

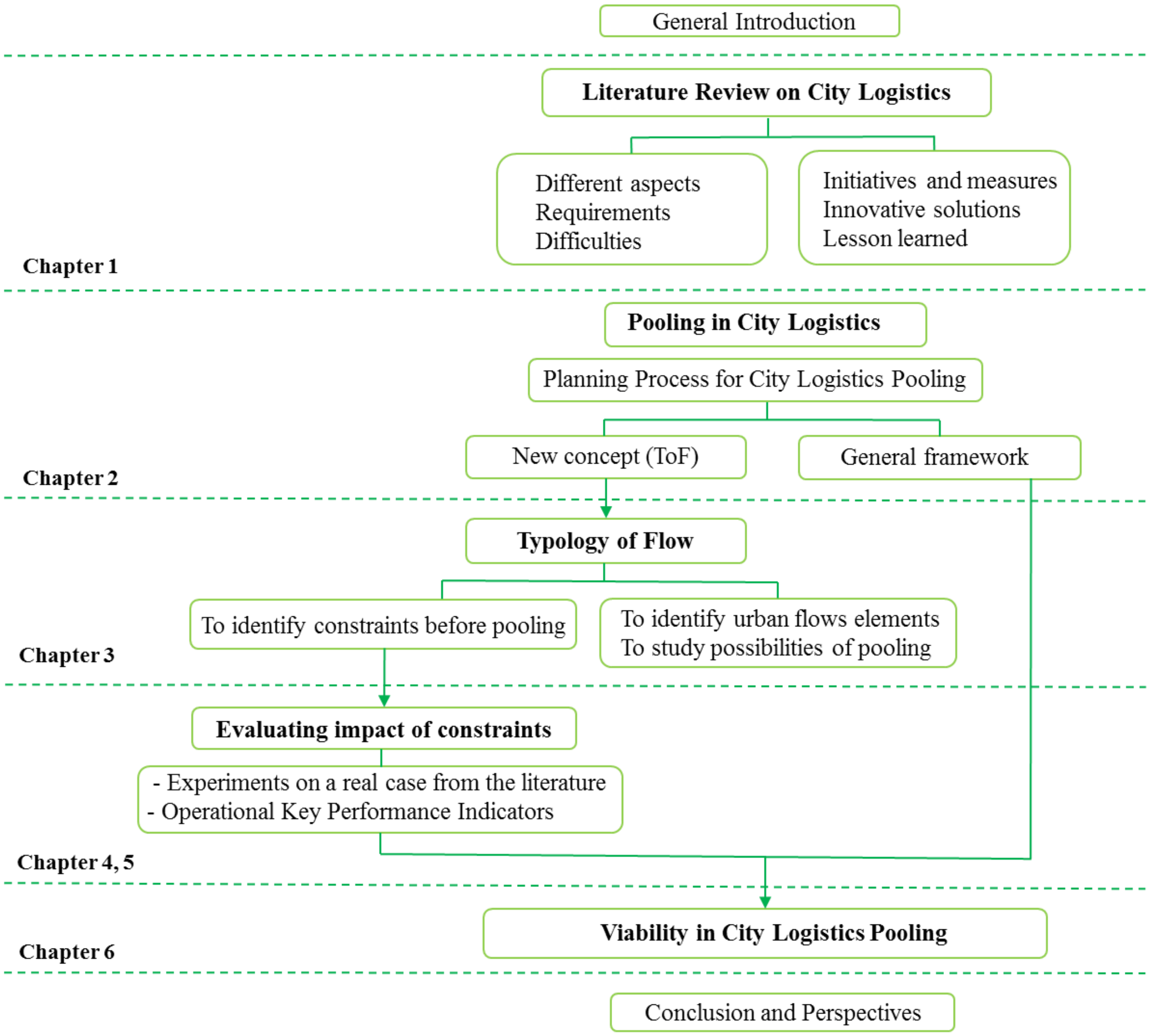


Figure I.1. Overall structure of this thesis.

Chapter 1. City Logistics

Introduction

City logistics is a field that studies the best solutions for urban freight distribution in order to increase urban mobility and contribute to achieve a sustainable city with decreasing negative externalities of transportations activities in urban area (Morana, 2014). Hence, it has become an immense research field in recent years. This chapter is dedicated to focus on this topic by proposing an innovative approach in order to break this problem down into several small sub-problems including different aspects of the original problem to investigate each of them more deeply and precisely. To do so, we start carrying out a comprehensive literature review on city logistics in order to highlight its characteristics, properties, issues and challenges. The objective of this review is to identify potential research directions in this field of study. During our research, we found that several authors have conducted in recent years some vital literature reviews focusing on substantial parts of city logistics issues. Some reviews have been conducted on different city logistics modelling efforts considering its trends and gaps (Anand et al. 2012, Comi et al. 2012, Bozzo et al. 2014 and Anand et al. 2015). City logistics development has been discussed by reviewing the international conferences on city logistics in 2009-2013 (Behrends, 2016). Using electric vehicles for goods distribution problem, as a potential initiative solution for city logistics has been also reviewed to propose some research perspectives in this area of study (Pelletier et al., 2014). Another review endeavours, reviews on challenges in urban freight transport planning (Lindholm and Behrends, 2012), the impact of public policies on urban mobility (Maggi and Vallino, 2015) and methodologies to assess urban freight initiatives (Zenezini and De Marco, 2016) can be referred to. Another paper has been presented which offers a more global view by referring to all journal articles on city logistics published between 2000 and 2015. They overview urban logistics solutions and methods to identify specific key contributors in each field by performing a citation network analysis (Lagorio et al., 2016). Each of these reviews has paid particular attention to a specific part of city logistics.

With regard to the previous works, our main goal in this chapter is to provide a comprehensive and well-structured review of all different aspects of city logistics in order to introduce various aspects of this research field, specify the research trends, and also to identify more and less noticed aspects of the topic. To this end, we propose an approach that combines a bibliometric analysis with a systematic literature review. This analyse is performed on more than 430 scientific works (journal articles, conference papers, and book chapters), written in English between 2010 and 2017. This period comprises a steady increase in contributions regarding city logistics. Our approach has led us towards a literature classification based on keywords listed in the articles. We propose six different categories to address systematically and efficiently various dimensions and aspects of this field. For each category, an extensive analysis of the main contributions and potential research directions are presented. It is worthy to mention that articles published between 2017 and June 2018 have been also reviewed in order to provide steady research directions.

The rest of this chapter is organized as follows. Section 1.1 presents the significance and position of city logistics. Section 1.2 describes our applied methodology for performing a systematic literature review and a bibliometric analysis. Section 1.3 is dedicated to present the results of the bibliometric analysis. Sections 1.4 presents literature classifications as results of our systematic literature review.

1.1. City Logistics: significance and position

City logistics is one of the most argued concerns in most cities around the world regarding recent phenomena such as urbanization and the rise of citizen's expected welfare level (Bozzo et al., 2014). City logistics is considered as the last step of supply chain and described as "The process of optimizing both logistics and transport activities done by private companies in urban areas while considering the traffic environment, traffic congestion and energy consumption within the framework of a market economy" (Taniguchi et al., 1999). The main objective of city logistics is to propose a proper planning for goods distribution within a city (Morfoulaki et al., 2015). It aims to optimally plan, manage and control the freight movements within a logistical network in a metropolitan area considering integration and coordination among involved stakeholders (Amaral and Aghezzaf, 2015). Efficient city logistics creates more productive and attractive urban areas (Taniguchi et al., 2014). City logistics is a complex system as there are numerous stakeholders involved in it with almost contradictory objectives, figure 1.1.

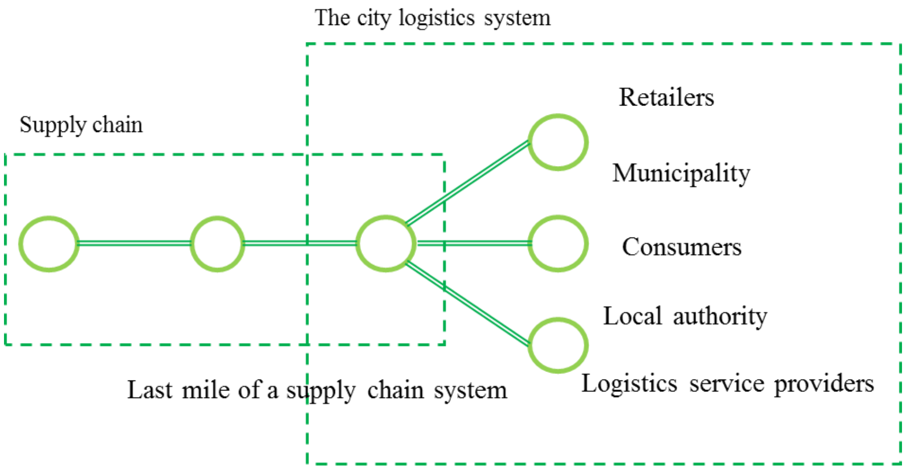


Figure 1.1. The complexity of a city logistics system (Björklund et al., 2017).

Figure 1.2 illustrates the number of academic studies published in city logistics between 2010 and 2017 including articles in peer-reviewed journals, conference papers, and book chapters. According to this chart, the number of publications per year within the under studied time frame does not follow a specified pattern, but basically an ascending trend can be accepted presenting scholars' attention to this area of research. It is worth mentioning that, since city logistics is a multi-disciplinary problem, this increase has not occurred merely on particular topics; in recent years, various issues of city logistics have been defined and discussed.

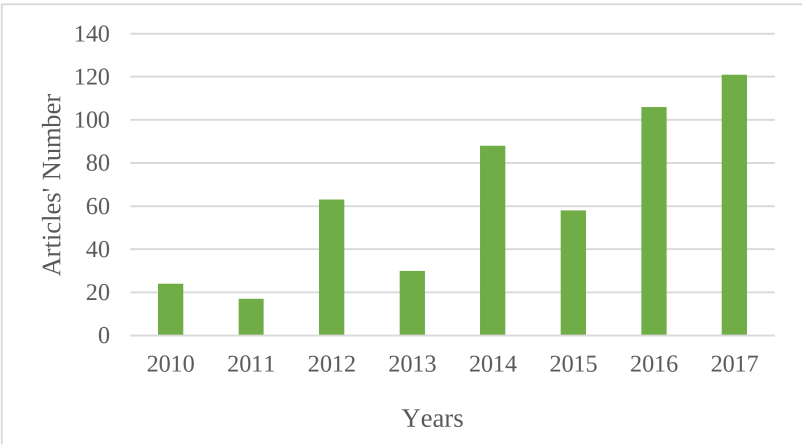


Figure 1.2. Number of academic publications on city logistics.

As previously mentioned, the population living in cities is growing day by day and consequently, urban areas are expanding. On one hand, technology development such as e-commerce offers new services that increase end customer expectations, for instance, same day delivery. On the other hand, satisfying all citizens' needs requires enormous resources and infrastructure deployment as well as efficient planning and managerial efforts that are extremely costly. Hence, resource sharing is currently being discussed in different scientific articles as well as communities as an achievable, reliable and affordable solution (Evrard Samuel and Carré, 2015). However, the first difficulty of resource sharing is its demand for a high level of collaboration which is hard to accomplish considering all the different stakeholders involved with contradictory behaviours and expectations. The second difficulty is related to the lack of reliable information systems to support collaborative activities. It is a far underestimated issue in practice mostly because of the unwillingness of stakeholders to share their information and local authorities' negligence in gathering information for city logistics.

Despite all these difficulties, researches in the city logistics domain are increasing with the common objective of proposing innovative solutions. There is a high number of interconnected problems that catches the attention of researchers. Beside well-known and accustomed problems in city logistics domain such as: urban freight transportation, urban distribution center, urban consolidation center, last mile delivery problem and urban goods movement, some new concepts, which have emerged and been discussed in recent years have emphasized a high level of resource sharing regarding to infrastructure, vehicles and routes to mitigate the inefficiency of experienced results (Fatnassi et al., 2016). Physical Internet is one of those interesting concepts that its confluence with city logistics creates hyperconnected city logistics (Montreuil et al. 2013, Crainic and Montreuil 2015).

1.2. Methodology

City logistics is a research area that crossbreeds several disciplines ranging from Social and Human Sciences to Engineering Sciences. In order to understand the status of this large field, more than 430 research works have been surveyed and analyzed in this paper. Applied methodologies to perform a literature review have practically the same procedure adopted in different fields of research (Wee and Banister 2016, Gahm et al. 2016, Behrends 2016). Generally, in the first step, the objective of the literature review and the research questions are identified in order to keep the research in its own direction. Then a comprehensive search is conducted to find all related articles. After constructing the reliable database including relevant articles, analyses with different objectives can be performed.

Our methodology used to review and analyse the literature on city logistics is presented in figure 1.3. First, the purpose and scope of the study are defined (I). The main objective of this research is to provide a general review of the city logistics problem firstly by investigating the main issues, concerns defining the body of this problem and secondly by analyzing available solutions, and propositions in the literature to address their pros and cons. In a second step, related keywords, which enable us to conceptualize the research and help to find relevant articles, are identified (II). We started our search by defining for the most known keywords related to the city logistics general definition such as city logistics, urban logistics, urban freight transportation, urban freight, city distribution, and urban distribution. Scientific platforms such as Science Direct, Web of Science, Google Scholar, Wiley Online Library, Informs, and Springer have been searched to find articles released since 2010. Concurrently, the main authors are identified in order to perform the second search according to their name. In addition, articles that had more than 10 citations were selected to find related articles through citation relations. To focus purely on city logistics, less related or non-related articles are eliminated. Therefore, the next step is to construct a primary database of the relevant articles selected among the articles initially found by discovering their scope and context through evaluating the article's title, abstract, keywords and full text (III). With regard to the basic database, the search continues iteratively for new pertinent articles which have cited the primarily articles. In the analysis phase, a bibliometric analysis regarding journal, papers' authors, publication year and papers' type is performed (IV a); in parallel, a systematic literature review is organized concentrating on papers keywords (IV b). The detail of steps IV a. and IV b. will be explained in section 4 and 5. The last step proposes different classifications as a result of the systematic analysis (V). Eventually, by merging information retrieved from bibliometric analysis with our proposed classification based on the systematic literature review, the final categories are presented (VI).

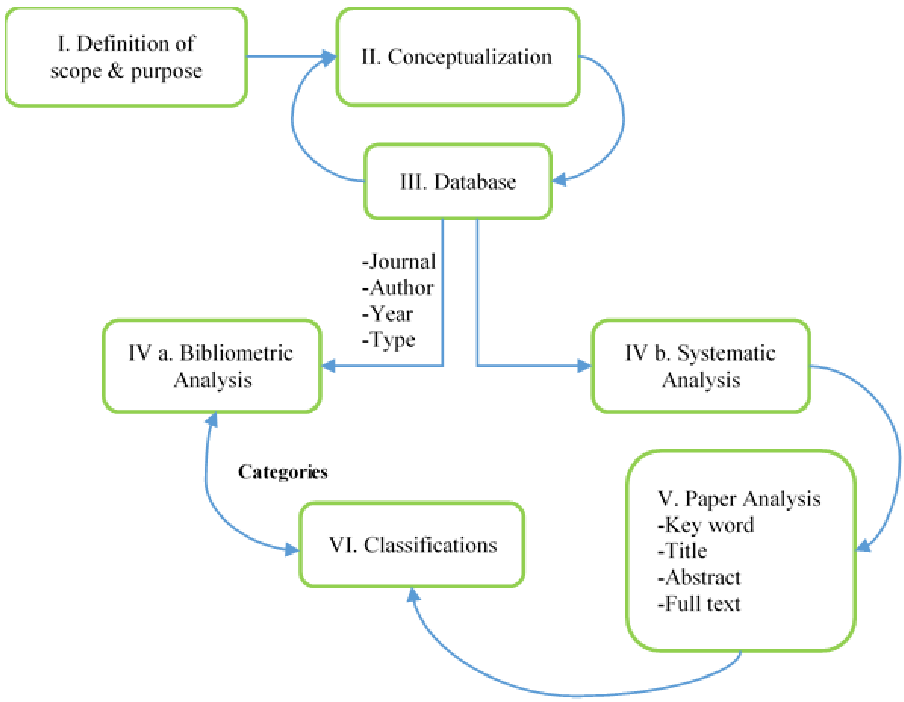


Figure 1.3. Applied framework for literature analysis.

1.3. Bibliometric Analysis

Bibliometric analysis can be conducted for different purposes (Prevot et al., 2010). Our objective is to efficiently interpret and scan the structure of city logistics. At first, we mostly focused on information such as a paper's author(s), title, type, publication year, journals' information, keywords and affiliation. This information assists in enriching the literature analysis and proposing a comprehensive framework for city logistics. On one hand, we merely focus on papers type analysis to identify different research trends in conference papers compared to journal articles and books. On the other hand, as the geographical conditions change from one city to another, different cities drive researchers to investigate a suitable solution for their problem, so we study a paper's regional profile in order to benchmark comparable information.

1.3.1. Paper Types

In this study, we take into consideration three different types of scientific works: 1) conference papers, which formed the highest percentage of the researches on city logistics in the last seven years; 2) articles published in scientific journals; 3) books and book chapters. Figure 1.4 represents the percentage of each research work type per year. This figure shows that the number of research works in city logistics is exponentially increasing, and this growth has been obvious since 2012 for the total number of published works, especially for conference papers.

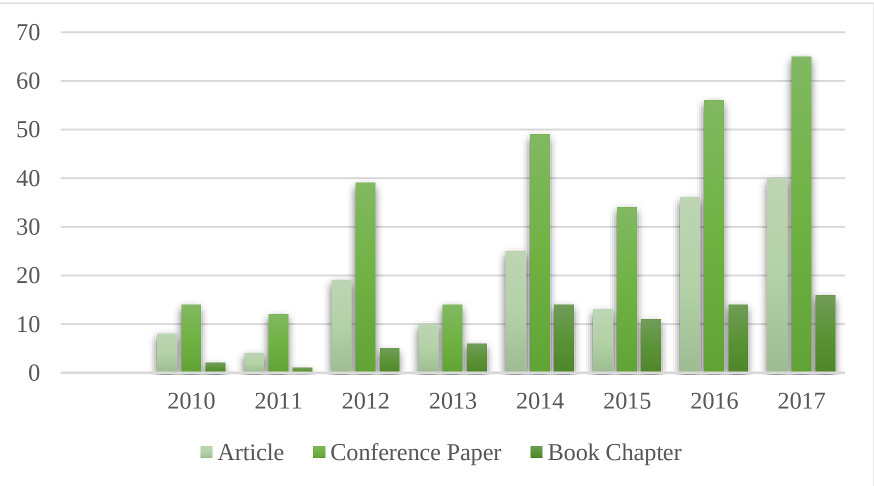


Figure 1.4. Classification of different scientific works by origin and by year.

All conference papers and journal articles have been investigated through their research nature. Around 52% of articles are empirical, which means they rely on at least one case study. This percentage increases to 63% when we just consider conference papers. This shows that in city logistics, firstly one of the most important steps is to profoundly know real world cases, as in the second step this knowledge could guide us to propose solutions which are reachable as well as feasible in the short term as they are highly demanded in practice. Most of the conference articles are attempting to investigate this phase of the city logistics problem before concentrating on solution propositions and methods.

1.3.2. Paper Regional Profile

We considered the affiliation of the first author to assign the research works to the countries. The classification of articles based on region proves that each continent has its own share, albeit low, in city logistics research. A high number of articles has been published by European countries, especially France, Italy, Poland and the Netherlands, figure 1.5 (a and b). This heterogeneity highlights different city logistics environments in Europe compared to other continents. In European countries, the most important issue is to deliver micro-size shipments into dense, historical city centers within larger urban areas. Contributions are mainly centered on improving last mile deliveries through narrow streets and historical centers to preserve heritage sites and, in parallel, attaining sustainable and socially efficient delivery systems. Local authorities in these countries are extremely interested in designing appropriate restrictions and policies to limit the number of vehicle movements in congested areas (Muñuzuri and Gonzalez-Feliu, 2013).

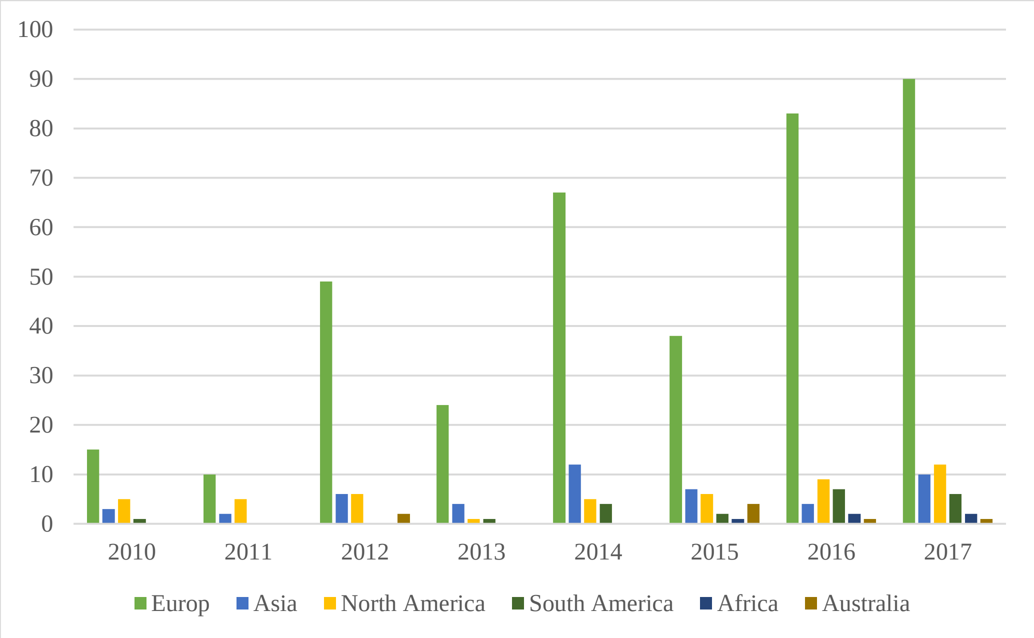


Figure 1.5 (a). Regional profiles by continents.

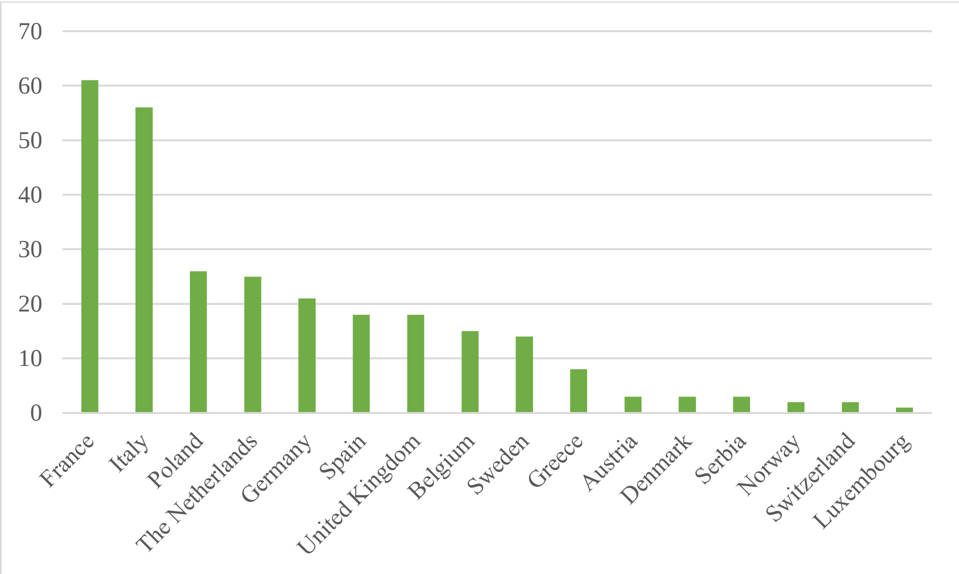


Figure 1.5 (b). Regional profiles, comparing European countries.

1.4. Literature classification derived from systematic literature review

With reference to the reviewed articles, we noticed that the keywords used by the authors were highly diverse, which reveals the magnitude of the scope of city logistics, the enthusiasm generated by it and its relative emergence. It also highlights the lack of a comprehensive framework to organize the studies in this immense field of research. A systematic literature review is a method that will enable us to locate previous studies, analyze contributions, synthesize data, conclude based on existing references, explain gaps and propose future research directions based on what has not been studied yet (Thomé et al., 2016). We propose a classification based on keywords used in the articles. Then this classification led to the identification of six different categories. After implementing the top-down methodology explained above, a bottom-up approach was employed to classify the keywords used in articles, and then to categorize them. The result of the approach is presented below.

The way we conducted keywords analysis is explicitly presented hereafter. Keywords are worthy representatives for the scope of each article. Their diversity and dissimilarity of keywords used reveal the propagation of city logistics issues, its various aspects and, the lack of consensus even among authors. This leads us to categorize keywords as shown in figure 1.6.

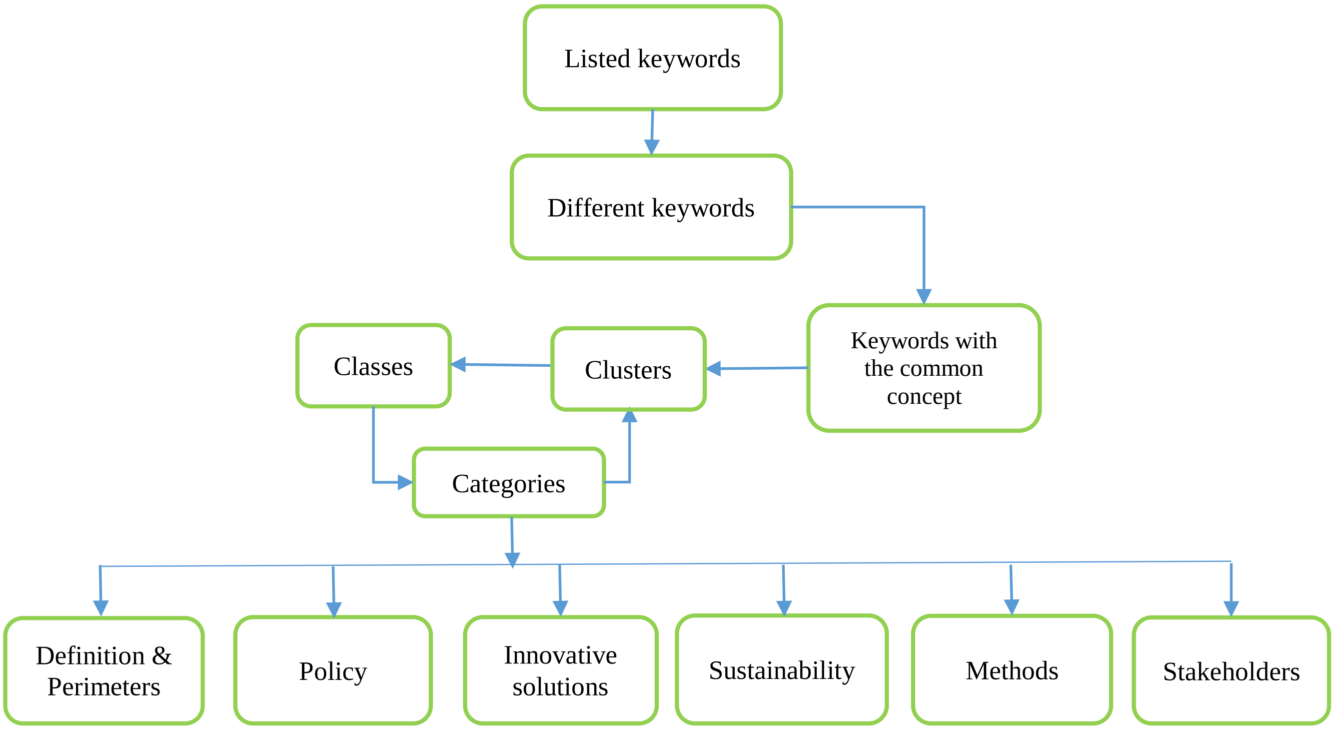


Figure 1.6. Keyword categorization procedure and final classification.

The first step is to group the keywords with common concepts into different clusters. We attempt to make several groups, even if they are not the arranged group in order to be able to review them more precisely. In this way, keywords are sorted to the clusters and the remaining keywords (which were cited only once) were discarded. Then, clusters were organized into different classes. As some keywords could be assigned to more than one class, the most related one is selected for each of them. Reassessing the proposed classes led to final categories. The assignment of keywords to clusters and then to the classes are reviewed iteratively to ensure a suitable allocation. These categories not only present all the different aspects of city logistics at a glance but also highlight the core of research activities in recent years. Six categories are introduced as follows: 1) Definition and Perimeters, 2) Policy, 3) Innovative Solutions, 4) Sustainability, 5) Methods and 6) Stakeholders. Each category will be explained in the following sub-sections. It is necessary to note that the words used to name categories are derived from keywords.

1.4.1. Definition and Perimeters

An ideal framework to conduct a study on city logistics commences with perimeter definitions, which could clearly define the problem's objective and its different aspects as well as initial expectations. This category comprises all keywords used to define different aspects of city logistics. The complexity and diversity of city logistics is reflected here in referring to different classes. We tried to distinguish between the close concepts to clarify their position in city logistics. The result of this effort is depicted in figure 1.7, which includes all the perimeters of city logistics. Since city logistics is considered as the last step of supply chain management, keywords including supply chain frequently appear in city logistics literature. Thus, city logistics is presented as a subset for a supply chain. However, if freight transport exists in different steps of supply chain, in city logistics, freight transport is considered only in an urban area. Logistics is a general concept, which comprises several activities, but in the city logistics domain, only logistics activities within cities are considered. Types and goals of logistics have been noticed such as logistics land use (Diziain et al., 2012), green logistics (Jedliński, 2014), and intermodal logistics (Bandinelli et al., 2016). Distribution in city logistics reflects freight distribution in the urban area, considering specific conditions (accessibility restriction, time windows, high demand rate, etc.). Delivery is a subset of distribution, and nowadays it is a notable issue in terms of pick-up and delivery spaces in the cities, mainly in European countries. Another important factor in city logistics refers to urban area that is mainly defined by the size, character and desired quality of the area studied. The flow of merchants within the city by the goal of distribution makes urban goods movement an important issue in city logistics. The last mile delivery issue, which has dramatically increased in recent years combine distribution with delivery purpose.

All these sub-problems could be handled by different points of view through designing new network or facilities, providing new infrastructures such as logistics information platforms (Liu et al., 2014) and geographical information systems (Guerlain et al., 2016) or management approaches such as freight distribution management (Jiang and Mahmassani, 2014) and freight demand management (Jaller et al., 2016).

Our analysis reveals that keyword citation for each class has been annually augmented, although there are some issues, which need to be more elaborated and developed. Urban goods movement has been studied mostly in France as a tool for urban planning, Delivery shows a sharp increase which could be related to e-commerce emergence in recent years and its effect on the pattern of the demand for goods. Urban goods movement has an unstable trend. Infrastructure has been noticed recently as its importance on the efficiency of city logistics is claimed (Jha et al., 2012). Design and management possess the smallest number of articles in this category.

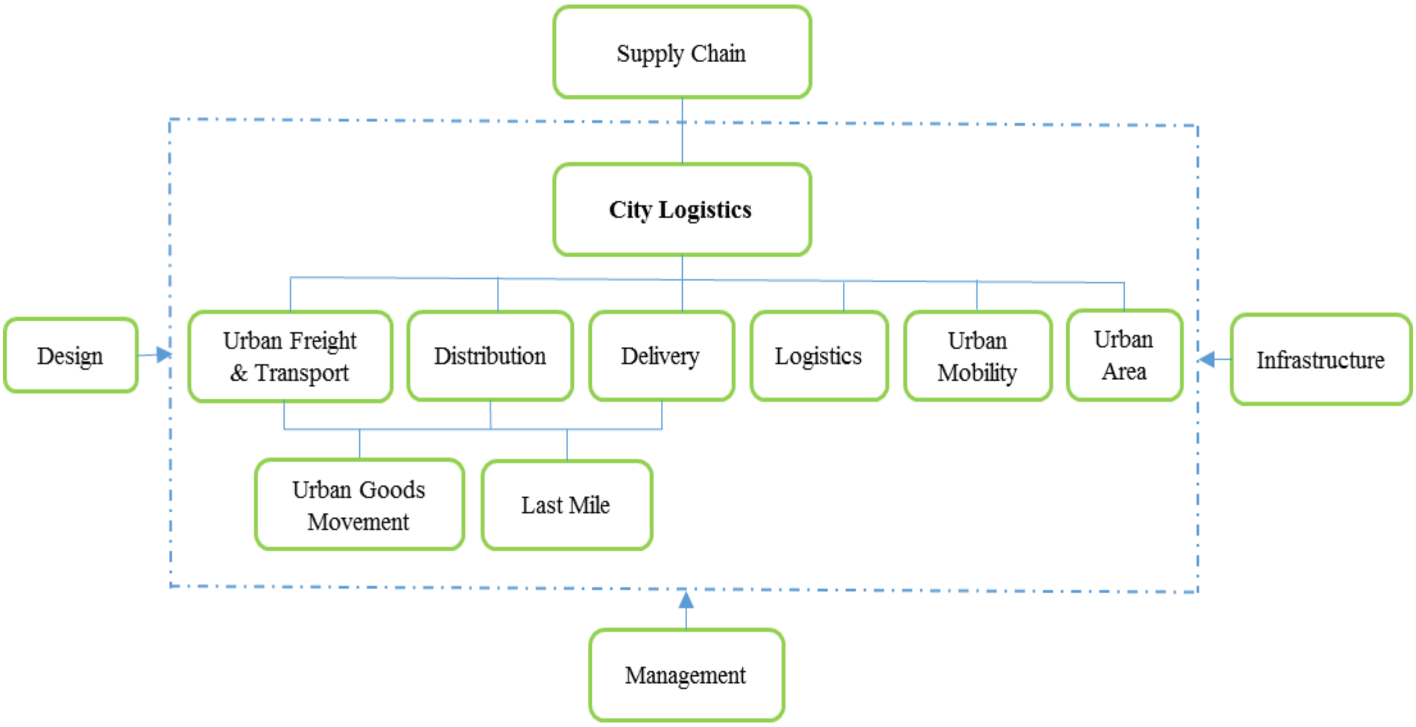


Figure 1.7. Definition and perimeter categories extracted from keywords.

Regarding the definition and perimeters, city logistics not only comprises urban freight transportation and distribution, but also encompasses the goods handling and storage, waste and return management and home delivery services. Most articles in the literature focus significantly on urban freight transportation. Regarding urban goods storage, a growing number of papers have focused on innovative storage solutions developed to facilitate inventory management (Crainic et al. 2010, Dablanc and Rakotonarivo 2010, Perboli et al. 2011, Baldi et al. 2012, Dablanc 2014, Winkenbach et al. 2015, Gonzalez-Feliu and Salanova

Grau 2015, Aljohani and Thompson 2016, Sakai et al. 2017, Patier and Toilier 2018). Despite these studies, there are still the lack of attention for several aspects of urban freight transportation. The seasonality of activities in city centers has not been much discussed and could gain better consideration as an impacting factor in urban goods demand. In the same way, reverse flows including both waste and return flows (or called non-delivery flows) (Buhrkal et al., 2012) have received less attention; especially return flows offering a new range of services that could be proposed to the retailers, and may contribute to increase urban goods movement efficiency and create new business models. In addition, contributions on reverse logistics focusing on waste collection, end-of-life goods collection and simultaneous distribution and collection (Lin et al. 2014) could be adapted to the context of city logistics in order to develop new solutions. The solution implemented in Zürich to collect bulky waste with the tramway is an example of what can be done in a large city to improve waste collection.

Home delivery known as a Business to Consumer (B2C) service is also a disputable topic in city logistics. Morganti and Gonzalez-Feliu (2015) have identified constraints attached to these flows. A recent study has been conducted to study operational models for home delivery. The authors have analyzed 31 case studies across five continents in order to identify diverse set of operational setups for home delivery (Winkenbach and Janjevic, 2018). Increasing competition between logistics service providers have caused to offer a new option called same-day delivery. This service concerns merely end-consumers in the B2C market. Regarding the dynamic nature of same-day delivery operations, this innovative service leads to interesting new optimization challenges (Savelsbergh and Van Woensel, 2016). An avenue for the future research can be to respond to this question that despite the fact that same-day delivery services is not necessarily environment friendly. It has been shown that crowdsourcing is a promising solution for lessening the time, fuel, and emission cost related to same day delivery service (Lin et al., 2017). However, with regard to the importance of same-day delivery in providing high level of service and its ability to address effectively the requirement of last mile delivery, more evaluation and analysis necessitate to assess its functionality and to clarify its advantages and backwards.

Urban mobility is a key challenge in most European countries (van Rooijen and Quak, 2014). To reach this, efficient management of freight transport combined with passenger transport in urban areas is required (Maggi and Vallino, 2015). The discussion about the impact of electric cargo bikes uses in in going toward sustainable mobility is an example for efforts in this context (Melo and Baptista, 2017). Another study has presented a method for optimizing the number, location and usage of loading/unloading bays for urban freight vehicles in order to improve mobility in urban area (Alho et al., 2018). Furthermore, studying the possibility of using urban infrastructure such as tramways, traffic lanes and so on, simultaneously for both freight and passenger transport is another research developed for the goal of urban mobility (Sdoukopoulos et al., 2016). As a future direction research, it is worthy to take the dynamic nature of cities into account while studying mobility. This dynamism literally affects urban freight activities; furthermore, cities and urban freight are exposed to a variety of risks, such as economic restructuring risk, structural risk etc. (Yang et al., 2012), which are more and more essential to be studied. Hence, addressing risks at the strategic, tactical and operational levels is also a promising avenue that deserves to be developed.

New network design for city logistics has been discussed by proposing innovative configurations, such as multi-tier distribution networks and collaborative transport networks. The main objectives of these innovative networks are to design more collaborative networks (Montoya-Torres et al. 2016), to use intermediate storage in order to minimize the vehicles routing within city centers (Deutsch and Golany 2018, Snoeck et al. 2018) and finally to enable the integration of environment friendly means of transport (Muñoz-Villamizar et al., 2017). The effect of these networks on reducing transportation costs and environmental externalities has been illustrated by (Crainic et al. 2010, Perboli et al. 2011, Crainic et al. 2011, Baldi et al. 2012, Hemmelmayr et al. 2012, Crainic et al. 2012, Winkenbach et al. 2015, Gonzalez-Feliu and Salanova Grau 2015, Savelsbergh and Woensel 2016, Zhao et al. 2017, Zhou et al. 2018, Zhang et al. 2018). Despite these positive impacts, the creation, implementation and operations management of these networks remain a big challenge. One reason of such difficulty is the existence of various service providers who run their own activity planning separately and therefore, makes several separated logistics networks within a city (Cherrett et al., 2012).

Another interesting study domain refers to the role of physical internet in city logistics, which has been primarily presented by (Montreuil, 2011). The Physical Internet is defined as an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols (Pan et al., 2017). Its ultimate objective is to find an innovative solution to the inefficiencies of traditional proprietary models by introducing an open, global, interconnected and sustainable logistics system (Sarraj et al., 2014). A recent study has concentrated on modelling and solution approaches through applying physical internet concepts for the interconnected city logistics (Ben Mohamed et al., 2017). Another study has been conducted to examine how hyperconnectivity created by physical internet enables the parcel logistics industry to meet the worldwide challenges by providing deliveries that are more efficient across urban agglomerations (Montreuil et al., 2018). The adaptation of physical internet principles to urban moves offers an ambitious perspective for city logistics, which suffers from the lack of a system to gather flow-related data. This domain of study is still in its early stages and requires more attention in order to discover its various aspects with more details.

1.4.2. Policy

Policies are defined to organize a comprehensive framework for planning and developing efficient freight distribution systems in urban areas (Stathopoulos et al., 2011). The policy is an overarching word and can be broken down into three different fields, as shown in figure 1.8.

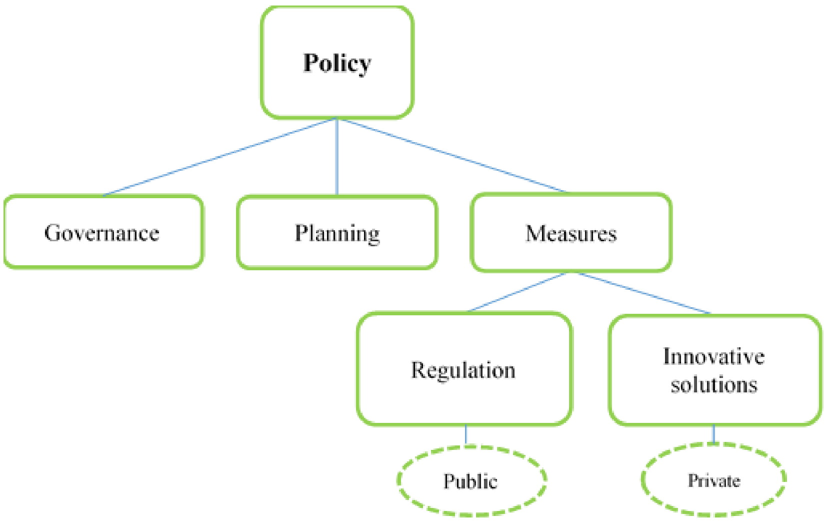


Figure 1.8. Policy category extracted from keywords.

Keywords placed in the Policy class are those that mostly focus on general concepts such as freight policy, urban policy and local policy and so on. Policy execution requires a comprehensive planning procedure for each level of decision making. The high number of articles in this class demonstrates its importance in the literature of city logistics. In addition, there are several articles which have put their attention on evaluation of these policies and their deep assessment (Dablanc and Rakotonarivo 2010, Stathopoulos et al. 2012, Lindholm and Blinge 2014, Marcucci et al. 2015, Gatta and Marcucci 2016, Le Pira et al. 2017b, Holguín-Veras et al. 2017, Rai et al. 2017, Marcucci et al. 2018, Oka et al. 2018).

To explain each class, Governance alludes to the manner of governing projects. In the literature, urban governance (Schliwa et al. 2015, Gammelgaard et al. 2017) and new governance model (Marciani and Cossu 2014, Marciani et al. 2016, Marcucci et al. 2017, Kin et al. 2017), are referred to. Planning is essential to achieve medium and long term objectives and is performed for different aspects of city logistics such as city logistics planning (Nuzzolo and Comi 2014, Jiang and Liu 2016, Awasthi et al. 2016, Gonzalez-Feliu 2018, Russo and Comi 2018), and transport planning (Betanzo-Quezada et al. 2013, Comi 2018). Measures are defined as actions that are taken to implement a plan or a decision. Measures are divided into two subsets regarding their application. First, regulations related to city logistics are defined by local authorities (considered as public sector) to exert restrictions in order to preserve the liveability of cities (Ville et al. 2013, Kaszubowski and Heleniak 2017, Borghesi 2017, Christensen et al. 2017, Chen et al. 2017). The second subset of measures is innovative solutions which are widely applied and developed by private sectors but their success highly depends on public sector support. This subset comprises considerable studies so it is elaborated separately in the following section.

Because of existing interactions among different stakeholders (e.g. carriers, retailers, shippers, large or small transport operators and local authorities) with contradictory interests, implementing policies is a demanding task. Several types of research concentrate only on Policy and endeavour to recognize its characteristics and influences on whole parts of city logistics (Marcucci and Musso 2010, Stathopoulos et al. 2011, Ville et al. 2013, Gatta et al. 2017).

