# Last Mile Delivery in the Retail Sector in an Urban Context

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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## Declaration

I certify that, except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the project is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and ethics procedures and guidelines have been followed.

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Joerin Motavallian

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## Dedication

This thesis is dedicated to:

My loving wife,

*Mojdeh,*

My dearly loved daughters,

*Emitis and Pardis,*

and

My beloved parents

*Ebrahim and Sakineh*

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## List of Abbreviations

| | |
|---|---|
| 3PL | Third-party Logistics |
| B2B | Business-to-Business |
| B2C | Business-to-Consumer |
| BCHEAN | Business College Human Advisory Network |
| C2B | Consumer-to-Business |
| C2C | Consumer-to-Consumer |
| CBD | Central Business District |
| CVRP | Capacitated Vehicle Routing Problem |
| DC | Distribution Centre |
| GA | Genetic Algorithm |
| LMD | Last Mile Delivery |
| MDVRP | Multi-depot Vehicle Routing Problem |
| MILP | Mixed-integer Linear Programming |
| NP-hard | Non-deterministic Polynomial Time Hard |
| NSGA II | Non-dominated Sorting Genetic Algorithm |
| SCOR | Supply Chain Operations Reference |
| UCC | Urban Consolidation Centre |
| VRP | Vehicle Routing Problem |
| VRPB | Vehicle Routing Problem with Backhauls |
| VRPSPD | Vehicle Routing Problem with Simultaneous Pickup and Delivery |
| VRPTW | Vehicle Routing Problem with Time Window |

## Abstract

Last mile delivery (LMD) is a critical yet ambiguous stage of every supply chain. Previous studies have indicated that LMD is one of the most expensive, inefficient and polluting stages of the supply chain, yet, despite its importance, the concept of LMD remains unclear in both academic and industry contexts. The use of different phrases, unclear boundaries and uncertain definitions and structures cause LMD to remain unclear. Thus, this study aims to demystify the basic understanding of LMD in terms of terminology, definition, scope, dimensions and structures. It then aims to introduce an initiative to improve the performance of LMD. A systematic literature review and content analysis are used to clarify the definition, dominant terminology and boundary of LMD, and investigate how the literature addresses these. The study then uses the ontology concept to discover and classify the LMD component, which provides a framework for extracting potential problems, solutions and structures for LMD. The proposed ontology is also used to map the LMD literature and identify the gaps in the literature.

Using the proposed ontology, LMD is categorised into 40 structures that are employed to discover the structure of LMD used by major retailers and third-party logistics in the city of Melbourne. The results indicate that warehouses and distribution centres are the most common places that the investigated companies used to begin LMD. The results also indicate that the LMD process is usually finalised at stores in the business-to-business (B2B) context, while it is finalised at consignees' location in the business-to-consumer (B2C) context. The companies investigated in this study mostly prepared the orders at factories, warehouses or distribution centres in the B2B context and prepared orders at stores in the B2C context.

Considering these findings, along with coopetition strategy, this study develops an initiative to improve LMD performance. This study proposes a conceptual model for collaboration in the form of coopetition between retailers and logistics providers, and develops mathematical models to evaluate and optimise the initiative. The conceptual model is formed based on sharing ‘empty running vehicles’ between different delivery networks to decrease the cost and lead-time of delivery simultaneously. A mixed-integer linear programming model solved by genetic algorithm is developed to discover the optimised vehicle-sharing combinations. The results indicate that the proposed model with coopetition decreases delivery cost and lead-time by 60% and 56%, respectively. The results also indicate that the model reduces travelling distance by 66%, which contributes positively to environmental effects. The scenarios with and without coopetition strategy are then compared using real data from the city of Melbourne, which confirms the improvements of the proposed model with coopetition. The results of a case study show that the LMD model with coopetition strategy reduces cost, lead-time and travelling distance by 55%, 46% and 64%, respectively, which is almost similar to the results of random instance sets.

This thesis makes significant theoretical and practical contributions in relation to LMD and employing coopetition strategy in this area. This thesis provides a conclusion regarding the domain terminology, definition and scope of LMD, and presents classified components and structures of LMD, which help create a common understanding among people working and studying in this field. This study presents an LMD model with coopetition among carriers sharing empty running vehicles, which decreases cost, lead-time, travelling distance and the number of vehicles required. The implementation of the proposed model on a large scale can reduce congestion and improve the sustainability aspects of deliveries in cities.