1.4.3. Innovative Solutions

For several years, many measures have been proposed and implemented in order to alleviate negative externalities of the complex system of city logistics. One important group of solutions are those that have relied on collaboration between stakeholders. Keywords like distribution center (Morganti and Gonzalez-Feliu 2015, Diziain et al. 2012) consolidation (Faure et al. 2013, Van Duin et al. 2013, Janjevic et al. 2013, Gonzalez-Feliu et al. 2014), collaborative network (Battaia et al. 2014, Muñoz-Villamizar et al. 2015, Faure et al. 2015, Muñoz-Villamizar et al. 2017, Arango-Serna et al. 2018), pooling (Ballot and Fontane 2010, Gonzalez-Feliu 2011, Xu et al. 2012, Morana et al. 2014, Ferreira et al. 2017) and hub (Lange et al. 2013, Wasiak et al. 2017, Montreuil et al. 2018) refer to the innovative solutions based on collaboration. Meanwhile, urban consolidation center is most discussed innovative solution regarding logistics spaces, however, other innovative solutions have been recently emerged and their feasibility and applicability are discussed (Evrard Samuel and Cung, 2015), more information on these new storages alternatives and means of transport will be presented in chapter 3. Other mostly argued solutions, as demonstrated in table 1.1, are the use of light goods vehicle (Browne et al., 2010) including electric vehicles (Van Duin et al. 2013, Anand et al. 2015, Schöder et al. 2016, Lebeau et al. 2016, Kunze 2016, Giordano et al. 2017, Deflorio and Castello 2017), as well as the use of cycles or cargo cycles (Schliwa et al. 2015, Choubassi, 2015, Deflorio and Castello 2017, Melo and Baptista 2017) for last mile deliveries. Solutions regarding off hour deliveries which propose to manipulate urban deliveries at night (Holguín-Veras et al., 2014; Dos Santos and Sánchez-Díaz 2016, Verlinde and Macharis 2016, Jaller et al. 2016). And finally, the integration of intelligent transport system for both managing and optimizing urban freight activities in urban area (Adamski 2011, Małecki et al. 2014, Baudel et al. 2016, Oskarbski and Kaszubowski 2016, Guerlain et al. 2016, Comi et al. 2018).

Table 1.1. Most discussed solutions regarding leader countries.

Innovative solutions	**Leader countries**
Urban Consolidation Centre	Netherlands (2010, 2011, 2012, 2013, 2014, 2015, 2017), France (2013, 2014, 2015, 2016, 2018), Belgium (2012, 2013, 2016, 2017), United Kingdom (2011, 2012, 2014)
Light Goods Vehicles	United kingdom (2010, 2012, 2017), Greece (2013, 2014), Netherlands (2013, 2015), Belgium (2015, 2016), Italy (2015, 2017), Germany (2016, 2017)
Cargo Cycles	Belgium (2012, 2017), United States (2015, 2016), United Kingdom (2015, 2017), Germany (2017, 2018) France (2016, 2017)
Off-Hour Deliveries	United States (2010, 2012, 2015, 2016), Brazil (2015), Belgium (2016), Italy (2017), Colombia (2018)
Intelligent Transport System	Poland (2011, 2014, 2016), France (2016), Luxembourg (2016), Germany (2017), Italy (2017, 2018),

We observe that solutions are almost identical all around the world. In France, a high percentage of research works insists on collaboration concepts to cope with the city logistics issues. Italy has focused mainly on Policy definition and its execution. In the Netherlands and the United Kingdom, the use of electrical vehicles and cycles are further discussed. In this context, the United States and China mostly focus on internet-based technology and mathematical approaches to optimize the proposed solutions. The most argued issues in vehicle routing problems discuss the optimization problem. (Cattaruzza et al. 2015, Heng et al. 2015, Lim et al. 2016).

Our analysis of literature has revealed that solutions related to off-hour deliveries, cargo cycles and hubs emerged more recently than others. In addition, there are some keywords related to innovative solutions in our basic database that could not be assigned to the innovative solutions classes as they occurred just recently and they have not been discussed exhaustively, although they seem interesting to be studied more; for instance, crowdsourcing, outsourcing (Faccio and Gamberi, 2015) and crowdshipping (Chen and Pan, 2016).

Measures as one of the introduced classes of policy in city logistics, and their impact on improving urban activities have been studied more than two other classes presented as governance and planning (Russo and Comi 2010, Tamagawa and Taniguchi 2010, Russo and Comi 2011, Teo et al. 2012, Arvidsson et al. 2013, Bjerkan et al. 2014, Taefi et al. 2016). Therefore, governance model and planning still need to be deepened. Despite the importance of the governance model on system management and liveability of the city logistics projects, it is an underestimated topic in academic researches. Regulations, particularly those implying restrictions in urban area access should be coupled to complementary supports suggested as innovative solutions. To this end, planning a process with more detail in synchronizing regulations performance and innovative solutions implementation could be an interesting research direction. Several studies have recently focused on stakeholders' acceptability before urban freight transport policies (Le Pira et al. 2017a, Punel and Stathopoulos 2017). More discussion and assessment are still recommended as the acceptability of policies by different stakeholders remains one of the main issues affecting successful implementation of city logistics projects. This offers new perspectives, particularly the development of tools to assess its impact in the viability of urban logistics projects. A recent study has been conducted to evaluate innovative solutions for sustainable city logistics. They have used the Multi Actor Multi Criteria Analysis (MAMCA) methodology to analyse different possible measures for urban freight transportation (Van Lier et al., 2018). However, the city logistics literature still lacks a general framework to explain how a feasibility study could be conducted for a new proposition in terms of initiatives, innovative solutions or policies where complexity of system could result in unexpected consequences in long term.

1.4.4. Sustainability

Environmental, social and economic considerations create a category known as sustainability. This is known as one of the most significant issues among the researches in both supply chain management and city logistics. The competitive business environment, resource shortages, and conflicting goals caused this concept to be created. City logistics could be established as a specialized discipline to face sustainability issues encountered in urban freight transport

(Anand et al. 2012, Rudolph and Gruber 2017, Wang and Thoben 2017). Sustainable city logistics almost addresses the problems caused by freight transportation within city centers (Russo and Comi 2012, Kin et al. 2017).

The improvement of city logistics efforts impacting on the urban area is one of the precious goals of researchers as it is regularly addressed in the terms of sustainable urban freight (Holguín-Veras et al., 2016), sustainable mobility (Trentini et al. 2012, Melo and Baptista 2017) and sustainable urban logistics plan (Foltyński 2016, Morfoulaki et al. 2016, Gonzalez-Feliu 2018). A recent study has been performed to review common practices in current urban logistics planning in Scandinavia and the UK to examine sustainable urban transport plan (SUMP), sustainable urban mobility plans (SUMP) and sustainable urban logistics plans (SULP) (Fossheim and Andersen, 2017).

Achieving sustainability through environmental protection, social development and economic development is the ultimate goal of most of policies, initiatives and innovative solutions implementation in urban areas (Van Rooijen and Quak 2010, Awasthi and Chauhan 2012, Russo and Comi 2012, Arvidsson 2013, Arvidsson et al. 2013, Lindholm and Blinge 2014, Gonzalez-Feliu and Morana 2014, Taniguchi 2014, Goh et al. 2015, Faccio and Gamberi 2015, Nuzzolo and Comi 2015, Rao et al. 2015, Crainic and Montreuil 2016, Schöder et al. 2016, Rai et al. 2017, Rai et al. 2017, Kin et al. 2018).

Our literature analysis has shown that a significant percentage of articles merely talk about environmental impacts like as fuel consumption (Koç et al., 2016) or polluting emissions and externalities (Sathaye et al. 2010, Małecki et al. 2014, Daniela et al., 2014, Kijewska and Johansen 2014, Andriankaja et al. 2015, Duarte et al. 2016, Gan et al. 2018, Muñuzuri et al. 2018, Marujo et al. 2018). Social impacts are discussed from time to time as they are important to citizens' quality of life and preserving historical urban areas. In this context, social preoccupation mainly points to the quality of life (Witkowski and Kiba-Janiak, 2014), congestion (Figliozzi 2010, Amaral et al. 2014, Jiang and Mahmassani 2014, Jaller et al. 2016, Alho et al. 2018) and concerns related to historical urban area preservation (Pulawska and Starowicz, 2014). Regarding economic aspects, costs related to carbon emissions are occasionally considered as economical aspects of sustainability (Xu et al., 2012). We also observe that the most cited issues concerning sustainability are almost related to environmental impacts and negative externalities of these activities Economic and social considerations are rather underestimated (Browne et al., 2012). Hence, economic aspects need more discussion and elaboration. Other factors such as profitability and liveability of projects in long term are suggested to be formulated in order to properly calculate economic effects. Furthermore, to adequately evaluate sustainability, consequences related to the social aspects of the projects are deeply demanded as well, to guarantee the attractiveness of city centers on one side, and the quality of life of habitants on the other side (Witkowski and Kiba-Janiak, 2012).

In addition to these studies, in recent years an increasing attention has been dedicated to measurement of activities regarding sustainability. An innovative classification for sustainable city distribution has been proposed called 4 A's: Awareness, Avoidance, Act and Shift and Anticipation of new technologies. This classification can be considered to differently evaluate and interpret sustainability of city distribution (Macharis and Kin, 2017). Moreover, a research has been performed to find representative indicators to make it possible to efficiently monitor and evaluate the sustainability of cities (Buldeo Rai et al., 2018). And finally, a recently published article has evaluated existence sustainability indicators in order to select sustainable configurations for urban freight transportation with using a fuzzy multi-criteria decision making approach (Bandeira et al., 2018).

1.4.5. Methods

There is a large number of techniques and approaches developed to solve the city logistics problems concentrating on different aspects. However, novel approaches which have been presented to cope with the city logistics problems still require, in practice, a high infrastructural support in order to be launched (Nowicka, 2014); some approaches mostly try to only improve existing situations by defining and assessing different scenarios. There are also other solutions that have already been established, and for which researchers try to optimize their efficiency. The different types of methods used in the city logistics problems are shown in figure 1.9.

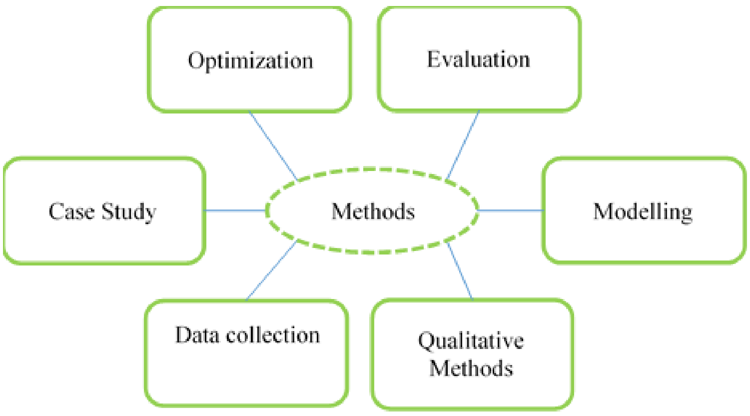


Figure 1.9. Subdivision of the 'Methods' category extracted from keywords.

Our literature review based on keywords analysis have let us to conclude that a high number of optimization problems in city logistics deal with vehicle routing problem. Several heuristic and metaheuristic approaches are applied to solve as optimally and as quickly as possible these complicated problems. Reliability, robust and fuzzy approaches have been touched on and not been discussed in depth. Different simulation tools, assessment methods, and evaluation frameworks are applied to assess current projects or proposed solutions (Van Heeswijka et al., 2018). Different modelling approaches have been developed in the literature, agent based modelling has attracted the attention of authors in recent years because of its flexibility in modelling dynamic situations. Multi-criteria analysis is applied largely as a qualitative method in city logistics. As mentioned before, heterogeneous objectives among stakeholders create a situation, which needs to be treated by multi-actor context analysis. Q-methodology, cluster analysis, and discrete choice are other qualitative used methods. Furthermore, various data collection approaches have been applied to collect real data with the aim of treating real problems. As a high number of scientific works in city logistics is considered to be efficient and practical, analyzed case studies are presented as well to share experiences.

Since there are numerous studies in this category, a comprehensive list of used methods in six classes presented above is provided in appendix 1.1. With regard to this list, we observe that the optimization class has the highest number of articles. Optimization keywords in city logistics refer to vehicle routing problem, distribution center location, inverse routing, etc. Evaluation approaches have been proposed to provide strong analyses concerning city logistics projects. Defining the evaluation framework, impact assessment, geographical analysis, etc. are the discussed topics placed in this class. Data collection has an increasing trend, as a comprehensive survey of city logistics is needed in recent years.

However, this category (methods) comprises the highest number of keywords in the city logistics literature; there are still not efficient methods to model the complexity of real world cases. The most used methods are mathematical programming and simulation modelling. In most researches, constraints are mostly simplified to be applied to a unique problem. Versatile simulation tools that are able to simulate the whole system are still needed to face with different aspects of the problem and also their implementation and integration phases. Vehicle routing problem is one of the most studied problems in city logistics where mathematical programming approaches have been extensively used; here, we refer to (Cattaruzza et al., 2015) in which an extended literature review on vehicle routing problems for city logistics has been provided. Furthermore, an article has been recently published which discusses multi-commodity feature

of the freight distribution problems in city logistics. It is claimed that the literature on this theme is quite scarce and needs to get more attention (Boccia et al., 2018).
Considering the contradictory objectives among different stakeholders and their desire to obtain as many benefits as possible, games theory approach could be interesting to be applied in order to balance the advantages for the different stakeholders and to consider the impact of the responsibilities of each partner. Several article have applied this approach to anticipate the activity level of collaborative networks (Xu et al. 2012, Battaia et al. 2014, Wang et al. 2018).
In this category, data collection still seems a big challenge and need to be investigated more. The need to collect data in city logistics has been claimed by both researchers and practitioners; hence, several studies have recently focused on this issue by analyzing data needs for the integrated urban freight transport management system (Kijewska et al., 2016). In this context, a data collection framework has been proposed to contribute to the lack of data and understanding of urban freight flows known as main obstacles to the improvement of operational efficiency and planning process for a sustainable urban freight transportation (Campagna et al., 2017). To overcome data collection problem, the reasons of problems with data collection in urban freight transportation are identified and then a data collection process is explained to freight traffic flows in urban freight transportation systems (Kijewska et al. 2017). Another study has been carried out in order to collect required data on urban freight vehicles delivering or picking up to explore the feasibility of freight parking and loading bay management solutions (Dalla Chiara and Cheah, 2017). In a nutshell, a high level of synchronization between different tasks and activities in the city logistics system would not be achievable without having a shared information system (Crainic et al., 2015). Such kind of system would serve the different stakeholders considering different level of decision making. Nevertheless, it cannot be denied that strong competitiveness between different stakeholders is still a real barrier to data sharing. Studying best practices and analyzing lesson learned are recommended in order to gain a clear vision about results of new policies, initiatives and innovative solutions. In addition, with regard to the failure experiences in several city logistics projects, a review on urban freight initiatives implementation in the main Italian cities is provided, particularly with focus on the failed ones (Borghesi, 2017). However, these studies are descriptive, but more scientific analysis are still required to derive main success or failure reason of city logistics projects in order to make it possible to compare these factors profoundly in different areas with different characteristics. Uncertainty is another important factor which should be taken into account in city logistics problems. This issue has been discussed few times

in recent years by focusing on demand uncertainty (Crainic et al. 2012, Baldi et al. 2012, Crainic et al. 2015). In a recently presented study, different stochastic variants of vehicle routing problem (VRP) have been used in order to handle uncertainty in comparing non-collaborative and collaborative scenarios in the city logistics problems (Quintero-Araujo et al. 2017). Despite all, regarding the dynamic and complex nature of the city logistics system, different aspect of uncertainty such as demand uncertainty, infrastructure accessibility uncertainty etc. deserve to be more developed. Quantifying reliability seems to be an efficient approach to predict efficiency of measures in the city logistics system in where new solutions are being implemented, objectives are contradictory and there is almost competition. A recent study has proposed a measure model to evaluate reliability level of multilayer urban distribution network (Zhang et al., 2018). Hence, reliability based analysis are more and more requested to provide a concert prove in order to guarantee the benefits of projects and involvement of stakeholders.

1.4.6. Stakeholders

Different stakeholders with contradictory goals are an intrinsic feature of city logistics. Two general divisions of stakeholders refer to public and private stakeholders. Local authority or local government are as public stakeholders (Lindholm and Behrends, 2012). Manufacturer, supplier, retailers, consumer, and logistics service provider are grouped as private stakeholders. The most conflicting interactions happen between private and public stakeholders (Gonzalez-Feliu et al., 2013). The necessity of all stakeholders' involvement at a different stage of decision making and planning (strategic, tactical and operational) has been claimed (Anand et al. 2012, Anand et al. 2016, Lagorio et al. 2016, Le Pira et al. 2017, a). Thus, it is essential to consider stakeholders' behaviour in city logistics measures evaluation (Tamagawa et al. 2010, Castrellón-Torres et al. 2018). Stakeholders are being analyzed with a different point of view. Several authors have studied and analyzed stakeholders' perceptions, needs, objectives, and perspectives to cope with different problems in city logistics. Their common aim is to investigate stakeholders' potential and actual actions and reactions (Kordnejad 2016, Kiba-Janiak 2016). Furthermore, the importance of scenario assessment has been pointed out when local policy makers have to deal with diverse preferences among stakeholders (Gatta and Marcucci 2016, Gardrat 2018). Several studies have focused exclusively on stakeholders' perspectives to design and evaluate last mile solutions (Harrington et al. 2016, Nathnail et al. 2016, and Van Duin et al. 2017). It is worthy to mention that stakeholders should be considered in both decision-making and implementation phase as their expertise is undoubtedly valuable. Their involvement, engagement and willingness are determinant factors to ensure efficiency increase in the city logistics system (Marcucci and Gatta et al. 2017, Le Pira et al. 2017, a). Several articles have been recently published which show that stakeholder analysis is getting more attentions day by day. A recent study has been performed to describe the positive effect of stakeholders' involvement while developing new governance model in city logistics (Marciani et al., 2016). Another study has worked on stakeholder's implication and its impact during initiatives' implementation (Paddeu, 2017). Another research has been devoted to analyse stakeholder's perception about urban goods distribution initiatives by interviewing different stakeholders (inhabitants, carriers, retailers and government) (Oliveira, G and Oliveira, L 2017). Another scientific work has been carried out to analyse the receivers' willingness-to adopt two novel urban goods distribution practices: off-hour deliveries and urban distribution center in two Spanish cities (dell'Olio et al., 2017). It has been also claimed that a primary step to gain stakeholders' support is to understand their needs, preferences and viewpoints (Van Duin et al., 2017). Trust among stakeholders has recently emerged and been discussed as a crucial factor (Daudi et al., 2016). However, it still seems necessary to discuss more about trust and commitment with regard to the complexity of relations among stakeholders. This complexity is caused by the contradictory objectives in one hand and the confidentiality of information on the other hand. To assess the efficiency of a city logistics system, the ability of trust prediction could be fruitful as well.

Conclusion

In this chapter, we presented the significant result of our systematic literature review on city logistics. Based on our approach, we proposed six categories to discuss each aspects of city logistics problems. For each category, perspectives and directions for future research have been presented. In general, our study reveals that however city logistics is the last step of supply chain management, it includes numerous sub-problems, which must be considered simultaneously in order to increase total efficiency of freight transportation in urban areas. Increasing numbers of initiatives and innovative solutions are another reason to insist on requirements for an efficient city logistics system. Here, it is worthy to mention that with regard to the complexity of a city logistics system, one solution will no longer be sufficient. Diversity of urban flows on one hand and contradictory objectives of stakeholders on the other hand require combination of solutions to make a city logistics system more flexible, profitable and viable. Moreover, we found that in the literature the methods used are mostly those that have been developed in supply chain management and logistics filed and then been applied in city logistics, although, a city logistics system is different than a classical logistics system and needs to be studied with considering its specific characteristics.

Regarding these points, in this thesis, we focus on city logistics pooling as a promising solution for increasing efficiency of a city logistics system. We intend to clearly conceive the differences between classic logistics and city logistics to be able to discuss about pooling implementation in such a system. To do so, we deeply study a city logistics system in order to identify its main elements. In the following, we attempt to indicate how a combination of solutions can result in pooled networks for urban freight transportation. We will also study the potential constraints in front of city logistics pooling. Eventually, we will develop an approach to model pooling in city logistics in order to provide quantified analysis regarding different scenarios.

Chapter 2. Pooling Integration in City Logistics

Introduction

Cooperation is defined as the action or process of working together to the same end. During years, it has been discussed as an opportunity that could bring productivity, high customer service and elevated market position within supply chain. In general, cooperation is divided into two concepts: horizontal cooperation and vertical cooperation as shown in figure 2.1 (Barratt, 2004). Horizontal cooperation is defined as cooperation between two or more actual or potential competitors, meaning the actors of the same level, for example cooperation between logistics service providers (3PL). Vertical cooperation is defined as cooperation between companies operating at different levels of the production or distribution chain, for instance cooperation between suppliers and 3PL or cooperation between 3PL and customers (Cruijssen, 2006).

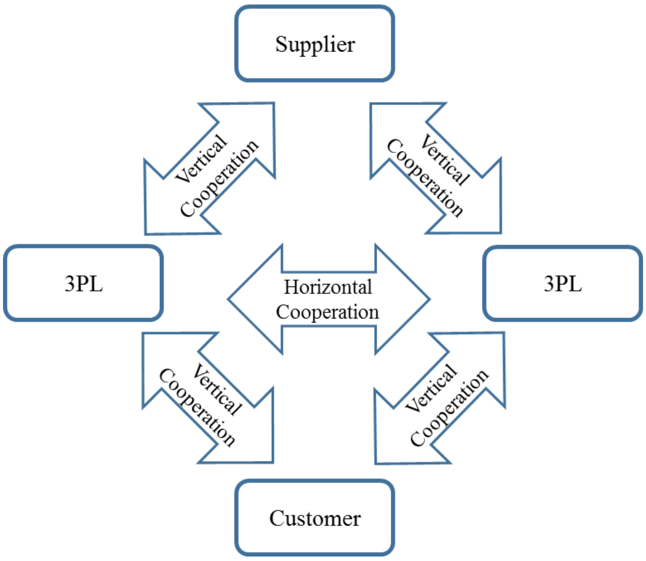


Figure 2.1. Horizontal cooperation and vertical cooperation (adapted from Barratt, 2004).

This cooperation might give companies the possibility to access the skills and capabilities of their partners (Kogut 1988, Westney 1988, Hamel 1991). In this way, each company could enhance the quality of its operational processes by increasing its ability to either control or reduce the activities costs (Gibson et al., 2002). In addition to economic benefits, high cooperation could lead partners to access superior technology and learn from each other's skills and capabilities to acquire greater customer value added at lower cost (Kogut 1988, Westney 1988, Zineldin and Bredenlöw 2003). Furthermore, horizontal cooperation could expand geographic coverage in order to increase the number of potential customers (Bleeke and Ernst, 1995).

Beside “cooperation”, “collaboration” has also been widely used in the literature to express the concept of working together to achieve the same target. However, there are great differences between the two terms. Traditionally, cooperation means relationships that are based on contractual obligations such as outsourcing or subcontracting. In contrast, collaboration is based on reciprocal trust and centers on a sense of shared purpose. Therefore, collaboration is much more sophisticated and requires more discussion and analysis (Weaver, 2012). Collaboration is a very broad and encompassing term. Hence, “pooling” has been proposed as a strategy to highlight the link between horizontal collaboration and sustainable development in order to achieve the environmental, economic and societal objectives (Moutaoukil et al., 2012). It is worth mentioning that in some studies pooling and collaborative scenarios have been used interchangeably (Moutaoukil et al. 2012, Alfaki and Haugland 2013).

The remainder of this chapter is structured as follows. Section 2.1 is dedicated to present a literature review on application of pooling in different fields. Section 2.2 studies definitions and classifications for pooling in logistics and transport in supply chain management. Section 2.3 contains a summary on discussed subjects regarding pooling and its application in the literature of city logistics. Section 2.4 provides the main differences between logistics pooling and city logistics pooling; and finally in section 2.5, we provide a discussion about pooling implementation and its main issues in city logistics. We also present our proposed framework in order to explain required steps to integrate pooling in city logistics.

2.1. Pooling in Different Fields

The word “pooling” has been frequently used in different fields wherever the objective has been to describe any type of collaboration or/and resource sharing among different organizations. Resource sharing has also been identified as an approach that have significant potential savings for offshore wind energy installations (Beinke et al., 2017). Resource sharing in manufacturing has also been proposed to empower companies’ reaction in dealing with disturbing events. In this case, the main idea of resource sharing is that cooperating company allows others to access its manufacturing resources according to a previous agreement instead of maintaining safety capacities or redundant systems (Becker and Stern, 2016). Furthermore, resources pooling has been employed in inter-university collaboration mechanisms in order to organize sharing of resources and research facilities among selected partners (Kitagawa, 2010). To give another example, the pooling problem has been studied during years as a global optimization approach in production planning of petroleum (Alfaki and Haugland 2013, Haugland and Hendrix 2016, Dai et al. 2018). In the health care field, resources pooling has been discussed to evaluate whether or not pooling could improve the system's performance without adding additional resources into medical clinics (Vanberkel et al., 2012). Patent pooling has been also cited in the literature as a beneficial collaboration to enhance business relationships in a synergistic manner (Halt, G. B et al. 2014).

Since resources sharing has almost resulted in economic saving, Silbermayr et al. (2017) have carried out a research to examine whether or not inventory pooling stays advantageous while taking into account both environmental and economic performance simultaneously; the ultimate goal being to find a trade-off between economic and environmental performance. Furthermore, Schlicher et al. (2018) have defined pooling as a collaboration via sharing critical and low-utilization resources. Pooling impact was evaluated by assuming an environment including several independent service providers. Cooperative game theory was used in order to examine profit allocation in such a pooled situation. Sharing of a taxi by more than one passenger, defined as taxi pooling, has also emerged in recent years to decrease the number of empty taxis rate and consequently to reduce traffic congestion, pollution, and accidents (Yan et al., 2012). Although, pooling appears to be a promising solution, there are still several challenges to overcome. In this context, the question on how the savings achieved through resources pooling can be shared between stakeholders involved has been treated. Authors have modelled the problem as a cooperative game and used the resulting allocation schemes to distribute the savings (Reinhardt and Dada, 2005).

2.2. Pooling in Logistics

Increasing issues related to resource scarcity, climate change and new restricting regulations emphasize the need to develop solutions that focus on physical supply chain innovative practices. In this regard, collaboration has been proposed as a solution in logistics and transport to overcome challenges concerning sustainability, reliability and cost efficiency on one side and effective resource planning, scheduling and utilization on the other side (De Souza et al. 2014, Cleophas et al. 2018). Several studies have focused their attention on this solution by discussing different aspects of the problem. In supply chain, collaboration is defined as an approach to promote negotiation between companies in order to increase the global performance (Marcotte et al., 2008). Since 2000, logistics pooling has emerged in supply chain management (Schmitt et al., 2015) as a collaboration that results in sharing and mutual use (either temporarily or permanently) of resources (such as vehicles, warehouse, platform and land use etc.) to achieve the personal objectives such as a reduction in logistics costs and environmental impacts, as well as an increase in efficiency. In the literature, logistics pooling is generally referred to as either warehouse or transport pooling. Warehouse pooling has been discussed to show how the implementation of this concept improves performance and enhances the eco-efficiency of logistics systems (Makaci et al., 2017).

In the context of logistics pooling in supply chain, four major types of pooling have been identified: club pooling, domination pooling, district pooling and customs pooling (figure 2.2.) (Rouquet and Vauché, 2015).

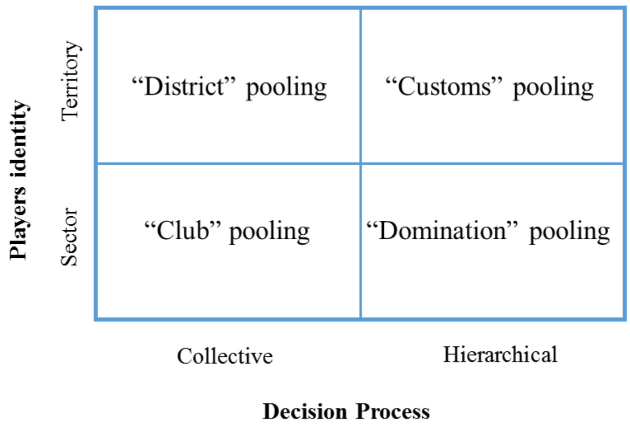


Figure 2.2. The four types of logistics pooling proposed by (Rouquet and Vauché, 2015).

- **Club pooling** refers to collaboration where large companies (which can be also competitors) from the same sector decide to share their logistics resources to supply the same network of retailers. A limited number of companies (usually less than ten) is involved.
- **Domination pooling** happens when numerous small companies from the same sector face difficulties in satisfying the demand of retailers. In other words, a single retailer forces the companies to share part of their logistics to be able to improve their service level.
- **District pooling** is about the sharing of resources by a small number of companies located in the same district (or area) in order to supply the same retailers. In this case, companies are medium-sized, small or very small and are not necessarily in the same sector.
- **Customs pooling** concerns retailers located in the same area that have been obliged to pool their upstream logistics. Since small retailers are not able to perform a high-volume sourcing, local authority provides them a common platform to pool their deliveries.

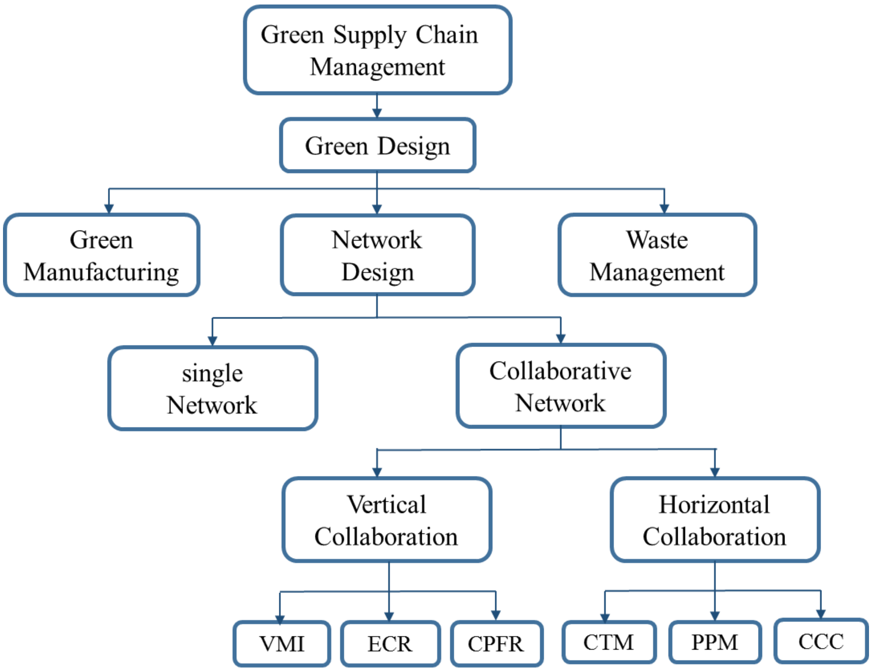
Regarding the provided survey in this section, we will see that, as for other fields presented in section 2.1, it is not always easy to perceive the differences between pooling and collaboration in logistics. Hence, in addition focusing on pooling, we also review the studies citing horizontal collaboration and collaborative network.

A typology of collaborative practices has been developed by Blanquart and Carbone (2014) to examine collaborative supply chain practices and their relative ways of integrating environmental dimensions. This typology identifies four different types of collaboration:

- A contract-based collaboration in response to retailing constraints;
- Taking advantage of specific characteristics of distribution channels;
- Optimisation of reverse logistics management;
- Network organization to provide complementary industrial logistics services.

However, actors find out that the positive impacts of environmentally friendly initiatives increase their own image in the marketplace, although, this typology proves that the way of addressing environmental concerns in the collaborative practices is neither univocal nor simplistic and the ultimate objective is always reducing logistics cost (lean-green attitude) (Blanquart and Carbone, 2014).

In 2014, Amer and Eltawil (2014) have shown that economic gain of collaborative strategies has been widely discussed, but there is still a lack of concern on the importance of environmental investments in the design phase. To this end, a classification upon the practices of green logistics has been presented as shown in figure 2.3.



VMI: Vendor Managed Inventory Management
ECE: Efficient Consumer Response
CPFR: Cooperative Planning Forecasting Replenishment
CTM: Collaborative Transportation
PPM: Pooling Procurement Management
CCC: Collaborative Consolidation Centers

Figure 2.3. Collaborative Sustainable supply chain network design, retrieved from (Amer and Eltawil, 2014).

Later in 2017, results of a literature survey on supply chain collaboration have revealed that despite the growing number of studies regarding collaborative supply chain with the purpose of sustainability, environmental and economic considerations are dominant compared to social concerns. Moreover, most of the time collaboration partners have merely been the company and its customers and suppliers, whereas competitors and other horizontal collaboration partners have not been studied as extensively (Chen et al., 2017).

In addition to the theoretical and empirical studies about collaboration and pooling in logistics and transport which mostly focus on managerial aspects of the issue, several studies have been conducted to evaluate and analyse the impact of this solution by considering its different aspects through mathematical models. In this respect, a research has been conducted to evaluate the environmental impact of supply chains pooling at the strategic level in which long-term and deeper collaboration between the actors of supply chains were needed. In this study pooling was spotted as the geographical consolidation among suppliers or retailers with similar flows. This study showed that a significant reduction of CO_2 emissions was achieved via supply chain pooling (Pan et al., 2013). Another research has been dedicated to the analysis of resource combination in collaborative logistics network. The applied method consisted of a two-stage quantitative framework for enabling decision makers to choose the optimal network design scheme for collaborative logistics networks under uncertainty (Xu et al., 2017). In the context of vehicle routing problem, a study has been performed with the focus on resources pooling with the aim of reducing both carbon footprints and economic costs; to this end, a vehicle routing problem with time windows has been adapted. The results of this research have shown that the more resources are shared, greater is the benefit. The authors have also claimed that operating in complete cooperation resulted in better savings (Sanchez et al., 2016). More information about the literature of collaborative vehicle routing are accessible in (Gansterer and Hartl, 2017).

2.3. Pooling in City Logistics

Same as other fields, collaboration and pooling have also become topical alternatives in city logistics' initiatives. As mentioned above, collaboration is a broad term and could be interpreted in different manners. A comprehensive classification about the different levels of collaboration in city logistics has been proposed by (Morana et al., 2014):

- **Transactional collaboration** refers to collaboration regarding the coordination and standardization of administrative practices.
- **Informational collaboration** consists of exchanging and sharing information with respect to the confidentiality and competition concerns.
- **Decisional collaboration** concerns different planning and management decisions divided into three levels:
    - Strategic planning: long term planning decisions such as network design, location selection, financial strategies and commercial policy.
    - Tactical planning: medium term decisions regarding inventory management, quality control etc.
    - Operational planning: planning and management of daily operations.

In this context, the main elements of collaborative city logistics have been identified as shown in figure 2.4.

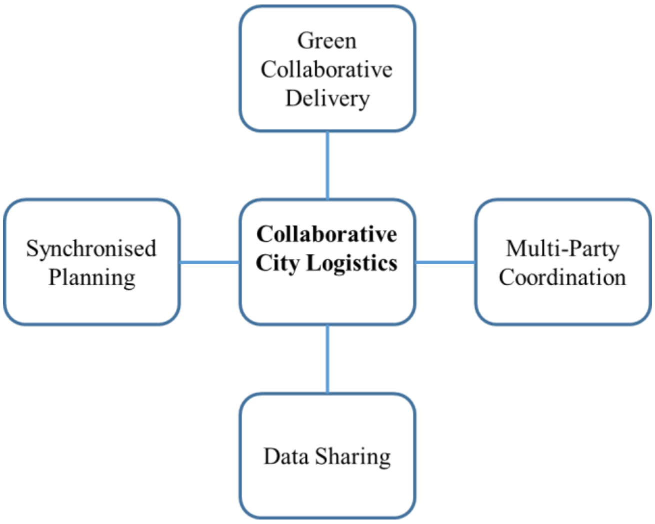


Figure 2.4. Main elements of collaborative city logistics, adapted from (De Souza et al., 2014).

Accordingly, pooling in city logistics is interpreted as a specific form of collaboration where the ultimate goal is to share required resources, either material or immaterial, in order to efficiently perform last mile delivery and distribution activities. Pooling concept in the city logistics domain is relatively new; Hence, it has been become a debatable subject and being studied under different definitions and forms (Gonzalez-Feliu and Morana 2010, Pan 2010, Chanut et al. 2011, Blanquart and Carbone 2010, and Senkel et al. 2013). Referring to the literature, the three main applications of pooling in city logistics are:

Delivery system pooling. This type of pooling focuses on urban goods flow consolidation through using intermediate facility such as urban distribution center (Durand, 2017), micro consolidation (Janjevic et al., 2013) etc. More details about different storage facilities based on collaboration will be presented in chapter 3.

Information pooling. Here, pooling concentrates on sharing information in order to facilitate collaboration and interaction between actors. Communication and transaction tools have been proposed to make this process possible and sustainable (Baglin et al., 2009). One application of this type of pooling was to evaluate the efficiency of information pooling in the context of e-commerce and home delivery (Durand et al., 2014).

Resource pooling. Sharing resources and infrastructure for the goal of optimizing urban freight transportation is called resource pooling (Gonzalez-Feliu and Battaia, 2017). Resource can be vehicles, personnel, etc. and infrastructure refers to storage capacity, cross-dock platform etc (Dolati Neghabadi et al., 2018).

Regarding these aspects, it is observed that not only a standard definition for pooling has not been provided but it is, in most cases, stated as collaborative logistics practices. In fact, wherever the intention is to shape a systematic collaboration for maximizing the efficiency of activities, the word pooling is employed. However, it is worth mentioning that there is a significant difference between collaboration and pooling: pooling is rather a strategy which insists on informing actors involved and having their direct influence on organizational decisions. Therefore, pooling is a kind of long term collaboration which needs more organizational planning, communication and even negotiation.

Nevertheless, collaborative scenarios and pooling are interesting on a theoretical level, and it is important to identify possible barriers as well as motivations in the practice. In this respect, the motivating factors have been listed as: stakeholders' participation in policy initiatives in order to encourage sharing of information and knowledge (Stathopoulos et al., 2012), profound assessment of stakeholder requirements (Regan and Golob, 2005), identification of stakeholders' expected benefits and finally making cost–benefits analysis transparent to all stakeholders. Concurrently, barriers have been identified, as the competitive intelligence risks that may pose a strong concern for stakeholders, especially those smaller businesses who worry to lose their competitive advantage by sharing their operational data or information. To overcome this, business top management must be informed about the underlying competitive intelligence risks and be prepared to put in place the requisite mitigation strategies for their firms to be sustained (Lindawati et al., 2014).

Furthermore, a deep understanding of pooling application in city logistics could be obtained through studies that have been conducted to evaluate, either empirically or experimentally, potential advantages of pooling. Along with this, Durand et al. (2013) has performed a research in which three different scenarios have been defined concerning delivery towards urban online shoppers. In the first scenario, represented as initial scenario, no pooling is considered. The second scenario depicts a partial pooling via nearby pickup points (NPP), meaning parcels are picked up directly by the consumer at local retail outlets. An entire pooling has been spotted in the third scenario where it is assumed that goods ordered online by shoppers living in the town center are grouped together in a local delivery depot (LDD) to be then pooled by the addresses. The evaluation of these scenarios via simulation reveals a real willingness to improve performance (either economically or ecologically) of distribution to urban online shoppers while considering pooling.

Liakos and Delis (2015) has conducted a research with a focus on pooling of the final stage of freight distribution. To this end, an interactive freight-pooling has been proposed. The applied approach is consisting of three phases. The first phase is dedicated to collecting user-specified constraints; such an example, the preferred time window of involved stakeholders is taken into account in order to achieve a fair cost-effective schedule. The second phase is in charge of clustering the delivery points with regard to the constraints recognized in the previous phase; and finally, in the third phase, a Traveling Salesman Problem (TSP) corresponding to each cluster is solved to find the best route. Moreover, a cost model has been built in order to calculate potential money saved during this collective strategy. The results of this study has shown that pooling is an option for efficient urban freight distribution which guarantees cost minimization without sacrificing the service level quality (Liakos and Delis, 2015).

Another study has been accomplished based on concept of GoodsPooling with proposing a conceptual model whose main goal is to profit from daily home/work trips in order to pick and deliver goods flow. To do so, the ICT tools (mobile devices and cloud environments) have been also suggested to contribute to sharing of transportation resources. The advantages of this approach have been stated as: increasing drivers' income while using their regular mobility process, more efficient city logistics with a low price for senders and receivers; and no need for supplementary facilities (Ferreira et al., 2017).

Furthermore, a decision support system based on combination of enterprise resource planning (ERP) with an algorithm for route optimization planning has been proposed to sustain freight pooling in urban area. This study has been conducted to justify efficiency and sustainability of a collaborative transportation system in City Logistics (Perboli and Rosano, 2016).

Another study has been carried out to quantify the impacts of collaboration in city logistics. To this end, mathematical modelling has been used to provide a comparison between traditional distribution network and fully collaborative distribution network. Results obtained through applying this approach to real data taken from the city of Bogotá have proven the significant benefits relating to both transportation costs and environmental impacts (Montoya-Torres et al., 2016). As an extension to this work, the impact of using electrical vehicles in collaborative urban distribution of goods have been studied. In this case, the ultimate goal has been to evaluate the contribution of electrical vehicles to reducing externalities while keeping the desired level of services (Muñoz-Villamizar et al., 2017).

With regard to e-commerce growth and increasing challenges related to last-mile delivery, planning and scheduling to minimize the global traveling cost are required. To contribute to this issue, an effective large-scale mobile crowd-tasking model has been developed using this concept in city last-mile delivery. The advantages of this system compared to traditional last mile delivery are high parallelism and independent delivery in crowd delivery, one-to-one communication, and being eco-friendly as millions of citizens could be part-time delivery personnel in city logistics and fewer number of vehicles are needed for service providers (Wang et al., 2016).

By studying pooling application in logistics and city logistics, it is observed that there are several specialized features for the city logistics system that makes it different from general logistics, these differences must be taken into account for pooling integration as well. This point is further discussed in the next section.

2.4. Differences between logistics pooling and city logistics pooling

Literature on logistics pooling is mainly based on analytical methods while assuming strong hypothesis to simplify the models in order to be solved by optimization approaches (Cruijssen 2006, Ballot and Fontane 2010). In these cases, pallets are generally considered as shipment unit, demands are supposed to be stationary and there are often long delays through warehouses and logistics hub. In addition, the main objectives are to minimize emissions and achieve full truckload delivery. The method used for this purpose is usually a Vehicle Routing Problem (VRP) (Neubert et al., 2014). Despite these studies, it must be noted that urban freight transportation is not equal to mass distribution. The specific characteristics of the city logistics system make it different from general logistics systems. Here, we intend to list these differences below:

- **Destinations** are located in different districts with different access conditions.
- **Goods** have different characteristics and they sometimes need different facility to be kept, transported and delivered.
- **Logistics flows** are constructed by non-stationary demands of mostly small quantities.
- **Shipment units** in city logistics are very variant: parcels, cartons, pallets, rolls, crate, clothes rack are different types of units to be delivered in urban context.
- **Short delay** is another important feature of city logistics as demands practically should be distributed the same day or in the following day.
- **Tight time window** is a specific feature of city logistics. Since it is desired that deliveries, which are mainly B2B must be done in the morning or at the end of evening. This constrain has become a challenging issue in urban freight transportation.

Regarding these differences some points must be taken into account while studying pooling in city logistics:

- **Strong competition.** Since logistics service providers (3PL) offer similar services, they are often competitors. Pooling benefits must be attractive and clear enough to convince the stakeholders.
- **Engagement.** Pooling not only requires strong collaboration of stakeholders but also their long term engagement to guarantee the viability of projects, which is always a challenge in collaborative initiatives.
- **Supplementary facilities.** Pooling can be realized through different scenarios. In some cases, where intermediate storages are used as a cross-dock, all aspects of these supplementary facilities must be studied: balance between cost, service level, environmental impact and profitability.
- **Distribution network change.** Pooling is not attainable without provoking some changes in traditional distribution network. In addition to changes, psychological aspects in the behaviour of stakeholders should be taken into account in analyzing pooling outcomes.

These characteristics of the city logistics system imply that a precise understanding and analysis of the system as well as a strong collaboration among stakeholders are compulsory to manage and move forward pooling schemes; in other words, agreement and commitment of all stakeholders involved are essential to achieve a successful pooled system in city logistics (Morana et al. 2014).

2.5. Toward Pooling Integration in City Logistics

2.5.1. Contribution of pooling in city logistics

In addition to the characteristics of logistics activities, there are also some other parameters that can greatly affect system performance of city logistics. Demand variability, political situations, regulations and environmental concerns must be mentioned in this regard (Amer and Eltawil, 2014). Concerning demand variability, most of the time resources sharing is considered to serve a homogeneous demand, although, in reality demand is always heterogeneous (Ata and van Mieghem, 2009). In parallel, the lack of attention regarding societal aspects must be compensated through studying the expectations of different stakeholders in decision making process of companies (Makaci et al., 2017).

An efficient pooled system, which is taking all these points into account, would mitigate these challenges. Hence, this system can provide regular deliveries with full vehicles, ensuring the presence of goods upon its demand while reducing storage sites; controlling routing costs, reducing CO_2 emissions and increasing the reliability of transport with fixed delivery schedule. In order to summarize all important recommendations and suggestions for this goal, we propose a general framework in which all required steps to systemically integrate pooling in city logistics have been listed and discussed. This framework is described in the next section.

2.5.2. Proposed framework

In the literature of pooling in city logistics, authors have mostly focused on overall problematical aspects (Morana et al. 2014, Gonzalez-Feliu and Morana 2014, Rouquet and Vauché 2015), since it causes inevitable changes in the current system which is already complicated. This is why more information about the logistics and transportation system on one hand and knowledge concerning their operations on the other hand are required while studying the integration of pooling in a city logistics system. Moreover, the functionality of a city logistics system is highly influenced by the decisions of multiple stakeholders (Holguín-Veras et al., 2015). Participatory planning processes are claimed as a valid opportunity for initiatives implementation in city logistics (Morana and Gonzalez-Feliu, 2014). Hence, for implementing pooling, known as a promising initiative in city logistics, a systematic planning is needed to contribute to system identification and to analyse decision making procedures in order to identify required steps towards an efficient implementation of pooling.

Therefore, the objective of this section is to help bridge this gap by proposing a general framework, as shown in figure 2.5. The role of this framework is to provide a profound analysis into a city logistics system and its processes as a first step and to explain the whole urban freight transportation decision making process taking into account all stakeholders influence on decision making in a second time. Hence, this framework consists of two main parts that are complementary and should be followed sequentially. Each of these two parts will be discussed further.

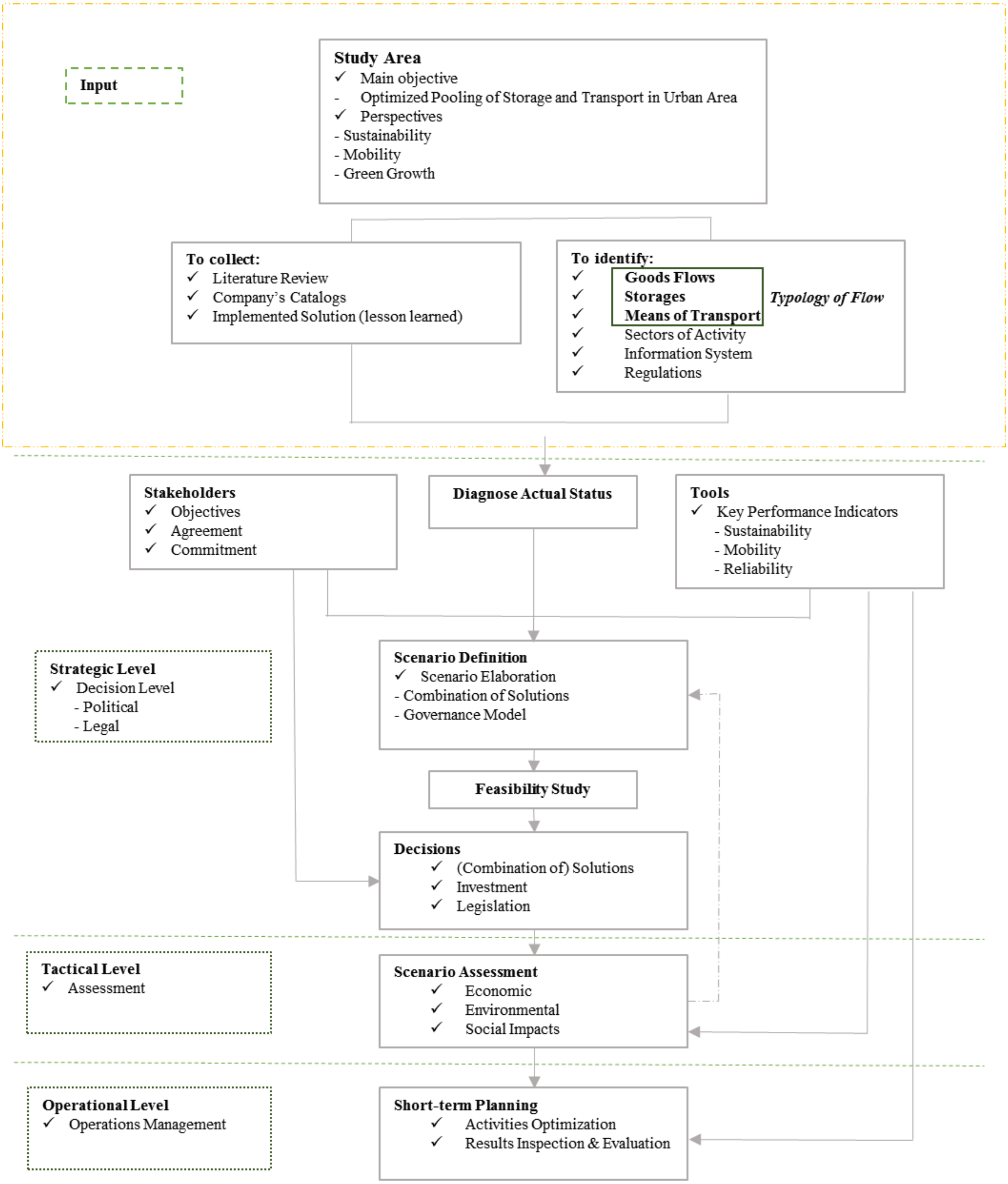


Figure 2.5. General framework explaining Pooling Integration in City Logistics

The first part of the framework is composed of three steps. The first step is devoted to defining reasons of interest in pooling implementation. In fact, one must find answers to questions such as: the main objectives of pooling and which perspectives are assumed to be reached through pooling. The answers determine the **study area**. As shown in the framework, the main interest for pooling is its capacity in using shared resources to optimize logistics and transportation activities in urban areas. Furthermore, the most discussed perspectives for this initiative is to reach sustainability, mobility and green growth in mid and long term.

The two other stages in this first part are dedicated to information gathering in order to diagnose the current status of the city logistics system. To do so, one step is to **collect** already proposed ideas, implemented initiatives and lessons learned through literature review, companies' catalogue and implemented solutions' report. The proposed ideas and implemented initiatives presented in the literature have been discussed in chapter 1 and will be extensively discussed in chapter 3.

To collect information about the implemented solutions in practice, we reviewed the report released by Urban Lab (2017) in which 22 innovative projects implemented in Paris have been evaluated to gather expertise on the different types of projects and to develop a decision support methodology for territorial action. The other report is a research roadmap presented by ERTRAC (European Road Transport Research Advisory Council) and ALICE (Alliance for Logistics Innovation through Collaboration in Europe) (2016). The goal of this report is to identify research priorities related to urban freight delivery and returns as well as urban logistics to improve the efficiency, sustainability and security of this activity in urban area. We also revised those reports released by CIVITAS (City VITAlity and Sustainability) which are related to urban freight transportation. The main focus of these reports is on establishing new knowledge or exploring the feasibility of new or improved technologies, products, processes, services or solutions. We also read the report entitled SUGAR, (Sustainable Urban Goods Logistics Achieved by Regional and local policies, 2016) which provided a comprehensive list of best practices in city logistics in order to analyse lessons learned, primary obstacles, critical success factors and transferability considerations. This database helps to understand about the different aspects of the issue, to recognize the difficulties that may be encountered and also to obtain a global vision of the whole process. In addition, we studied three technical reports from the European Commission first on Indicators and data collection methods on urban freight distribution, second on logistics schemes for E-commerce and third on Treatment of logistics activities in Urban Vehicle Access Regulation Schemes (2017).

The last step in this part is to **identify** the current system including *goods flows*, different *sector of activities* in urban area, infrastructures (*storage facility*, *means of transport* etc.), *information* *system* and *regulations*. In all cases, not only the current situation of the system has to be identified but also probable changes or development in long term must be foreseen. During our study, we have noticed that there is a lack of knowledge about detailed elements of the city logistics system. However, this knowledge is very important when the objective is to study possibility of urban flows pooling through available storages and means of transport alternatives in urban area. To characterize urban flows and to study different possibilities of pooling, we propose the new concept of "Typology of Flow" that lets us elaborate fundamental and supportive elements of the city logistics system. More details on this concept are provided in chapter 3. All steps of this part (let us call it data preparation part) provides the requisite input that would lead to **diagnose the actual status** of the system.

The second part describes how to achieve a pooled system through taking into account necessary considerations such as stakeholders' involvement at different steps, hierarchy of decisions and the importance of feedback during the procedure. To realize this part, the decisional collaboration stages containing strategic, tactical and operational planning are pursued in order to plan and manage decision making. Furthermore, this framework shows the dynamics of city logistics and its demand to maintain communication and exchange during whole pooling procedure. Three stages are further described.

The first stage, **strategic level**, concerns long-term decisions planning and strategies. Here, referring to the pooling definition in which the stakeholders' influences on decision making is essential, recognizing involved **stakeholders** and their own objectives (often contradictory) are two aspects required in this primary step. At the same time, identifying *key performance indicators* (KPIs) are needed as important evaluation **tools** to enable us to evaluate the proposed scenario in this phase. Regarding KPIs, several points are worth mentioning. It is claimed in the city logistics literature, that most of the proposed KPIs are related to public authority and mostly used for individual decisions, however, in city logistics pooling the KPIs have to be able to evaluate the objective of all stakeholders (Gonzalez-Feliu, 2018). Furthermore, it should be taken into consideration that KPIs can be used at different levels. On one hand, at the strategic level when a scenario has not been implemented yet, KPIs are used to evaluate it regarding pre-determined assumption. It means assessments are based on hypothetical situations. On the other hand, at the operational level when a scenario has been implemented and the objective is to evaluate its functionality, KPIs are then used as control tools. In chapter 4, we will present our proposed KPIs in order to evaluate impacts of pooling after its implementation.

Afterwards, obtained information about already implemented solutions, new ideas and system's requirements, make it possible to **define scenarios** in order to satisfy stakeholders' objectives and to drive towards defined perspectives. Scenarios could be the benchmarking of an existing solution, a new innovative solution or a combination of solutions. Furthermore, scenarios must be adequately elaborated by taking into account political and legal considerations, experts' opinions and geographical characteristics of the city. Then, the next step is to conduct a **feasibility study** to assess the practicality of the scenarios. The result of this study leads to making **decisions** more effective**.**

Tactical level is in charge of **assessment phase**. Scenarios in the last phase are assessed and evaluated regarding economic and environmental considerations through suitable key performance indicators in the scenario assessment step. This step comprises more detailed analysis and interpretations over the scenarios to provide a reliable passage towards operational phase. Here, a link is required between scenario assessment and scenario definition, it means scenarios could be adjusted in this level by returning to strategic level; in fact, a feedback loop is needed between these two steps as it is probable to neglect some impacting factors in scenario definition step, which could become clear during the implementation phase.

The last phase, **operational level**, is responsible for short term planning that includes the operations management of all related activities. In fact, not only optimizing daily activities is performed in this level, but also inspecting and evaluating results are needed to qualify tasks efficiency and applicability. Since environmental concerns are a topical issue, regulation modification is predictable in the near future, so revisions in operational level seem imperative to adjust operations, if need be.

Conclusion

In this chapter, we have focused our attention on pooling as a promising solution in city logistics. In this context, we have reviewed the application of pooling in different fields, as well as in logistics and city logistics. We have also presented a summary about the proposed definitions and classification of city logistics pooling in the literature. Furthermore, we have discussed the differences between logistics pooling and city logistics pooling while providing specific characteristics of city logistics. In the last section, we have highlighted the importance of an organized plan in driving towards pooling integration in the city logistics system. To this end, we have proposed a general framework as a guidance to help to plan, organize, assess and implement pooling in city logistics.

Chapter 3. Typology of Flow

Introduction

The city logistics system is often a conglomerate of sub-systems, which are more or less interconnected, with rather independent functioning. Furthermore, there are numerous stakeholders involved in the system, each with their own objectives and constraints. In addition to these complexities, there are inevitable competition between stakeholders that makes pooling implementation more and more difficult to achieve. Hence, an overall understanding of the system with regard to the functionality of each sub-system is crucial when the objective is to study pooling implementation. This complexity of the system has motivated researchers to study it in depth. Along with this, the term “Logistics Profile” has been suggested to classify homogenous groups of urban zone according to three main attribute: agents’ needs, city area features and product characteristics (Macário, 2013). The objective of this classification is to provide the possibility of best practices’ transferability in city logistics. Furthermore, urban typology has been presented to analyse the feasibility of rail use in urban area (De Langhe, 2014). A quantitative approach has been used as well in order to apply this concept and to analyse its applicability (Alho and Silva, 2015). Another research has been conducted to present a typology based on an international overview of the geography of urban freight to classify global cities regarding their logistics systems and their city logistics initiatives (Dablanc and Rodrigue, 2017). In addition, another classification based on goods movement is proposed to identify urban flows. Three main flows have been identified as inter-establishment movements, end-consumer movements and urban management movements (Cattaruzza et al., 2017). To the best of our knowledge, there is no research regarding underlying layers of logistics and transportation system in urban area in order to recognize operational details of these activities. In this chapter, we focus on studying a city logistics system. We propose a new concept “Typology of Flow” (ToF) that leads us to identify main elements of a city logistics system. Moreover, we use this concept in order to discuss on different urban flows and their characteristics. Finally, we present how this new concept can help to construct collaborative network as pooling solutions.

The rest of chapter is structured as follows. Section 3.1 is dedicated to provide a discussion on urban goods movement in urban area. Section 3.2 presents our proposed concept, Typology of Flow (ToF) in order to study in depth a city logistics system to describe its main elements. Section 3.3 focuses on supportive elements of a city logistics system and describe available solutions in term of means of transport and storage alternatives. Finally, section 3.4 explains how ToF can be used to perform a compatibility analysis for delivery system pooling.

3.1. Urban goods movement in urban area

The complicated and dynamic nature of logistics systems especially in urban area motivated us to focus on this field to contribute to the system apprehension and elaboration. As mentioned earlier, there is a handful of studies focusing on flows typology in urban area. These studies have proposed different classification either to categorize urban zones (Macário 2013, De Langhe 2014, Dablanc and Rodrigue 2017, Dablanc 2017) or to identify urban goods movements (Cattaruzza et al., 2017). The aim of this section is to identify different elements of a city logistics system and their activities. This analysis will lead to recognize the relationship between these elements in order to propose a typology with regard to urban flows and facilities required to realise these flows. Subsequently, our proposed typology of flows will help us to study different possibilities of pooling in city logistics and to identify required conditions to implement them successfully. In this context, we will also identify potential constraints before pooling using our proposed typology of flows. To do so, we consider a general scheme for a city logistics system as presented in figure 3.1. This scheme contains suppliers generally located outside the city, retailers located in the city (center) and final customers dispersed in urban area. The arrows indicate direct flows in urban freight transport.

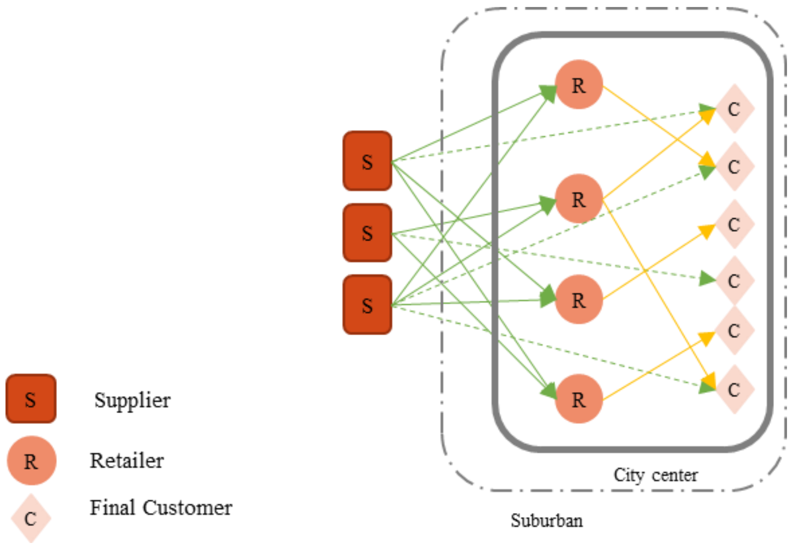


Figure 3.1. Classic elements of city logistics system.

Suppliers, receivers (retailers or final customers) and physical flows are classic elements identified in a city logistics system. To be able to get into more details, we ask the three following questions concerning transportation and delivery activities considering direct flow in urban area. We intend to use the answers to these questions in order to develop a detailed scheme for a city logistics system.

- What should be transferred? (Goods flow)
- Where should they be delivered? (Origin/destination)
- How can they be transported? (Means of transport)

Goods flow represents all physical and nonphysical characteristics of transport unit. Any flow (meaning goods movement) begins from a departure point and goes either to a storage or to a final destination. Flow's origin, destination, storage, and their placement are important parts of a city logistics system that intensively affect goods flows itinerary. Means of transport refers to tools and infrastructure that can be utilized to perform goods flows. Hence, a city logistics system includes goods flow, origin/destination and means of transport. More detail on this classification is presented in the next sections.

3.2. Typology of flow: characteristics of urban flows

We define Typology of Flow (ToF) in order to provide more details about a city logistics system. We intend to use this detailed information for studying different possibilities of pooling in city logistics and for identifying required implementation conditions as well as possible potential constraints. Here, we explain step by step how we manage to present our proposed concept, ToF. As mentioned earlier, a city logistics system consists of goods flow, origin/destination and means of transport. Regarding goods flows, a flow is created, as shown in figure 3.2, when a physical movement occurs between two points (origin and destination) according to a demand. Therefore, an urban flow has three main components: origin/destination, demand of (final) customer and physical movement of goods. Physical movement corresponds to goods transfer; **Goods** can be any type of products demanded by customers. We also define **Path**, as a travel from an origin toward a destination that is performed according to a demand. **Demand** includes all requested information to enable dispatching a physical movement (orders quantity, exact destination, desired delivery time etc.).

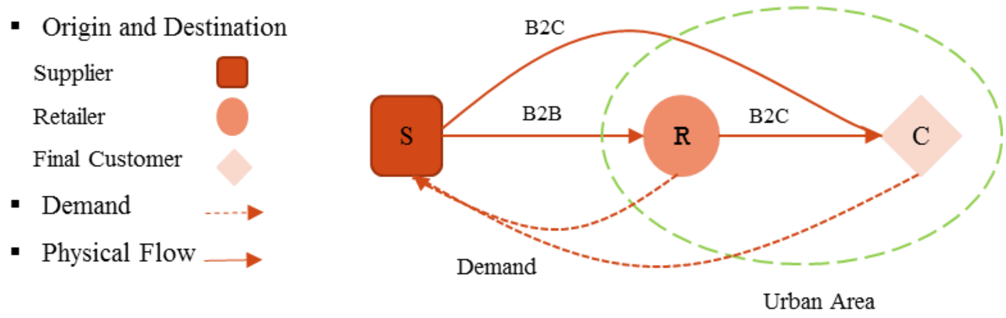


Figure 3.2. Flow components in the city logistics context.

In the following, origin is considered as a departure point, which could be a supplier, a storage or a warehouse located in the outskirts of the city or even a retailer in urban area. Destination is considered as a receiving point which could be either an intermediate storage or a final customer (retailer (B2B[1]) or a home delivery (B2C[2])) placed in urban area. It is supposed that origin is known and destination is then being known as soon as a demand arrives. As shown in figure 3.3, we construct our definition of typology of flow based on goods, demand and path as fundamental elements and means of transport and storage alternatives as supportive elements. It is worth mentioning that goods, demand and path are considered as fundamental elements since they are the elementary bricks of an urban flow. Whereas, means of transport and storage alternatives are considered as supportive elements since they support logistics activities according to variable situations.

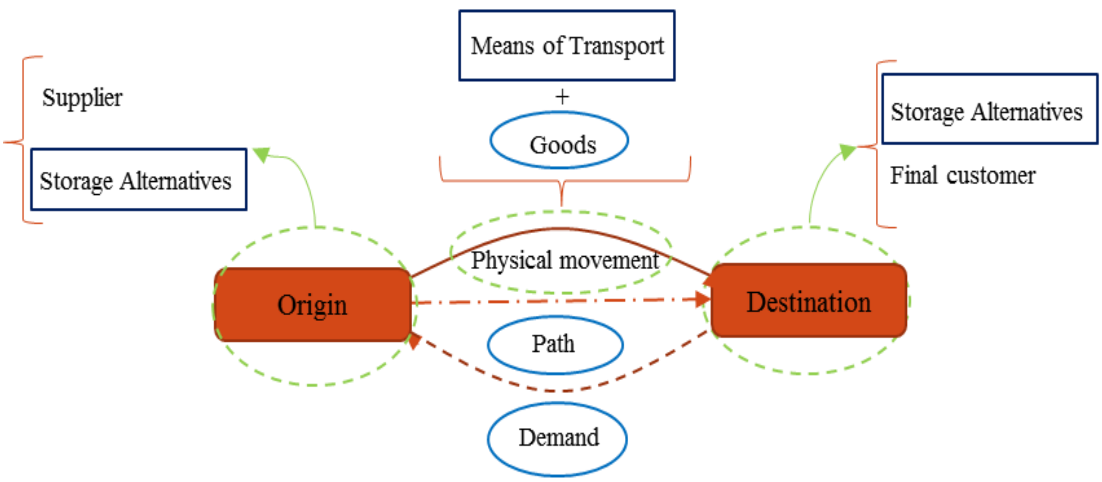


Figure 3.3. Typology of Flow.

[1] Business to business
[2] Business to consumer

To study each of these elements in detail and to identify their various types, let us ask several questions in order to drive towards features and role of each elements in the system. Questions are asked as follows:

• Where are the origin and destination? What are their features and access condition?

• What are the components of a physical movement? What characteristics do they have?

• Which data can be obtained through a demand?

We return to goods characteristics, demand, and path to generally answer the above-mentioned questions. Goods characteristics include all physical features of a good and its handling conditions. Demand provides a detailed list of information about an order. Path focuses merely on transportation aspect in which the main required information about origin and destination points and their accessibility is listed. These three components make it possible to perceive different flows and to describe characteristics of an urban flow. More detailed description is provided in the following sections.

3.2.1. Goods characteristics

Goods can generally be classified according to different criteria. For instance, in the contract of sale, goods are classified into three groups: existing goods (goods that physically exist at the time), future goods (goods to be acquired by seller) and contingent goods (goods that depend upon a contingency)[3]. In marketing, two general groups of goods have been identified: consumer goods and industrial goods. Consumer goods comprise conveniences goods (widely distributed and relatively inexpensive goods), shopping goods (premium products occasionally bought by consumers), specialty goods (goods that are extraordinary or unique) and unsought goods (goods that the consumer does not know about or does not normally think of buying). Industrial goods include raw materials, fabricating parts and materials[3].

In the presented classification, no detail on characteristics of goods is provided, however these characteristics are crucial for an effective freight distribution in urban area and for deciding on suitable means of transport and, if necessary, storage alternatives. As our objective is to provide more information on urban flows, we propose a new classification in order to take into account physical and intrinsic characteristics of goods. The features of this element are fixed since they do not change during the movement. Explanation for these features and proposed classification are described in table 3.1.

[3] http://www.businessdictionary.com/

Good's dimension, weight, packaging and transport unit are physical characteristics. In addition, there are still some other features related to intrinsic characteristics of goods such as safety regulation and requirement, shipment condition like being temperature controlled or requiring technical concerns and special condition for handling.

Table 3.1. Fixed Features: Goods characteristics and Classification.

Goods Characteristics	Description	Classification
Dimension	It specifies goods physical dimension: Width, Height, and Depth.	Small/ Medium/Large
Weight	It specifies goods weight.	Light/Average/ Heavy
Transport unit	Goods are transported in their own special transport units.	Parcel/ Pallet/ Cloths rack/ Carcass/ Roll/ Box/Crate/Barrel
Safety regulations	Some goods require safety concerns as they have a dangerous feature.	Corrosive/ Flammable/ Explosive/ Toxic
Safety requirements	Several goods are precious so they need more attention during their transportation.	Ordinary/ Precious
Shipment Condition: - Temperatures controlled - Technical concerns	 Several goods require special facilities in order not to lose their quality. Several goods, for example liquid or gas, need technical and sanitary cares. For instance, they may need special cargos and technical control during transportation.	 Frozen goods/ Fresh goods (fruit, vegetable, plant, flower etc.)/ Pharmaceutical products Chemical goods/ Petrochemical goods/ Mining
Handling concerns	- In some cases, goods have some intrinsic features that make them sensitive. Therefore, they need to be handled carefully in order to keep their quality and not to be destroyed. For instance: if rice or flour bags were torn, it would become useless. - In some other cases, handling concerns cope with specific facilities requested for transportation (loading/ unloading) as goods cannot be handled without these supplementary tools.	Fragile/ Delicate/ Sensitive to shock, vibration, etc. / Bulky

3.2.2. Demand characteristics

For our ToF, demand is a general concept that defines a list of information achieved based on an order. Demand cannot be always controlled, since demand for a good can change during different time horizon regarding changes in the orders (e.g. quantities, frequency and delivery lead-time), or time windows. In addition, demand can change according to external factors, for instance: demand pattern change caused by market change (for example new product introduction) and seasonal demand pattern (seasonality or a promotional event) etc. This is why demand features are considered as changeable. More details about this classification and these features are provided in table 3.2.

Table 3.2. Changeable Feature: Demand Characteristics and Classification.

Demand	Description	Classification
Orders quantity	The quantity of demand is considered as requested number of unit of transport of a good	Small/ Medium/Large
Prediction of demand	Whether it is possible to predict a demand or not is predictability of demand.	Regular/ Sporadic/ Emergency
Frequency of demand	Interval in which a demand arrives is considered as frequency of demand.	Daily/ Weekly/ Monthly/
Seasonality	This feature determines if the demand for the good is seasonal or not.	Yes/ No
Delivery lead time	The desired time for a customer to receive his command once he ordered it.	One hours/One day/ One week/…
Time window	It points the desired delivery time for reception point. It can be determined as a preference or due to an obligation. For instance, the newspaper has to be received in early morning. Cloths could be received at any time, however, a receiver may prefer to be delivered in the evening when his store is empty of client.	Morning/ Afternoon/ Evening/ Night/ Or more precise delivery time
Flexibility of time window	Two type are identified for time windows; those that can be violated with a penalty known soft time window and those that must be respected known as hard time window	Soft time window/ Hard time window

In this table, we attempt to make a list of required information related to demand in urban area. Each of this feature can affect the way of performing urban freight transportation.

3.2.3. Path characteristics

Path represents a **distance** between an origin and a destination. Origin is supposed to be either in outskirts of the city or in the city center in the case where origin is an intermediate storage. Destination is located mostly within the cities: an intermediate storage or final customers (retailer (B2B) or a home delivery (B2C)). To explain our proposed classification for path, we break it into three levels: district, reception point and delivery area. Our reason to define it in this way is that any destination is located in a **district** within the city. Hence, we focus on districts instead of destinations to be able to consider supplementary factors that play important roles in classifying features of a path. We consider other attributes as districts features impacting urban freight transportation: traffic statement, access condition, geographical condition and risk assessment. **Reception point** is considered as the exact location of destination and its accessibility is one of the important points in path features. Finally, **delivery area** is simply the area where the shipment would be unloaded. The availability of delivery area is one of the important factors for managing efficiently last mile delivery. More details about these features are described in table 3.3.

Table 3.3. Changeable Feature: Path Characteristics and Classification.

Path	Description	Classification
Distance	Distance between origin and reception point.	Short/ Average/ Long
District		
- Traffic state	Traffic state depends on the schedule; it will be used in the further steps when a tour is planned.	Crowded/ Spacious
- Access condition	The condition to enter to a district is considered as access condition. May a district be forbidden for some type of means of transport due to regulations or its own structural or infrastructural features?	Access restricted area/ Narrow street/ Access only permitted for specified mean of transport
- Geographical condition	Where a district is situated is important to identify requirements to serve it.	On a hill/ On a flat/ On an island
- Risk assessment	It specifies the condition of being protected from theft or injury in a district.	Priority security zones
Reception point		
Reception point type	It shows whether the reception point is a retailer (B2B) or a home delivery (B2C).	Retailer delivery / Home delivery
Reception point accessibility	The location of a reception point is important to perform last meter delivery. The condition to reach a reception point specifies this classification.	Easy to access/ Access only by walk (pedestrian area)
Delivery area	If there is an available delivery area in the proximity of the reception point.	Does not exist/ Available with reservation/ Available but it is far/ Available anytime

3.3. City logistics solutions as supportive elements in ToF

With regard to the complexity of urban freight transportation on one hand, and environmental concerns and restricting regulations on the other hand, various mode of transport and innovative storages have been proposed in order to increase efficiency of logistics activities in urban area while respecting existing constraints. As discussed earlier in 3.2, means of transport and storage alternatives are considered as supportive elements in our ToF. Recent developments on this field propose different innovative solutions to be integrated into traditional distribution networks. Although, these solutions cannot be used for all type of goods flow, as described in last section. There should be a compatibility between goods flow characteristics and innovative solutions. To give an example, cargo cycles, as one of the topical means of transport, cannot be served for those goods that are heavy or fragile. They also are not a suitable option for those destinations that are far from dispatching center or located on a hill. In this section, we review frequently discussed innovative solutions in term of means of transport and storage alternatives. We then discuss all possible distribution network design through these storage solutions.

3.3.1. Means of transport

Challenges in city logistics, especially in last mile delivery, have resulted in the development of various means of transport all around the world. Each mean of transport can be used for several types of goods regarding their characteristics and its required handling conditions. These factors must be considered for vehicle selection and vehicle assignment as well, when one has several options. The list of topical means of transport are as follows:

- **Electrical vehicles** are not new concepts; over the years, their use for urban freight has become one of the most discussed solutions in city logistics. The combination of urban consolidation centers and electrical vehicles is a topical issue. Nevertheless, there is a high motivation to use electrical vehicles because of being environment-friendly; it has been shown that there are not much differences regarding operating costs in using electrical vehicle instead of diesel vans (Browne et al. 2011). Van Duin et al. 2013 have claimed that the use of electrical vehicle can become competitive if the cost saving achieved through reduction of operational costs gradually compensate the high initial purchase costs. In addition, the support from public authority is necessary to succeed in driving toward mobility and sustainable urban freight transport by using electrical vehicles (Foltyński 2014). These supports can be the regulation that impose the use of clean vehicle or subsidiary help to enable logistics service providers to replace their traditional trucks with the electrical vehicles (Iwan et al., 2014). With regard to the development of various types of small sized electrical vehicles, two successful factors have been recognized: geographical coverage and the potential of market for being served by these means of transport (Melo et al., 2014). Despite mentioned advantages, the need for a high investment, the technological constraints of batteries and limited capacity comparing to traditional vehicles on the other hand cause complexity in their application for urban freight transportation (Feng and Figliozzi 2012, Arvidsson and Browne 2013). More detailed information about the use of electrical vehicle for urban freight system can be found in (Pelletier et al. 2014, Macé-Ramète and Gonzalez-Feliu 2015, Taefi et al. 2015, Wang and Thoben 2016, Duarte et al. 2016, Quak et al. 2016, Taefi et al. 2016, Ahani et al. 2016, Rize et al. 2016, Pelletier et al. 2016, Lebeau et al. 2016, Muñoz-Villamizar et al. 2017).

- **Tramways**. A joint use of transport resources between passengers and goods flows is another challenging issue in urban freight transportation. From this perspective, several study have focused on the use of tramways, as a more sustainable mode, in order to evaluate whether employing the available capacity of tramways for urban freight would increase mobility and transport efficiency. Because of good image of new freight tram services, many urban authorities want to develop these initiatives (Strale, 2014). It is argued that tramways might be more adapted when used to bring goods to the city center and pool them, and then use other types of light vehicles to provide last meters' delivery (Gonzalez-Feliu, 2014). Furthermore, the analysis of available capacity to be transported by tramways has been mentioned as an important factor for using them (Comi and Nuzzolo, 2015). However, it is claimed that additional infrastructures and technologies are required to make it possible to integrate tramways into the current transport systems (Trentini and Malhene, 2012). Along with this, the main barriers against the use of this mode of transport for urban freight distribution have been identified as limited physical flexibility, high initial investment, poor knowledge about urban freight flows, and competition with passenger service providers who insist to keep adequate service quality (Robinson and Mortimer 2004, Arvidsson and Browne 2013, Filippi 2014, Gonzalez-Feliu 2014, Strale 2014). In contrast, success factors for this mode of transport have been described as follow: comprehensive information about the configuration of the network, good knowledge about urban freight realities in the city, identification of available capacities of tramways and information on potential customers (Strale, 2014). However, there are still several challenges that need to be overcome. A high level of security is required to perform both urban freight transportation and passengers transportation at the same time; More detailed information about the integration of tramways into urban freight system can be found in (Alessandrini et al. 2012, Arvidsson and Browne 2013, Gonzalez-Feliu, 2014, Strale 2014, Comi and Nuzzolo 2015, Fumasoli et al. 2016, De Langhe 2017, Behiri et al. 2018, Gonzalez-Feliu, 2018).

- **Waterways** are proposed as fluvial solutions for cities where there is a possibility to implement barges or express boats. Inland waterway has been presented as a viable alternative for urban freight transportation as it is the only transportation infrastructure that does not has capacity constraint; in contrast, inlands waterways are not dense enough to be able to deliver a considerable volume of urban freight (Janjevic and Ndiaye, 2014). Furthermore, it is difficult to implement and use waterways for last mile deliveries of high volume flows (Diziain et al., 2014). To make it possible, it is proposed to install mobile containers terminals in the location that are easily accessible by road or rail transport. These terminals would be equipped by reach stacker vehicle to facilitate unload and loading process. The efficient implementation and integration of this mean of transport could result in reducing or eliminating of freight transport of heavy trucks in the city (Trojanowski and Iwan, 2014).

- **Cycles**, bicycles, tricycles, cargo cycle, innovative cycle for heavy goods are light means of transport for last mile delivery which have been presented to avoid city logistics externalities (Gruber et al. 2014). It is shown that 51 % of all motorized private and commercial trips in urban goods distribution in Europe can be shifted to cargo cycles (Reiter, 2015). However, cycles have several limits regarding long distance, shipments size and geographical condition but the main obstacle for a broader implementation is the lack of perception of cycles as a suitable mode of transport. Actually, it is expected that cycles can be used for around a quarter of city center freight transport. Initial estimates indicate considerable reduction in air and noise pollution, although systematic analysis is required in this area (Lenz and Riehle, 2013). Cycles are considered as a potential mode for mobility and could play an important role in the transformation of urban logistics. Therefore, cycle use is a promising innovative service in urban logistics concepts in terms of sustainable urban transport and reliable last mile deliveries (Heinrich et al. 2016, Hofmann et al. 2017).

- **Trolley** has been introduced as a supplementary tool to be used in last meters of urban delivery. Two main applications are identified for this mean of transport. The first application is to use trolley in order to perform last meters delivery from vehicle towards reception point when delivery areas are not sufficiently provided. In this case, the driver is responsible for unloading goods into a trolley and manually pushing it down the street towards reception point to complete the delivery (Suksri and Raicu 2012, Arvidsson and Browne 2013). The second application is to accomplish the delivery through innovative storage solutions located in city center towards reception point. In this case, goods are transported during non-peak periods into storages, therefrom the final delivery is done using a trolley at a different, preferred time (Quak et al. 2014).

- **Drone** is a rather new technology emerged to enable aerial goods transportation in urban area. There is a potential opportunity to integrate drone into urban freight transportation as it could contribute to urban distribution mostly in areas of high traffic congestion by delivering goods quickly, reliably and directly (Mckinnon, 2016). Despite interests about this mean of transport, there are still several challenges to be faced with such as initial costs to implement this solution, a high technological requirement and support, concerns regarding safety aspects and finally risks of failing over a crowded area (Schliwa et al, 2015, Kunze, 2016).

- **Underground infrastructures** are considered as one of the promising and sustainable solution as they can reduce environmental, congestion and space problems (Alessandrini et al. 2012, Visser 2018). The idea is to develop new distribution system using underground infrastructures only dedicated to urban freight transportation (Behiri et al., 2018). This can be an alternative mode of transport to be integrated into distribution networks. (Visser, 2018). The trend for using this mode of transport is growing since this could combine the advantages of avoiding traffic movements and applying electrical vehicles resulting in low environmental effects with the economic advantages of automated transportation (Zargarian et al. 2016, Chen et al. 2017, Visser 2018).

- **Traffic lanes** are also proposed as infrastructures for urban freight transportation in order to reduce congestions in busy streets of cities (Rezende Amaral and Aghezzaf 2015, Evrard Samuel and Cung, 2015). Traffic lanes can be either used directly by trucks to avoid sticking in congestions or just used as areas for loading/unloading operations (Iwan et al., 2018).

3.3.2. Storage alternatives

Innovative storage solutions have been presented in recent years in order to efficiently organize growing number of goods flows in urban area. The ultimate goals of these intermediate storages are to pool urban flows as far as possible in order to minimize the number of vehicles entering to the city centers and consequently reduce urban traffics, to decrease externalities (like as, pollution, noise, fatality risks etc.) while providing the same (or even higher) service level. It should be pointed out that goods could be either stored in these places or just be unloaded and then loaded to be dispatched directly. In this case, the storage functions like as an intermediate platform for the goal of cross-docking.

In our ToF, storages and warehouses are considered mainly as origins but also destination points in a city logistics system. In this section, we present the different types of storage describing their features and functionalities. Two major types of storage are identified in the context of city logistics, as shown in table 3.4. The classification we proposed is on the basis of storage placements, meaning whether they are situated on the outskirts of a city or into the urban area. This classification has been adopted regarding different types of innovative storage solutions, which have been recently proposed in the context of city logistics. Those that are classically located at the edge of city centers, in close proximity to major access roads, are known under the term Urban Consolidation Centre (UCC) or Urban Distribution Centre (UDC) (Makaci *et al*. 2017). In contrast, the second group comprises innovative storages located in the dense center of cities, more closely to final customers. They are generally named Urban Logistics Spaces (ULS) and with regard to their application, different types of these storage have emerged. Proximity Logistics Spaces (PLS), Goods Reception Points (GRP), Urban Logistics Boxes (ULB) and Mobile Depot (MD). Each of these solutions is comprehensively described in the following pages.

Table 3.4. Storage solutions.

Located in Suburban
Urban Consolidation Centre (UCC) Urban Distribution Centre (UDC)
Located in City Centre
Proximity Logistics Spaces (PLS) Goods Reception Points (GRP) Urban Logistics Boxes (ULB) Mobile Depot (MD)

Urban Consolidation/Distribution Centre (UCC/UDC). UCC or UDC, terms that are used almost interchangeably, are the most topical storage innovative solution in city logistics (Nordtømme et al., 2015). There are no clear differences between UCC and UDC; UCC refers to the concept of consolidating entering flows within cities, thought UDC focuses mostly on the location for these activities. The attention has been attracted to this solution when it had been experienced that collaboration could not be achieved without a physical platform (Morana et al. 2014). The primarily objective of UCC/UDC has been to receive the goods flow, unload and then mutualize the goods by loading them onto environment-friendly vehicles at their maximum load factor in order to deliver customers situated in the city center. Consequently, the movement of large vehicles in the city center and/or dense areas would be decreased (Brown 2005, Allen et al. 2007, Evrard Samuel and Cung, 2015, Björklund and Johansson 2018).

Although, UCC/UDC has theoretically been considered as an efficient solution (Verlinde et al. 2012, Ville et al. 2013), their implementation in recent years have shown various degrees of success (Nordtømme et al., 2015). Indeed, their viability highly depends on support from public authorities, either regulatory or through funding. Hence, where these supports have been absent, operations have ceased (Morana, et al., 2014). In fact, the profitability of UCC/UDC requires adapted regulations in order to enable them to capture a sufficient amount of urban flows. Moreover, without financial support of local authority, additional service costs for using UCC/UDC tends to reduce the interest of final customers in using them (Janjevic and Ndiaye, 2017).

To respond to these issues related to UCC/UDC, several studies have recently analyzed the current situation of UCC implementation with regard to different stakeholders: haulers, citizens, retailers and store managers. In this context, a study has been carried to analyse cooperation strategies in order to ensure the financial equilibrium of these platforms (Trentini et al., 2013). Another study has been performed to identify the main barriers to UCC implementation. The lack of a credible financial model and low acceptability from carriers and end-receivers have been recognized as the main obstructions for implementing an UCC. (Nordtømme et al., 2015). A study has paid attention to the evaluation of the entire energy pathway to assess the carbon reduction potentialities of an UCC. Their results have indicated a significant potential yearly saving of CO_2 (Nocera and Cavallaro, 2017). Another research has been conducted to analyse whether UCCs were able to decrease delivery costs further in the transport chain, through distance or time gains. The intention has been to demonstrate the supplementary cost of using UCC for the users could be compensated through decreasing time-related costs (Janjevic and Ndiaye, 2017). Despite the importance of robust business models for implementation of UCCs, it has been scarcely discussed in the literature. To contribute to this issue, a research has been done whose results identify seven critical factors for a viable UCC. These factors have been described as follows: the flexibility to scale up and down, the ability to adapt to a dynamic environment, entrepreneurial role of the initiator, the acknowledgment of society, to provide new services, high competence in logistics and supply chain, and to integrate ICT tools (Björklund et al., 2017).

In addition to the attention given to the benefits of UCC/UDC, it would be worth mentioning their deficiencies as well. In this regard, the impact of possible delay in delivery through UCC/UDC should be managed to avoid dissatisfaction. The change of distribution network should be also examined from two points of view; first the changes in the logistics process regarding existing restrictions and secondly, the impact of these changes on the behaviour of receivers and their tendency to adopt new delivery habits (Moutaoukil et al., 2015). The doubt about financial success of UCC/UDC in long term is the other topical issue. To overcome these issues, it is suggested to develop new services in addition to routine tasks of UCC/UDC. The added value services could be buffer stock of goods to provide same day delivery either for a retailer or home delivery, integrating waste management to the direct goods distribution and finally control pre-tailing (Nordtømme et al. 2015, Winkenbach and Janjevic 2018).

Proximity Logistics Spaces (PLS). PLS acts as micro-logistics platforms where goods can be unloaded from a mode of transport, be arranged and then be reloaded onto another mode of transport to be delivered to final customers located in dense areas (Gonzalez-Feliu and Malhéné et al. 2013, Boudoin et al. 2014). This transshipment point is not intended to store goods; in contrast, it is secure areas to perform cross dock in urban area (Winkenbach and Janjevic, 2018). A garage, a parking space or a part/ whole of private commercial warehouses can be used as a PLS, however these spaces were originally operated by municipalities and drivers were in charge of performing last mile delivery (Evrard Samuel and Cung, 2015). PLS might provide an opportunity to use various environment-friendly modes of transport for last meters' delivery.