The results of this study encourage decision makers in government authorities to identify empty running vehicles in cities and facilitate collaboration among different networks and companies. Moreover, LMD stakeholders—such as residents, authorities and end consumers—may enjoy the benefits of the proposed coopetition model without being involved in the coopetition practice directly. A shorter time for receiving parcels and lower price of service are the potential benefits experienced by end consumers, while reduced traffic and reduced negative environmental effects are the potential advantages for residents and government authorities. An initiative two-echelon vehicle routing problem (VRP) model is presented to simultaneously minimise lead-time and cost in this study, which has not previously been presented in the LMD context. Moreover, the proposed two-echelon VRP model can be used in other contexts and disciplines.

**Keywords:** Last mile delivery, coopetition strategy, collaborative last mile delivery, ontology, mathematical modelling, optimisation, empty running vehicles.

# Chapter 1: Introduction

The last phase of every supply chain is known as last mile delivery (LMD), and is a critical yet ambiguous stage. LMD is one the most expensive and polluting stages of all supply chains; therefore, companies are seeking solutions and initiatives to cope with this stage. As such, this thesis focuses on the LMD phenomenon and its performance. This chapter presents an overview of the thesis and describes how the research was undertaken. First, Section 1.1 presents the background of the LMD phenomenon. It briefly explains the importance of LMD, and the initiatives and solutions used to deal with this phenomenon. This is followed by Section 1.2, which identifies the problems considered in this study. This study investigates LMD in the retail sector within an urban context, with the Melbourne urban area considered as the case study. Section 1.3 presents a brief description of the LMD situation in the city of Melbourne, while Sections 1.4 and 1.5 describe the research objectives and research questions. Section 1.6 briefly presents the methodology used in this study to address the problem, followed by discussion of the research implications of the study. Section 1.7 discusses this study’s theoretical and practical contributions, while Section 1.8 explains the structure of the thesis. Finally, Section 1.9 presents the conclusion to the chapter.

## 1.1 Background

Rapid urbanisation and the rising popularity of online shopping have created a surge in goods movement, especially in the central business districts (CBDs) of cities, where there is competition for the limited space in the public realm. According to a United Nations (2014) report, the urban population of the world has grown rapidly since 1950, from 751 million in 1950 to 4.2 billion in 2018. This growth is continuing, and it is estimated that 2.5 billion people will be added to the world's urban population by 2050. In addition to the growth in urbanisation, online shopping has also been growing rapidly. The number of global digital buyers in 2014 was around 1.32 billion, and it is expected that over 2.14 billion people worldwide will purchase goods and service online in 2021 (Statista 2019). Moreover, this situation is exacerbated by increasing customer expectations for superior services and related costs (Goethals et al. 2012). LMD is the final stage of supply chains in delivering goods to customers, and has become a critical issue in the context of the urban goods movement system. Studies suggest that LMD (which has various names) is one of the most expensive, inefficient and polluting stages of any supply chain (Brown and Guiffrida 2014; Ehmke and Mattfeld 2012; Gevaers et al. 2011). It is estimated that LMD is responsible for 13% to 75% of the total logistics cost and 16% to 50% of the pollution emissions generated by transport activities within cities (Battaia et al. 2014; Gevaers 2013).

With the objective of minimising delivery costs and environmental effects and increasing service quality, various strategies to address LMD have been considered in various cities globally, such as the creation of urban consolidation centres, the development of underground logistics systems and the implementation of low emission zones. For example, London, Monaco and several Dutch cities—including Rotterdam and Utrecht—have implemented an urban consolidation centre strategy. Low emission zones have been considered in cities such as Utrecht and Yokohama. In Australia, the city of Melbourne has implemented strategies including loading zones and a vehicle access permit scheme to reduce the adverse effects of LMD. In addition, a few studies have used optimisation modelling techniques to minimise the costs and adverse effects of LMD. For instance, Thompson et al. (2011) found that cost saving is possible when optimisation models are used. Similarly, Maden et al. (2010) indicated the way an optimisation algorithm can minimise LMD total travel time and pollution.

Although the above-mentioned strategies and optimisation methods have had positive effects on the performance of LMD, the contribution is limited. In the recent past, as a result of the escalating competition and increasing expectation for higher service quality, organisations have been led to consider collaborative strategies within so-called cooperation–competition ('coopetition') relationships. Coopetition is a relationship between two or more competitors to improve services, reduce overall costs and protect market position (Thompson and Hassall 2012; Yang et al. 2015). Although this strategy has been used in many organisations over the last decade, it has received little attention in the wider logistics industry. Within this strategy, organisations share their resources to improve the delivery process. This study aims to investigate the coopetition strategy by focusing on sharing vehicles between different parties involved in LMD processes. This study compares LMD models with and without coopetition, focusing on cost, service and environmental effects. The proposed model with coopetition strategy can be used with minor adjustment in similar situations in other cities and industries.

## 1.2 Problem Definition

Companies can potentially share a variety of resources with others to improve their delivery process, and vehicles are one of the major resources that logistics companies can share within coopetition strategies. In most industries, logistics companies cannot fully use the capacity of their vehicles, and generally run their business with a low vehicle utilisation rate. Statistics show that a considerable number of goods vehicles run empty in the business-to-business (B2B) context. Buhrkal et al. (2012) claimed that 24% of the goods vehicles operating in Europe run empty. Meanwhile, in Florida in the United States, 30% to 50% of trucks run empty (Florida Department of Transportation 2018). In Australia, the level of empty running vehicles is around 29% (Fremantle Ports 2014). Obviously, empty running vehicles increase transportation costs. In fact, empty running vehicles are one of the main reasons for the high LMD cost (Gevaers 2013). As such, companies can collaborate with other companies—even their competitors—to share their empty running vehicles to attain higher performance. Eliminating or decreasing the number of empty running vehicles can decrease the cost of LMD, which is the main criterion for generating competitive advantage.

However, although sharing empty running vehicles can decrease the cost of delivery, there is a threat to increasing the operation time (the lead-time of delivering goods to customers). The lead-time of delivery is also one of the most important performance criteria for a firm's competitive advantage (Hong et al. 2007; Larson and Gammelgaard 2001; Li et al. 2014). To satisfy customers and gain competitive advantage, carriers need to respond to customers quickly. Promising a shorter lead-time has an immediate effect on the cost of delivery. Therefore, carriers must trade-off between cost and lead-time. Studies have indicated that many logistics service providers may sacrifice lead-time for LMD cost (Hong et al. 2007). Gevaers (2013) concluded that the high degree of empty trips (empty running vehicles) and customers' requirement for a short delivery lead-time are the two main reasons for high LMD costs. Therefore, collaboration strategies must simultaneously consider both cost and lead-time indicators. Thus, the sharing of empty running vehicles is successful when it simultaneously improves both cost and lead-time indicators.

Lack of common understanding and perception is a cause of conflict in collaboration (Tidström 2006). Different perceptions of the main concepts may cause different actions in the same situation. Therefore, to avoid conflict in LMD collaboration, actors must have a common basic understanding of LMD. The main issue regarding LMD is that LMD is not a clear phenomenon and there is no unique perception among people working in this area. Despite various initiatives and studies, LMD remains ambiguous in terms of terminology, definition, scope, components and structure. For example, various phrases are used to describe the LMD phenomenon, such as 'last mile logistics', 'last mile supply chain' and 'last kilometre freight'. There is no unique definition and scope for LMD, and it is unclear when and where the LMD starts and finishes. Therefore, before developing and implementing LMD with a coopetition strategy, it is important to demystify the phenomenon.

## 1.3 The Case of Melbourne City

This study considers Melbourne city as a case study and focuses on the structure of LMD in a B2B context, as LMD is used by logistics service providers and retailers working in this city. Like other major cities, the city of Melbourne is growing rapidly, with significant increases in jobs and residents in Melbourne's CBD. The city has more than 844,000 daily users, including 387,000 workers and 105,000 residents, and it continues to grow at a rapid rate and is estimated to reach to 202,000 residents by 2030. Melbourne's retail trade, as one of the major trades in the city, provided 19,320 jobs and contributed $2.83 billion to the local economy in 2012. Since 2002, the numbers of retail businesses, people employed and floor space have increased by 38%, 14% and 10%, respectively (The City of Melbourne 2013). This increase means that more goods and services are being delivered to the CBD to meet this growing demand.