Goods Reception Points (GRP). GRP is assumed as an intermediate point to avoid regular home delivery. In this case, customer orders are delivered to these points and are kept until final customers pick them up (Ducret and Delaître 2013, Boudoin et al. 2014). Different actors in city center can be independent pick-up points, such as repair shops, appliances stores etc. and logistics service providers and post offices can coordinate GRPs (Evrard Samuel and Cung, 2015). Some new services are emerging as well to increase the interest for this storage solution (Yano and Saito, 2016). To give an example, some pick up points are incorporating the final delivery to the customer's home on more flexible time window upon the customer's request, here last mile delivery is outsourced and is supposed to be realized via environment-friendly mode of transport (Winkenbach and Janjevic, 2018).

Urban Logistics Boxes (ULB). The delivery process via a ULB is, like GRP, a solution storage to provide services regarding home delivery. The main difference is that while using ULB, customer' orders are delivered to automatic lockers instead of reception points (Boudoin et al. 2014). Goods can be kept until being picked up by customers. The additional advantages of ULBs comparing to GRP are being automatic, easy to access and available 24/24 hours (Rodrigue 2015). ULB could be either a fixed structure or a mobile structure that can be used when home delivery demand increases in high season periods (Evrard Samuel and Cung 2015, Winkenbach and Janjevic, 2018, Deutsch and Golany, 2018)

Mobile Depot (MD). The function of MD is alike PLS, though in MD transshipment point is a mobile depot instead of being a fixed place. This storage might bring a multimodal delivery service. Furthermore, its mobility opens the possibility to use it whenever it is needed and wherever the best location would be regarding dynamic delivery pattern (Verlinde et al. 2014, Winkenbach and Janjevic 2018). The idea of combining mobile depots with light vehicles has been recently a topical practice. Several recent studies have been carried out to analyse the impact of simultaneously use of light electrical vehicles and mobile depots for delivering to customers in restricted area. They have concluded that such a system can be environmentally and socially acceptable while keeping economic viability for the transport operators (Arvidsson and Pazirandeh 2017, Marujo et al. 2018, Perboli et al. 2018).

3.3.3. Collaborative distribution networks as pooling solutions

Regarding provided survey on pooling in chapter 2, we have noticed that pooling in city logistics has been applied in different sectors of urban freight distribution; sharing resources, using intermediate platforms for pooling flows, integrating ICT tools etc. It is important to mention that each city has its own features and characteristics, thus pooling and collaborative scenarios must be defined upon its particular capacity and requirement. It means that, in some cities, pooling through sharing resources may be sufficient enough. In contrast, others may need collaborative distribution networks to be able to pool urban flows as much as they want. In addition, regarding the variety of urban flow, sometimes more than one solution has to be adapted to satisfy all involved stakeholders' expectations. In this case, new flows are created in distribution networks that can be served by different mode of transport.

In this section, with reference to ToF and considered storage alternatives as supplementary elements, we intend to provide a comprehensive list of possible combination of storage solutions that can be conceived as pooling alternatives in delivery system. Along with this, adding any intermediate storage (or platform) will totally change the network and make it more complicated. Furthermore, it results in creating new types of flows between new added storages, suppliers and receivers. In the next sections, the general scheme of urban distribution network in the presence of innovative solutions has been described and their applications for providing new services have been discussed. It is to noted that, only direct flows have been considered in these schemes.

3.3.3.1. Traditional distribution network

In traditional distribution network, suppliers, who are usually out of the city, deliver directly their own customers with their own vehicles. This network and its main types of flow has been shown in figure 3.4. In this case, vehicles have to do a tour in the city to serve all customers. The major problems encountered in traditional distribution network can be stated as follows:

- Vehicles working in this network are mostly large trucks as they come from far away and transport large quantities of goods for different destinations.
- It is difficult to find suitable delivery area to unload goods in order to be delivered. This problem can become more complicated when a retailer in dense urban area receives a many demands and must plan his warehouse organization at the same time.
- Customers may receive several deliveries per a day from their different suppliers who evidently are not synchronized while pursuing their own activities according to their own schedule.

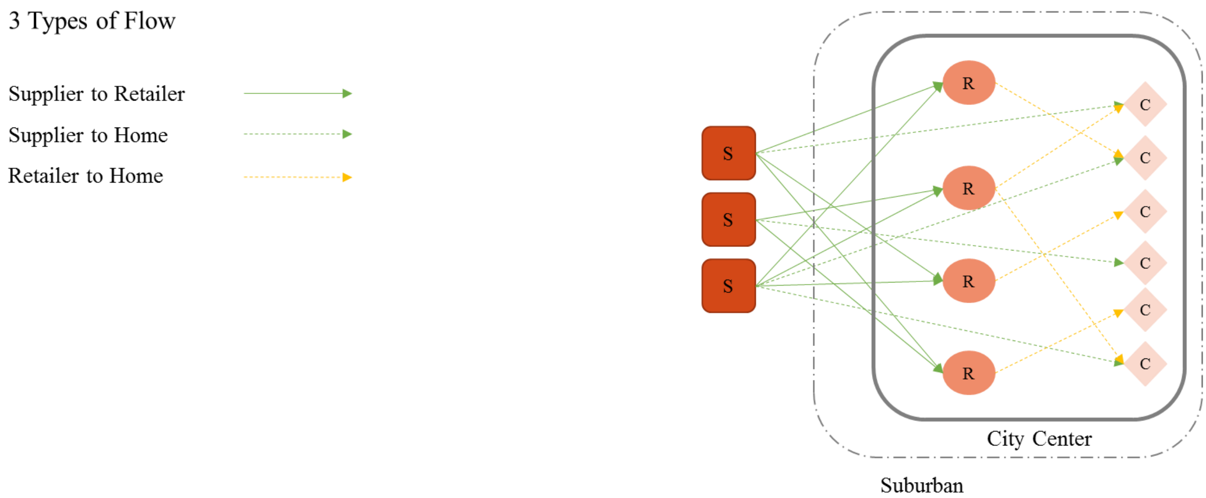


Figure 3.4. Traditional distribution network.

These problems along with environmental concerns and perspectives regarding sustainability and green growth justify the interest of both researchers and practitioners to study innovative networks based on collaboration. As already explained, in the context of city logistics, horizontal collaboration is worth considering as involved stakeholders are merely those who work at the same level of distribution network, meaning at last mile distribution. Next sections are devoted to analyse different innovative collaborative networks in city logistics.

3.3.3.2. Distribution network design via UDC

This network is the most discussed network in the city logistics literature. In this case, flows are broken by passing through UDC. Then pooled flows are dispatched to the city centers by light vehicles at their maximum load factor, although in practice, this procedure is not easy to perform. The involvement of both public and private stakeholders is a necessary factor for UDCs success. Public stakeholder's involvement is merely required for the implementation phase and the involvement of private stakeholders is needed for efficient operation of the system. To this end, it is necessary that logistics service providers collaborate for realizing deliveries in one side and that retailers are motivated to use this platform for improving their delivery performance and contributing to reduce environmental impact on the other side. This network has three new flows as shown in figure 3.5. One new flow is from supplier to UDC, the two others are from UDC to retailers and final customers.

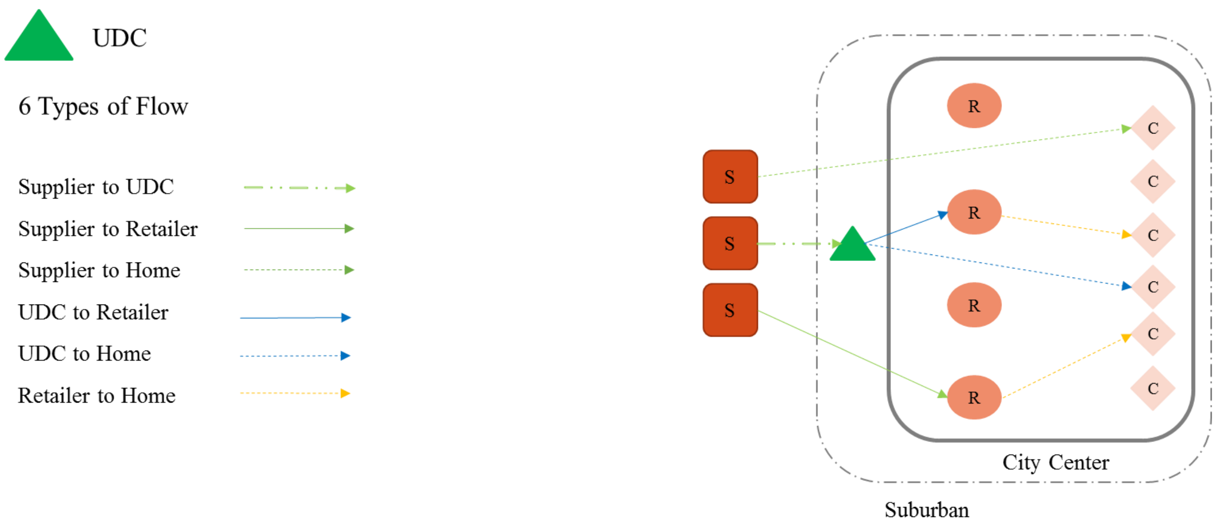


Figure 3.5. Distribution network design via UDC.

The contribution of this network to urban freight distribution comparing to the traditional network can be expressed as follows:

- Vehicles coming from away do not need to enter to the cities and unloading can be done faster and without pressure for driver.
- Since goods are gathered in this platform, they can be pooled and be delivered into the cities by light vehicles according to their maximum load factor.
- Pooling in this platform can be realized according to different criteria; delivering all quantity of goods demanded by a customer in a vehicle can be one criterion.

- This platform makes it possible to prepare goods for a quick delivery in order to minimize the delivery time and stay of vehicle at delivery point.

In addition to these advantages, new services can be proposed to UDCs user, for example, UDCs can be used as a storage to keep goods for retailers and to deliver them upon their demand. In this case, one difficulty can be that the retailer prefers to check received goods by himself. This case is more likely with retailers who have not adapted a fully automated order system.

3.3.3.3. Distribution network design via PLS/DM

In this network, a platform is located near to dense urban areas to provide a cross-dock space. This network creates changes to traditional network by adding three new types of flow. These new flows and their composition in the urban distribution network are shown in figure 3.6. Like for the las network, new added flows are from supplier to PLS/DM and from them to final customers.

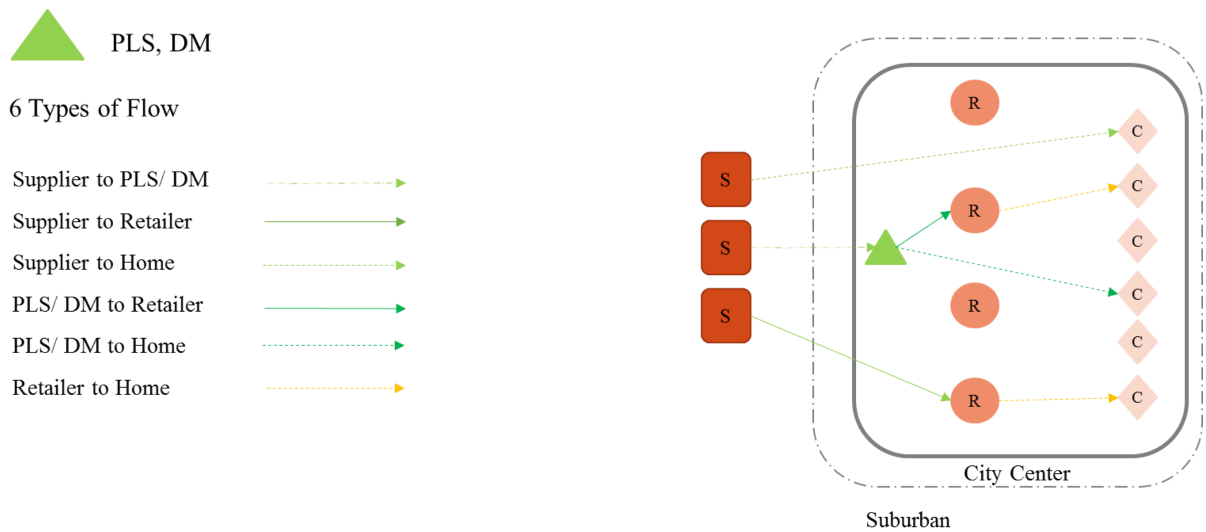


Figure 3.6. Distribution network design via PLS and DM.

As already mentioned, PLS and DM are integrated into distribution network in order to receive large trucks goods to prevent them from entering city centers. The advantages of this innovative network will be:

- By integrating this innovative storage idea into the traditional distribution network, it will be possible to use light vehicles for last meters' delivery.
- However, regarding the location of these platforms, vehicles may sometimes enter to the cities but they do not need to make a tour to deliver their customers one by one.
- These platforms are not equipped to be able to keep goods. So, they need a high security

before and during preparation of the final dispatching.

In contrast, there will be several drawbacks: the location of these platforms must be chosen in a manner that helps to adapt the suitable means of transport and optimizes the delivery routing. Furthermore, since the exact information about the arrival time of long distance supplier is rare, the decision making process can sometimes be suspended. In addition, coordination of related tasks will be an important factor for success. Finally, yet importantly, these platforms are not equipped to be able to do cross-dock for any good; flows characteristics will be effective on the efficiency of this storage solution.

3.3.3.4. Distribution network design via GRP/ULB

This innovative network is mostly used for B2C where the goal is merely home delivery. The new added flows regarding this new network and their composition has shown in figure 3.7. Goods can be put on these platforms directly by suppliers, logistics service providers or even by retailers who provide online services to their customers. The third new flow is between GRP and ULP that have been assumed to be realized by final receivers.

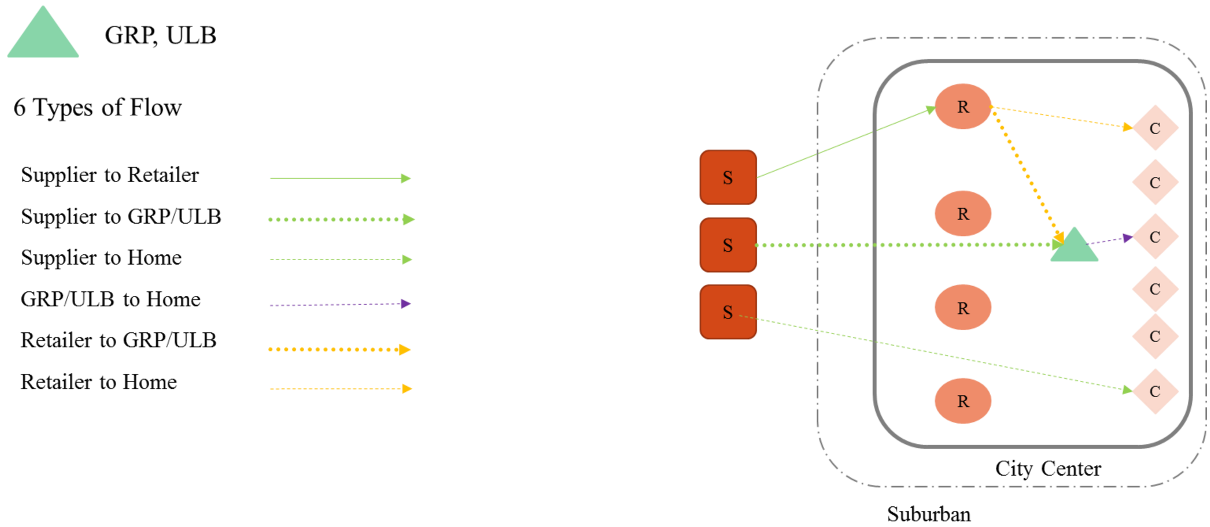


Figure 3.7. Distribution network design via GRP and ULB.

This solution can interest the e-commerce customers, as these platforms are usually accessible 24/24. In addition, this solution could reduce the rate of failed home delivery. Some initiatives like as automatic locker increase the flexibility of B2C delivery. However, this solution (using lockers) cannot be used for all types of goods; these lockers can be used only for parcels of certain sizes. In addition, safety considerations are also important for being able to use the platform; for instance, dangerous goods cannot be kept on these platforms. Finding the best location for implementing these platforms is another issue for this innovative solution.

3.3.3.5. Distribution network design via UDC and PLS/DM

This network shows a combination of two innovative storage solutions that results in a three-echelon distribution network. This network has seven new flows compared to traditional network, as shown in figure 3.8. Here, final customers can be delivered through three different ways: their own supplier can serve them, as with the traditional way; they can be delivered through either UDC or PLS/DM depending on their demand, preference and other characteristics of their goods flow; and finally through two storages. This last aspect will result in increased cost due to two intermediate steps before final delivery; hence, this case can be used in order to pool flows as much as possible and integrate light vehicles into distribution network.

Despite the opportunities created by this innovative network, there are several challenges that should be overcome. Profitability of this network regarding its supplementary cost need a deep analysis. An adapted business model will be strongly required to justify the success of this network at an operational level. As the number of new added flows are rather large, it can help on one hand to implement a multi-modal network and on the other hand to complicate the coordination between different stages and stakeholders, as well. To cope with this, perfect synchronization between stakeholders involved in this innovative network is required to inform them and ensure them about the progress of delivery procedures.

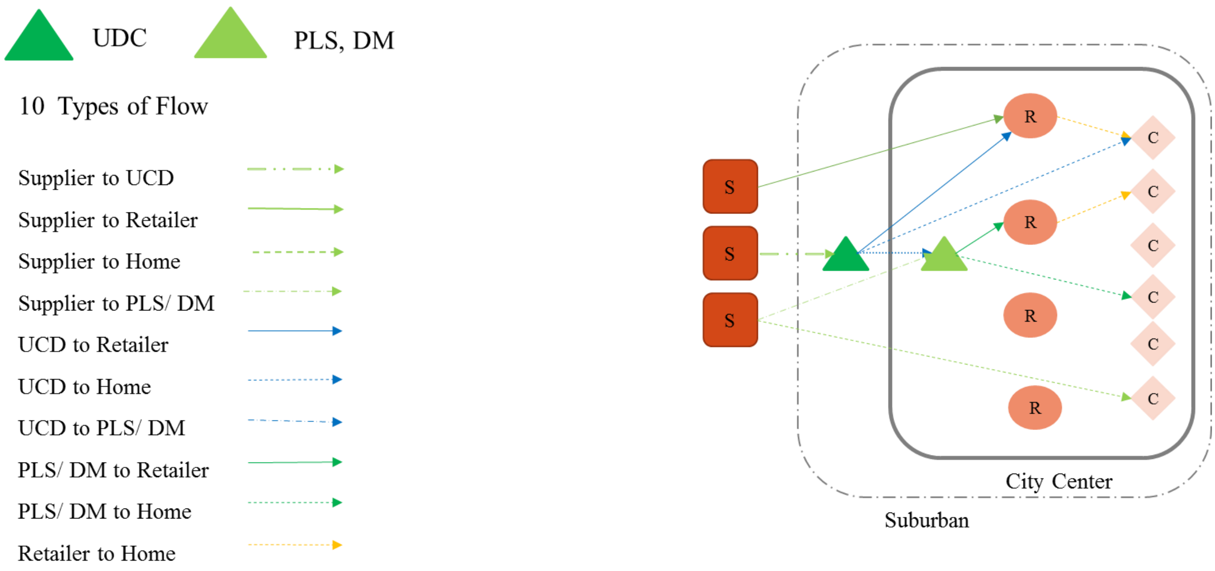


Figure 3.8. Distribution network design via UDC and PLM.

Despite the opportunities created by this innovative network, there are several challenges that should be overcome. Profitability of this network regarding its supplementary cost need a deep

analysis. An adapted business model will be strongly required to justify the success of this network at an operational level. As the number of new added flows are rather large, it can help on one hand to implement a multi-modal network and on the other hand to complicate the coordination between different stages and stakeholders, as well. To cope with this, perfect synchronization between stakeholders involved in this innovative network is required to inform them and ensure them about the progress of delivery procedures.

3.3.3.6. Distribution network design via UDC and GRP/ULB

This network is constructed through the combination of two storage solutions. This combination causes a three-echelon network. There are also seven new flows comparing to traditional network as shown in figure 3.9. This network not only has the advantages of adding each network solutions, but also provides the required infrastructure for innovative services in order to improve urban freight distribution and make it more active and sustainable at the same time. One example for this innovative service can be e-delivery, meaning customer can buy a product in a shop and then be delivered directly to their home or to a GRP/ULB from UDC; in this case, the retailers do not need to dedicate a large space to keep their goods in their shop. This service has been already realized by chain stores for mostly heavy products. This innovative network can also offer the possibility to provide this service in cities for various types of goods and not just for heavy ones.

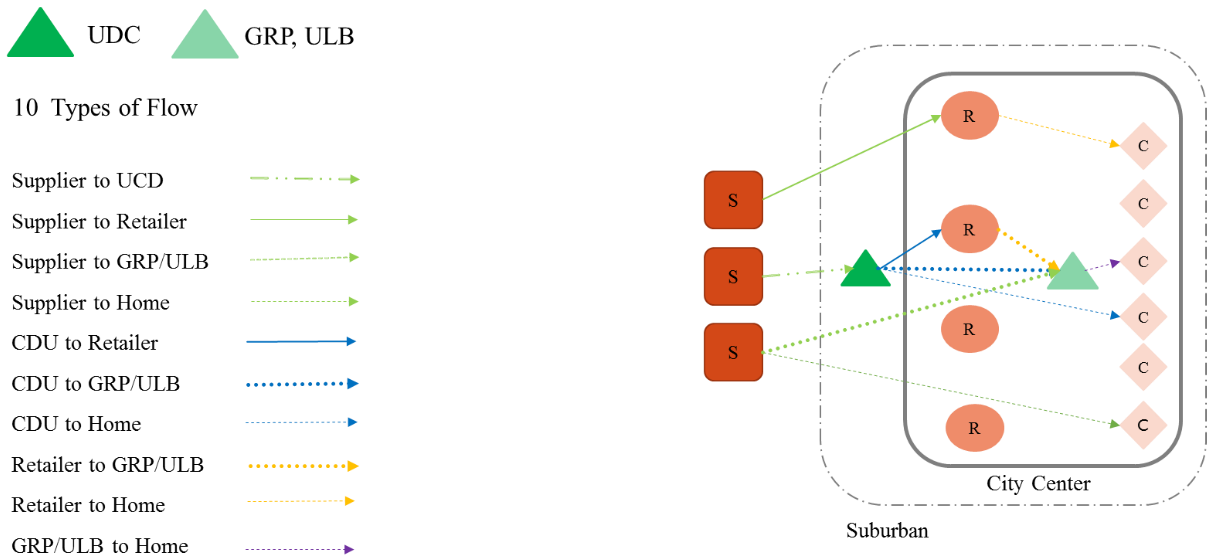


Figure 3.9. Distribution network design via UDC and GRP/ULB.

Regarding goods flows (goods, demand and path characteristics), the choice of using UDC or ULB/GRP or combination of both can be made for providing new services. However, the main idea of this innovative network is to use both of these storage solutions at the same time. In this case, UDCs can be used not only as cross-dock platform but also as remote storage that deliver customer of retailers upon their demand.

3.3.3.7. Distribution network design via PLS/DM and GRP/ULB

This network is another type of three-echelon network for urban freight distribution network, which results in seven new flows. Here, two intermediate storages are located in the urban area.

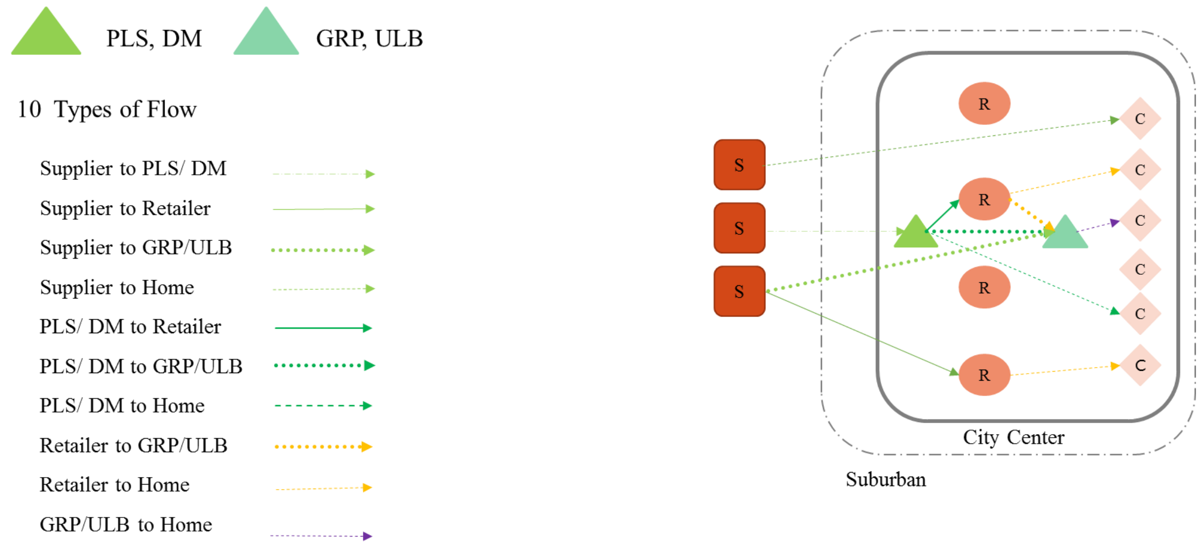


Figure 3.10. Distribution network design via PLS/DM and GRP/ULB.

Cumulative advantages of two storage solutions can smooth last meters' delivery concerning home deliveries. In fact, in this network, using PLS/DM and GRP/ULB at the same time could reduce vehicles tour for providing home delivery and consequently reduce the failed delivery rate.

3.3.3.8. Distribution network design via UDC, PLS/DM and GRP/ULB

This network consists of all types of innovative storage solutions. However, this combination of solutions provokes twelve new types of flow comparing to traditional network as shown in figure 3.11.

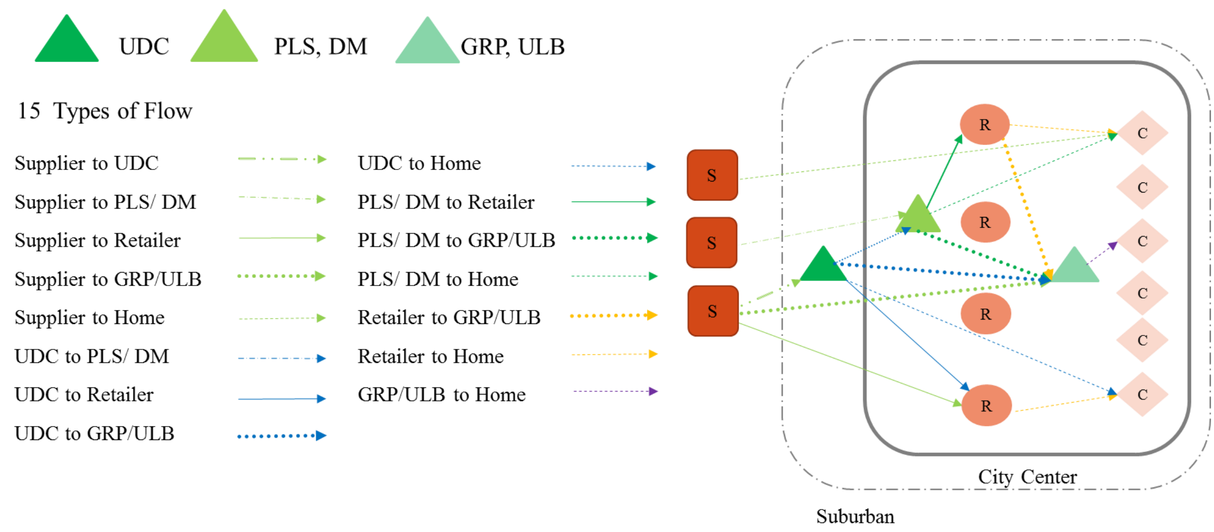


Figure 3.11. Distribution network design via UDC, PLS/DM and GRP/ULB.

Consequently, distribution network becomes more complicate in this case. On one side, it provides a strong infrastructure to adapt different modes of transport and to provide new services for both retailers and home delivery. Indeed, all discussed services in the last sections can be provided simultaneously in this innovative network. On the other side, since variety of flows increase in this case, strong management and coordination are required to efficiently organize all flows and find the suitable storage solution or combination of solutions for all these flows. A very interesting perspective of research is to find a balance between these solutions for the city and to evaluate the share of each solution in obtaining sustainability goals.

3.3.4. Conditions for collaborative networks implementation

Regardless of the type of storage solutions or even their combination, there will be fundamental changes that will consequently create some challenges. We have implicitly mentioned these conditions in each section and here we intend to sum up these conditions. Hence, we have identified following the challenges as necessary conditions in order to efficiently and successfully implement and then operate these innovative solutions:

- The users of these solutions are retailers and logistics service providers; hence, their **acceptability** is an important factor to lead to the viable operation of innovative solutions.
- Since innovative storage solutions cut usual flows, a strong **commitment** on the part of all stakeholders should be presented to final customers to ensure them and attract their interest to accept, break their habits and integrate new systems.
- The receivers might desire to **personally receive and control** their goods. This

preference might be due to the nature of goods or the personal desire of receivers mostly those who do not have an automatic demand management system.

- A high degree of interaction is mandatory for the development of innovative distribution networks. In this way, **trust between stakeholders** is created and play important role to guarantee the efficient transaction and benefit exchange.
- Innovative networks provoke significant changes and, as shown in this section, creates new flows in order to manage efficiently all operations; a strong **synchronization** between tasks and operators is essential.
- As lead-time for urban delivery is short, it is important that to use of intermediate steps should not cause an increase in **delay**.
- **Competition** between the two beneficiaries of these innovative networks (logistics service providers and retailers) is quite high. It must be ensured that their involvement in innovative networks would protect their business purpose, identity as well as confidential data.
- **Supplementary cost** will be charged regarding rent and operation of these platforms as initial cost in implementing an extended and connective network.
- In several cases, users of the system (transport and logistics companies, repair services) will find it difficult to **reorganize** their logistics activities integrating new networks.
- In order to be able to serve various types of goods, the required **conditions to keep goods** must be adapted by innovative intermediate solutions.
- The consideration regrading **security** of goods during their storage in intermediate location is another important point that must be taken into account in order to attract user's confidence and increase the quality of service.

In addition to the presented conditions for implementing these networks, we notice that there is an inevitable relation between goods, demand and path characteristics (introduced as goods flow), alternatives storage solutions and means of transport, as shown in figure 3.12.

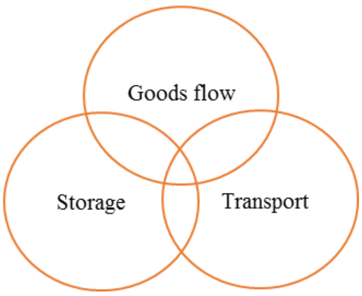


Figure 3.12. Intertwined elements of urban freight distribution.

This indicates that innovative solutions cannot be studied without taking into account these three factors together. Innovative storage solutions cannot be efficient without considering goods flows and supplementary tools required (meaning means of transport) to realise these flows. Hence, analysis of goods flow has an important role on choosing the suitable means of transport, as well. In next section, we discuss how our ToF makes it possible to analysis different elements of urban flows in order to perceive real world conditions and constraints.

3.4. Compatibility analysis for Pooling

As already presented in chapter 2, pooling as a promising solution in city logistics, can be realized through different strategies. Delivery system pooling, resource pooling and information pooling are most referred type of pooling in city logistics. Information pooling focuses on information sharing and there is no physical sharing. In resource pooling, the main idea is that stakeholders involved allow each other to access their resources in order to enhance their system performance without adding additional resources. In this case, it is necessary to analyse how resources can be shared between stakeholders involved regarding compatibility of their requirements and all available resources. While studying delivery system pooling, the main idea, at a first stage, is to design innovative distribution network by using intermediate storages; and at a second phase, to use these facilities in order to integrate light vehicles into the distribution network. Hence, in this type of pooling, one important point to be taken into account is how to analyse which storage solution and/or mode of transport can be feasible for which type of goods flow. As shown in figure 3.13, there must be a compatibility analysis to enable us to find storage solutions compatible with goods flow and then compatible mean of transport in order to carry out required displacement between origin and destination points.

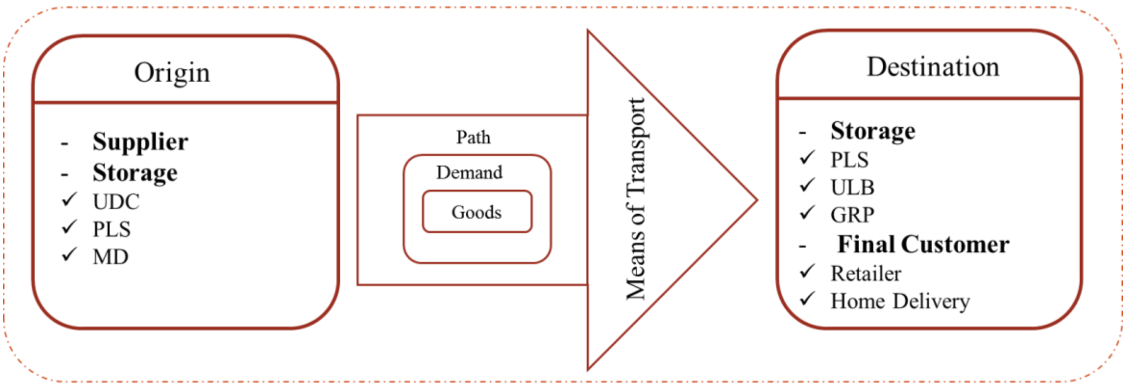


Figure 3.13. Solution combination via storage alternatives for pooling in city logistics.

Our proposed typology of flow provides a framework to analyse various type of compatibility between fundamental element (goods flow) and supportive elements (means of transport and storage solutions) in urban distribution network. These compatibility analyses could lead to identifying potential constrains before the implementation of different pooling strategies.

We intend to explain how our ToF can be used to perform compatibility analysis for both delivery system pooling and resource pooling. Regarding delivery system pooling, we consider the collaborative distribution network in 3.3.3.8 where all innovative storage solutions have been into account in designing the network. In fact, we will present the compatibility analysis using ToF for this network. Outcome of this analysis could help to estimate what proportion of goods flows are accessible (possible) to be delivered through each storage solution; in other words, each solution could approximately absorb what percentage of goods flows. Further analysis could be examined to evaluate whether or not this percentage of goods flows could make the storage profitable. Consequently, it could be also analyzed that those goods passing through compatible storage could be then transported by its available vehicles. Figure 3.14 presents an illustrative example for a multi-level multi-modal urban distribution network. In resource pooling, we go even further to evaluate the impact of these potential constraints on pooling efficiency. This problem will be more described in chapter 4 and 5.

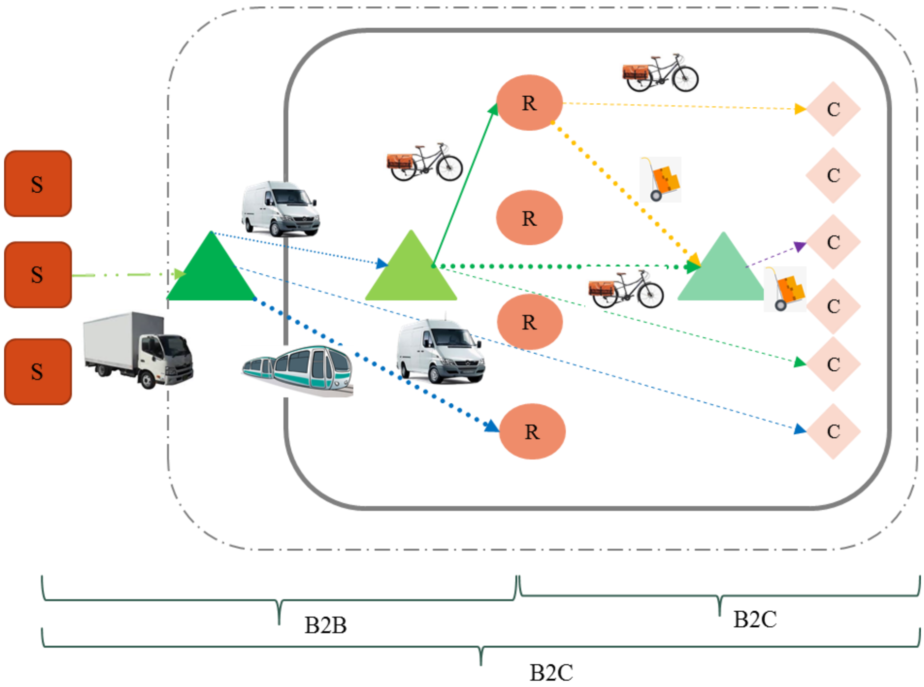


Figure 3.14. Multi-Level Multi-Modal Urban Distribution Network.

3.4.1. Compatibility Analysis for Delivery System Pooling

To implement pooling strategies, we need an in-depth knowledge about the system as well as the potential constraints to satisfy and challenges to overcome. In this section, we focus on compatibility analysis for delivery system pooling where innovative storage solutions are used to design a collaborative network. In this case, compatibility analysis helps us to analyse which urban flow can be assigned to an innovative storage and then whether the available modes of transport for this can be used to achieve required transportation for this flow. To do so, we propose to study five types of compatibility analysis: compatibility between storage and characteristics of goods and demand at the first stage, then compatibility analysis between means of transport and goods, demand and path characteristics at a second stage, as shown in table 3.5. Importantly, we suppose that, after the decision on choosing the type of storage and its location has been done, we do compatibility analysis for operational management of their functioning. Hence, there is no sense in studying compatibility analysis between storage facility and path characteristics in this stage.

Table 3.5. Compatibility analysis for delivery system pooling.

Compatibility Matrix	Goods Characteristics	Demand Characteristics	Path Characteristics
Storage facility	√	√	-
Means of Transport	√	√	√

As already discussed, these compatibility analyses need more detailed information concerning urban flows. Our objective here is to explain how these compatibility analyses can be performed for delivery system pooling by a deep study of urban flows characteristics. In the following sections, each of these compatibility analysis will be elaborated.

3.4.2. Compatibility of Storage Facility and Goods Characteristics

Goods, which should be handled towards their final destination have different characteristics. While using an intermediate storage facility, it should be taken into account whether or not this platform is suitable enough for this good. Whether the platform is just used to do cross-docking or used as an intermediate platform where goods will be kept temporarily, it should be checked that the required equipment is available. As mentioned in section 3.2, we identified two main characteristics for goods: physical characteristics and intrinsic characteristics. Goods can be deposited into a storage if the storage has efficient facility as well as competence to receive and store this type of goods. Some examples regarding this issue can be expressed as follows:

- Dangerous goods or frozen goods demand special facilities to maintain their initial qualities.
- Liquid or gas require technical and sanitary cares.
- Heavy goods need suitable handling and conveying facilities.
- Precious goods should be kept with more supervision in secured places.

Therefore, these compatibilities must be assured before deciding which innovative storage solution can be used for a specific type of goods. A grid as shown in table 3.6 can be used to decide whether each goods flow can be transported through available storage or not. To give an example, fresh goods cannot be placed in ULB, or it is not secure to use MD for fragile goods.

Table 3.6. Storage facilities and goods characteristics compatibility matrix.

Goods / ***Storage***	Dimension	Weight	Transport unit	Safety	Security	Shipment condition	Handling
UDC							
PLS							
MD							
GRP							
ULB							

3.4.3. Compatibility of Storage Facility and Demand Characteristics

Demand characteristics according to typology of flow includes features other than only the order quantity; indeed, frequency of demand, seasonality, delivery lead-time and time windows are factors that must be taken into consideration while performing a compatibility analysis. The following questions must be asked before decision making on the suitable storage solution concerning demand of a goods flow:

• Has this storage got enough space to receive and/or store quantity of a new order for this good?

• Could this storage receive goods at different times during a day, week or month?

• Can desired time window for this demand be respected while using this storage?

• For those goods whose order quantity is influenced by seasonality, are there adequate facility and resource in this storage?

Table 3.7 shows that responding to these questions would lead to identify compatible storage concerning demand of each urban flow. It is also possible that demand feature in a special period time of the year (before Christmas holidays for example) provokes a need for a storage different than normal time. Hence, such a grid can be used and updated to be flexible according to changes.

Table 3.7. Storage facilities and demand characteristics compatibility matrix.

Demand / ***Storage***	Orders quantity	Prediction of demand	Frequency of demand	Seasonality	Lead-time	Time window
UDC						
PLS						
MD						
GRP						
ULB						

3.4.4. Compatibility of Means of Transport and Goods Characteristics

Public stakeholders attempt to decrease negative impacts of urban freight distribution while increasing urban mobility. Moreover, private stakeholders try to respect imposed regulations, get more visibility in the market and gain higher benefits by being flexible in the way they perform their activities. These factors motivate both private and public stakeholders to invest on multi-modal distribution network. In fact, the main goal is to use the maximum capacity of different modes of transport in urban area to efficiently complete urban deliveries while minimizing as much as possible unnecessary freight vehicles trips. In order to decide for each goods flow which mode of transport can be employed, before trying to optimize the routing, one must analyse whether transportation of the good is feasible by the mean of transport of interest. Here compatibility of both physical characteristics of goods, such as goods dimension, weight, transport unit, as well as intrinsic characteristics, such as shipment conditions, safety requirements and handling concerns, must be analysed. For example, frozen goods cannot be transported on board a vehicle that is not equipped with a refrigeration unit. To give another example, a heavy goods order cannot necessarily be delivered by all light vehicles. Therefore, this compatibility analysis is essential. A grid as shown in table 3.8 can be used to help find possible modes of transport for each goods flow with regard to its characteristics.

Table 3.8. Means of transport and goods characteristics compatibility matrix.

Goods / ***M. Transport***	Dimension	Weight	Transport unit	Safety	Security	Special condition	Handling
Electrical vehicle							
Tramways							
Waterways							
(Cargo) Cycle							
Trolley							
Drone							
Underground infrastructures							

3.4.5. Compatibility of Means of Transport and Demand Characteristics

Not all modes of transport have the same capacity nor the same handling functionality. Regarding ToF, orders quantity and frequency of demand are the main features that must be analysed to make a decision on the compatibility of means of transport and demand characteristics. Changes in orders quantities, according to seasonality for instance, may result in incompatibility of usual mode of transport and demand. Furthermore, change in demand pattern can lead to adoption of a new mode of transport. Time window for each demand is another important factor for choosing suitable mode of transport. A grid, as shown in table 3.9, can help to identify compatible mode of transport for a goods flow.

3.4.6. Compatibility of Means of Transport and Path Characteristics

Regarding typology of flow, path comprises travel length between two origin and destination, district, reception points and delivery areas features. Hence, it is necessary to analyse whether a mode of transport is compatible with path that must be passed to deliver final customers. For instance, if a customer is situated in a restricted area in where diesel vehicles are not permitted, diesel vehicles cannot serve this customer. As another example, imagine a customer is placed in a pedestrian area and it is needed to reach the reception point by a trolley; in this case it should be analysed to know if the assigned mode of transport is equipped to provide these last meters' delivery. A suitable mode of transport for delivering customers in restricted area can be use of tramways. In this case, another means of transport such as cycle or trolley will be necessary to perform last meters delivery. Table 3.10 shows how a grid can be designed to analyse compatibility of means of transport and path characteristics of a goods flow.

Table 3.9. Means of transport and demand characteristics compatibility matrix.

Demand / ***M. Transport***	Orders quantity	Prediction of demand	Frequency of demand	Seasonality	Lead-time	Time window
Electrical vehicle						
Tramways						
Waterways						
(Cargo) Cycle						
Trolley						
Drone						
Underground infrastructures						

Table 3.10. Means of transport and path characteristics compatibility matrix.

Path / ***M. Transport***	Distance	District characteristics				Reception point type	Reception point accessibility	Delivery area
		District Safety	Access condition	Traffic state	Geographical condition			
Electrical vehicle								
Tramways								
Waterways								
(Cargo) Cycle								
Trolley								
Drone								
Underground infrastructures								

An example for analyzing the compatibility between goods and path characteristics has been shown in table 3.11. In fact, this grid shows how decision of choosing means of transport for goods can be affected by urban flows characteristics. For example, for goods that have not special handling conditions, there is a vast type of means of transport for short distances. In contrast, goods with special handling conditions are not so flexible to be transported by different modes of transport and for being able to transport them adaptations must be performed.