A recent survey indicated that 19% of all traffic on Melbourne's roads is commercial vehicles, of which 11.5% are light commercial vehicles and 7.5% are trucks (Victoria 2013). Approximately 13.4% of the total vehicles entering Melbourne's CBD are commercial vehicles and are involved in LMD (Casey et al. 2014). In a B2B context, different types of vehicles carry different types of goods to shopping centres, street shops and restaurants in Melbourne's CBD. There are 19 main shopping centres (see Table 1.1) and five department stores, including Myer, David Jones, Big W, Debenhams and Target Centre in the Melbourne CBD (The City of Melbourne 2019). Considering LMD in a B2B context, these shopping centres and department stores are the main destinations of goods in Melbourne's CBD. There is no information about the level of empty trips for LMD in the city of Melbourne; however, the Melbourne-based companies investigated in this study suffered from their empty running vehicles. Currently, the City of Melbourne Council is investigating strategies to reduce the adverse effects of LMD. Recently, Melbourne City Council identified efficient LMD practices as the main strategy to improve the freight movement and liveability of the city (The City of Melbourne 2015).

Table 1.1: Shopping Centres of Melbourne CBD

| Shopping Centres in CBD | Address | Website | No. of Stores |
|---|---|---|---|
| 206 Bourke Street | 207 Bourke St | Unknown | Unknown |
| Centreway Arcade | 259–263 Collins St | Unknown | Unknown |
| Collins234 Boutique Place | 234 Collins St | http://collins234.com.au/ | 15 |
| Collins Place | 45 Collins St | http://collinsplace.com.au | 46 |
| Emporium Melbourne | 287 Lonsdale St | http://emporiummelbourne.com.au/ | 197 |
| Galleria | 385 Bourke St | http://www.galleria.com.au | 23 |
| Georges On Collins | 162–168 Collins St | http://www.georgesoncollins.com.au | 8 |
| Melbourne Central | 183–265 La Trobe St | http://www.melbournecentral.com.au | 283 |
| Melbourne's GPO | 350 Bourke St | http://melbournesgpo.com.au/ | 8 |
| Midcity Centre | 194–200 Bourke St | https://www.midcitycentre.com.au/ | 45 |
| Midtown Melbourne | 246 Bourke St | http://www.midtownmelbourne.com/ | 13 |
| QV Retail | 221 Little Lonsdale St | http://qv.com.au/ | 116 |
| Spencer Outlet Centre | 201 Spencer St | http://www.spenceroutletcentre.com.au | 103 |
| St Collins Lane | 258–274 Collins St | http://www.stcollinslane.com/ | 23 |
| St James | 527–555 Bourke St | https://www.stjamesmelb.com.au/ | 8 |
| Target Centre | 222–244 Bourke St | http://targetcentre.com/melbourne/ | 19 |
| The Paramount Corporate Centre | 108 Bourke St | http://theparamount.com.au/ | 52 |
| The Strand Melbourne | 260 Elizabeth St | http://thestrandmelbourne.com.au/ | 16 |
| The Walk Arcade | 309–325 Bourke St | http://www.thewalkarcade.com.au/ | 25 |

Source: The City of Melbourne (2019).

The goods are mainly distributed from local distribution centres (DCs) to the retailers' stores and shopping centres. Dandenong in the southeast and Laverton in the west of Melbourne are two popular locations where many retailers' DCs are located. For example, Myer, Kmart, and Target DCs are located at Laverton and surrounded areas and Bunnings and Nick Scali DCs are located at Dandenong and surrounded areas. Some retailers such as Woolworths and Aldi have DCs in both areas.

## 1.4 Research Objectives

The overarching objective of this research is to develop models for LMD in the retail sector within an urban context, and investigate the effect of these models on delivery performance, measured in terms of cost, service and environmental effects, with and without a coopetition (collaboration) strategy.

## 1.5 Research Questions

To address the main objective stated in Section 1.4, we first need to elucidate a basic understanding of the LMD phenomenon. Therefore, the first research question (RQ1) of this study was formulated to demystify the LMD phenomenon. The second and third research questions (RQ2 and RQ3) were developed to address LMD with and without a coopetition (collaboration) strategy:

- RQ1: To what extent is the LMD phenomenon understood in terms of its terminology, definition, scope, components, problems, solutions and structures?
- RQ2: Will LMD performance—in terms of cost, service and environment—be improved when a coopetition strategy is adopted?
- RQ3: To what extent will the performance of LMD with and without coopetition vary when the decision variables are changed?

RQ1 investigates different aspects of LMD. To address these aspects, RQ1 is divided into four sub-questions, as follows:

- RQ1a: To what extent is the LMD phenomenon understood in terms of its terminology, definition and scope?

- RQ1b: To what extent is the LMD phenomenon understood in terms of its components?
- RQ1c: To what extent is the LMD phenomenon understood in terms of its problems and solutions?
- RQ1d: To what extent is the LMD phenomenon understood in terms of its structures?

## 1.6 Methodology

As discussed in Sections 1.1 and 1.2, the ambiguity and low performance of LMD caused by empty running vehicles are the two main problems examined in this study. To address the first problem, this study explores the literature and conducts content analysis to conventionalise the domain terminology, definition and scope of LMD. An ontology concept is then used to classify the LMD components. The proposed LMD ontology framework provides a platform to extract possible LMD structures and potential problems and solutions for LMD. Through interviews with logistics managers of various firms, this study investigates the structure of LMD used by the retail sector in the Melbourne CBD.

This study considers the coopetition strategy to address the low performance of LMD caused by empty running vehicles. According to Figliozzi (2007), mixing collection and delivery tours can be a suitable solution to decrease or eliminate empty trips in LMD. A group of carriers can mix their collection and delivery tours to minimise empty running vehicles. To achieve superior results from mixing the collection and delivering tours of different carriers, cooperation among carriers is a critical factor. Carriers are encouraged to share vehicles, destination facilities and information with each other, even with their competitors, to maximise vehicle use and decrease the number of vehicles and travel distances. This approach has not yet been used appropriately in the LMD context.

This study applies the coopetition strategy to simultaneously minimise the cost and lead-time of LMD via minimising empty trips. The study introduces an LMD model with a coopetition strategy that employs empty running vehicles via the amalgamation of different collection and delivery tours that are conducted to collect goods from and deliver goods to stores. Plenty of vehicles travel directly from DCs to retail stores to deliver goods, and these vehicles return to their origin DC empty. In the proposed model, these empty vehicles are used to collect the goods that belong to other networks. Thus, one network shares its empty running vehicles with other network(s) to be used for carrying goods, which improves the performance of the total system.

Using empty running vehicles may decrease LMD cost, yet may also negatively affect lead-time. Consignments may wait a longer time to be dispatched by empty vehicles, and this affects lead-time and influences suppliers' ability to meet customer delivery time requirements. Thus, the proposed LMD model with coopetition strategy must aim to determine the optimum way to decrease both cost and lead-time simultaneously. As such, this research is a multi-objective optimisation study in which the solution procedures are divided into four main stages. The stages are described as follows. First, a conceptual model of LMD with coopetition strategy is developed based on the findings from the literature and interviews with logistics managers. A mathematical model is then established based on the proposed conceptual model to calculate and compare the performance indicators, including cost, lead-time, utilisation rate and vehicle travelling distance for scenarios with and without a coopetition strategy.

Second, because there are various possible routes in the model with a coopetition strategy, a multi-objective optimisation model is developed to determine the best routes. The results of the optimisation model are investigated and compared with the scenario without a coopetition strategy. The scenarios are examined by using the instances generated randomly in this stage. In the third stage, the model is investigated by using real data from an LMD network in the city of Melbourne. The indicators are calculated and investigated for scenarios with and without a coopetition strategy. In the final stage, a sensitivity analysis is conducted to investigate the effects of the variables included in the model. This stage investigates how changes in the number of retailers, number of shopping centres and number of running vehicles contribute to the performance of the scenarios with and without a coopetition strategy.

## 1.7 Contributions of the Study

This research makes both theoretical and practical contributions, as discussed below.

### 1.7.1 Theoretical Contributions

This research presents conclusions on LMD terminology, definition, scope and structures, which enrich the literature on the basic understanding of LMD. This research enhances the understanding of different components of LMD and their interrelationships. By developing LMD ontology, this research presents a framework from which various forms of LMD, as well as various potential problems and solutions, can be theoretically extracted. Moreover, this research enriches the literature on using a coopetition strategy for LMD. The research contributes through the development of a model of sharing empty running vehicles to improve cost and lead-time simultaneously.