Table 3.11. An example for the compatibility analysis of goods characteristics and means of transport

Goods characteristics	Distance Volume	Means of transport	
		Short	Long
Goods without any special condition ✓ Non-food products ✓ Cultures and leisure ✓ Books ✓ Home appliance ✓ ….	Small	- Light vehicle - Electric vehicle - Cargo cycle - Cycle - Trolley - Drone	- Light vehicle - Electric vehicle - Waterway
	Big	- Light vehicle - Electric vehicle	- Heavy track - Waterway - Tramway
Special goods Fresh goods ➢ *Frozen food* ➢ *Flower* ➢ …	Small	- Adapted electrical vehicle - Adapted cargo cycle	- Adapted light vehicle - Adapted electrical vehicle - Adapted cargo cycle
	Big	- Adapted electrical vehicle	- Adapted heavy truck - Adapted electrical vehicle
Dangerous products ➢ *Flammable products* ➢ *Explosive products* ➢ *Corrosive products* ➢ ...	Small	- Light vehicle - Electric vehicle	- Light vehicle - Electric vehicle
	Big	- Light vehicle - Electric vehicle	- Light vehicle - Electric vehicle
Fragile and delict products ➢ *Luxury* ➢ *Glassware* ➢ …	Small	- Light vehicle - Electric vehicle - Cargo cycle	- Light vehicle - Electric vehicle
	Big	- Light vehicle - Electric vehicle	- Light vehicle - Electric vehicle - Waterway - Tramway
Costly products ➢ *Jewelry* ➢ *Luxury goods* ➢ ...	Small	- Light vehicle - Electric vehicle	- Light vehicle - Electric vehicle
	Big	- Light vehicle - Electric vehicle	- Light vehicle - Electric vehicle - Waterway

Conclusion

In this chapter, we proposed a new concept “Typology of Flow” (ToF) that enabled us to identify main elements of a city logistics system. We identified two main two main elements for a city logistics system: fundamental elements and supportive elements. Fundamental elements refer to goods flows, which consist of goods, demand and path. Supportive elements are means of transports and storage alternative, which help to perform urban freight transportation. Moreover, we showed that how this new concept can help to construct collaborative network as pooling solutions. We also discussed that compatibility analysis is necessary for being able to efficiently implement delivery system pooling.

Chapter 4. Resource Pooling: Conditions for Implementation

Introduction

As already presented in the previous chapters, three main types of pooling in city logistics have been identified as delivery system pooling, information pooling and resource pooling. In this thesis, we have focused on delivery system pooling and resource pooling as they include urban flows and the way these flows are handled. We have found in the literature that almost overall problematical aspects of pooling with concentration on decisional issues have been studied (Morana et al. 2014, Rouquet and Vauché 2014, Gonzalez-Feliu and Morana 2014). Nevertheless, in spite of these studies, precise understanding and information about the logistics and transportation system as well as quantitative analysis of its operations are still requested. These assessments could enable stakeholders to evaluate different scenarios and help to make the best decisions in order to drive towards an efficient pooling implementation. In chapter 3, we have discussed, in detail, delivery system pooling and its different possible types. In this chapter, we focus merely on resource pooling. Our main objective here is to provide a profound discussion about conditions concerning resource pooling implementation in city logistics. To this end, we have proposed an innovative analysis approach built based on our new proposed concept, typology of flow, to identify operational constraints in the face of resource pooling. In the following, we present our approach in order to quantify impacts of theses constraints on pooling efficiency. Furthermore, we define several scenarios with taking into account different assumptions concerning identified constraints. We also propose our adapted indicators in order to evaluate each of these scenarios. Our experimental results for a real case study raised from the literature is presented in chapter 5.

The rest of this chapter is organized as following. In section 4.1, our research question is presented and the problem is described. Section 4.2 is dedicated to present the results of our study on potential constraints before resource pooling. Section 4.3 explains our proposed indicators for the evaluation of resource pooling efficiency. Section 4.4 presents our proposed approach to quantify the impact of identified constraints on pooling efficiency. Finally, section 4.5 introduces our case study and available data for testing our approach.

4.1. Problem description

In traditional distribution networks, each logistics service provider is in charge of its own customers to serve them by using its own resources such as vehicles, personnel depot etc. In this state, the ultimate goal of logistics service providers is to optimize their activities and provide a high quality service rate. Figure 4.1 shows an example of a traditional distribution network in which there are three logistics service providers shown in three colors. We assume that each logistics service provider possesses a depot that is a platform to receive, keep and prepare demand of customers for delivery. Customers are retailers who are located in urban area. Such distribution network is an example for a B2B delivery. Each logistics service provider owns required resources to serve its own customers. These resources can be vehicles, personnel available storage spaces, handling facilities etc. Hereafter, for describing our problem, we will use simply "depot" instead of logistics service provider and "delivery point" instead of customer.

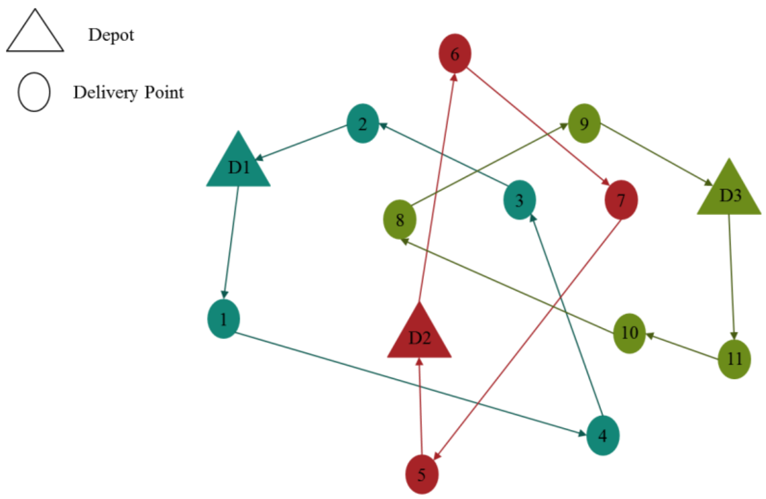


Figure 4.1. Traditional distribution network, adapted from (Montoya-Torres et al. 2016).

Nowadays, in recent distribution networks, collaboration among logistics service providers are a topical issue. Resource pooling is one of the emerging type of collaborations, which is also known as collaborative distribution network (Muñoz-Villamizar et al. 2015, Montoya-Torres et al. 2016, Muñoz-Villamizar et al. 2017). Resource pooling is defined as sharing resources and infrastructures by stakeholders for optimising urban freight transportation. Therefore, we define resource pooling in our case as follows: all logistics service providers involved in pooling share their depots, vehicles and even customers for the goal of optimising their activities concerning urban freight distribution. With these assumptions, as one of the exemplary advantages of resource pooling is to provide a possibility for each depot to serve delivery points that are closer in order to minimize the total travelled distance as much as possible. Figure 4.2 represents a fully pooled distribution network in which all resources can be shared in a way to make it possible serving delivery points with minimum delivery tours. In other words, in a pooled distribution network, each depot can improve its individual benefits with finding an optimum routing that minimize its individual operational cost.

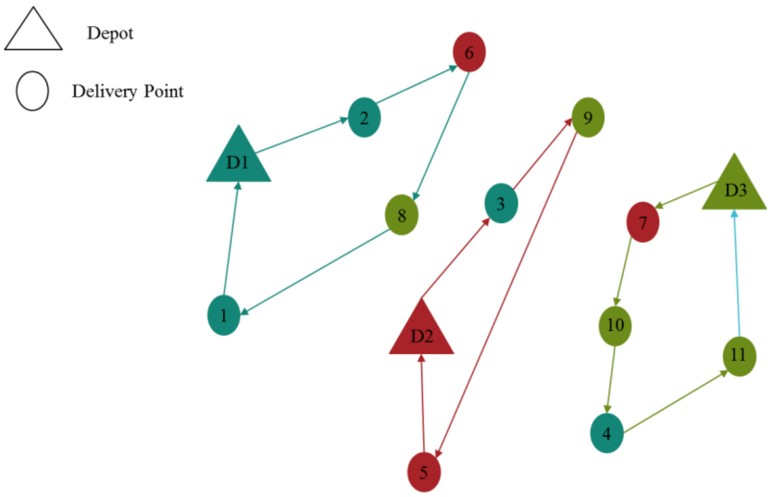


Figure 4.2. Fully pooled distribution network, adapted from (Montoya-Torres et al. 2016).

Despite these advantages, it must be taken into account that in this case, a 100% pooling is only possible if all depots accept to share all their resources without any preconditions. In the presence of such a total agreement for pooling, the initial arrangement of distribution network changes totally. An entire pooling seems to be an optimistic assumption. In real world, stakeholders are not always ready and flexible to share their own resources and their customers. It might not be desirable for a depot to lose its habitual customers with who it have had a long work relationship.

This example indicates that there can be several potential constraints before resource pooling in city logistics. These constraints can emerge due to inevitable competition among the actors of the same level of a system on one side and the lack of required facilities for being able to serve new delivery points on the other side. Here, our research question is how real world conditions for successful resource pooling implementation in urban freight distribution can be identified. In this context, two main questions arise:

- Which constraints can be identified as an obstacle in resource pooling?
- How (much) pooling can be effective in presence of these constraints?

To respond to the first question, we refer to our proposed framework presented in chapter two and to our proposed term 'typology of flow', which aims at identifying the main elements of city logistics system presented in chapter three. According to these discussions, two main types of constraints could be recognized for resource pooling study:

- Constrains provoked by stakeholders' policy
- Compatibility constraints between goods flows and depots' facilities

Each of these constraints individually or a combination of these constraints might cause that depots refuse to share their resources and customers. In this case, a fully pooled distribution network will no longer be possible. In the following, the effect of two different constraints on the pooled distribution network design are discussed. Figure 4.3.a shows a network in which some depots refuse to share some of their delivery points due to their own policy. In this example, depot D1 refuses to share its delivery points number 1 and 4 meaning that these delivery points must be reserved for this depot while network is designed for pooling. In contrast, depot D2 is ready to share all its delivery points with other depots. In the following, depot D3 refuses to share one of its delivery points, number 9. We see that in this network, optimal assignment after pooling is not the same as fully pooled distribution network.

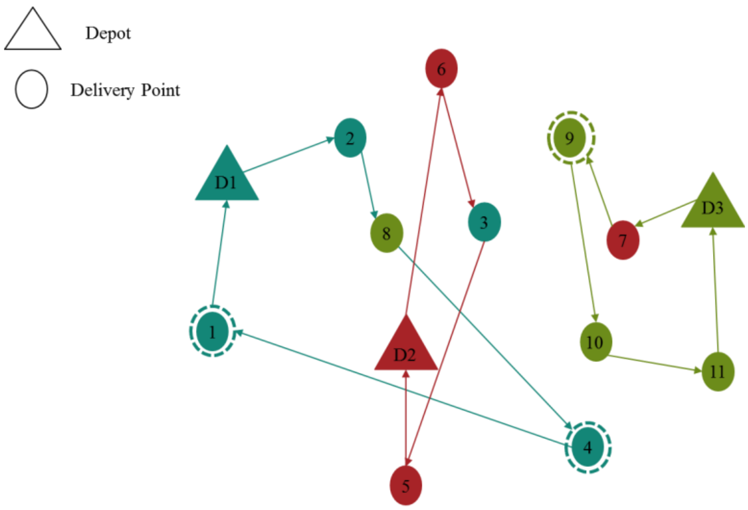


Figure 4.3.a. Partially pooled distribution network (policy constraints).

Furthermore, it could also be possible that depots refuse to serve some new customers because of compatibility constrains. To give an example, imagine depot D1 refuses to serve one delivery point of depot D2, number 5 and one delivery point of depot D3, number 8; since it does not have required facilities to receive or keep the goods of these delivery points. Depot D2 refuses to serve one delivery point of depot D3, number 10; since it does not have suitable means of transport to deliver this delivery point. In contrast, depot D3 accepts to occasionally serve all shared delivery points as it has facilities required to receive and deliver shared goods flows. Figure 4.3.b shows how these constrains can change distribution network pooling. In this example, pooling is still attainable but, it is less efficient than fully pooling where the network is designed in an optimal level.

Thus, two main constraints for resource pooling are addressed as policy-oriented constraints and compatibility constraints. As shown above, these constraints could prevent to achieve a fully pooled network where all resources and customers can be shared by all depots.

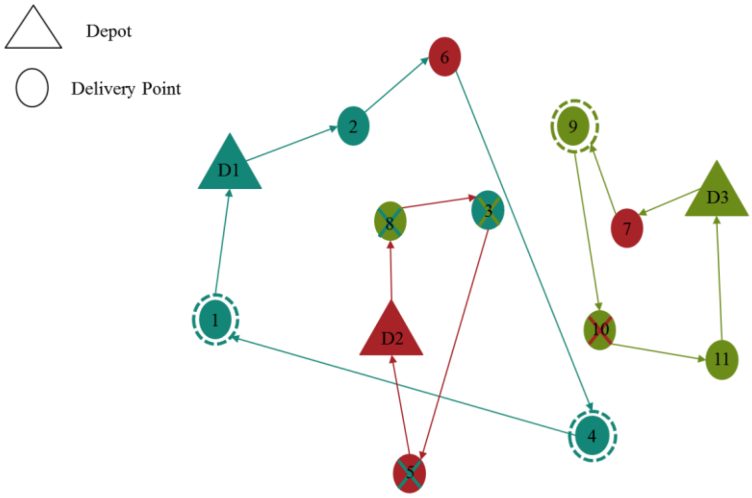


Figure 4.3.b. Partially pooled distribution network (compatibility constraints).

Now, the second question is how (much) pooling can be effective in presence of these constraints. To deal with this question, we describe the identified constraints before collaborative networks. Then, we present our adopted operational indicators and our approach to quantify the impacts of these constraints on resource pooling efficiency. To quantitatively evaluate the effect of constraints on pooled distribution networks, we define and model the problem as Multi Depot Capacitated Vehicle Routing Problem (MDCVRP) which is a well-known problem in operations research literature. We firstly assume that all depots accept to share their resources and customers for participating in pooling. Then, in order to evaluate the impact of identified constraints on pooling efficiency, we gradually add the presented constraints to the problem and calculate the achieved improvements in the presence of pooling constraints.

4.2. Constraints before resource pooling

Generally, we have recognized two main groups of constraints that could affect resource pooling implementation efficiency. The first factor refers to stakeholders' policy and their own long-term strategies. This factor has been extensively discussed in the literature of this thesis under the term of motivations and barriers, acceptance of resource sharing etc. (Lindawati et al. 2014, Quak et al. 2016, Le Pira et al. 2017, Punel and Stathopoulos 2017). The second factor is about constrains related to compatibility analysis. We have discussed these constraints in section 3.4 for delivery system pooling. As a reminder, we have used the proposed term ToF in order to explain how these constraints can impact on pooling efficiency. In addition, we have shown how ToF provided a foundation according to which the possible constraints can be concretely disclosed. In fact, we intend to describe the application of this concept in identifying constraints for resource pooling. Therefore, two main types of constraints in front of resource pooling are policy-oriented constraints and compatibility constraints which are discussed in the next sections. Taking into consideration these constraints while studying urban freight distribution pooling helps to simulate pooling operation closer to the real world cases.

4.2.1. Policy-oriented constraints

Each company has its long-term strategies and planning to maintain its viability and benefice. These strategies could affect companies' decisions on collaboration. Motivations for stakeholders to agree to participate in pooling have been already discussed in chapter 2. As some of these motivations, desire to have a good image in the market, ability to respect regulations, benefits from subsidies, and prospects for gain in long term are notable. In contrast, logistics service providers (depots) might refuse to either share their own customers or serve new customers for different reasons. These disinclinations can be caused by different origins that are often intertwined and causal. Here, we intend to make a comprehensive list of the origins of policy oriented constraints:

Potential competition. Collaborative urban distribution network cannot be reached without the involvement of the actors of the same level. Nevertheless, each company must compete in order to survive in the dynamic business environment.

Reliability and trust. As discussed before, while designing collaborative network, it is highly probable that the initial arrangement of customers completely undergoes a change. Reliability and trust built during long-term relationship between receivers and logistics service providers would be affected while network change. The fear of losing reciprocal trust can be an impediment factor before pooling.

Complexity of collaborative networks. More communication, coordination and transaction are required to manage efficiently a collaborative network. These factors cause to make a collaborative network more complicated.

Resist to changing habits. As mentioned earlier, collaborative network is more complex comparing to traditional distribution network. In order to involve in such a system, it would be necessary to break several daily habits and follow some new tasks. It can be another reason for what stakeholders might refuse to participate in the pooling implementation.

Lose of reputation or visibility. An independent entity whose responsibility is to coordinate stakeholders involved and to manage tasks and ensure entrusted relationships might be essential to manage pooling implementation and its functionality. Hence, it might be possible that stakeholders find it risky to cooperate with others, since it can result in losing reputation or visibility of their own company.

Probable supplementary cost. However, with considering compatibility constraints, it is guaranteed that collaboration is performed regarding ability and capacity of each depot, it could be likely that construction of a new network generates supplementary cost such as transaction management cost, trial period cost etc.

Delay. One of the important features of urban delivery is the tight lead-time. If it is not guaranteed that collaborative network would not cause any additional delay to serve customers, it can be another obstacle in acceptance of involvement in the pooling process.

Policy-oriented constraints can be overcome in different manners. Incentive provided by local authorities or regulations to force moving towards collaborative networks can be helpful solutions to encourage stakeholders to participate in different types of pooling.

4.2.2. Compatibility constraints

The second identified group of constraints against pooling are compatibility constraints. To be able to explain clearly these constraints, we refer to our proposed concept of 'typology of flow'. Three main elements introduced by typology of flow are goods flows as fundamental elements because of constructing the skeleton of the system, and means of transport and storage alternatives as supportive elements for being able to realize goods flows. Regarding this classification, five main components of urban flows are:

- **Goods** can be any type of products demanded by customers.
- **Demand** includes all requested information to enable dispatching a physical movement.
- **Path** is defined as a travel from an origin toward a destination according to a demand.
- **Storage alternatives** is a supportive platform to receive, keep or prepare goods.
- **Means of transport** is a tool to realize goods transportation between origin and destination.

Hence, as already discussed in chapter 3, in ToF, goods also refer to information concerning dimension, weight, packaging and transport unit of an order as well as its features such as requiring safety consideration, shipment condition or technical concerns and special condition for handling. Demand includes orders' quantity, frequency, delivery lead time and desired time window. Path comprises information about district, location of destination and conditions to access reception points and delivery areas.

While studying resource pooling, we should be aware that even if logistics service providers accept to share their resources and customers, it does not mean that new pooled network would be feasible. To be able to assign new customers to depots, a compatibility between depot's facilities and assigned goods flow must be taken into account. For instance, a depot that does not possess a fridge cannot receive and even prepare fresh products. As another example, depots without strong security features cannot receive precious products. These examples concern compatibility between storage alternatives and goods. Demand feature must also be compatible with depot; for instance, a big quantity of goods cannot be handled in a small space. In addition, types of means of transport in the disposition of each depot could cause some compatibility constraints. Dangerous products need special means of transport. A short time window for a demand in a strict area cannot be served without having light vehicles. Finally, the available vehicles of each depot must be usable with regard to reception points feature and accessibility. Regarding components of goods flow (goods, demand and path) and supportive elements (storage alternatives and means of transport), we have identified five type of compatibility constraints to be studied while resource pooling, table 4.1.

Table 4.1. Compatibility item for pooling in city logistics.

Compatibility Matrix	Goods Characteristics	Demand characteristics	Path characteristics
Storage facility	√	√	-
Means of Transport	√	√	√

Briefly, the compatibility constraints, as one type of potential constraints against resource pooling, can be listed as follows:

- Compatibility between storage facility and goods characteristics.
- Compatibility between storage facility and demand characteristics.
- Compatibility between means of transport and goods characteristics.
- Compatibility between means of transport and demand characteristics.
- Compatibility between means of transport and path characteristics.

Note that, as we suppose that depots have been already installed, compatibility analysis between storage facility and path is not reasonable.

In presence of these constraints, urban freight distribution network cannot be pooled entirely and new network design through pooling will be affected. The proposed approach to formulate urban freight distribution pooling taking into consideration these potential constraints (policy-oriented constraints and compatibility constraints) are comprehensively explained in the next section.

4.3. Pooling Key Performance indicators

Key Performance indicators (KPIs) help managers to make the best decisions according to their criteria. KPIs used for city logistics are almost related to public authority and are used for individual decisions, however, in city logistics pooling the KPIs have to be able to evaluate the objective of all stakeholders (Gonzalez-Feliu, 2018). Regarding pooling literature, classic KPIs are almost used to evaluate the impacts of pooling in freight transportation efficiency by quantifying improvement concerning total travel cost (Pan et al. 2013, Gansterer and Hartl 2017), CO2 emissions (Durand et al. 2013, Pan et al. 2013), successful delivery rate (Durand et al. 2013) and total travelled distance (Montoya-Torres et al. 2016, Muñoz-Villamizar et al. 2017). Since our objective is to evaluate the impact of identified constraints in network design via pooling, we propose to adopt four performance indicators that can lead us to evaluate the network efficiency as well as provoked changes in the network after pooling. Two of these indicators for quantifying pooling benefice and calculating load factor, have been already presented and used in the literature ((ALICE report 2016, Montoya-Torres et al. 2016, Muñoz-Villamizar et al. 2017). In addition, we propose two new performance indicators to quantify disruptive impact and demand change while pooling for evaluating the impact of pooling in changing network design for designing a collaborative network. These indicators are defined in the following.

4.3.1. Pooling benefits

The main objective of pooling is to use the maximum capacity of resources in order to minimize cost as much as possible and to alleviate externalities of urban freight distribution. The first indicator that we propose is defined to calculate improvement achieved through pooling for each scenario. To this end, the amount of objective function that returns total distance travelled are compared in two cases, when there is pooling and when there is no pooling. To express clearly this indicator, we use the following notations:

TD_x^0 = Total travelled distance without pooling returned by method x

TD_x^h = Total travelled distance returned by method x for scenario h

IP_x^h= Improvement achieved via pooling by method x for scenario h

$$IP_x^h\ (\%) = \frac{TD_x^0 - TD_x^h}{TD_x^0} * 100$$

Where $h = 1, \dots, H$ is the scenario number and $x = SA\ or\ VNS$ refers to the type of algorithm used to solve the problem (SA: simulated annealin, and VNS: variable neighbourhood search). This indicator also helps to compare improvement achieved in the presence of different constraints and to find the most efficient arrangement of customers for an efficient pooling.

4.3.2. Disruptive impacts

As mentioned before, while constructing a pooled network, customers are shared fully or partially (when there is some constraints) due to policy of stakeholders or compatibility between depots and customers. In this way, they are allocated once again. This results in changing the initial arrangement of network. This change might cause dissatisfaction for the same reasons explained in section 4.2.1. In order to be able to evaluate the rate of change in a new network, we introduce two other indicators under the term of disruptive impacts. The first indicators return the percentage of change in the number of customer of a depot compared to its initial case where there is no pooling. Following notations are used to describe this indicator.

${NC_I}_i^0$ = Initial number of customers served by depot i

${NC_P}_i^h$ = Number of customer served by depot i after pooling regarding scenario h

CCR_i^h = Customer change rate for depot i regarding scenario h

$$CCR_i^h(\%) = \frac{{NC_P}_i^h - {NC_I}_i^0}{{NC_I}_i^0} * 100$$

Where $h = 1, \dots, H$ shows scenario number and $x = SA \text{ or } VNS$ refers to the type of algorithm used to solve the problem.

To give an example, when the initial number of customers served by depot D1 is 10 and after pooling this number shifts to 12, this indicator will return +20% which shows the gain of supplementary customers compared to its initial number of customers.

This indicator returns the change in the number of customers but one cannot realise how percentage of these customers are the initial customers of the depots and how many are new customers assigned after pooling. This is the reason why the second indicator of this group is defined to calculate the percentage of new customers for a depot after pooling. It means for each scenario and for each depot the number of new customers compared to its initial case. Following notations are used to describe this indicator.

NCI_i^h = Number of new customers allocated to depot i after pooling regarding scenario h that did not belong to this depot before pooling

TNC_i^h = Total number of customer to be served by depot i after pooling regarding scenario h

PNC_i^h = Percentage of new customers for depot i regarding scenario h

$$PNC_i^h(\%) = \frac{NCI_i^h}{TNC_i^h} * 100$$

To give an example, consider the previous example where the percentage of customer number change is +20%, if percentage of new customers for this depot returns 50% it means 6 of 12 customers allocated to this depot after pooling are new customers that initially did not belong to it. In other words, however this depot earned 2 new customers compared to its initial number of customers, it lost its 4 initial customers. These two indicators together help to analyse and understand changes a fully/partially pooled network.

4.3.3. Demand change

However, the disruptive impacts help to recognize the change in arrangement of pooled network, it seems necessary to analyse whether this change in number of customers has an impact on the demand quantity served by each depot or not. In other words, we intend to know if involving in collaboration would affect the market share of stakeholders or not. To do so, we introduce demand change as a new indicator to calculate the change of demand quantity for each depot before and after pooling. The following notations help to describe this indicator.

${DC_I}_i^0$ = Initial quantity of demands delivered by depot i

${DC_P}_i^h$ = Quantity of demands delivered by depot i after pooling regarding scenario h

DCR_i^h =Demand change rate for depot i regarding scenario h

$$DCR_i^h(\%) = \frac{{DC_P}_i^h - {DC_I}_i^0}{{DC_I}_i^0} * 100$$

Where $h = 1, \dots, H$ is the scenario number and $x = SA \; or \; VNS$ refers to the type of algorithm used to solve the problem.

It is quite conceivable that a depot gains more customers but with low demand quantities or in contrast, it gains less customers but with high demand quantities.

4.3.4. Load factor

The last indicator presented here has been already discussed as an important factor to evaluate the efficiency of urban freight distribution (ALICE report, 2016). Load factor means the used capacity of a mean of transport divided into its available capacity. Since one main objective of pooling is to use the maximum capacity of resources, we introduce this indicator to calculate the load factor of vehicles before and after pooling. As a depot can dispose more than one vehicle, the average load factor of all vehicles belonging to a depot has been used to calculate this indicator. This indicator is calculated as follows:

${LF_I}_i^0$ = Initial average load factor of vehicles belonging to depot i

${LF_P}_i^h$ = Average load factor of vehicles belonging to depot i after pooling regarding scenario h

LF_i^h = Improvement of average load factor of depot i regarding scenario h

$$LF_i^h(\%) = \frac{{LF_P}_i^h - {LF_I}_i^0}{{LF_I}_i^0} * 100$$

Where $h = 1, \dots, H$ is the scenario number and $x = SA \; and \; VNS$ refers to the type of algorithm used to solve the problem.

Load factor can be calculated in different manners. Maximum weight capacity, maximum available space, maximum number of pallets or parcels etc. can be a reference to calculate the load factor of a means of transport. It is worth mentioning that to be able to use this indicator; only one reference must be selected to provide the ability to interpret the results obtained upon this indicator.

4.4. Proposed approach

As mentioned earlier, we formulate our problem of resource pooling in urban distribution network as a Multi Depot Capacitated Vehicle Routing Problem (MDCVRP). This problem has an abundant literature. Several solution approaches have been proposed over years for solving this problem. A recent study has been used MDCVRP in order to evaluate the impact of collaborative strategies for goods delivery in city logistics (Montoya-Torres et al. 2016). Since our problem also concerns urban freight distribution, we use their approach as our basic approach and then we adapt it according to definition of our problems.

Since MDCVRP is a NP-hard problem, Montoya-Torres et al. 2016 have proposed to use a two-phase hierarchal heuristics approach. Their approach consists of two successive phases. The first phase uses a classic allocation model to assign shared delivery points to depots and the second phase solves a Capacitated Vehicle Routing Problem (CVRP) to find optimal routing for each depot.

For our problem, we follow the same steps by adding several adaptations. At the first step, we use the classic allocation model with a new added set of constraints that incorporates identified constraints into the allocation model. The demonstration and formulation of these constraints will be explained in the next section. For the second phase, we use two metaheuristics widely used for CVRP in the context of city logistics. And at the end, we use our adapted indicators to evaluate the impact of identified constrains on resource pooling efficiency. The summary of our approach is shown in figure 4.4.

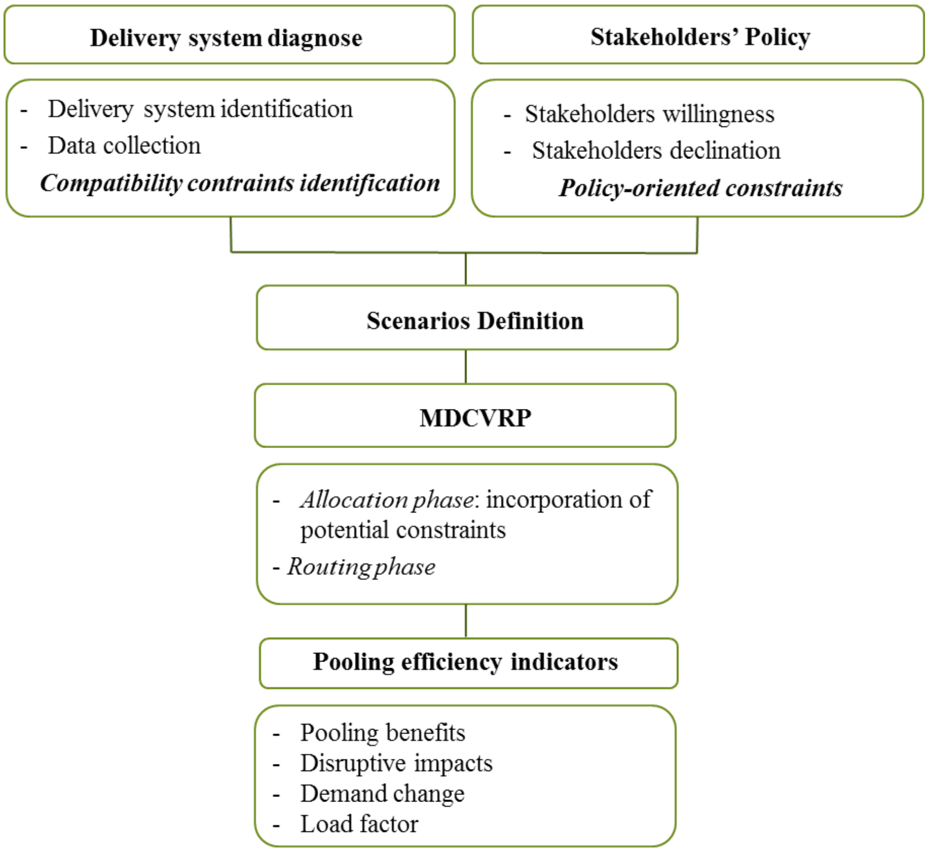


Figure 4.4. Proposed approach for evaluating resource pooling in presence of constrains.

Delivery system diagnose is an output of typology of flow by which the delivery system of interest is identified, required data is collected in order to identify existing compatibility constraints between resources of stakeholders involved and required facilities for being able to serve new customers. A deep analysis of stakeholders' willingness and declinations can lead to identify possible policy-oriented constraints. Consequently, we define different scenarios according to each group of identified constraints. To evaluate each scenario, we solve a MDCVRP in two stages. The first stage is allocation phase where potential constraints are integrated into the allocation model. The next step is then to find the best tour with solving a CVRP whose objective is to minimize total travelled distance. In the following, we use our presented indicators to evaluate the impact of these constrains on resource pooling efficiency. Each of these steps are respectively presented in the following sections.

4.4.1. Allocation phase

To assign delivery points to depots through pooling, when all depots share all their resources and customers (delivery points), we use the allocation model presented in (Muñoz-Villamizar et al. 2017). The notation and the mathematical model for the allocation phase is presented as follows:

Sets	
$i = \{1, \dots, n\}$	Depots
$j = \{1, \dots, m\}$	Delivery points
Parameters	
C_{ij}	Distance between depot i and delivery point j
D_j	Demand of delivery point j
CAP^i	Capacity of vehicles belonged to depot i
U	Minimum level of vehicles utilization, in percentage
Variables	
X_{ij}	= 1 if there delivery point j is assigned to depot i, 0 otherwise
Y_i	The number of required vehicles for depot i

$$\text{Min} \quad \sum_i \sum_j C_{ij} X_{ij} \tag{1}$$

S.t:

$$\sum_i X_{ij} = 1, \qquad \forall j \tag{2}$$

$$Y_j \geq \frac{\sum_j X_{ij} D_j}{CAP^i}, \qquad \forall i \tag{3}$$

$$\sum_j X_{ij} D_j \geq U * CAP^i * Y_i, \qquad \forall i \tag{4}$$

$$X_{ij} \in \{0,1\}, \qquad \forall i, j \tag{5}$$

$$Y_i \in Z^+, \qquad \forall i \tag{6}$$

Objective function (1) is defined to minimize distance of allocated delivery points to each depot. Constraints (2) guarantee to assign each delivery point to one and only one depot. Constraints (3) calculate the required number of vehicles for each depot to satisfy its total assigned demand, note that it is assumed that all vehicles of a depot have the same capacity. As this allocation problem is solved to pool as much as possible goods flows, constraints (4) is added to ensure a minimum load factor rate. At the end, constraints (5) and (6) define the variables’ domain.

To incorporate the identified constraints into this allocation model, it is enough to add a set of constraints that force the model to make assignment with regard to acceptance/refuse of depots to share their customers (policy-oriented constraints) and with regard to the compatibilities between depots' facility and goods flow of new customers (compatibility constraints). We use binary matrices to model each type of constraints. Following notation are used to demonstrate these constraints.

Policy oriented constraints representation

To demonstrate policy-oriented constraints, we construct a binary $n \times m$ matrix whose number of rows show the number of involved depots in pooling and number of columns show the total number of customers shared by all depots. So we have:

$i = 1, \dots, n$: number of depots involved in pooling

$j = 1, \dots, m$: number of all delivery points shared by depots

We suppose that there could be two sets of constraints concerning policy-oriented constraints:

1. Set of constraints regarding acceptance/refuse of depots to **share** their own customers.
2. Set of constraints regarding acceptance/refuse of depots to **serve** customers of other depots.

To present the first set of constraints, matrix I^a is used as shown in figure 4.5.a.

$$I^a = \begin{bmatrix} p_{11}^a & \cdots & p_{1m}^a \\ \vdots & \ddots & \vdots \\ p_{n1}^a & \cdots & p_{nm}^a \end{bmatrix}$$

$$p_{ij}^a = \begin{cases} 1 & if\ depot\ i\ accepts\ to\ share\ its\ own\ customer\ j\ with\ others \\ 0 & if\ depot\ i\ refuses\ to\ share\ its\ own\ customer\ j\ with\ others \end{cases}$$

Figure 4.5.a. Policy-oriented constraint representation: acceptance/refuse to share customers

figure 4.5.b shows the matrix for the second set of constraints, named I^r.

$$I^r = \begin{bmatrix} p_{11}^r & \cdots & p_{1m}^r \\ \vdots & \ddots & \vdots \\ p_{n1}^r & \cdots & p_{nm}^r \end{bmatrix}$$

$$p_{ij}^r = \begin{cases} 1 & if\ depot\ i\ accepts\ to\ serve\ the\ new\ customer\ j\ of\ other\ depots \\ 0 & if\ depot\ i\ refuses\ to\ serve\ the\ new\ customer\ j\ of\ other\ depots \end{cases}$$

Figure 4.5.b. Policy oriented constraint representation: refuse to serve new customers.

Compatibility constraints representation

To demonstrate compatibility constraints, we use the same structure as policy-oriented constraints representation. The difference is that for compatibility constraints, we need five matrices to show each identified compatibility constraints. Each of these matrices represents respectively:

Compatibility between depots facility to receive, keep or prepare goods, meaning:

1. Compatibility between a depot facility with goods characteristics

2. Compatibility between a depot facility with demand characteristics

Then, compatibility between available mode of transport for a depot with goods flows, meaning:

3. Compatibility between available means of transport with goods characteristics
4. Compatibility between available means of transport with demand characteristics
5. Compatibility between available means of transport with path characteristics

These matrices are constructed as follows:

$i = 1, \dots, n$: number of depots involved in pooling

$j = 1, \dots, m$: number of all delivery points shared by depots

$k = 1, \dots, 5$: number of compatibility constrains

$$A^k = \begin{bmatrix} p_{11}^k & \cdots & p_{1m}^k \\ \vdots & \ddots & \vdots \\ p_{n1}^k & \cdots & p_{nm}^k \end{bmatrix}$$

$$p_{ij}^k = \begin{cases} 1 & if\ delivery\ point\ j\ is\ compatible\ with\ depot\ i\ according\ to\ compatibility\ k \\ 0 & otherwise \end{cases}$$

Figure 4.6. Compatibility constraints representation.

Since, even one incompatibility between a depot facility with goods flows causes to make it infeasible (impossible) to assign a delivery point, five compatibility constraints matrices are multiplied by Hadamard product to construct the final compatibility matrix. This matrix represents as follows:

$$A_{cc}[\alpha_{ij}] = A^1 \circ A^2 \circ A^3 \circ A^4 \circ A^5$$

$$\alpha_{ij} = \begin{cases} 1 & if\ delivery\ point\ \ j\ is\ compatible\ to\ be\ assigned\ to\ depot\ i \\ 0 & otherwise \end{cases}$$

Figure 4.7. Final compatibility matrix.

These matrices can be used to integrate policy-oriented constrains and compatibility constraints into the allocation model in order to evaluate different scenarios. Therefore, three types of scenario can be defined according to these constraints:

1. When the objective is to consider acceptance/refuse of depots to **share** their own customers while assigning, it is enough to add following constraints to the allocation model:

$$X_{ij} \leq p_{ij}^a, \quad \forall\ i, j$$

2. When the objective is to consider acceptance/refuse of depots to **serve** customers of other depots while assigning, it is enough to add following constraints to the allocation model:

$$X_{ij} \leq p_{ij}^{r}\ , \quad \forall\ i, j$$

3. And, when the objective is to consider compatibility constraints while assigning, it is enough to add the following constraints to the allocation model:

$$X_{ij} \leq \alpha_{ij}\ , \quad \forall\ i, j$$

These constraints cause to design a pooled network with regard to the identified constraints, meaning network achieved through this approach will not be a fully pooled network. The more information about scenarios definition and their evaluation will be presented in chapter 5.

4.4.2. Routing phase

Before starting routing phase, we intend to state that this part of thesis has been carried out in collaboration with Emmanuel Lionet, as part of his master project (Travaux d'Etude et de Recherche) under supervision of Parisa Dolati Neghabadi and Marie-Laure Espinouse.

Once the allocation has been done according to potential constraints, the second phase is to find the optimal routing for each depot. To do so, a capacitated vehicle problem (CVRP) must be solved. The CVRP, first studied by Dantzig and Ramser (1959) is a major issue in literature. Indeed, determining the optimal solution for a CVRP is NP-Hard (Toth and Vigo 2002, Yassen and Vigo 2002). In the literature, several metaheuristics algorithms are used to find satisfying result in limited time. These procedures explore a solution space trying to find better solution. Most of them randomly modify an initial feasible solution, and accept changes made under conditions. Since many years, these algorithms are studied and improved in order to find better solutions on larger instances. We have conducted a literature review on methods used in recent years for solving VRP variants, figure 4.5. From the results obtained from our literature review, we have chosen two algorithms to solve our CVRP. The first one is simulated annealing as this method was proved to be very efficient for a similar VRP of the one studied in our problem (Yassen et al., 2017). The second algorithm is a variable neighbourhood search, using neighbourhood structures and local search methods (Dantzig and Ramser 1959, Kancharla and Ramadurai 2018). This method is one of the most used in the recent literature and was proved to be efficient for multiple VRP variants including CVRP. This method has been also frequently used in recent years for VRP in the context of city logistics (Grangier et al. 2016, Masson et al. 2017, Schiffer and Walther 2017, Wang et al. 2017, Amarouche et al. 2018).

However, both of these algorithms were proved to be efficient and well-studied methods, it is not possible to determine if these algorithms are the best in our case for different reasons:

- Computers used to run these algorithms does not have the same hardware, and the number of processor core is not always mentioned.

- Dataset are different (number of customers, distances, vehicle capacity…).
- Programming languages are different
- It is almost never mentioned if the program is multi-threaded, even though it is expected not to be.

Authors	**Objective to be minimised**	Total distance	Travel time	Fuel consumption	Amount of vehicle	**Constraints**	Vehicle capacity	Time window	Installation time	2 dimensions items arrangement	3 dimensions items arrangement	Items compatibility	**Algorithm**	Linear Programming	Branch and Cut	Hybrid Variable neighbourhood Search	Variable neighbourhood Search	Tabu Search	Column Generation Based Algorithm	Greedy Randomized Adaptive Search Procedure	Evolutionary Local search	Ant colony optimisation	Hybrid Evolutionary search	Hybrid Large neighbourhood Search	Discrete Hybrid Invasive Weed Optimization	Genetic Algorithm	Gravitational Emulation Local Search	Symbiotic Organism Search
Belhaiza, Hansen, and Laporte (2014)			×				×	×								×		×										
Dhahri, Zidi, and Ghedira (2014)		×					×	×						×		×												
Wei, Zhang, Z., Zhang, D. and Lim (2015)		×					×			×							×											
Mahvash, Awasthi, and Chauhan (2015)		×					×				×								×									
Zhang, Z., Wei, L. and Lim (2015)				×			×				×										×							
Brito, Martínez, Moreno, and Verdegay (2015)		×					×	×														×						
Koç, Bektaş, Jabali, and Laporte (2015)		×					×	×															×					
Akpinar (2016)		×					×															×		×				
Zhao, Leng, Qian, and Wang (2016)		×					×																		×			
Schneider (2016)		×			×		×	×										×										
Bae and Moon (2016)		×					×	×	×																	×		
Hosseinabadi, Rostami, Kardgar, Mirkamali and Abraham (2017)		×					×																				×	
Wang, Shao, and Zhou (2017)				×			×							×		×												
Yu, Redi, Yang, Ruskartina, and San-tosa (2017)		×					×																					×
Braaten, Gjønnes, Hvattum, and Tirado (2017)		×						×																				
Yassen, Ayob, Nazri, and Sabar (2017)		×					×	×										×										
Alinaghian and Shokouhi (2018)		×			×		×					×					×											
Hu, Lu, Liu, and Zhang (2018)		×					×	×																				
Dalmeijer and Spliet (2018)		×					×	×							×													
Wei, Zhang, Z., Zhang, D. and Heung (2018)		×					×				×																	

Figure 4.8. Literature review of metaheuristics used for CVRP.

Another point to mention is that in the most of articles, minimizing total distance is considered as objective function for CVRP. More detailed information on each of these methods are presented in the following sections.