### 1.7.2 Practical Contributions

This study presents an LMD ontology framework that provides a valuable source of information. Different parties involved in LMD can use this framework to extract potential LMD problems, solutions and structures that suit their processes. This will help decision makers to develop improvements and restructure their business processes. Decision makers may be from government authorities who make decisions about transportation rules and regulations in cities, or from companies who determine the structure of LMD and business strategies.

Moreover, this research demystifies the LMD phenomenon, which helps create a common understanding of LMD among people who work and study in this area. Having a common understanding and perception of LMD can help ensure better communication on this issue, which will facilitate the coopetition process.

Further, this study presents an LMD model with coopetition strategy, which can be applied in many situations with minor adjustments. It can be used as a basic platform for different parties in LMD to conduct coopetition. The proposed model can decrease cost and lead-time simultaneously, which can satisfy various parties, including retailers, logistics providers, residents, consumers and government authorities. Cost reduction and lower lead-time are the main benefits for retailers and logistics providers, while consumers can enjoy lower price and faster delivery. Government authorities and residents may be satisfied with reduced traffic congestion and negative environmental effects.

## 1.8 Structure of Thesis

This thesis is divided into seven chapters. The thesis structure is displayed in Figure 1.1. Chapter 1 has presented the introduction to this study. This chapter began with a background of LMD, which provided an overview of LMD and the context. It then explained the problem considered in this study, and then presented a brief overview of the city of Melbourne as the case study. Following this, the chapter has described the research objectives and questions, followed by the methodology employed in this study. Finally, this chapter discussed the research contributions. The chapter finishes with an explanation of the thesis structure.

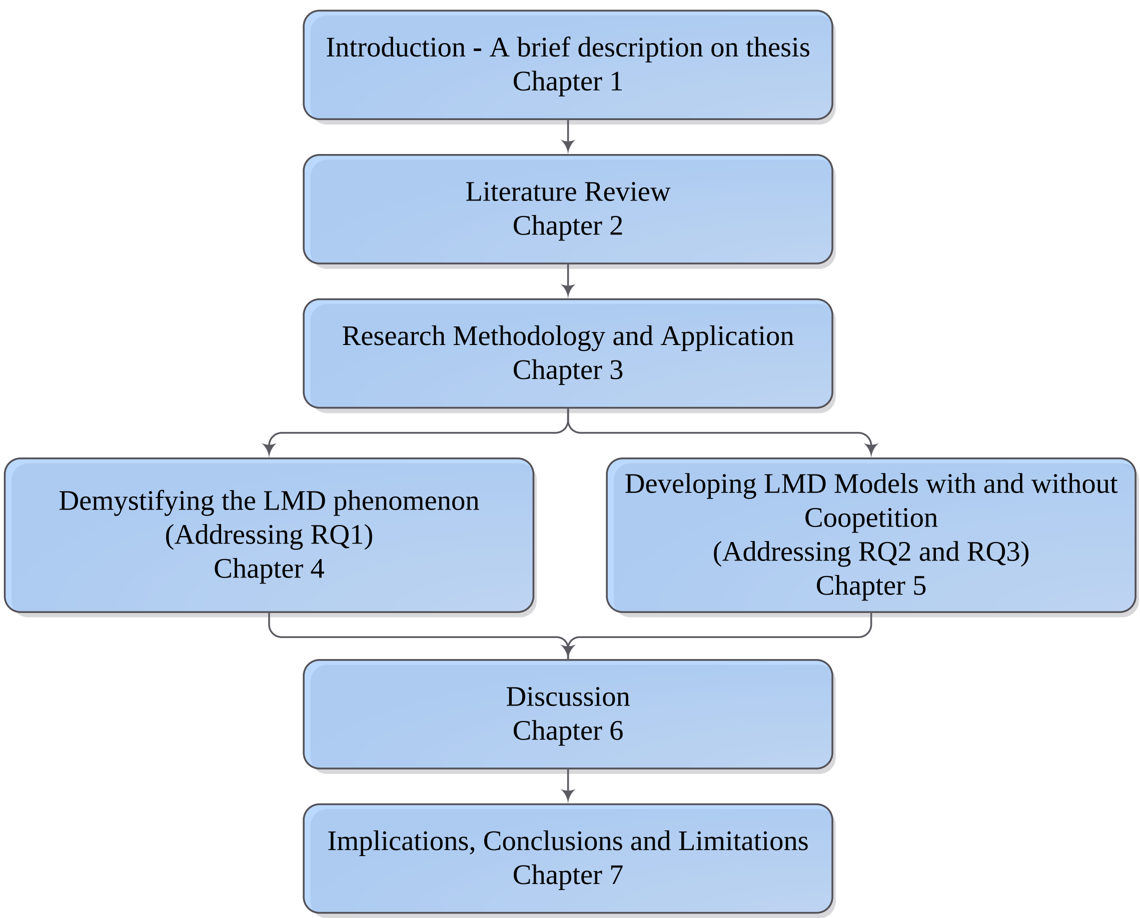



Figure 1.1: Thesis Structure

Chapter 2 reviews the LMD literature, mathematical models of LMD and coopetition strategy. First, it reviews and discusses the LMD phenomenon and the terminologies, definitions and scope used to address LMD. It then explores the LMD problems and solutions, followed by a review of the different LMD structures. The literature addressing LMD ontology and the components of LMD is reviewed, and then the stakeholders involved in LMD and their functions and interests are discussed. The following section reviews the mathematical models applied in LMD. Finally, the coopetition strategy in general and the application of this strategy in the logistics industry in the LMD context are reviewed.

Chapter 3 explains the methodology of this study. This chapter describes the research design and data collection and data analysis methods used in this research. The purposes and approaches of each research question are explained. This study uses both quantitative and qualitative approaches to address the different research questions. This chapter explains the ways in which the systematic literature review, content analysis, ontological analysis, case study and interviews were conducted to demystify the LMD phenomenon. It then explains this research's modelling approach, including conceptual, mathematical and computer modelling. At the end of this chapter, it also explains how sensitivity analysis is conducted in this study.

Chapter 4 discusses the findings from the content analysis, ontological analysis and interviews. This chapter first discusses the findings from the analysis of LMD phrases, and then presents the results of analysing LMD definitions, and introduces the proposed definition and scope of LMD. It then classifies the components of LMD in the form of ontology, and discusses how the LMD ontology framework can depict the problems, solutions and structures of LMD. Next, the results of the ontological analysis of the LMD literature are presented. Finally, some structures for LMD are developed and the chapter explores how the main logistics providers and retailers in the city of Melbourne conduct their LMD based on the proposed LMD structures.

Chapter 5 presents and evaluates LMD models with and without coopetition. The conceptual model of LMD with a coopetition strategy is presented in the first section. The conceptual model includes three scenarios and is developed based on the findings from the literature reviews, the interviews and exploring the current situation of LMD in urban areas. The second section presents the mathematical model of the proposed LMD model with coopetition. The third section describes the solution and the algorithm used to optimise the proposed LMD model with coopetition. The outcomes of the computational test of the proposed model are also presented in this section. Following this, the next section discusses the outcomes of applying the proposed model in a case study. It also presents a comparison of scenarios. Finally, the last section of this chapter explores the sensitivity analysis. It discusses how the solutions are affected by changes to the model's components, and the influence of different variables on the performance of LMD.

Chapter 6 discusses the results and findings, and then debates some of the main concerns related to applying the proposed model. This chapter first debates the results of the analysis undertaken in this study to clarify LMD. The findings from the content analysis, ontological analysis and interviews are discussed and concluded. The chapter then discusses the results of our investigation into using a coopetition strategy in the LMD context. The results of LMD with coopetition scenarios are compared with the LMD without a coopetition scenario. This chapter also discusses the reasons for the changes in the results for various situations of the systems with and without coopetition.

Chapter 7 present the conclusion and the study implications. It also discusses the limitations of the study. The thesis ends by providing recommendations for further research.

### 1.9 Summary

This chapter has presented an overview of this thesis. Section 1.1 presented the background to LMD as the main subject of this thesis. Section 1.2 reviewed the problems and challenges of LMD. This section also identified the problems to be addressed in this study. Section 1.3 reviewed the situation of LMD in the city of Melbourne as a real case study examined in this research. Sections 1.4 and 1.5 presented the research objectives and research questions, while Section 1.6 described the methodology used in this research to address the problems. Section 1.7 presented the expected research contributions, while Section 1.8 explained the structure of the thesis, followed by a summary of the chapter.