4.4.2.1. Simulated annealing

Simulated annealing (SA), firstly studied by Kirkpatrick, Gelatt and Vecchi in 1983, is a method used to solve combinatorial optimization problems. The SA version proposed in this paper is almost the same described by Wei, Z. Zhang, D. Zhang and Leung (Wei et al., 2018). It uses an initial solution and randomly chooses one of the local search procedures in order to modify the solution. Changes provided are accepted in two cases:

- They strictly improve the current solution
- They deteriorate the current solution but are accepted with a certain probability, calculated with the current temperature T of the algorithm

Algorithm. 1. Simulated annealing

```
   SA()
 1. Construct the initial solution S
 2. S* = S, T = T0, Tb = T0
 3. while time limit is not exceeded
 4.   for k = 1 to Len
 5.     Select a local search method LS randomly
 6.     Generate a feasible solution S’ from S with LS
 7.     if cost(S’) < cost(S)
 8.       S = S’
 9.     else
10.       S = S’ with a probability p, where p = e^(-(cost(S')-cost(S))/T)
11.     if S’ is better than S*
12.       S* = S’, Tb = T
13.     T = α × T
14.     if T < 0.01
15.       Tb = 2 × Tb, T = min(Tb, Tmax)
16. return S*
```

The main idea of this algorithm is to modify constantly a solution in order to find local optimums. These modifications are controlled by the temperature T, whose value varies during the execution. More precisely, the probability of accepting a solution is calculated with T (algorithm 1). At the beginning, its value is high which means deteriorating modifications can be accepted. This strategy allows exploring the vast solution space without staying stuck in a local solution. As the execution continues, the temperature is cooled by the cooling factor α (line 13). As a result, the probability of accepting deteriorating modifications decreases. When the temperature becomes low, only improving moves are accepted, which leads to obtaining local optimum. The main difference of this SA version in comparison to the classic SA (Wei et al. 2018) is that the temperature rises again after decreasing beyond a given threshold (lines 14, 15). By increasing the temperature, a worse solution can once again be temporary accepted in order to escape the current local optimum. This allows to explore as much local optimums as possible. At the end, the best solution found is returned.

Constants values are set as indicated in the reference article (Wei et al. 2018). Initial temperature T_0 is set such that a solution $w\%$ worse than the initial solution has a 50% chance to be accepted. Which means:

$$T_0 = \frac{w * cost(S)}{In(0.5)}$$

The value of Len is set to N^2. Moreover, the value of w is set to 0.1, which means that a solution 10% worse than T_0 will have a probability of 50% to be accepted at the beginning. The value of the cooling factor α is set to 0.9. Finally, authors propose to set $Tmax\ at\ 25$, but experiments have shown that this value is excessively low for our dataset. These same experiments have shown that $Tmax = 50000$ is a better value and gives satisfying results.

4.4.2.2. Variable neighbourhood search

Variable neighbourhood search (VNS), first proposed by Mladenovic and Hansen in 1997, is a method that uses the idea of systematically changing neighbourhoods during the search. It uses the theory that a better local optimum is not necessary so far from another. The VNS version selected in this paper is the one described by Wei et al. 2015.

Algorithm. 2. Variable neighbourhood search

```
    VNS()
 1. Construct the initial solution S
 2. Define a set of neighbourhood structures NSi(i=1…k)
 3.  S* = S, nonImp = 0
 4.  while time limit is not exceeded
 5.   nonImp = nonImp + 1
 6.   k = 1
 7.   while k ≤ |NS|
 8.            repeat K times
 9.                 Generate a random neighbouring S' of S using NSk
10.                 S" ← LocalSearch(S')
11.                 if S" is better than S*
12.                      S* = S", S = S"
13.                      K = 0, nonImp = 0
14.                      break
15.            k = k + 1
16.       S = Diversify(S*)
17.  return S
```

In each iteration on the main loop, a random neighbouring S' of S is generated using NS_k, and taken as a temporary solution. This solution is then optimized by the local search procedure to find its local optimum S''. Unlike the classical VNS, this loop is executed K times for each neighbouring structure (line 8). When a better solution is found, we resume the search with the new solution and revert the neighbourhood structure back to NS_1. Else, we continue exploring with the next neighbourhood structure. Once every structure has been tried, we employ a diversification procedure to produce a new initial solution (line 16). This procedure brings drastic changes to the solution in order to reach other regions that neighbourhood structures cannot easily find.

The neighbourhood structures are utilized to diversify the starting point of local search. They are the main characteristics of VNS. We use the 6 structures described in the reference article (Wei et al. 2015).

- Segment exchange (**SE**): Select two sub-routes of same length from different route, overturns them and exchange their position. As recommended in the article, sub-routes length must be 2 or 3. These structures are denoted **SE2** and **SE3** (depending of the length).
- Move combination (**MC**): Randomly chose two moves from the six presented in section 4.4. This structure is denoted **MC2**.
- The last structure is the idea of repeating each individual previous structures several times, controlled by a variable $strength$. We use the same value as indicated by Wei et al. 2015, which means $strength$ is equal to 1 or 2.

To sum up, the 6 structures used in this VNS version are **SE21** (performs **SE2** once), **SE22** (performs **SE2** twice), **SE31**, **SE32**, **MC21** and **MC22**.

Once again, constants initialization is done as proposed in (Wei et al. 2015). Thus, K is equal to the number of available vehicles. Constant $nonImp$ corresponds to the number of iterations without improvement after calling VNS. The diversification procedure $Diversify$ uses the same mechanism as the initial construction procedure. From a given solution, it randomly removes a given number of customers, and then reinsert them in the same order as the one indicated in $Initial\_solution$. The number of removed customers is equal to min $(0.5 \times N, 0.1 \times N + nonImp)$.

It is worthy to mention that the runtime limit for each instance has been set as indicated in (Wei et al. 2015 and Wei et al. 2018): 1800 seconds for SA (it is supposed to be 3600 if N > 50 which is never the case in this paper), and 900 seconds for VNS (supposed to be 1800 or 3600 if N > 50). Each in-stance has been executed once for each algorithm, unlike the articles (Wei et al. 2015 and Wei et al. 2018) in which methods are executed 10 times for each instance.

4.4.2.3. Local search methods

Both SA and VNS use local search methods to explore a solution:

- Intra-swap: Exchange the position of a pair of customers within the same route
- Inter-swap: Exchange the position of a pair of customers from different route

- Intra-shift: Shift the position of a customer elsewhere in the same route
- Inter-shift: Shift the position of a customer elsewhere in another route
- Intra-2opt: Select a sub-route and overturns it
- Inter-2opt: Select two sub-routes from different routes, overturns them and exchange their position

A move is performed only if the new solution is feasible, i.e. each route does not exceed the capacity of the vehicle. In order to avoid blocking situation, "inter-" methods have a limited number of attempts before returning the given current solution. Our observations showed that setting this limit to 100 is a good compromise. Indeed, even though most of moves are performed in under 10 attempts, few of them require up 100 attempts.

4.4.2.4. Construction of the initial solution

The same algorithm is used by both algorithms to create the initial solution. In our experiments, this algorithm has proven to be efficient and allows to find quickly a good solution (in term of weight balance and distance).

Algorithm. 3. Initial solution

```
Initial_solution()
S = K empty routes
T = Customers sorted by decreasing value of their demands
T' = empty list
while T is not empty
  if can insert T1 in S
    insert T1 in the least full route of S in term of weight, such as it increase
the least the distance
   else
     while cannot insert T1 in S
                c = randomly chosen customer in S
                remove c from S
                add c in T'
          T = T U T'
          resort T by decreasing value of customers' demands
return S
```

4.5. Data collection

In this chapter, we have identified potential constraints against resource pooling in the context of urban freight distribution. We have also presented our proposed approach for quantifying the impacts of these constraints on resource pooling efficiency. In order to verify our identified constraints as well as our proposed approach, we use a real case study raised from the literature (Montoya-Torres et al. 2016). Real data in this case study have been provided by three major last mile logistics service providers (depots) operating in Bogota, Colombia. Bogota is the capital of Colombia and its largest city. It is the fifth largest city in Latin America and twenty-fifth in the world (City Mayors, 2015). Using this data as our case study allows us to have a complex and complete example to study the impact of potential constraints on city logistics pooling in large cities. In our case study, there are three depots, first depot (D1), second depot (D2) and third depot (D3) own respectively 16, 35 and 10 customers (delivery points).

The origin-destination matrix based on the shortest path was obtained using actual driving distances using Google MapsTM mapping service (accessed: 24 August, 2014). In order to perform statistical analysis, we have randomly generated demand from a uniform distribution. We use two different range for demand generation to be able to analyse its impact on pooling efficiency, therefore demand was generated once between 1% and 10% of the maximum load capacity of the vehicle and then between 5% and 25%. We suppose that available type of vehicles for depots is "Renault Master Euro 6" that its useful capacity is 12 or 15 m3. Then, it can be loaded by 100 parcels of large format. The more detail on this and the manner of scenarios definition and also their evaluation is provided in chapter 5.

Conclusion

In this chapter, we focused on implementation conditions for resource pooling in city logistics. We identified potential constraints against resource pooling with regard to stakeholders' policy (policy-oriented constraints) and compatibility analysis (compatibility constraints). Furthermore, we defined different scenarios taking into account different assumptions concerning identified constraints. In the following, we presented our approach as well as adapted performance indicators in order to evaluate each of these scenarios.

Chapter 5. Scenarios Definition and Experimentations

Introduction

In chapter 4, we explained the contribution of ToF concept for identifying potential constraints in front of pooling. In the following, we addressed two groups of constraints, policy-oriented constraints and compatibility constraints, with focusing on resource pooling. In this chapter, we intend to evaluate impacts of these constraints on pooling efficiency. To do so, we develop different scenarios according to the identified potential constraints for resource pooling. Thus, six different scenarios are defined, two first are regarding policy-oriented constraints and four second are concerning compatibility constraints. The first scenario regarding policy-oriented constrains is defined to evaluate impacts of acceptance/refuse of depots to either share their own customers or to serve new customers (meaning customers of other depots). The second scenario in this group is defined to consider simultaneously both policies of depots concerning their acceptance/refuse to share their own customers and to serve new customers. The second group of four scenarios concern compatibility constraints. The first scenario of this group is defined to consider impacts of compatibility constraints in resource pooling. As we described in chapter 4, compatibility constraints are stricter than policy-oriented constraints. As we described in chapter 4, compatibility constraints are stricter than policy-oriented constraints. Hence, three following scenarios are defined to simulate pooling in different conditions in order to evaluate how pooling efficiency in these cases changes in presence of compatibility constraints. In this manner, to analyse the share of each depot in pooling efficiency in presence of compatibility constraints, the fourth scenario is defined under condition of putting aside one depot and to do resource pooling using two other depots; in this case, we suppose the removed depot runs in its initial state. In two last scenarios, we intend to consider impact of compatibility constraints when quantity of demand is larger comparing to the previous scenarios. To this end, we increase quantity of demand for each customer and then repeat the third and fourth scenarios again. We applied our proposed approach (explained in 4.4) in order to evaluate each of these scenarios for our case study presented in 4.5.

The remainder of this chapter is organized as follows. In section 5.1, a comprehensive explanation about each of scenarios is provided. Section 5.2 presents the approach for evaluating scenarios. Section 5.3 is dedicated to the presentation of experimental results and discussion concerning each scenario.

5.1. Resource pooling scenarios definition

As already discussed in chapter 2, pooling has become a discussable topic in recent years. Its potential advantages have been discussed in order to prove its ability in mitigating undesirable externalities due to urban freight transportation. However, pooling seems an interesting solution at first glance, impacts of potential constraints against pooling especially concerning its implementation phase have never been studied. In chapter 4, we concentrated on identifying potential constraints in front of resource pooling. We also described our proposed approach in order to evaluate impacts of these constraints on resource pooling efficiency. In this chapter, we define several different scenarios in order to evaluate impacts of both policy-oriented constraints and compatibility constraints on our case study.

In our case study, we have three depots: D1, D2, and D3. These depots own respectively 16, 35, 10 customers (delivery points). We set customers (delivery points) of each depot by C1, C2, and C3. Each scenario includes different tests. A series of test for each scenario is defined to make it possible to evaluate different moods of a set of constraints. More detail information on the way of scenarios definition for police-oriented constrains and compatibility constraints are provided in next sections.

5.1.1. Scenarios concerning policy-oriented constraint

Under term of policy-oriented constraints, two different situations are described to represent the possible reaction of stakeholders involved for the goal of resource pooling. We recall that the roots of such decisions have been widely discussed in section 4.2.1. Two situations regarding policy-oriented constraints are defined as follows:

1. Depots accept/refuse to share their own customers.
2. Depots accept/refuse to serve new customers (customers of other depots).

In the first case, each depot independently decides either accept/refuse to share each of its own customers with other depots. As described in 4.4.1, to represent the set of constraints, we use a binary matrix whose row are the depots and columns indicates all customers (delivery points), such a matrix is presented in figure 5.1. In this matrix, elements regarding column C_j and rows D_i take 1 or zero regarding policy of depot D_j to accept/refuse to share its customers with these depots. To give an example, if an element from column C1 and row D3 takes 1, it means that depot D1 accepts to share this delivery point of C1 with depot D3 while pooling. In other words, while assigning delivery points to depots in the allocation phase, it is allowed to assign this delivery point of C1 either to the depot D1 or to the depot D3. To give another example, if an element of column C3 and row D1 takes zero, it indicates that depot D3 refuses to share this delivery point of C3 with depot D1 and in the allocation phase, this delivery points of C3 cannot be assigned to the depot D1.

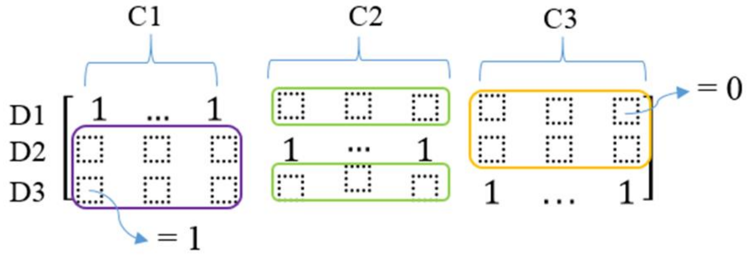


Figure 5.1. Matrix representation for depots policy to accept/refuse to share their own customers.

In the second case, each depot individually decides to either accept or refuse to serve new customers that have initially being served by other depots. As explained above, a binary matrix is used to represent this set of constraints. As shown in figure 5.2, in this matrix, elements regarding rows D_i and columns C_j take 1 or zero regarding policy of depot D1 to accept/refuse to serve these new customers.

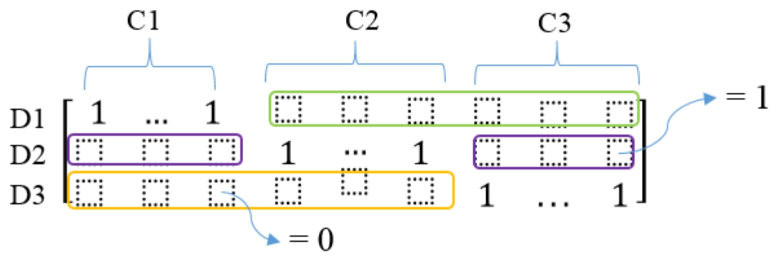


Figure 5.2. Matrix representation for depots policy to accept/refuse to serve new customers.

With reference to above description, we can define three different scenarios with regard to policy-oriented constraints:

1. Pooling with considering depots' policy in order to accept/refuse to share their own customers
2. Pooling with considering depots' policy in order to accept/refuse to serve new customer
3. Pooling with considering depots' policy in order to accept/refuse to share their own customers and to serve new customers.

In each of these scenarios, depots' policy could be permissive. It means that they do not impose many constraints in front of pooling. In other words, they are ready to participate in pooling without preconditions. In contrast, their policy could be strict meaning they do not open enough to collaborate with all involved stakeholders. In order to evaluate different level of imposed constraints by depots' policy, we define different series of test for each scenario mentioned above.

Series of test for each scenario is defined as follows: in the first test, it is assumed that a fully pooling is possible and there are no constraints. In the second test, it is supposed that each depot accepts to share only 95% of its customers. Similarly, constraints gradually become stricter, it means in third test, rate of acceptance to share customers decreases to 90%. Figure 5.3 represents how we generate matrices for each series of test. For each test, we generate each element of this matrix (excluding those that are already given 1 since they are always accepted by their initial depots) using a probability of acceptance of P_k. In figure 5.3, K represents the number of test. As mentioned above for test 1: $P_1 = 1$, for test 2, $P_1 = 0.95$, for test 3: $P_1 = 0.90$.

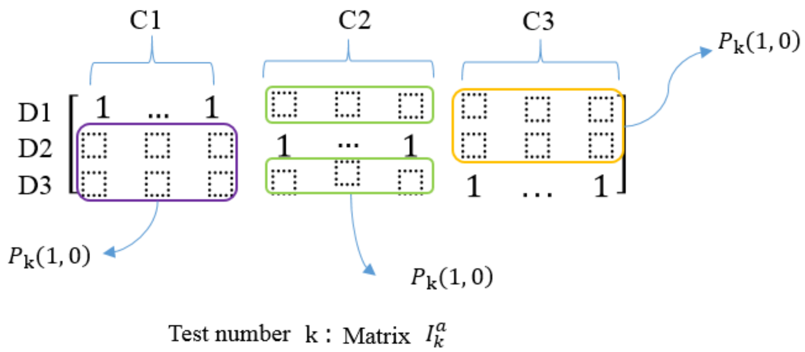


Figure 5.3. Matrix representation for accepting to share customers in test k.

Figure 5.4 shows matrix representation for the second scenario, which concerns depots' policy regarding acceptance/refuse to serve new customers.

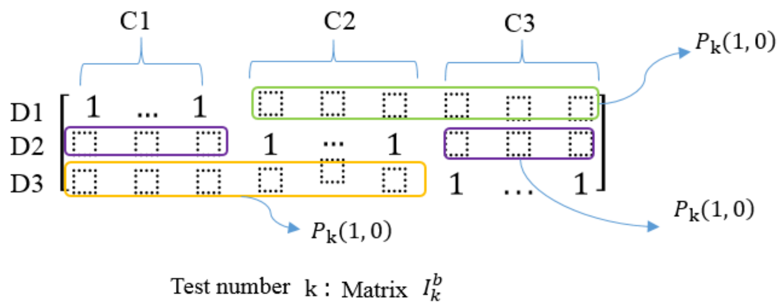


Figure 5.4. Matrix representation for accepting to serve new customers in test k .

It is important to note that since the way that these matrices representing policy-oriented constraints for the first and second scenarios are finally made is the same, therefore, we will have $I_k^a \approx I_k^b \ \forall k$. Hence, these two scenarios can be grouped as scenario 1. Note that despite considering these two scenarios alike, the results can be differently interpreted with regard to each case.

For matrix representation of third scenario, we remind that here we consider simultaneously both depots' policy regarding acceptance/refuse to share their customers and also acceptance/refuse to serve new customers. Therefore, for constructing policy-oriented matrix for this scenario it is enough to use Hadamard product[1] of two previously described matrices. Thus, for third scenario, we have $I_k^{ab} = I_k^a \circ I_k^b \ \forall k$.

Ultimately, we come up with two different scenarios:

1. Scenario 1: pooling with regard to constraints represented by matrix $I_k^a \approx I_k^b \ \forall k$ in where depots' policy in order to accept/refuse to share their own customers or accept/refuse to share serve new customers is taken into account.
2. Scenario 2: pooling with regard to constraints represented by matrix $I_k^{ab} \ \forall k$ in where depots' policy in order to accept/refuse to share their own customers and to serve new customers are taken into account.

Each series in these two scenarios includes 13 tests, it means that $k = 1, \dots, 13$. The list of probability used to define different series of tests for both scenario 1 and 2 is presented in table 5.1. Hereafter, we will set L_k for representing the k tests of scenario 1 and P_k for representing the k tests scenario 2.

Table 5.1. Probability of restriction concerning policy oriented constraints.

Test	**Probability (%)**
Test 1	$P_1 = 100$
Test 2	$P_2 = 95$
Test 3	$P_3 = 90$
Test 4	$P_4 = 85$
Test 5	$P_5 = 80$
Test 6	$P_6 = 75$
Test 7	$P_7 = 70$
Test 8	$P_8 = 60$
Test 9	$P_9 = 50$
Test 10	$P_{10} = 40$
Test 11	$P_{11} = 30$
Test 12	$P_{12} = 20$
Test 13	$P_{13} = 10$

5.1.2. Scenarios concerning compatibility constraints

Compatibility constraints are strict as five constrains of compatibility between depots' facility with goods and demand characteristics on one hand and compatibility between depots' available means of transport with goods, demand and path on the other hand. In order to evaluate impacts of this set of constraints in resource pooling efficiency, we define four different scenarios. The first scenario in this group is defined to generally evaluate pooling

[1] ***Hadamard product*** is a binary operation that takes two matrices of the same dimensions, and produces another matrix where each element i, j is the product of elements i, j of the original two matrices (Johnson,1974).

efficiency in presence of compatibility constraints (scenario 3). With regard to the stricter nature of this set of constraints, the second scenario is defined to analyse one depot's importance in constructing pooled network. To this end, three different sub-scenarios are defined with putting aside one depot and doing pooling just using two other depots; in this case, we suppose the removed depot runs in its initial function (Scenario 4). It means, in the first sub-scenario, depot D1 is put aside and pooling is performed between depot D2 and D3. In the second sub-scenario, depot D2 is put aside and pooling is performed between depot D1 and D3. Finally, in the third sub-scenario, depot D3 is put aside and pooling is performed between depot D1 and D2. In the following, the two last scenarios are defined to analyse impacts of quantity of demand on resource pooling in presence of compatibility constraints. Hence, scenarios 3 and 4 are repeated when demand are increased for all delivery points (scenario 5 and 6) in order to evaluate impacts of compatibility constraints on pooling efficiency when are larger than normal. To summary scenarios definition regarding compatibility constraints, the four scenarios of the second group are:

3. Pooling with considering compatibility constraints
4. Pooling with considering compatibility constraints when a depot is put aside
5. Pooling with considering compatibility constraints when demand quantity is increased
6. Pooling with considering compatibility constraints when a depot is put aside and demand quantity is increased

For each of these scenarios, the compatibility matrix for each of five compatibility constraints is constructed as shown in figure 5.5 In this matrix, elements regarding row Di and column Cj takes 1 if depot Di is compatible with this customer of Cj with regard to the compatibility constraint. In contrary, it takes 0 if depot Di is not compatible with this customer of Cj regarding the compatibility constraints.

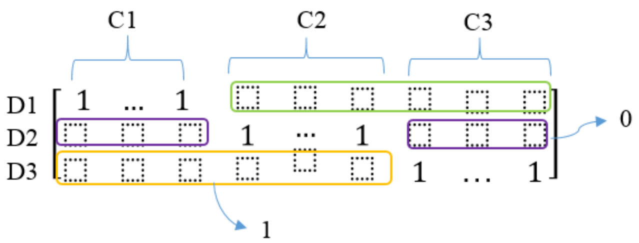


Figure 5.5. Compatibility matrix representation.

As scenarios defined concerning policy-oriented constraints, we define series of test for scenarios of this group, as well. It means, we start from permissive compatibility constraints and gradually we make them stricter. For example, for the matrix regarding compatibility between depot facility and goods characteristics, in the first test, we assume that all shared delivery points C2 and C3 (note that delivery points initially served by the depot are compatible with it) are compatible with depot D1 facility, so they can be occasionally served by depot D1. In the second test, we assume that only 95% of shared delivery points are compatible with each depot. Figure 5.6 shows the matrix construction for each test. Note that, P_k represents probability of compatibility for each set of constraints in test k. Moreover, the way of constructing these five matrices, each representing one of five compatibility constraints are identical. Furthermore, as already mentioned, one depot can be compatible with a delivery point if all five compatibility constraints are satisfied. To give an example, one delivery point of depot D1 can be compatible with depot D1 (an element in column C2 and row D1), if this element takes 1 in all five compatibility matrices. Five matrices final are multiplied by Hadamard product to achieve final compatibility matrix. So, we will have:

$A_k^{cc} = [\alpha_{ij}]$: final compatibility matrix

$i = 1, \dots, n$: number of depots involved in pooling

$j = 1, \dots, m$: number of all delivery points

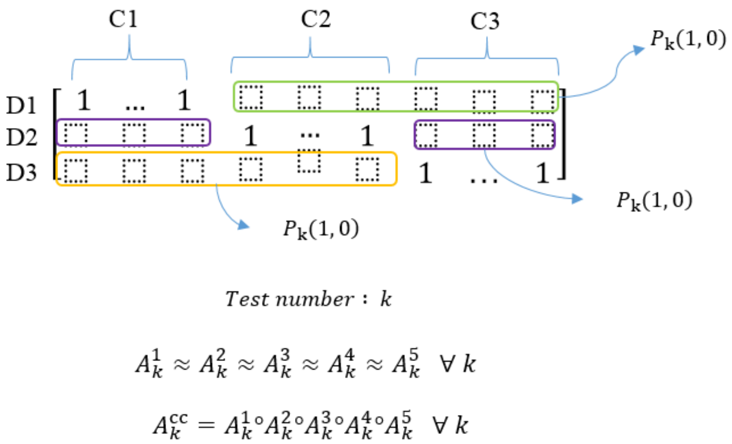


Figure 5.6. Final compatibility matrix construction: A_k^{cc}.

As explained above, compatibility probability for each series of test in this group of scenario start from 100 and then decreases steps by steps to 95, 90, 85, 80, 75, 70, 60 and 50. Moreover, as already pointed out, final compatibility matrix reveals compatible delivery points for each depot. In other words, elements that are given 1 are “poolable” delivery points regarding compatibility constraints. In order to have a reference to be able to compare impacts of compatibility constraints on pooling, we propose to calculate the compatibility rate. Two type of compatibility rate can be defined. To explain the first type of compatibility rate, first we remind that we suppose that a depot’s initial delivery points are always compatible with it.

Thus, in the first compatibility rate, we count all compatible delivery points (meaning including initial delivery points of each depot) returned by final compatibility matrix. However, for the second one, compatible delivery points among shared delivery points are counted, in deed, initial delivery points of each depot are excluded from computation. The following notations show the definition of these two compatibility rate.

$A_k^{cc} = [\alpha_{ij}]$: final compatibility matrix

$i = 1, \dots, n$: number of depots involved in pooling

$j = 1, \dots, m$: number of all delivery points

Total compatibility rate: $\frac{\sum_i \sum_j \alpha_{ij}}{m*n}$

Pure pooling compatibility rate: $\frac{\sum_i \sum_j \alpha_{ij} - m}{m*n}$

We generate 9 random matrices with different probability of compatibility as explained above and the results are shown in table 5.2. It is important to notice that beyond 50 percentages for compatibility probability, pure compatibility becomes equal to zero. This seems reasonable since each matrix is randomly generated and final compatibility matrix is a matrix with compatibility probability of $(P)^5$; therefore, the probability for an element to take one becomes very small.

Table 5.2. Probability of compatibility for each test.

Scenarios	Probability of compatibility concerning each constraint (%)	Compatibility percentage of final matrix (%)	
		Total compatibility	Pure pooling compatibility
Test 1	$P_1 = 100$	100	-
Test 2	$P_2 = 95$	84	50
Test 3	$P_3 = 90$	66	48
Test 4	$P_4 = 85$	62	43
Test 5	$P_5 = 80$	57	24
Test 6	$P_6 = 75$	48	22
Test 7	$P_7 = 70$	43	15
Test 8	$P_8 = 60$	36	4
Test 9	$P_9 = 50$	34	2

An overview of six defined scenarios and related assumption is provided in table 5.3. The proposed approach in section 4.3 is applied to evaluate these scenarios.

To explain this table, it shows that for scenario 1, there are 13 test for series representing by L1 to L13. Three depots are involved in pooling; therefor, there are 65 delivery points in total.

Demands used for this scenario are generated from a uniform distribution between 1% and 10% of maximum capacity of available vehicles.

Table 5.3. Summary of defined scenarios.

Assumption / **Scenario**	*Series of test*	*Number of customers*			*Demand*
		D1	*D2*	*D3*	
Scenario 1	L=1,... ,13	16	35	10	$U(1\%\ CAP, 10\%\ CAP)$
Scenario 2	P=1,... ,13	16	35	10	$U(1\%\ CAP, 10\%\ CAP)$
Scenario 3	H=1,... ,9	16	35	10	$U(1\%\ CAP, 10\%\ CAP)$
Scenario 4	I=1,... ,9	-	35	10	$U(1\%\ CAP, 10\%\ CAP)$
	J=1,... ,9	16	-	10	$U(1\%\ CAP, 10\%\ CAP)$
	K=1,... ,9	16	35	-	$U(1\%\ CAP, 10\%\ CAP)$
Scenario 5	D=1,... ,9	16	35	10	$U(5\%\ CAP, 25\%\ CAP)$
Scenario 6	E=1,... ,9	-	35	10	$U(5\%\ CAP, 25\%\ CAP)$
	F=1,... ,9	16	-	10	$U(5\%\ CAP, 25\%\ CAP)$
	G=1,... ,9	16	35	-	$U(5\%\ CAP, 25\%\ CAP)$

5.2. Scenarios evaluation through proposed approach

As already presented in chapter 4, all defined scenarios in this chapter are evaluated by using real data from the three major last mile logistics service providers (depots) operating in Bogota, Colombia[2] (Montoya-Torres et al. 2016). In this case study, there are three depots and depots own 16, 35 and 10 customers respectively. To generate demand, for scenario 1 to 4, a uniform distribution is applied to randomly generate demands between 1% and 10% of the maximum load capacity of the vehicle as suggested in (Muñoz-Villamizar et al. 2017). Moreover, for scenarios 5 and 6, as the objective is to evaluate impacts of demand increase on pooling efficiency, we use again a uniform distribution to generate this time demands between 5% and 25% of the maximum load capacity of the vehicle. We also assume that all demands are transported as parcels. The obtained results are presented in the next section.

5.3. Experimental results and discussion

In this section, results obtained for each scenario are presented in the order of proposed indicators in section 4.4. Figure 5.7 shows actual location of all delivery points. We can see on the left of the map, the sixteen delivery point of depot D1 (meaning C1), in the middle thirty-

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[2] I would like to thank you Professor Montoya-Torres for providing me with real data from their case study in Bogota, Colombia.

five delivery points of depot D2 (meaning C2) and finally on the right, ten delivery point of depot D3 (meaning C3).

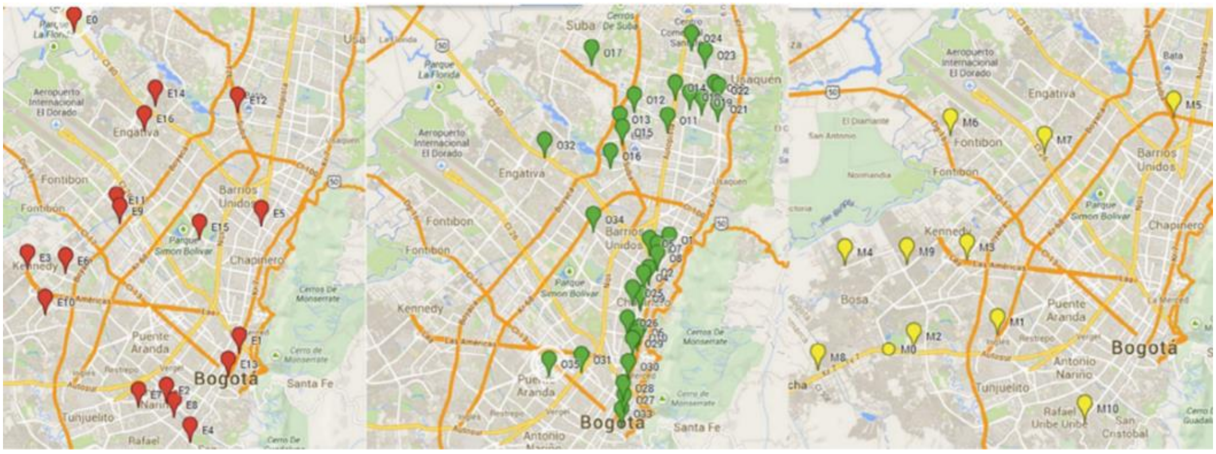


Figure 5.7. Actual location of three depots customers (source: Google Maps™), retrieved from (Montoya-Torres et al. 2016).

5.3.1. Improvement through pooling for each scenario

The first indicator presented in section 4.3 was defined to quantify pooling benefits through calculating improvement achieved concerning total travelled distance while resource pooling. Just to remind, since we decided to use metaheuristics to solve our CVRP to calculate the total travelled distance for both case of before pooling and after pooling, we decide to apply two different optimization methods to obtain indicators of the performance of city logistic not optimization method dependent. Hence, in this section, we present improvement achieved from reduction of total travelled distance, calculated by the two optimization methods (SA and VNS) presented in chapter 5 for all six scenarios.

- Scenario 1 (series L)

This scenario is defined to quantify impact of depots' policy to accept/refuse to either share their customers or serve new customers in pooling. As shown in figure 5.8, for this scenario, improvements in total travelled distance achieved via pooling by two used metaheuristics method for all series of test (L1 to L13) return a decreasing trend when stricter constraints are imposed. This seems rather reasonable, since for each test the probability of accepting to share or serve a new customer by depots becomes smaller. In better words, the probability to refuse to involve in pooling becomes greater. Nevertheless, we observe two notable points: tests L7 and L8. By seeking the reasons, we observe that since the matrices are generated randomly, in tests L7 ($P_7 = 70\%$) and L8 ($P_8 = 60\%$), some delivery points are given 1 (however in the previous tests were given zero) and can then be assigned to other depots. This consequently results in finding a more suitable routing. Here, one important lesson to be learned is despite importance of rate of compatibility (involvement in pooling), it is also important which delivery points are shared or refused to be served. As observed in this scenario, a little probability of acceptance can be more effective if final poolable delivery points are effective delivery points in improving routing. Effective delivery points are those delivery points that have a significant role in pooling efficiency that is to say if they can be served by other involved depots. To give an example, suppose that one delivery point belonging to depot D1 is located close to depot D2. If depot D1 accepts to share this delivery point and accordingly this customer is assigned to depot D2, routing phase will return a greater improvement.

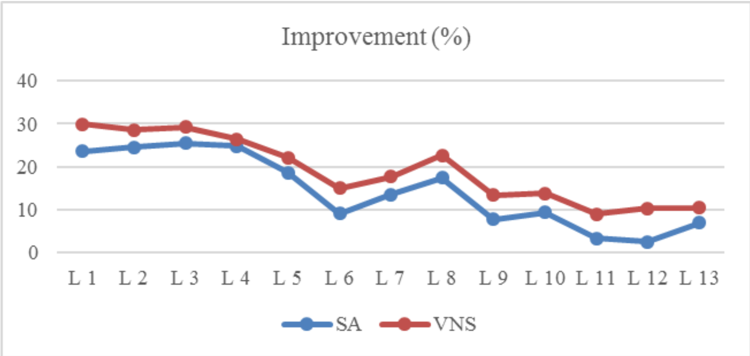


Figure 5.8. Total travelled distance improvement via pooling for scenario 1 (series L).

- Scenario 2 (series P)

This scenario is defined to take into account simultaneously depots' policy to share their customers and serve new customers. As shown in figure 5.9, improvements in total travelled distance achieved via pooling for series of tests of this scenario (P1 to P13) also return a decreasing trend, when constraints become gradually stricter. Furthermore, this decreasing rate is quicker than previous scenario since imposed constraints in this scenario are two time stricter than scenario 1. The same change of trend as scenario 1 occurs this time for test P8 and P9 of scenario 2, the reason is the same as for scenario 1. Effective poolable delivery points have been refused to be shared in test P7 and then in the next two tests, they have been allowed to be shared.

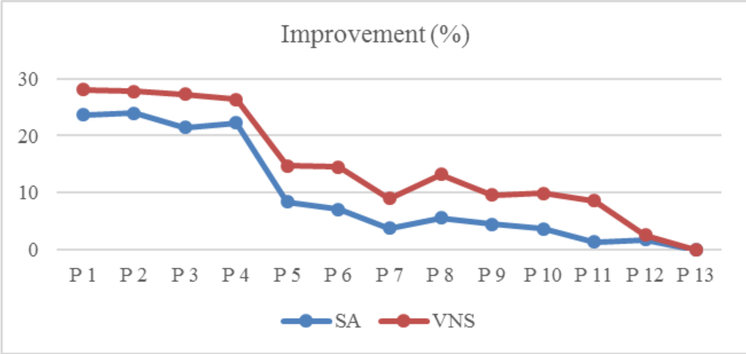


Figure 5.9. Total travelled distance improvement via pooling for scenario 2 (series P).

- Scenario 3 (series H)

In scenario 3, where the objective is to evaluate the impact of compatibility constraints on pooling efficiency, a decreasing trend is also observed for series of test (H1 to H9), as shown in figure 5.10. Steep slope between test H1 and test H2 shows the critical impact of compatibility constraints on pooling efficiency. Note that in test H1, a 100% pooling is permitted (meaning delivery points are totally shared and no compatibility constraints exist), although, in test H2, 95% of compatibility is assumed for each of five compatibility constraints. Forasmuch as each of these five constraints must be satisfied to allow a pooled network design, compatibility rate between a depot and delivery point reduces to $P = (P_2)^5 = (0.95)^5 \approx 0.77$. Hence, in this scenario 95% of compatibility for each constraint in test H2 results in an improvement equivalent to probability of acceptance of 70% in scenario 1 (test L7) and 80% in scenario 2 (test P5). Thus, this justifies this sudden change concerning improvement via pooling in presence of compatibility constraints.

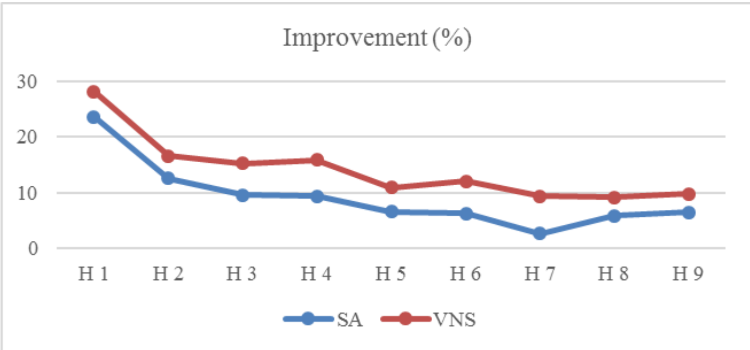


Figure 5.10. Total travelled distance improvement via pooling for scenario 3 (series H).

- Scenario 4 (series I, J, K)

The objective to define scenario 4 is to analyse the impact of totally removal of one depot from pooling and evaluate pooling benefits in presence of compatibility constraints. Figures 5.11, 5.12 and 5.13 represent the improvements achieved for total travelled distance via pooling in three different sub-scenarios of scenario 4. Series I (figure 5.11) represents results of pooling when depot D1 is withdrawn from pooling; series J (figure 5.12) represents the results while removing depot D2, and finally series K (figure 5.13) represents results for removal of depot D3 from pooling.

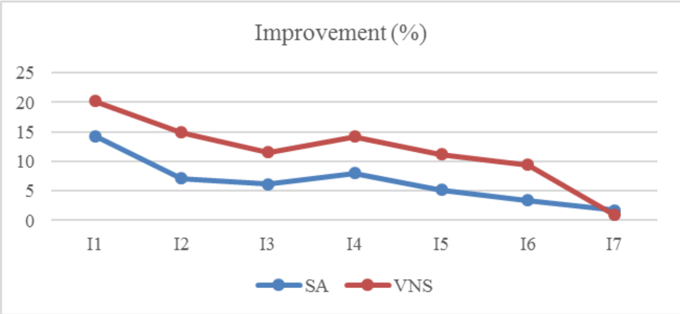


Figure 5.11. Total travelled distance improvement via pooling for series I of scenario 4.

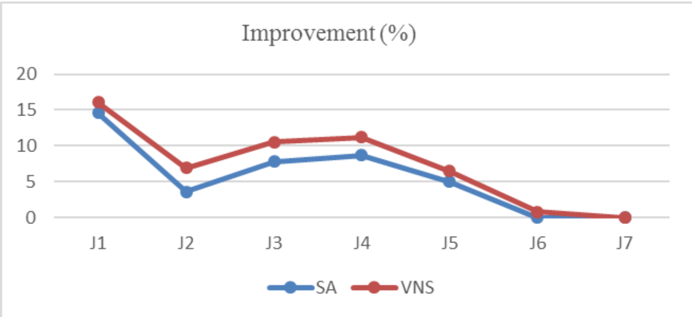


Figure 5.12. Total travelled distance improvement via pooling for series J of scenario 4.

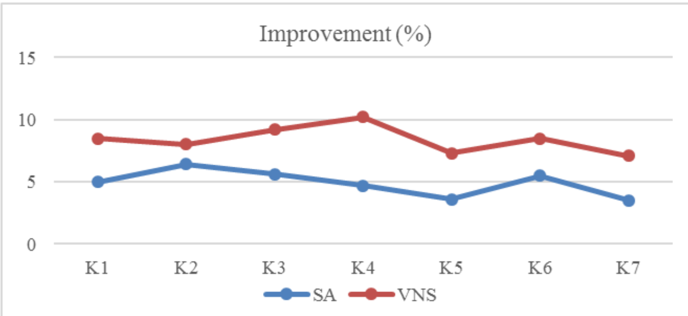


Figure 5.13. Total travelled distance improvement via pooling for series K of scenario 4.

The first main highlight regarding improvement achieved via pooling for this scenario (and its series) is that no pooling is occurred from test 8 for series I and K and from test 7 for series J. As it is shown in table 5.3, series I and K have respectively 45 and 51 delivery points in total and series J has only 26 delivery points due to removal of one depot in each case. This indicates that when the number of shared delivery points become smaller, pooling cannot be go further in presence of stricter constraints. Consequently, this can be concluded that in presence of compatibility constraints, more delivery points are shared more benefits are achieved.

Another important point is that removal of depot D3 results in significant descent in pooling improvement. This change reveals the critical role of depot D3 for achieving pooling benefits. In our case study, the reason is that customers of other depots are almost closer to this depot compared to their initial depot. Therefore, when these delivery points are compatible with depot D3 and are allowed to be assigned to this depot, a larger improvement occurs in routing phase. In other words, depot D3 is dominant as it can absorb more goods flows during pooling. In addition, as it is obvious in figure 5.13, improvement trend for this (series K, removal of depot D3) is smaller than other sub-scenarios and improvements achieved do not change really in presence of compatibility constraints and follow a flat trend.

- Scenario 5 (series D)

Scenario 5 is developed in order to analyse impacts of an increase in demand quantity in pooling efficiency when there are compatibility constraints. With regard to this point that all assumptions of this scenario are same as scenario 3, except quantity of demand, this result can be elicited that in presence of compatibility constraints when the demand quantity becomes larger, improvement achieved via pooling become smaller, as shown in figure 5.14. In fact, improvement decrease with a steeper slope while imposing stricter constraints. Furthermore, large quantity of demand also causes pooling to be stopped in the test D8, however, in scenario 3 pooling continues until test H9. It shows that, when quantity of demand is small, pooling can be realized with more flexibility.

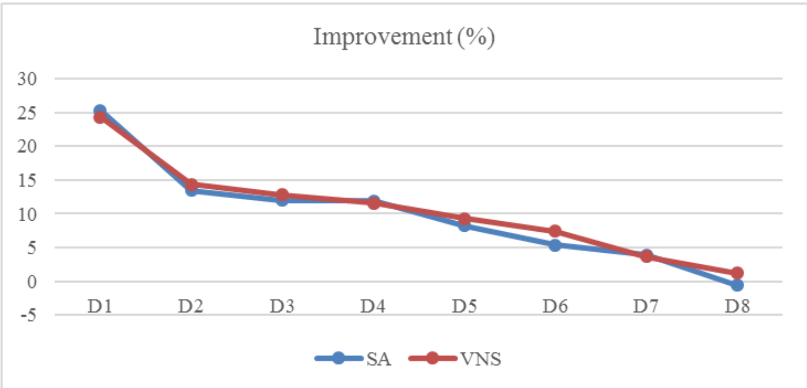


Figure 5.14. Total travelled distance improvement via pooling for scenario 5 (series D).

- Scenario 6 (series E, F, G)

As already mentioned, scenario 6 is the repetition of scenario 4 with a larger quantity of demand. The obtained results for this scenario reveal that improvements achieved for this scenario are generally small compared to scenario 4. With regard to the figures 5.15, 5.16, 5.17, which represent respectively series E, series F and series G, it is observed that there is always a decreasing trend for all three series as scenario 4.

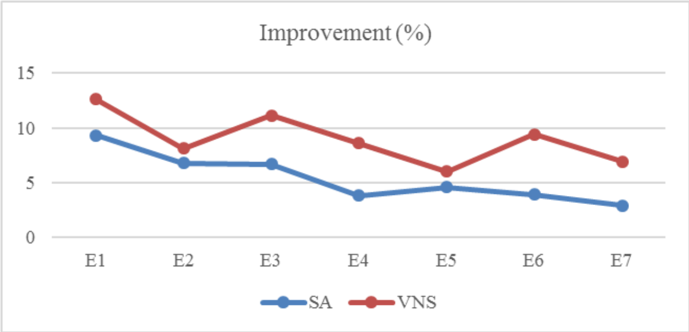


Figure 5.15. Total travelled distance improvement via pooling for series E of scenario 6.

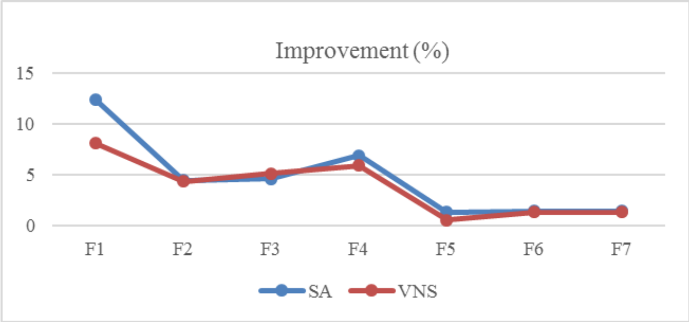


Figure 5.16. Total travelled distance improvement via pooling for series F of scenario 6.

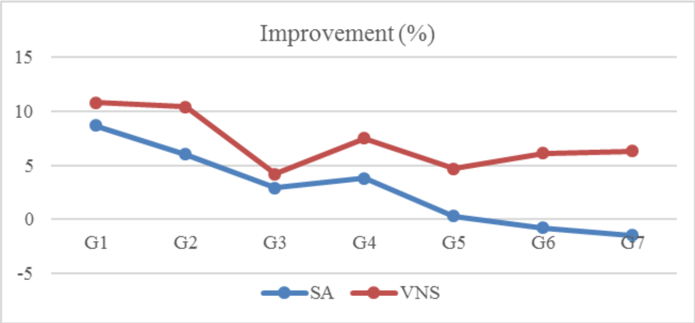


Figure 5.17. Total travelled distance improvement via pooling for series F of scenario 6.

In series F (figure 5.16), it is observed that improvements achieved via pooling are exactly same for test F6 and test F7. By analyzing the root, we note that neither the assignments nor routing values are not identical for these two tests, although, the sum of routing for three depots returns the same amounts. By reminding that constraints in test F7 are stricter than test F6, this point can be drawn that even in a strict condition, a high improvement via pooling can be achieved if effective poolable delivery points are compatible with depots that are closer to them. In this case, the assignment of these delivery points to these depots improve total travelled distance.

Concerning improvement achieved via pooling for series G (figure 5.17), it is noticed that two last tests, meaning test G6 and G7, return a negative amount of improvement using method SA. By seeking the reasons, we observe that the assignments for these two tests have been optimally done with taking into account compatibility constraints. Since improvements reported by method VNS is positive, we conclude that SA could not find the best solution in the determined time (after thirty minutes) and it returned a local solution which was not absolutely the best answer. In addition, in this series, the decrease in improvement follows again the lower slope. It shows that regardless of the quantity of demand, removing a depot that has an important role in pooling benefits results in reducing improvement.

5.3.2. Disruptive impacts of pooling

To redesign a distribution network through pooling, fundamental changes must be imposed on the initial network. Changes in customers number for a depot after pooling and the proportion of new customers compared to the initial case are several type of potential changes in resource pooling. We propose to use the proposed disruptive impact indicators described in section 4.3.2. Using these two indicators simultaneously helps to analyse changes caused during pooling in a distribution network. To this end, for each depot in all six scenarios firstly customers number change after pooling is calculated and then the percentage of new customers is figured.

- Scenario 1 (series L)

According to figure 5.18, we observe that customers number change for all tests of this series (L1 to L13) are negative. This means that the number of customers allocated to this depot after pooling is always less than its initial number of customers (meaning before pooling). Moreover, figure 5.19 shows that except in test L3, L9 and L10, there is no new customers assigned to this depot. From this observation, it can be concluded that despite improvement achieved via pooling for this scenario, not only depot D2 loses mostly its initial delivery points but also it does not earn new customers. It means it is dominated by other depots during pooling. In contrast, depot D3 has a great positive changes in its customers number in each test of this series. It means that whenever constraints are more permissive, depot D3 absorbs a great number of customers.

Regarding L4, we notice that although the customers number reports no change for depot D1, there is new customers assigned to this depot as percentage of new customers for this test (L4) is positive (figure 5.19). The reason for this event is that the total number of customers after pooling is equal to its initial number of customers. For other tests regarding depot D1, it can be also noticed that however the customers number change is not as great as depot D3 but it earns always new customers. It means depot D1 has a quite reasonable exchange in pooling, it loses some of its own customers and in return it earns some new customers.

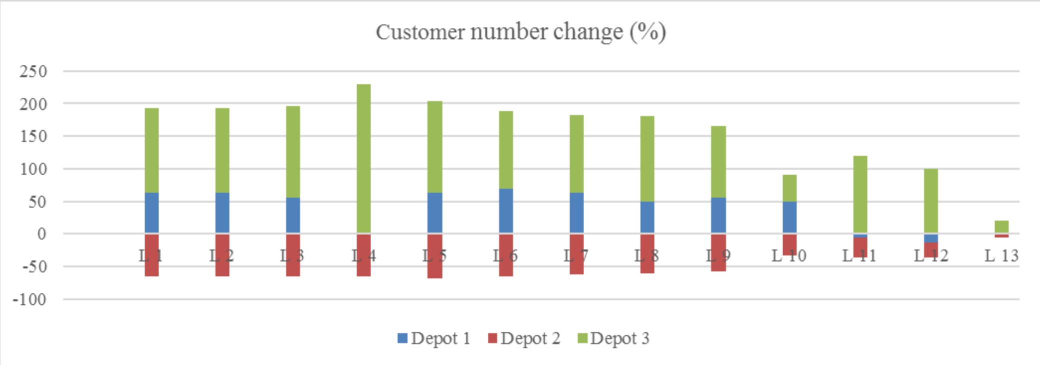


Figure 5.18. Customers number change via pooling for scenario 1 (series L).

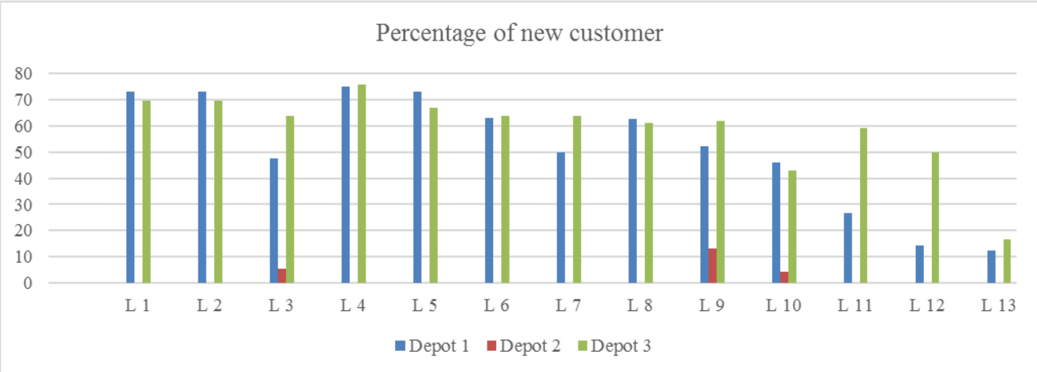


Figure 5.19. Percentage of new customers of each depot after pooling for scenario 1 (series L).

- Scenario 2 (series P)

According to figures 5.20 and 5.21, we perceive although there is several difference in network arrangement comparing to scenario 1, general trend of disruptive impacts for scenario 2 is merely similar to scenario 1. The difference is that the slope regarding the customer change number and percentage of new customers are sleeper in this scenario. As you may guess, this difference is because of imposing stricter constraints in scenario 2.

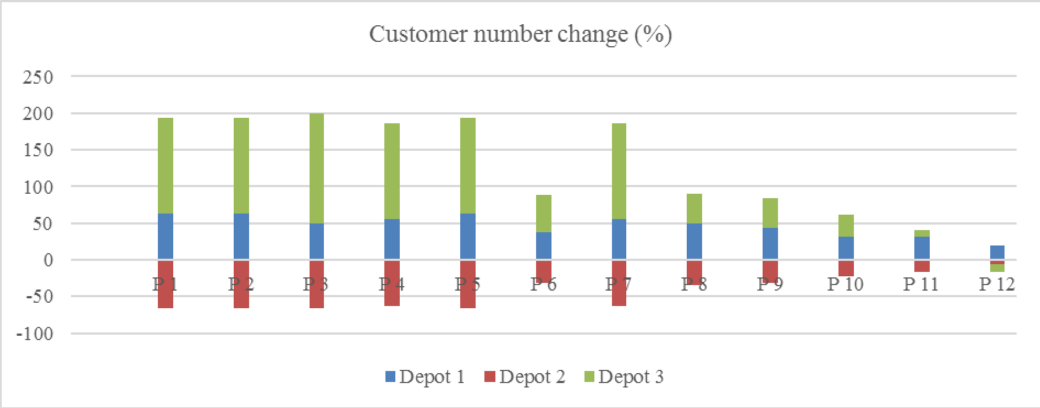


Figure 5.20. Customers number change via pooling for scenario 2 (series P).

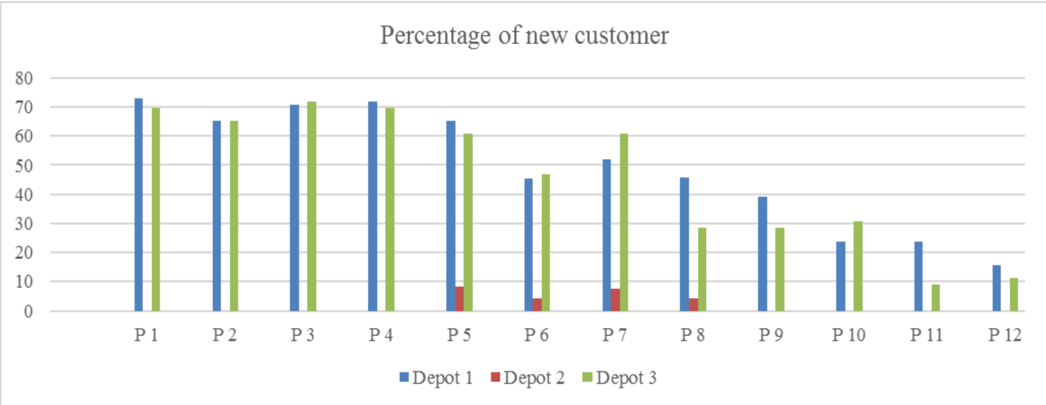


Figure 5.21. Percentage of new customers of each depot after pooling for scenario 2 (series P).

- Scenario 3 (series H) and scenario 5 (series D)

As scenario 3 and 5 have the same assumption except differences in quantity of demand; hence, we present these two scenario together in order to easily analysis the results obtained through disruptive impacts. As shown in figure 5.22 and 5.23, calculated values regarding disruptive impacts for each depot in scenario 3 (H1 to H9) and scenario 5 (D1 to D7) return generally same results as scenario 1 and 2. Depot D1 has a balanced change during pooling, depot D2 always loses its customers without having great new customers, and finally depot D3 has a great positive change in earning new customers. We note that however increasing quantity of demand causes series of test not to go further than test D7, general trends regarding disruptive impacts are approximately the same. In both scenarios 3 and 5, when quantity of demand for tests is between 1% and 10% of maximum capacity of vehicles as well as when this amount increases to 5% and 25%, there is always a balance for depot D1 in sharing its own customers and serving new customers; depot D2 loses mostly its own customers without getting new customers and finally depot D3 gets a high percentage of new customers.

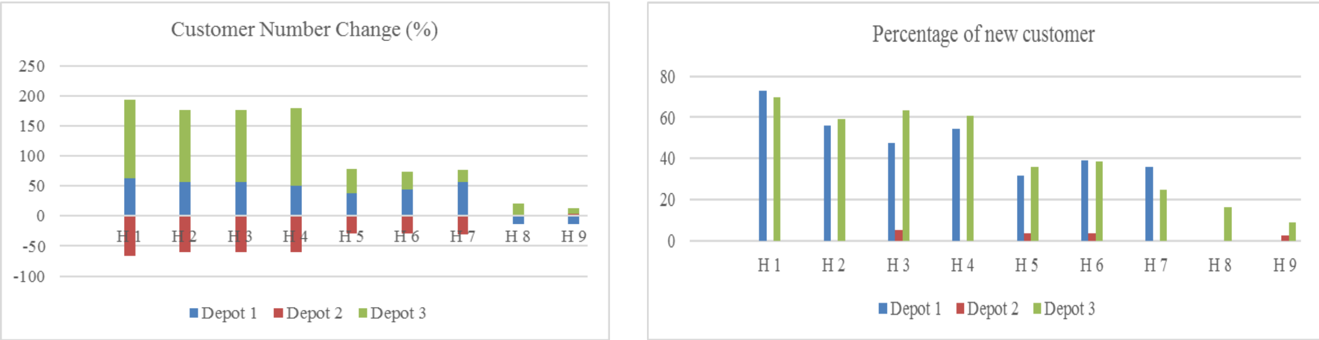


Figure 5.22. Customers number change and percentage of new customers for scenario 3 (series H).

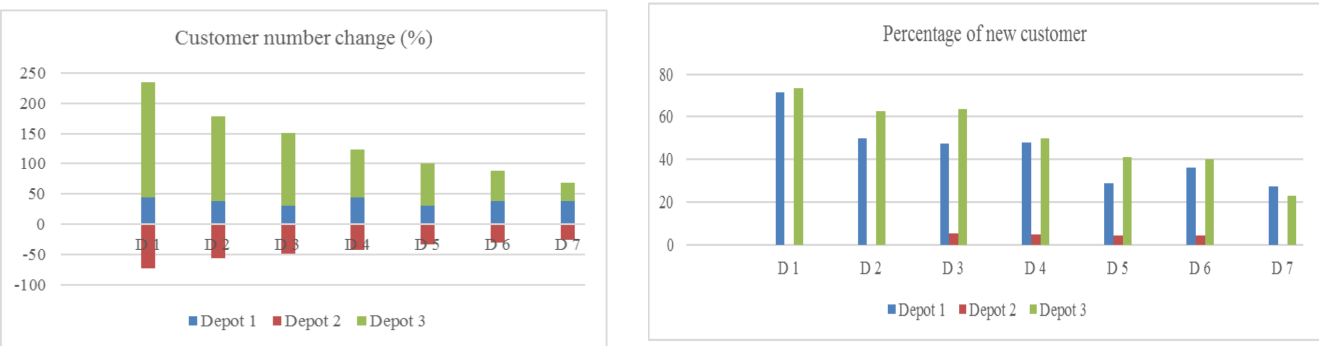


Figure 5.23. Customers number change and percentage of new customers for scenario 5 (series D).

- Scenario 4 (series I, J, K) and scenario 6 (series E, F, G)

The only difference between scenario 4 and scenario 6 is the quantity of demand. We remind that these two scenarios are defined to evaluate impacts of removal of one depot from pooling in its efficiency. Results obtained from three sub-scenarios of scenario 4, meaning series I (figure 5.24), series J (figure 5.25) and series K (figure 5.26) and three sub-scenarios of scenario 6 meaning series E (figure 5.27), series F (figure 5.28) and series G (figure 5.29) show that however some minor differences exist between series of these two scenarios, the general trends are identical for both. In series in which depot D2 involves in pooling (series I, K, E and G), this depot mostly returns a negative customers number change. In series I and E, depot D2 is totally dominated. However, in series I, depot D2 succeeded at least to have some new customers despite losing its own customers. In series E where demand is larger and pooling is become less flexible, depot D2 is absolutely dominated.

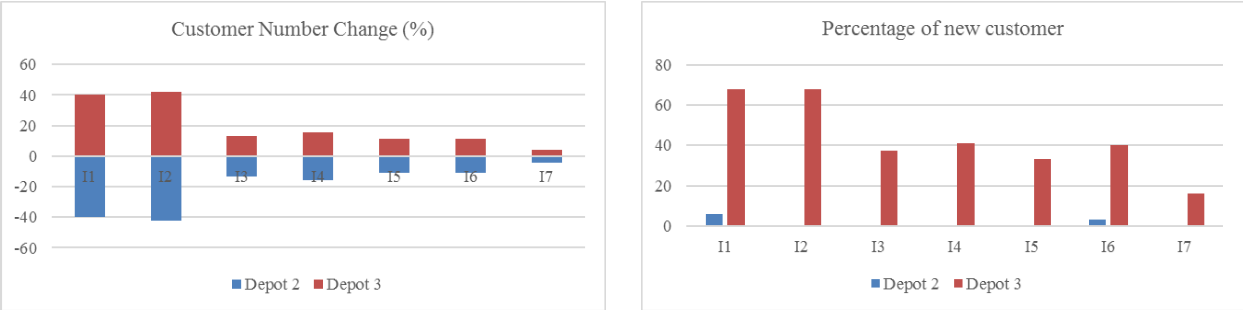


Figure 5.24. Customers number change and percentage of new customers for scenario 4 (series I).

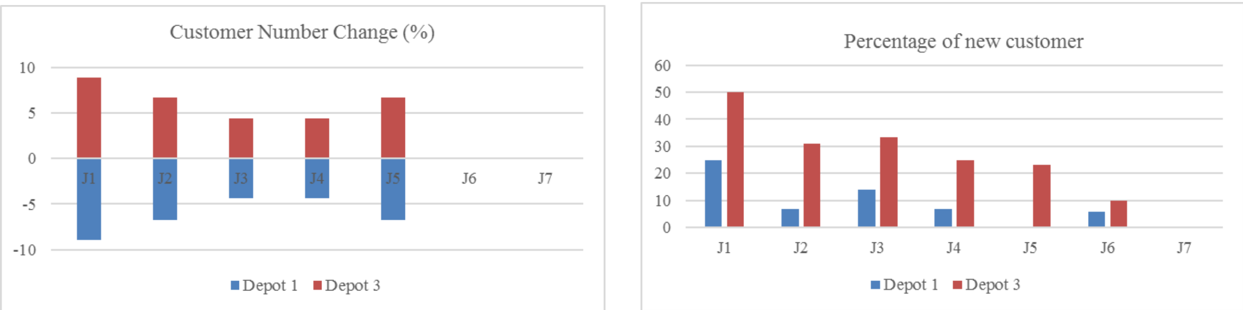


Figure 5.25. Customers number change and percentage of new customers for scenario 4 (series J).

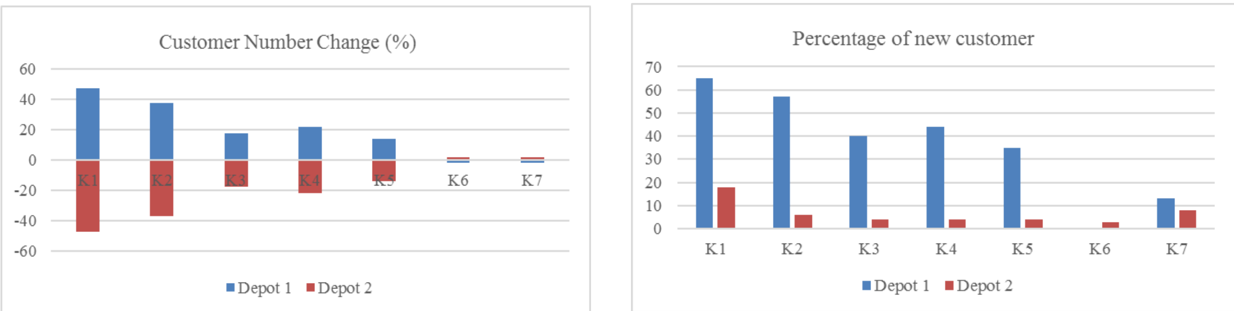


Figure 5.26. Customers number change and percentage of new customers for scenario 4 (series K).

Regarding pooling while involvement of depot D1 and depot D3 (series J and F), however depot D1 is totally dominated in series J concerning number of customers, it could serve several new customers. In series F, this change regarding serve new customer is become a little greater.

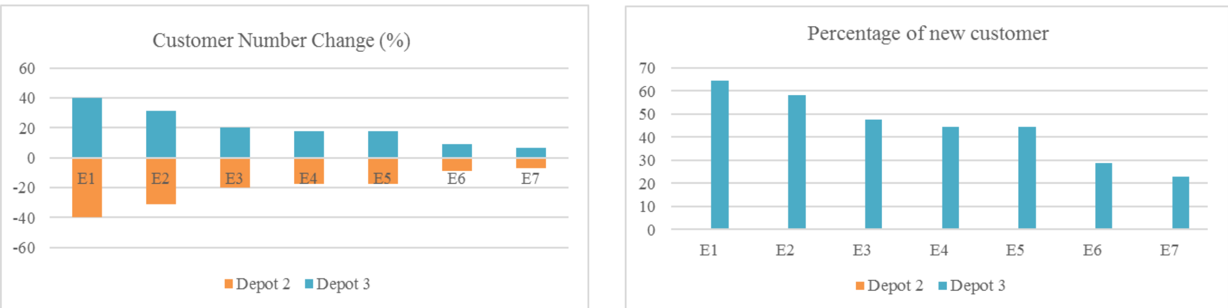


Figure 5.27. Customers number change and percentage of new customers for scenario 6 (series E).

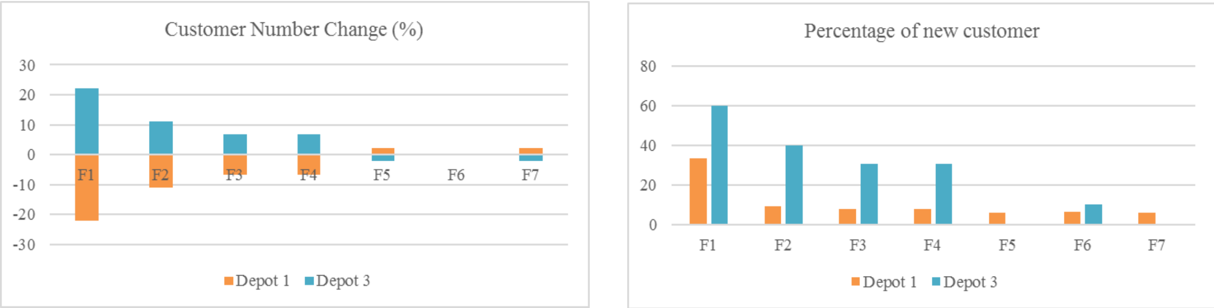


Figure 5.28. Customers number change and percentage of new customers for scenario 6 (series F).

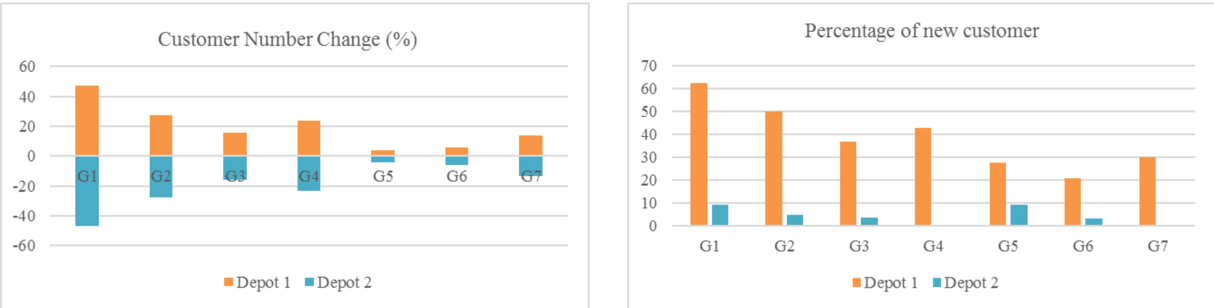


Figure 5.29. Customers number change and percentage of new customers for scenario 6 (series G).

This indicator reveals that despite improvements achieved; in our case study, pooling does not result in a fair network design. As already explained, depot D1 makes rather reasonable exchange, it loses some of its customers and in return it gets some new ones, however, depot D2 always loses its share and get no newer customers and depo D3 absorb most of customers. It is worth mentioning that, the objective function in our problem is defined to minimize total travelled distance for both allocation and routing phase. The strategic location of depot D3 as being closer to shared customer justifies its power in getting more customers.

5.3.3. Demand change after pooling

The main objective of defining an indicator to calculate demand change after pooling is to analyse whether changes in the arrangement of initial network impose any changes in the quantity of demand allocated to each depot after pooling. Using this indicator in our case study reveals that there is a direct relation between customers number change and demand change after pooling in all scenarios. Whenever number of customers decreases, there is a reduction in demand quantity as well. We expected to observe kind of different trend after increasing demand in scenario 4 and 5, thought always a straight relation between customers number change and demand change occurs, as shown in figure 5.30, 5.31, 5.32 and 5.33.

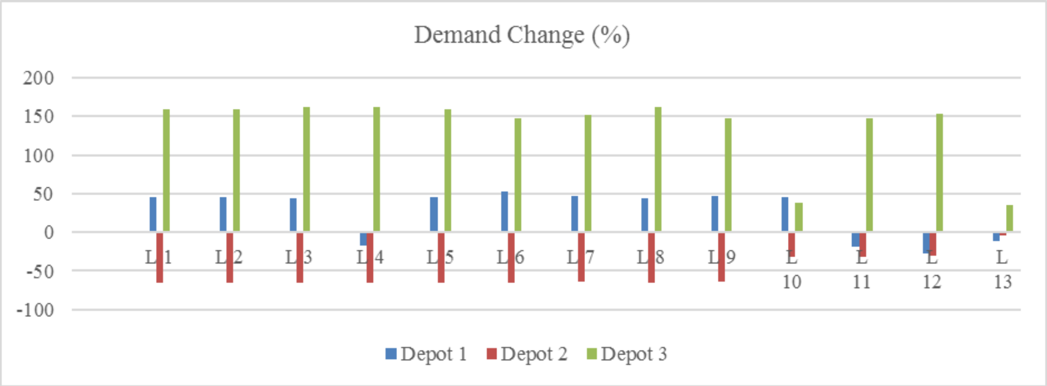


Figure 5.30. Demand change for scenario 1 (series L).

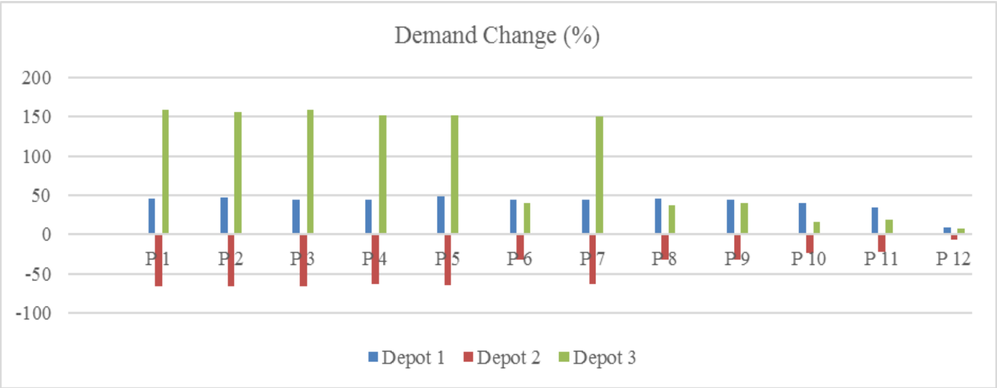


Figure 5.31. Demand change for scenario 2 (series P).

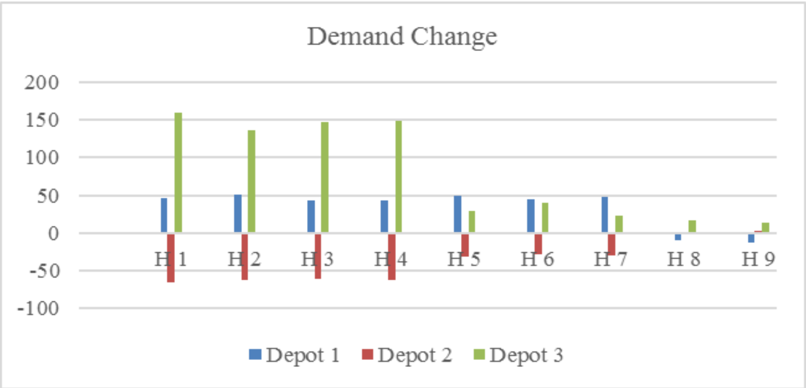


Figure 5.32. Demand change for scenario 3 (series H).

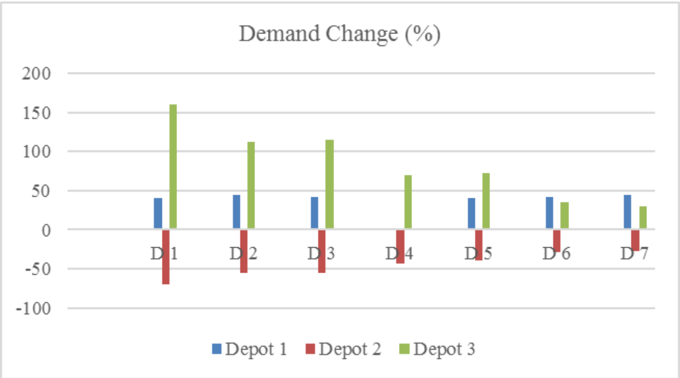


Figure 5.33. Demand change for scenarios 5 (series D).

As shown in figures 5.34, 5.35 and 5.36 that represent impacts of removal of one depot from pooling, we observe that demand change for each series of scenarios follow the same trend of customers number change.

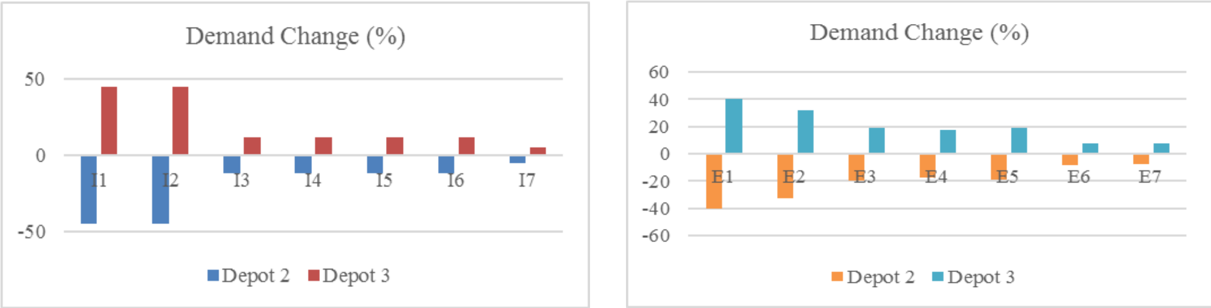


Figure 5.34. Demand change for series I of scenario 4 and series E of scenario 6.

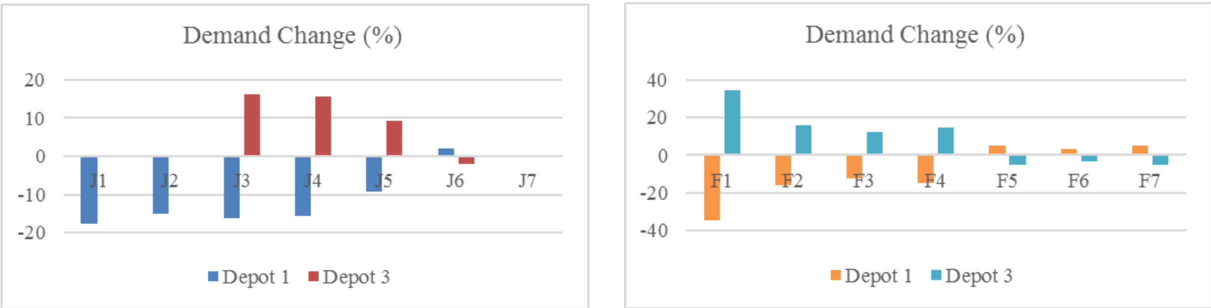


Figure 5.35. Demand change for series J of scenario 4 and series F of scenario 6.

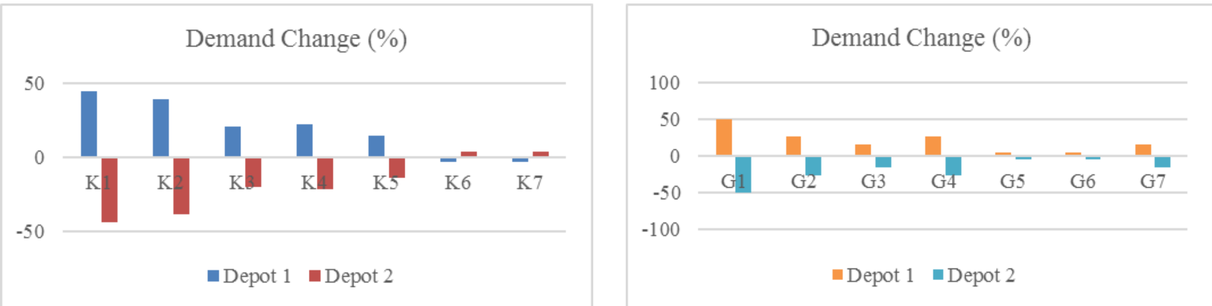


Figure 5.36. Demand change for series K of scenario 4 and series G of scenario 6.

Concerning results obtained by this indicator for our case study, it is important to highlight that in both cases of normal demand quantity and large demand quantity, demands are randomly generated from a uniform distribution. Thus, a direct relation between customers number change and demand change seems reasonable.

5.3.4. Load factor improvement after pooling

Another important characteristics of urban freight distribution is the small load factor of vehicles. As discussed before, pooling make it possible to load a vehicle as much as possible before its departure towards customers due to the small quantity of demand, short delay and high frequency of demand in urban freight transportation. Load factor improvement via pooling can be interpreted as a sustainable achievement, since it results consequently in the use of smaller number of vehicles and shorter trips in urban areas. In addition, high load factor for each vehicle can result in long term, in well use of resources and eventually decreasing transportation cost. Before starting to analyse results obtained by this indicator for our case study, it is important to emphasize that, as stated in 4.3.2, the number of required vehicles to serve customers of a depot is calculated in allocation phase after new arrangement of pooled network; hence, the average load factor of vehicles used by each depot is taken into account to calculate load factor improvement for each test of a scenario.

Results obtained through this indicator for scenario 1 (series L) and scenario 2 (series P), respectively figures 5.37 and 5.38, report a high load factor improvement in scenario 1 compared to scenario 2. Since constraints imposed in scenario 1 are permissive than those of scenario 2, it can be concluded that more flexibility in allocation phase can lead to a high improvement in load factor. In other words, more involvement occurs more benefits concerning the optimal use of resources archives.

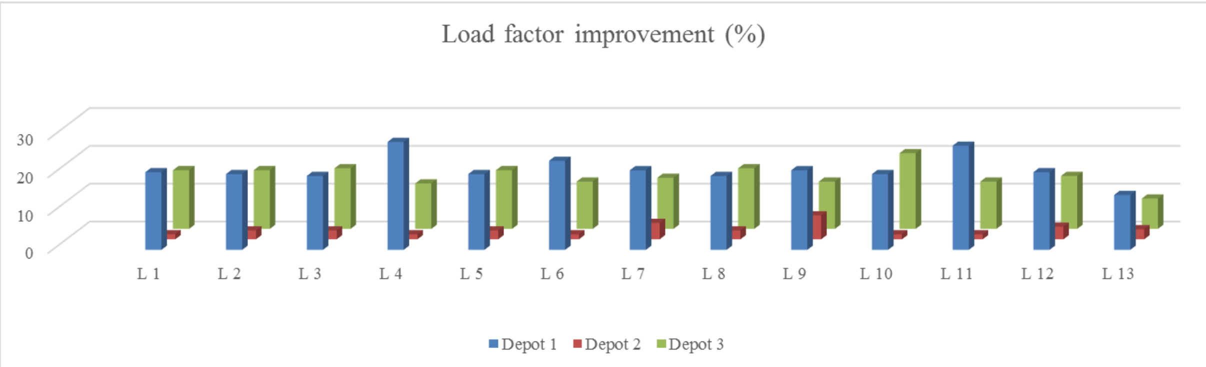


Figure 5.37. Load factor improvement for scenario 1 (series L).

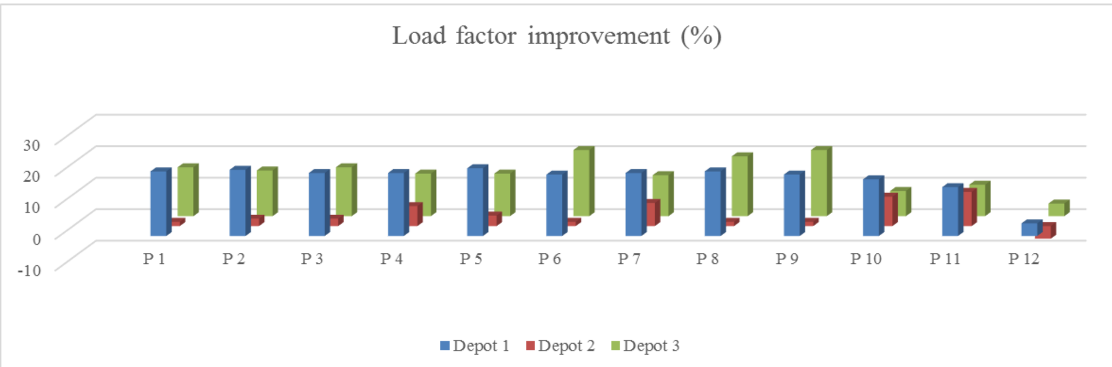


Figure 5.38. Load factor improvement for scenario 2 (series P).

Since the only difference between scenario 3 (series H) and scenario 5 (series D) is demand quantity, the significant difference concerning load factor improvement between these two scenarios make it known that when demands are smaller a higher improvement can be occurred, as shown in figure 5.39. Note that in both cases, the vehicles capacity is considered alike, hence small demand provide more flexibility for model to choose the best solution.

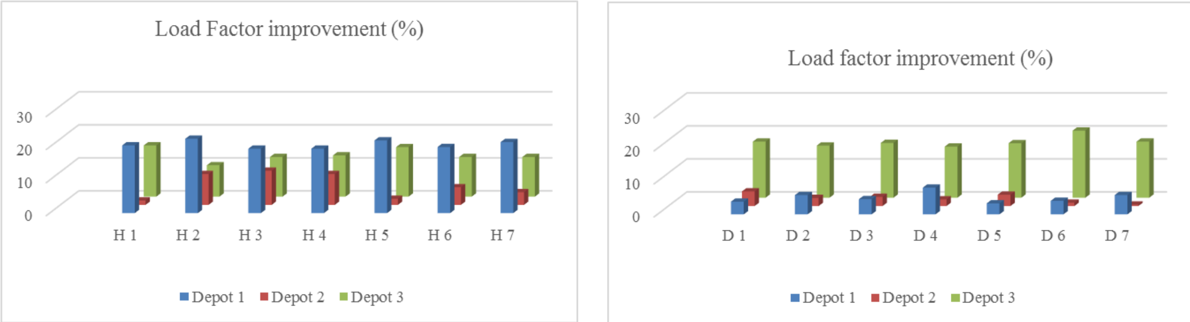


Figure 5.39. Load factor improvement for scenario 3 (series H) and scenario 5 (series D).

In general, calculated values by this indicator for scenario 4 (series I, J and K) and 6 (series E, F and G) confirm conclusion drawn from the scenario 3 and 5, which state the impact of demand quantity of load factor. As shown in figures 5.40, 5.41 and 5.42, a high load factor improvement is achieved for scenario 4 (series I, J and K) where demands are smaller.

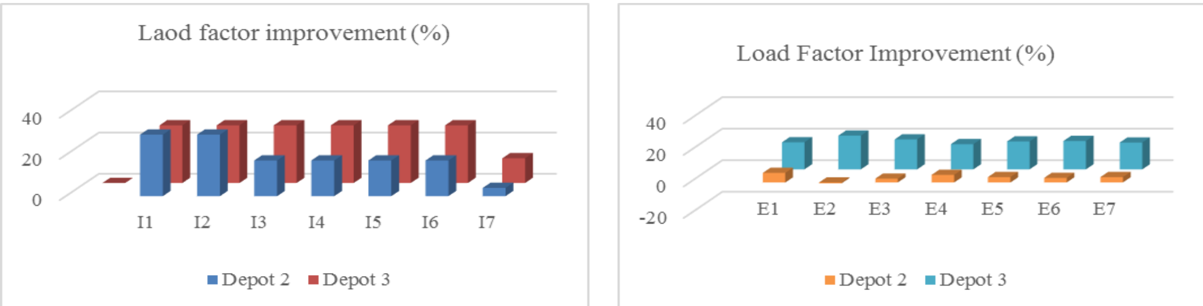


Figure 5.40. Load factor improvement for scenario 4 (series I) and scenario 6 (series E).

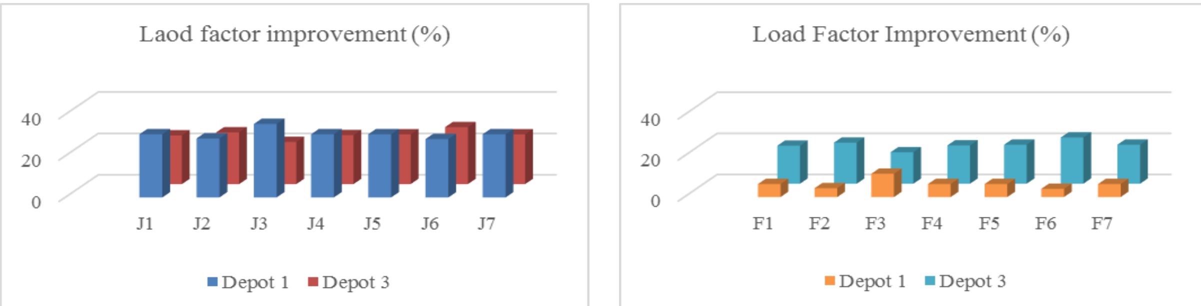
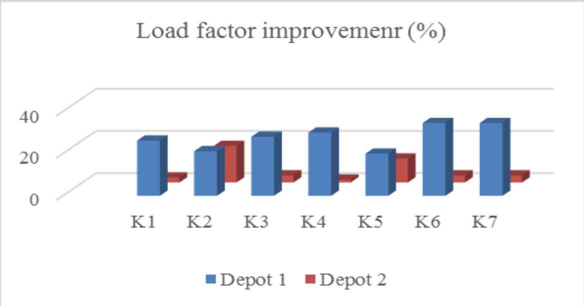


Figure 5.41. Load factor improvement for scenario 4 (series J) and scenario 6 (series F).



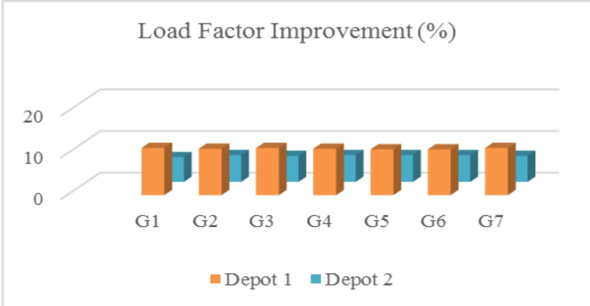


Figure 5.42. Load factor improvement for scenario 4 (series K) and scenario 6 (series G).

Discussion

Two groups of identified constraints result in reducing positive improvements achieved for total travelled distance in our case study. The slope of this decrease is steeper for compatibility constraints as they are stricter than policy-oriented constraints. Furthermore, we observed that an increase in quantity of demand in the case of compatibility constraints indicates a decrease in improvement. This decrease happens due to incompatibility between depots and delivery points, in this case one incompatibility makes a fully pooling infeasible and consequently cause to decrease achieved improvement. We also observed that in our case study pooling provokes significant changes in the initial networks. It means, when pooling is performed with a high rate of acceptance for share or serve customers or a high rate of compatibility, one depot is always dominated and earn less number of delivery point as well as quantity of demands to serve. In contrast, another depot gets a great number of delivery points until constraints allow this allocation. We also note that for our case study demand change for each series of test for each scenario follow the same trend as change in customers' number change. This can be due to the assumption of demand generating that uses a uniform distribution. At the end, we found that smaller quantity of demand results in better load factor after pooling. However, in both cases, when constraints become stricter this improvement decreases as well. It is worthy to mention that since in both cases the capacity of vehicles is the same; therefore, when quantity of demand is smaller, it allows for more flexibility to load a vehicle at its maximum capacity for an optimal routing.

Several prospects can be proposed concerning our proposed approach and used case study as future research directions. We generated random matrices for evaluating impacts of the potential constraints on pooling efficiency; hence, in order to be more robust and to avoid certain biases, it would be suggested to generate various matrices for each series of tests. This would help to avoid the problem of changing the status of effective delivery points due to the random generation of constraints representing matrices. Our approach can be used for other case studies. These kind of evaluation would make it possible to assess pooling efficiency in other cities with different features.

Conclusion

In this chapter, we defined six different scenarios in order to evaluate impacts of identified constraints, policy-oriented and compatibility constrains, on resource pooling efficiency in the context of city logistics. To do so, we used our proposed approach in chapter 4. Results obtained for our case study as a real-world problem reveal that pooling can result in improving urban freight distribution, although these benefits can be significantly affected by policy-oriented and compatibility constraints. We observed that the impacts are greatly for compatibility constraints than for policy-oriented constraints. We also noticed that in presence of compatibility constraints, removal of one depot from pooling can have significant impacts in pooling efficiency, especially when the removed depot is a depot that has an important role in pooling efficiency. In our case study, with regard to our objective function that is to minimize total travelled distance, depot that is closer to a large number of delivery points is an effective depot for pooling.

Chapter 6. City Logistics Pooling Viability

Introduction

For years, pooling as a systematic form of horizontal collaboration has become a topical solution in city logistics. At the same time, complexity of urban freight system, difficult access to real data, financial constraints, high number of stakeholders involved and competitions between them and the lack of any overall vision makes pooling a hard strategy to be efficiently implemented and operated, in other words to be viable. In general, viability is defined as the ability of a system to work successfully (Beer, 1984). Hence, several vital factors are required to make the implementation of a project viable. A system can be considered viable if it stays profitable, reliable, operative, competitive, and sustainable in long term. In the literature, discussions around viability of city logistics projects, including collaborative scenarios and pooling, have merely focused on financial viability (focusing on interrelation of the concepts of time, risk and money) and economic viability (affordable service cost). This attention is rather understandable since most of the innovative projects presented in city logistics have been stopped or reduced because of financing constraints (Gonzalez-Feliu et al., 2014). An extensive discussion about the city logistics financial viability has been provided in (Gonzalez-Feliu, 2013). Despite the importance of financial viability of city logistics' project, other factors are still required to guarantee its effective operation and survival in long term. This chapter is dedicated to discuss important factors for leading towards viability of city logistics pooling. To this end, we provide a quick review on viability definition for a system and then we discuss the important factors by divided them in three groups of antecedents, consequences and contingencies required to reach a viable city logistics pooling.

6.1. The viable pooling system

We proposed the novel concept of typology of flow in order to identify basic elements of urban flows. This concept also helps to understand urban freight transportation system. The results of our analysis revealed that the city logistics system is a complicated system due to its activities that are dynamic and are influenced, from time to time, by several external factors like as regulations, environmental concerns etc. on one hand, and also due to high number of stakeholders with contradictory objectives, on the other hand. In such a system, the goal of pooling is to satisfy all stakeholders objective or at least reach a compromise with identifying, understanding and managing all interactions in order to contribute to the overall efficiency and effectiveness of the system. Here, we decide to focus on viability of pooling, no matter what type of pooling, in city logistics as a complex system.

Regardless of the type of a system, some factors have been generally identified as required conditions to achieve a viable system (Amer and Eltawil, 2014). Along with this, three main factors have been presented, two internal factors and an external one, figure 6.1. Internal factors concern, on one hand, the nature of the system and its elements, actors, relations and operations; and on the other hand, the management of system regarding both monitoring and controlling of the operation of the whole system. In contrast, external factor is considered surrounding environment of the system that could affect the performance of the system and the way it is managed. Some of these parameters can be stated as demand variability, political situations, regulations and environmental concerns. To achieve a viable system, it is necessary to effectively control all three factors and maintain balance between them (Amer and Eltawil, 2014).

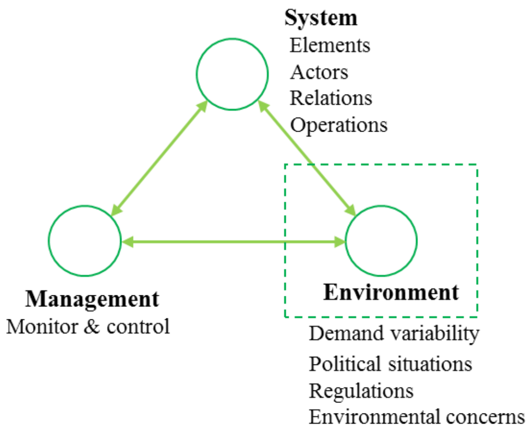


Figure 6.1. Conceptual presentation of the viable system (Amer and Eltawil, 2014).

Beer (1984) has stated that a system is viable when all its interactive sub-systems function well and are capable to maintain identity of the system. Five interacting sub-system of any system have been identified as follows:

- **System 1** is related to modelling primary activities responsible for achieving the ultimate goal of the system.
- **System 2** has a coordination function to assure balance and synchronization between sub systems.
- **System 3** is a command control to manage, control and monitor operations at the different sub systems. Note that, system 2 and system 3 are highly dependent, as they need to exchange information.
- **System 4** is in charge of maintaining a balance between internal and external factors.

- S**ystem 5** is responsible to follow and evaluate the progress of the system regarding its agreements, strategies and policies.

Briefly, theses sub-systems can be listed as operations management, coordination and balance, adaptive control, intelligence and policy. Amer and Eltawil (2014) have discussed how managing these five factors could guarantee the viability of the system in long term.

In addition to these viability factors for a system, despite its type, some further factors have been presented in the literature as critical factors to achieve a viable city logistics system. Björklund et al. (2017) have proposed several critical factor for viable business models of city logistics initiatives including collaborative strategies like as pooling. These factors have been defined as follows:

- The ability to unceasingly develop and adapt to a dynamic environment
- The capacity to scale up and down with regard to the market
- The ability to innovate new services
- The capacity to flourish competences regarding logistics and supply chain management
- The ability to adapt IT tools and take advantages of information technologies

Furthermore, Quak and Tavasszy (2011) have suggested studying two different aspects for viability of collaborative projects in city logistics. The first aspect refers to the system viability, defined as a benefit to be gained for all actors together. The second aspect refers to the user viability, defined as the possibility to gain a benefit from involving in collaboration. They have also concluded that the viability of a collaborative system and it users could gradually cause additional benefits for other stakeholders of city logistics with increasing reliability of deliveries (benefits for shop owners), lower response time for stock replenishment (benefits for customers) and better quality of life (benefits for inhabitants). They have also pointed out that all these benefits would be attainable in long term if enough considerations provided in the early steps of collaborative network design.

With considering all these issues, we discern that for being successful in attaining a viable pooling in city logistics, a deep analysis of the antecedents, consequences, and contingencies associated with it seems necessary. To this end, we propose to classify required factors for a viable city logistics pooling in these three levels of antecedents, consequences (both positive and negative) and contingencies. Each of these factors is discussed in the following sections.

6.2. Antecedents associated with city logistics pooling

To be able to talk about viability of city logistics pooling, it is important to identify stakeholders' motivations for involving in city logistics pooling and to recognize prerequisites steps. The answers of these questions help to find the main objective of the system, the way that it functions and then the definition of viability for such a system.

6.2.1. Motivations leading towards pooling

Here, the question is why pooling is chosen as a solution in city logistics, which is a system with multiple stakeholders each with its own objectives and expectations. We have identified two general reasons that could encourage stakeholders with contradictory objectives to involve in pooling: internal reasons or external ones.

Internal reasons concern a company or logistics service provider own policies that lead towards involving in pooling. The expectations to benefit from pooling advantage can justify this interest. They can accept to involve in pooling in order to share their resources for obtaining more economic advantages, being more sustainable, flourishing competences, using supplementary resources to be able to offer new services, benefiting from capacity of other stakeholders, being more flexible, getting more visibility in the market etc. To give an example, in recent years with regard to the regulations imposed by local authorities that restrict access to dense area of cities, logistics service providers have to adapt light goods vehicles in order to deliver their customers in these areas. Therefore, they have to either invest in adapting clean vehicles or outsource some part of their activities, if this investment is not profitable according to their market demand. In this way, pooling can be an interesting solution for logistics service providers to share some parts of their market. Moreover, urban deliveries are very complicated and time consuming, these result consequently in high delivery cost. In this context, involving in pooling can allow economy of scale. It is also important to point out that city logistics is a competitive sector; hence, pooling can help to broaden the market and to be able to propose new services, this type of services is discussed in chapter 3.

External reasons are imposed by external obligation to involve in such a collaboration. Regulations or restrictions imposed by local authorities (being a stakeholder in city logistics) in order to limit logistics service providers' activities in urban area can be considered as external reasons. In this context the first example is regulation concerning time window for accessing to some districts that resulted eventually in off-hour deliveries. This solution has become mostly implemented in United States and in some European countries as Netherlands. Prohibition of heavy vehicles entrance to the city centers is another example. In Rome and France, some zones are labelled as Low Emission Zone. Indeed, the mayor bans vehicles from driving through these zones based on vehicle emission standards or weight. These regulations are imposed to encourage logistics service providers to optimize their trip in these restricted areas.

In this research, we have addressed these reasons in both chapter 2 and 3. In addition, it is worthy to mention that motivations would not be limited just to one group; a combination of these two reasons can motivate stakeholders to involve in pooling.

6.2.2. Prerequisites to achieve a successful pooling

Once decision is made to lead towards pooling, some conditions are required to guarantee its successful implementation. As discussed in chapter 2, while studying the pooling implementation, not only a profound analysis and deep information about the city logistics system and its process is mandatory but also there must be an organizational planning to follow. To this end, we proposed, in section 2.5.2, a general framework describing any single steps to reach a successful pooling. Furthermore, we provided an extensive discussion about the city logistics system and its components by presenting the new concept of "typology of flow" in chapter 4. In this section, we just make a summary of prerequisites factors related to the pooling implementation.

Primary infrastructure to be available. Basic physical and organizational structures and facilities need for pooling must be initially available. The analysis concerning this step can be performed trough a feasibility study to examine the structural feasibility of this solution. For instance, the capacity of the system for pooling and its size can be stated as debatable points in this context. As observed in our case study, the number of involved depots have an impact on benefit of pooling. More stakeholders involved, more benefits gained. Hence, it is important that before pooling implementation, we assure that pooling would be profitable in our case with regard to the number of involved stakeholders.

Reliable platform. As we discussed in chapter 2, a distinctive difference of pooling with other type of collaboration is that in pooling all involved stakeholders must have a direct influence in decisions making and in supervising and controlling of the whole processes. To this end, an impartial platform for releasing this type of communication and exchange looks necessary. This platform can be managed either by a third party or a strong IT tool, which is at disposal of all involved stakeholders. This platform can be also used to ensures a better distribution of gains. In addition, this kind of platform can further facilitate to get involved stakeholders' support during operational phase of pooling.

Being realistic about pooling. After years of discussion about pooling and its advantages, it is time to talk about its potential constraints, especially those related to its implementation phase. Identifying potential constraints and evaluating their impacts on pooling efficiency could increase the knowledge about the system and then help to maintain it viable. We have already elaborated this issue in chapter 3 and 4 through identifying two types of potential constraints: policy-oriented constraints and compatibility constraints. Moreover, there might be another constraint appearing during the implementation phase. This is why pooling needs to be supervised and controlled during its performance. As we just mentioned above, a reliable platform can be a useful tool to perform these kind of control during processes.

Identifying potential risks. In a dynamic system such as city logistics, risk study in the early stages of a project is essential. To do so, potential risks must be anticipated in order to be able to prepare for them. The main types of risk possible in collaborative scenarios like as pooling have been identified as follows (Gonzalez-Feliu et al 2013):

- The risks related to the project resources in terms of finance, economy, technic and personnel.
- The risks related to the organizational planning of the project. Meaning risks related to the individually made decisions (operational level) and those related to collaborative decisions making.
- The risks related to functionality, robustness and compatibility of used technologies.
- The risks related to policies, processes and current practices. Since collaboration provoke some changes in tradition way of operation, the impact of these changes on actors and their reactions have to be anticipated.
- The risks related to the dependency of sub systems. These risks have to be identified in order to avoid dysfunctionality of whole system in the absence of a subsystem.

In general, there are two ways to treat the identified risks. The first way is to do everything possible to avoid them and the second way is to develop options and actions to make their consequences less severe. In this thesis, we identified potential constraints in front of pooling that can help to avoid some of above-mentioned risks. By studying these constraints in our case study, we observed that some customers (delivery points) have great impact on pooling efficiency comparing to others. Consequently, this kind of analysis can help, on one hand, to identify strategic stakeholders and on the other hand, to anticipate actions if these effective stakeholders decide to withdraw from collaboration.

Key performance indicators. To be able to effectively monitor a system and evaluate its functionality, it is necessary to define suitable and representative indicators. In chapter 4, we discussed the most used indicators in the literature for collaborative strategies including pooling. These indicators not only must be capable to measure the efficiency of the system but also must be able to report either system moves towards desired direction. To conduct a more elaborated analysis on the impact of the structure of pooled network, we proposed two new indicators as well. Calculating these indicators for our case study reflected interesting results. We observed that disruptive impact is inevitable in pooling. To explain more clearly, we noticed that one of depots was almost getting less number of delivery points comparing to its initial function (before involving in pooling) as other depots dominated it. This indicator can help to evaluate consequences of pooling beside its benefits. Our second indicator was defined to calculate, for each depot, the amount of demand to serve after pooling. We searched to know whether or not changing in the number of customers after pooling have an impact on the amount of demand to serve for each depot. Results obtained from our case study revealed that there had a direct relation between the number of delivery point to serve and the amount of demand. It means getting less delivery points consequently result in less quantity of demand to serve.

Rebuilding trust. Design of a collaborative network requires involvement and commitment of all stakeholders. Hence, trust is a crucial factor in the pooling implementation. Knowing that trust in human relationship in any business takes much time to be made; hence, once it is attained, it must be thoughtfully maintained. As discussed earlier, a third party who is trusted by all stakeholders can manage these relations. In addition, this third party can assure that everyone would benefit as much as his participation.

6.3. Positive and negative impacts of city logistics pooling

Results obtained from our case study using our applied approach have revealed some important impacts of city logistics pooling:

Benefits and positive impacts of pooling. For all scenarios tested in chapter 5, decreasing the total travelled distance and increasing the load factor highlighted the economic benefits of pooling and, subsequently, its contribution to the minimization of environmental externalities. However, we also observed that under different conditions, these improvements have fluctuated. For example, our case study showed that the quantity of demand had a significant impact on pooling efficiency. Meaning, when the quantity of demand concerning each delivery point is smaller, pooling is more efficient. This is due to the allocation phase in where assignment can be done with more flexibility. Our case study also indicated that potential constraints specially those of compatibility had a major impact on pooling benefits. How much constraints become stricter, decrease in total travelled distance become smaller. It shows that the benefits of city logistics pooling are not always definitive and surrounding environment must always be monitored. To give an example, if one of the involved stakeholders withdraws its depot and customers from pooling, this can decrease pooling benefits and also can make pooling less profitable comparing to its beginning.

Fair share of gained benefits. The main idea of pooling is to share as much as possible available resources with each other in order to achieve more benefits together. Benefit sharing among all stakeholders involved is a necessary condition for a successful pooling implementation. Hence, once benefits achieved, it is time to fairly share them. It might be a difficult task as we have seen, changes in the arrangement of pooled system differs it from its initial network and benefits allocation would not be easy. Providing conditions for offering new services by the dominated stakeholders could be a solution to balance the involvement in pooling.

Impact of constraints on pooling efficiency. The conditions under which our scenarios were defined were those of policy oriented constraints and compatibility constraints. The results obtained for our case study showed that in both cases, constraints cause to reduce the benefits and this decrease is more significant for compatibility constraints. Hence, the inaccuracy in identifying these constraints can lead to an incorrect estimation of the benefits.

Disruptive impacts of pooling. With regard to the results obtained for our case study, we discovered despite positive impacts of pooling, it sometimes provoked fundamental changes in initial distribution network. We found that in all scenarios, when constraints are permissive, depot 2 lost its customers. In contrary, depot 3, which had the small number of customers in the initial network, could absorb the majority number of customers while pooling. Moreover, we observed that this trend occurred for the served demand as well; meaning a decrease in the number of customers consequently result in the reduction of the quantity of demand served by depots. These results remind us that it is important while thinking about pooling and its benefits, we take into account the complexity of its governance model and the interest of stakeholders, which are merely very divergent.

Clear foresight on commitments. With regard to the obtained results, we found that it is sometimes possible that one stakeholder had more important role for achieving pooling benefices. Our case study displayed the important of a specific stakeholder share in pooling advantages. In this manner, if this stakeholder decides to withdraw from collaboration, it can make big changes in the expected benefits. We also noticed that, in some cases, adding more constraints does not really change the results. Seeking the reason, we found that this result is due to the fact that these constraints were not applied to effective customers (meaning those delivery points that are shared and are occasionally served by others). It means until constraints regarding policy of sharing customers or serving the new ones have not been applied on effective customers, the results have not been more affected. This fact states the importance of identification of effective customers in pooling and keeping them involved. To conclude this issue, we emphasize that the consequences of withdraw of such a commitment must be firstly anticipated and be prepared for.

More stakeholders involved, more benefits gained. Our results also showed the benefits achieved through pooling is more high when more stakeholders participate in it. A high number of stakeholders involved cause to more resources and customers be shared; consequently, flexibility increase for designing a pooled network. Therefrom, it can be concluded that the more stakeholders involved in pooling, the more benefits gained.

System change. As discussed earlier, any collaborative scenario results in changing traditional network. Our case study indicated great changes in network design via pooling especially when constraints are not very strict. Therefore, it is inevitable to pay for adjusting the system and its users in the presence of these changes. These costs can be money, time, reputation, market share or etc. Therefore, it must not be forgotten that there might be secondary costs during implementation and operation of pooling.

6.4. Contingencies associated with city logistics pooling

Contingency factors are evolutionary characteristics that influence decisions, actions and management of projects. With regard to the absence of certainty in real world, any project may encounter disruptive events or circumstances during its execution. Pooling is not an exception either. These events may affect the overall performance of the system and relationship between stakeholders. In this regard, it is necessary to find reasonable plans, since first stages, to be able to face with unexpected problems. Hence, a contingency plan is strongly suggested to make it possible to control the system if an unforeseen event happens (Maas et al. 2018). One example for such a problem can be the decision of one stakeholder to withdraw from collaboration. With regard to the experimental results and our literature survey, we point out three other factors that could have also impacts on pooling viability in long term. These factors are as following.

Profit investing on new services. Regarding the strong competition between urban freight forwarders and the increasing concerns about environmental effects of these activities, one distinctive factor for pooling success and viability is to invest gained benefits on the development of new services. We discussed in chapter 4, different kind of services that could be proposed while using delivery system pooling. Using innovative storages as remote depots and delivering customers upon their demand is one type of these innovative services. Offering these new services can help to efficiently survive under inevitable competitions and to be viable in dynamic environment of city logistics.

Impact of demand change in long term. Our case study pointed out that change in the quantity of demand made pooling more complicated as it made the network less flexible to be reallocated in an optimized manner. Since seasonality occurs regularly in demand pattern of urban freight (during sales period or Christmas days for instance), it seems important to take into consideration these kind of changes in demand quantity for planning a long term pooling plan.

Rebound effects. Our case study proved that there are always advantages regarding economic environmental aspects while integrating pooling into the distribution network, even when there were different constraints. However, there might be another effects regarding collaborative strategies that would appear later and not immediately after pooling implementation. Rebound effects is one of these effects that might appear in long term. Rebound effect means when a strategy works well in the beginning but gradually it destroys even the primary improvements. In the sector of transport, it has been applied to represent the difference between the anticipated benefits and the benefits actually obtained (Jägerbrand et al., 2014). This effect has to be taken into account by involved stakeholders in first stages as well as during the implementation in order to guarantee that the advantages of pooling won't be diminished in long term.

Conclusion

In this chapter, we discussed about the factors related to the viability of city logistics pooling. To this end, the identified factors for system viability have been presented. Moreover, the viability factors for collaborative urban freight have been discussed. We suggested to breaking these factors in three group of antecedents, consequences and contingencies in order to study the viability factors for city logistics pooling. The first group represents the factors that must be meticulously studied at first stages. A comprehensive knowledge about the origin of a project will make a clear vision about the necessary actions to keep it viable in the long term. The second group refers to the consequences of pooling, both desired and unexpected ones. The last group discusses the possible events that almost cannot be predicted in the first steps but it is necessary to be aware of their impacts if they occur. Pooling viability in long term highly depends on frequent verification of the system and its actual changes in order to be able to mitigate unexpected events and their effects on the system.

General Conclusion and Perspectives

General Conclusion

City logistics, considered as the last step of supply chain management, aims to optimally plan, manage and control urban freight transportation. Freight transportation causes significant negative impacts in urban areas in terms of congestion, emissions and space consumption. In recent years, pooling has emerged as a collaborative strategy that leads towards systematic collaboration between stakeholders in order to decrease negative externalities of urban freight transportation and increase efficiency of activities. The main objective of this thesis was to contribute to the development of pooling concept in city logistics by providing a deep analysis on conditions for its successful implementation.

To develop the framework of our research, we addressed in a first step the general problematic of city logistic. Thus, we conducted a comprehensive literature review on city logistics. Our results led us to propose a classification based on keywords listed in the surveyed articles in order to categorize related research activities in this filed. This synthesis of literature also aided to demonstrate different aspects of city logistics regarding its complexity as a real-world problem.

In the following, we focused on pooling concept in city logistics. We discussed pooling application in city logistics in recent years. Then, we focused on the development of a general framework in order to discuss required steps to integrate pooling into a city logistics system. Consequently, we came up with a top-down stepwise framework for identifying steps towards pooling implementation. This framework consisted of two parts; first part was dedicated to the identification of required information for pooling implementation; second part followed an organization planning steps in three levels of strategic, tactical and operational to describe the hierarchy of decision while planning for the pooling implementation.

Along our analysis concerning pooling implementation, we found that the pooling literature lacked an overall understanding about the city logistics system to be able to deeply discuss possibilities of pooling in such a system. To overcome this research gap, we introduced a novel concept, which we called it ‘typology of flow’, to analyse different possibilities of city logistics pooling at a first step and then, to identify potential constraints before pooling implementation. We elaborated different pooling possibilities for a delivery system in urban area. We also discussed how these kinds of innovative distribution networks could lead to a multi-level multi-modal network design on one hand and to propose new services in the context of city logistics on the other hand.

As mentioned above, we employed the proposed concept of 'typology of flow' in order to identify potential constraints against pooling implementation. In this context, we recognized two groups of constraints classified as policy-oriented constraints and compatibility constraints. Furthermore, we proposed an innovative approach for quantifying the impacts of these constraints on resource pooling efficiency. To do so, we modeled our problem as a Multi Depot Capacitated Vehicle Routing Problem (MDCVRP). To solve this problem, we adapted the classic method for solving MDCVRP, which consisted of two phases: allocation phase and routing phase. We incorporated the identified constrains (presented in chapter 3) into the allocation model in order to consequently evaluate their impacts on pooling efficiency. For the second phase, which was routing phase, we applied two mostly used metaheuristics approaches, simulated annealing (SA) and variable neighbourhood search (VNS), in order to find an appropriate routing for each depot. We also used our adapted key performance indicators in order to quantify both positive and negative impacts of resource pooling.

To verify the validity of our proposed approach, we used, with the agreement of the authors, the data retrieved from a real case study from the literature. This real case takes place in Bogota, Colombia. Using this data, as our case study, allowed us to have a complex and complete example to study impacts of potential constraints in resource pooling in the context of city logistics pooling in large cities. Results obtained from our case study revealed that pooling caused improvements regarding total travelled distance and load factor, although, on the other side, provoked significant changes in distribution network. However, these changes are not alike in all scenarios that we developed. Taking into account compatibility constraints, we observed that pooling benefits (improvement in total travelled distance and load factor) decrease with a steeper slope when constraints become stricter.

Finally, we discussed the important factors to achieve a viable city logistics system under different types of pooling. We identified important factors for viability of a system and then, proposed to discuss these factors for city logistics by dividing them into three groups. Three groups represent antecedents, consequences and contingencies required to achieve a viable city logistics pooling. The first group concerns motivations and perquisites for implementing pooling. The second group refers to the consequences of pooling, both desired and unexpected ones. Pooling contribution in reducing total travelled distance or increasing load factor can be mentioned as its desire consequences. In contrast, significant changes in traditional networks and customers to serve can be less desirable for involved stakeholders. Eventually, the last group discusses the possible events that almost cannot be predicted in the first steps but, it is necessary to be aware of their impacts if they occur. Pooling viability in long term highly depends on frequent verification of the system and its actual changes in order to be able to mitigate unexpected events and their effects on the system.

Perspectives for future research

This thesis aimed to provide a comprehensive discussion on city logistics pooling and the conditions for its implementation. Different extensions of this work, theoretically and practically, may be considered beyond the assumptions considered in this thesis. In order to enrich this research study several future directions are proposed as follows:

Among three types of pooling presented in the literature for city logistics as delivery system pooling, resource pooling and information pooling; in this thesis, we merely focused on the two first ones. Information pooling is a very important kind of pooling that arises serious challenging issues for city logistics issues. This topic has not been extensively studied in the literature and could be an interesting future research direction.

Our proposed step-wise framework was constructed based on our literature review and reports released by companies. This framework can be applied in real cases in order to validate its application in practice and if necessary to be improved according to its users' opinion.

Regarding delivery system pooling, we focused on theoretical discussion and provided different possibilities of pooling in city logistics by using innovative storage solution. One interesting avenue of research is to perform quantitative analyses for these pooled networks. However, two echelon distribution network has been already discussed by considering UDCs, there is still a lack of interest concerning three echelon distribution network (presented in 3.3.3) such as networks via UDC and PLS/DM, networks via UDC and GRP/ULB as well as networks via PLS/DM and GRP/ULB.

We identified two groups of constraints as potential constraints against pooling implementation. However, we only evaluated their impact on resource pooling efficiency. Evaluating impacts of these constraints on the other types of pooling, on delivery system pooling for example, can be a fruitful research direction. These evaluations make it possible to perform an ex-ante assessment in order to understand pooling advantages and drawbacks before its implementation.

There are also other perspectives concerning our proposed approach for quantifying impacts of pooling. In this thesis, we used an approach that breaks Multi Depot Capacitated Vehicle Routing Problem (MDCVRP) into an allocation model and a Capacitated Vehicle Routing Problem (CVRP). It would be interesting to apply an approach to solve these two phases together, meaning to propose optimization methods that take into account policy-oriented and compatibility constraints in the allocation optimization as well as routing phase. Moreover, the objective function of our mathematical model is to minimize total travelled distance, another promising avenue of research can be to propose optimization methods taking into account not only the distance, but also other important criteria for a successful pooling such as time windows, considering delivery area access and minimizing fuel consumption.

In our case study, we did not have access to logistics service providers for being able to collect real information concerning policy-oriented constraints and compatibility constraints; hence, we generated randomly these input data. Using real data for validating our proposed approach can result in more deeply knowledge about the impacts of potential constraints on pooling efficiency. In this regard, in order to be more robust, it would be suggested to generate various matrices for each series of tests to avoid the problem of changing the status of effective delivery points due to the random generation of constraints representing matrices. Concerning demands, they were also randomly generated from a uniform distribution. We considered deterministic demand; however, demands can be uncertain in reality. Using real data for demand can be more realistic and representative.

We further propose several perspectives in the continuation of this work in order to study other impacting factors on city logistics pooling. Seasonality is one of the important feature of urban freight distribution, although, we did not consider it in scenarios definition. With regard to the impact of quantity of demand on pooling efficiency, incorporating seasonality of demand in scenarios definition seems to be a fruitful future research. Furthermore, we developed our proposed approach regardless of its application for our case study. Therefore, this approach can be used for other case studies from any city in the world. This also can help to compare impacts of geographic features of cities on pooling efficiency. Eventually, another interesting research direction could be to study the impacts of various legal and political constraints on pooling efficiency.

List of publications and scientific productions

We have published scientific contributions of this thesis in the well-known international conferences and journals. In this section we present the list of articles.

Journal publication:

- Dolati Neghabadi, P., Evrard Samuel, K., and Espinouse, M. L. (2018). "Systematic literature review on city logistics: overview, classification and analysis". International Journal of Production Research, 1-23.

International conference publications:

- Dolati Neghabadi, P., Espinouse, M. L., and Evrard Samuel, K. (2018). "Planning process for pooling integration in city logistics". In 4th International Conference on Logistics Operations Management (GOL'2018). IEEE, pp. 1-11. Le Havre, France.
- Hofmann, W., Assmann, T., Dolati Neghabadi, P., Cung, V.D., & Tolujevs, J. (2017). A Simulation Tool to Assess the Integration of Cargo Bikes into an Urban Distribution System. In The 5th International workshop on Simulation for Energy, Sustainable Development & Environment (SESDE 2017). Barcelona, Spain. (Best Paper Award).
- Dolati Neghabadi, P., Evrard Samuel, K., & Espinouse, M. L. (2016). City Logistics: A Review and Research Framework. In International Meeting on Logistics Research (RIRL, 2016). At EPFL Lausanne, Switzerland.

Appendix

Appendix 1.1

Notice that authors name in bold refers to **journal articles**, in Italic refer to *books* and the rest are conference papers.

Methods	Articles
Qualitative Method	
Multi-Criteria Analysis	**Tadic et al. (2014), Verlinde et al. (2014), Taefi et al. (2016),** Morfoulaki et al. (2016), **Muñuzuri et al. (2016),** *Renata et al. (2018), Nathanail (2018)*
Multi-actor multi-criteria analysis	**Verlinde et al. (2014), Muñuzuri et al. (2016), Lebeau et al. (2018)**
Collaborative multicriteria analysis	Gonzalez-Feliu et al. (2013), Morana and Gonzalez-Feliu (2014)
Decision support (system)	Gonzalez-Feliu (2011**), Ambrosini et al. (2013), Muñuzuri and Gonzalez-Feliu (2013), Nuzzolo et al. (2014),** *Ducret (2014)*, Gonzalez-Feliu and Morana (2014), Bozzoa et al. (2014), Comi and Rosati, (2015), **Bouhana et al. (2015),** *Gonzalez-Feliu and Salanova Grau (2015)*, Arguello et al. (2016), *Barceló et al. (2017)*, *Castrellón-Torres et al. (2018), Perboli et al. (2018)*
Decision-making	Ambrosini and Routhier (2010), Delaître and Routhier (2010), Gonzalez-Feliu et al. (2010), Guyon et al. (2012), *Stumm and Kidd (2012),* **Muñuzuri and Gonzalez-Feliu (2013), Ducret et al. (2016),** Papoutsis et al. (2016), **Gatta et al. (2017), Rudolph, and Gruber (2017),** *Gonzalez-Feliu (2018)*
Decision makers	Lindholm (2012), **Gatta and Marcucci (2014).**
Collective decision	Guerlain et al. (2016)
Consensus	Morana and Gonzalez-Feliu (2014), Gonzalez-Feliu and Morana (2014)
Partner selection	**Awasthi et al. (2016)**
Preference heterogeneity	Marcucci and Gatta (2013), **Gatta and Marcucci (2014), Marcucci et al. (2015), Marcucci et al. (2017), dell'Olio et al. (2017)**
Country-approach	Muñuzuri and Gonzalez-Feliu (2013)
Profession knowledge	**Morganti, Jesus Gonzalez-Feliu (2015)**
Compatibility indicators	**Deflorio et al. (2012)**
Cluster analysis	Ren et al. (2010)
Discrete choice models	Domínguez et al. (2012), **Muñuzuri et al. (2016), dell'Olio et al. (2017), Marcucci et al. (2017), Le Pira et al. (2017)**
Optimization	
Objective	
Combinatorial optimization	*Mancini et al. (2014)*, **Gianessi et al. (2015),**
Optimization of traffic networks	Amaral and Aghezzaf (2015)
Inverse optimization	**You et al., 2016**
Vehicle routing	
Freight vehicle routing	Amodeo et al. (2015), Bandinelli et al. (2016), **Fernández et al. (2017), Wasiak et al. 2017, Gupta et al. (2017), Muñuzuri et al. (2017)**
Robust vehicle routing	Guedria et al. (2016)
Multi-level vehicle routing problem	Cattaruzza et al. (2015), **Zhou et al. (2018)**
Time-dependent vehicle routing problem	Cattaruzza et al. (2016), **Flamini et al. (2017), Barceló et al. (2017)**
Dynamic vehicle routing problem	Cattaruzza et al. (2015)

Multi-trip vehicle routing problem	**Crainic et al. (2015), Grangier et al. (2017), Muñoz-Villamizara et al. (2017)**
2L-CVRP	Crainic et al. (2012), Guedria et al. (2016), **Wang et al. (2017), Quintero-Araujo et al. (2017)**, **Wang et al. (2018), Fernández et al. (2018)**
Location-routing (problem)	Crainic et al. (2011), **Hemmelmayr et al. (2012), Winkenbach et al. (2015)**, *Herazo-Padilla et al. (2015),* **Koc et al. (2015), Zhao et al. (2017), Schiffer and Walther (2017). Simoni et al. (2018), Boccia et al. 2018**
Location selection	**Rao et al. (2015), He et al. (2017)**
Facility location	Guyon et al. (2012), **Deutsch and Golany (2017), Boccia et al. (2018)**
Parking slot assignment problem	**Roca-Riu et al. (2015)**
Approach	
Game Theory	**Xu et al. (2012)**, Simoni et al. (2015), **Wang et al. (2018)**
Genetic algorithm	**Yang and Moodie (2011)**, **Muñuzuri and Guadix (2012),** Muñuzuri, Guadix (2013), **Walteros et al. (2013),** *Jiao et al. (2013),* **Al Chami et al. (2017), Zhou et al. (2018),**
Bi-level optimization	*Shahraki and Türkay (2016)*
Integer programming	*Shahraki and Türkay (2016),* **Gianessi et al. (2015), Winkenbach et al. (2015), Zhao et al. (2017), Wang et al. (2017), Muñuzuri et al. (2017), Fernández et al. (2018)**
Set covering problem	Boschetti and Maniezzo (2015)
Lagrangian relaxation	Boschetti and Maniezzo (2016)
Markov models	Cedillo-Campos et al. (2014)
Simulated annealing	**Muñuzuri et al. (2015)**
Adaptive large neighborhood search heuristic	**Hemmelmayr et al. (2012), Grangier et al. (2016), Masson et al. (2017), Schiffer and Walther (2017)**
Reliability	*Hoerstebrock et al. (2014),* **Cedillo-Campos et al. (2014)**, GroB and Ulmer et al. (2015), GroB and Geisinger et al.(2015), Groß et al. (2018)
Robust	GroB and Ulmer et al. (2015), GroB and Geisinger et al. (2015), Guedria et al. (2016), *Snoeck et al. (2018)*
Fuzzy numbers	**Awasthi et al. (2015), Bandeira et al. (2018)**
Column generation	Qureshi et al. (2010), Qureshi et al. (2014)
Extreme Value Theory	Baldi et al. (2012)
Cloud computing	Wang et al. (2016)
Data Mining	**Ehmke et al. (2012)**, *Kretzschmar et al. (2016), Chen and Pan (2016)*
Time window	Qureshi et al. (2010), Qureshi et al. (2012), Buhrkal et al. (2012), Muñuzuri et al. (2013), Bhusiri et al. (2014), **Qureshi et al. (2014), Crainic et al. (2015), Roca-Riu et al. (2015), van Heeswij et al. (2017)**
Deterministic approximation	Baldi et al. (2012)
Data collection	
Focus Group Survey	*Stathopoulos and Valeri et al. (2012)*
Data Acquisition	Marcucci and Gatta (2016)**, Gatta and Marcucci (2016)**
Big data	*Kretzschmar et al. (2016)*
Survey	Agrebi et al. (2015), G. F. de Oliveira, L. K. de Oliveira (2016)
Survey technique	**Allen et al. (2012),** *Kaszubowski (2017),* **Oka et al. (2018)**
Lessons learned	**Nuzzolo and Comi (2015)**, Imanishi and Taniguch (2016), *Kant et al. (2016), Koning and Conway (2016),*
Best Practices	Quak (2012), **Schöder et al. (2016),** Marciani et al. (2016)
Research strategy	**Zunder et al. (2014)**
Key success factors	Lindholm (2014), *Kant et al. (2016),* Kiba-Janiak (2016), **Ahmad and Mehmood (2016), Kin et al. (2017)**

Delphi method	Kiba-Janiak (2016)
Evaluation approaches	
Evaluation	Danielis et al. (2012), van Duin et al. (2012), Taniguchi et al. (2012), Marcucci and Gatta (2013), van Rooijen and Quak (2014), Quak et al. (2014), Iwan (2014), **Macharis et al. (2014),** Amodeo et al. (2015), Gonzalez-Feliu (2016), Ducret et al. (2016), Lopez et al. (2016), Jedliński and Kijewsk (2016), Marcucci and Gatta (2016), Morfoulaki et al. (2016), **Muñuzuri et al. (2016), Wasiak et al. (2017),** *Karakikes et al. (2018)*, Groß et al. (2018), *Gonzalez-Feliu (2018)*
Assessment	
Assessment method	Zenezini and De Marco (2016), Ducret et al. (2016), **Kijewska et al. (2017)**
Ex-ante assessment	Filippi et al. (2010), **Russo and Comi (2011),** Bozzo et al., (2013), **Kijewska and Jedliński (2018)**
Impact assessment	Leonardi et al. (2012), Nuzzolo and Comi (2014), **Pamučar et al. (2016)**, *Balm et al. (2016)*
Scenario assessment	**Nuzzolo et al. (2014),** Andriankaja et al. (2015), **Montoya-Torres et al. (2016),** Lopez et al. (2016)
Analysis	
Geographical analysis	*Ducret (2014)*, **Ducret et al. (2016)**
Market Analysis	*Verlinden et al. (2015)*
Gray Relational Analysis	**Awasthi et al. (2015)**
Conjoint-based choice (analysis)	Lebeau et al. (2016), Gogas et al. (2017)
Multidimensional factor analysis	Kunze et al. (2016), Pietrzak (2018)
Life-cycle analysis	Andriankaja et al. (2015)
BOCR (benefits, opportunities, costs, and risks analysis)	**Awasthi et al. (2015)**
Risk prediction	**Yang et al. (2012)**
Social Cost-Benefit Analysis	Kin et al. (2016), *Gonzalez-Feli (2018), Holmgren (2018)*
Before-after survey	Leonardi et al. (2012)
Willingness to pay	Gatta and Marcucci (2014), Marcucci and Gatta (2016), **Gatta and Marcucci (2016**)
Efficiency of city logistics	Iwan an Małecki (2015), **Kijewska (2015),** Nathnail et al. (2016)
Modelling	
Agent-Based Model(ling)	Van Duin et al. (2012), **Anand et al. (2012), Anand et al. (2014), Maggi and Vallino (2016),** Anand et al .(2016), **Anand et al (2016),** De Oliveira et al. (2017), **Marcucci et al. (2017),** Alho et al. (2017), Schröder and Liedtke (2017), Le Pira et al. (2017)
Multi-agent model	Tamagaw et al. (2010) ,
Multi-agent system	Suksri and Raicu (2012), Teo et al. (2012), Teo et al. (2012), Wangapisit et al. (2014), **Anand et al. (2014), Teo et al. (2014),** *Borghesi (2017)*, **Le Pira et al. (2017)**,
Multi-agent framework	*Hoerstebrock et al. (2014)*
Agent-specific approach	*Marcucci et al. (2013)*, **Gatta and Marcucci (2014)**
Freight demand model(ling)	**Russo and Comi (2011),** Comi et al. (2012), *Nuzzolo and Comi (2014)*, **Nuzzolo and Comi (2014), Nuzzolo et al. (2014),** Nuzzolo and Comi (2014), *Kaszubowski (2017)*, **Aditjandra and Zunder (2017),** Thaller et al. (2017), **Sánchez-Díaz (2017)**
Demand System	*Qiu and Shi (2015)*
Commodity-based models	Comi et al. (2012)
Truck-based models	Comi et al. (2012)
City Logistics Modeling	**Anand et al. (2012), Muñuzuri and Gonzalez-Feliu (2013)**
Congestion modeling	**Figliozzi (2010)**
Governance Model	Marciani and Cossu (2014), **Marcucci et al. (2017)**

Economic replacement model	Feng and Figliozzi (2012)
Delivery-based models	Comi et al. (2012)
Truck-based models	Comi et al. (2012)
Planning model	Lindholm (2012), Ukkusuri et al. (2016)
Dynamics modelling	*Qiu and Shi (2015)*
Trip generation modelling	Gonzalez-Feliu et al. (2010), **Sánchez-Díaz (2017)**
Policy-oriented modelling	Gonzalez-Feliu (2012)
Urban modelling	*Ducret (2014)*
Transport modelling	**Ambrosini et al. (2013),** *Marcucci et al. (2014)*
Discrete choice models	Domínguez et al. (2012), Muñuzuri et al. (2016), **Punel and Stathopoulos (2017),** Le Pira et al. (2017)
Tour-based model	**You et al. (2016)**
Activity-based model	**You et al. (2016)**
Traffic flow modelling	Amaral and Aghezzaf (2015)
Modelling framework	Alho et al. (2014), Kunze et al. (2016)
Business Model	Quak et al. (2014), *Balm et al. (2016)*
Demand uncertainty	Crainic et al. (2012), **Crainic et al. (2015)**
Uncertainty	Baldi et al. (2012)
Systems' Innovation	Roumboutsos et al. (2013)
Origin-Destination Matrix	**Muñuzuri et al. (2010)**, Comi et al. (2012)
Simulation	
Transport simulation	Comi and Rosati (2013), Ukkusuri et al. (2016), **Chong and Osorio (2017)**, **Deflorio and Castello (2017),** *Simo et al. (2018)*, Heeswijk et al. (2018), **Comi et al. (2018)**
Micro simulation (model)	Lopez et al. (2016), Haas and Friedrich (2017), *Karakikes et al. (2018)*
Monte Carlo simulation	*Crainic et al. (2012),* Crainic et al. (2015), **Pinto et al. (2016),** *Karakikes (2018),*
Simulation-based comparative analysis	Gonzalez-Feliu (2012)
Agent-based simulation	*Van Heeswijk et al. (2016)*, **Le Pira et al. (2017)**
Case Study	
Case study	De Magalhães (2010), Feng and Figliozzi (2012), Hassall et al. (2012), Buhrkal et al. (2012), **Lindholm and Behrends (2012)**, Leonardi et al. (2012), Tozzi et al. (2013), *Morana (2014)*, **Swamy and Baindur (2014), Timms (2014),** Kordnejad (2014), **Córdova et al. (2014)**, **Alho et al. (2015),** Muñoz-Villamizar et al. (2015), Browne et al. (2016), de Oliveira et al. (2016), **Muñoz-Villamizara et al. (2017), Paddeu (2017), Muñoz-Villamizar et al. (2018), Rai et al. (2017)**

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