# Chapter 2: Literature Review

The objective of this chapter is to review the existing literature and practices regarding LMD and coopetition initiatives. Chapter 2 comprises three themed sections, along with a summary section. This chapter begins by exploring the LMD phenomenon, which is discussed in five subsections. First, the chapter discusses how the literature defines and addresses the LMD phenomenon and why the current definitions cannot clearly explain the phenomenon and its boundaries. It then reviews how the literature classifies the LMD components. Following this, it reviews the problems, solutions and structures of LMD, and discusses how different cities and companies around the world deal with LMD problems. The stakeholders involved in LMD and their roles and expectations are also discussed.

Previous studies have suggested various mathematical models to cope with different problems of LMD. These mathematical models mainly seek to evaluate and improve LMD performance indicators. Section 2.2 discusses the main mathematical problems in the LMD context and debates how the problems and models address performance indicators. This study applies the coopetition strategy to improve LMD performance. Section 2.3 reviews the coopetition strategy, and discusses how collaboration with competitors has been addressed in the literature. Finally, Section 2.4 presents a brief summary of the chapter.

## 2.1 The Last Mile Delivery Phenomenon

The demand to deliver goods to customer locations is rapidly increasing because of the increasing popularity of online shopping. Regardless of the size and weight of the order, at least one vehicle and a delivery crew are needed to deliver one online order to a customer. However, online orders placed by customers generally have a size that is much smaller than the capacity of delivery vehicles. This issue increases the number of delivery vehicles required for delivery, which provides many challenges to all stakeholders involved in this process, especially carriers. To decrease the number of vehicles and transportations required, carriers mainly try to consolidate goods in different stages of the supply chain. However, the final transportation of goods in the supply chain—the LMD—needs to be conducted to carry and deliver a package or small number of goods to customer locations. This issue has made LMD one of the most expensive, inefficient and polluting stages of any supply chain (Brown and Guiffrida 2014; Ehmke and Mattfeld 2012; Gevaers et al. 2011). It is estimated that LMD is responsible for 13% to 75% of the total logistics cost and 16% to 50% of the pollution emissions generated by transport activities within cities (Battaia et al. 2014; Gevaers 2013). According to Suksri et al. (2012), the key characteristics of the LMD phenomenon are as follows: a wide variety of goods, transported over relatively short distances in a congested urban setting, with a small shipment size and high frequency of delivery. These characteristics and the complex situation of city logistics render LMD a complicated issue in a supply chain.

### 2.1.1 Terminology, Definition and Scope of Last Mile Delivery

Various studies, initiatives and practices have been raised to improve the efficiency and effectiveness of LMD. Despite these attempts, the basic understanding of LMD still remains unclear. Studies have offered different perceptions, scopes and definitions of the LMD phenomenon. One of the earliest studies on LMD was undertaken by Chopra (2003), who considered LMD a type of distribution network. In his classification, LMD referred to delivering a product to the customer's home by the distributor or retailer, instead of using a package carrier. Besides LMD, Chopra (2003) also suggested five other distribution networks for the movement of goods from the manufacturer to the end consumer. In contrast, Minguela-Rata and De Leeuw (2013) and Edwards et al. (2010) considered LMD a part of a distribution network and defined it as the last link of goods movement to consumers. These are two different perceptions of LMD.

Reviewing the literature indicates that the scope and definition of LMD is unclear. For example, Gevaers (2013) limited LMD to business-to-consumer (B2C) processes, while other studies included wider commercial transactions for LMD, such as business-to-business (B2B) and consumer-to-consumer (C2C). Examples include Tipagornwong and Figliozzi (2014), who defined LMD in the contexts of B2B and B2C, and Allen et al. (2007), who considered B2B and C2C for the LMD context. Moreover, some studies limited their LMD definitions to a specific type of products or business. For example, Xu et al. (2008) and Allen et al. (2007) limited the LMD definition to the e-commerce business, while Gevaers (2013) limited LMD to parcel deliveries. Almost all definitions concurred with the view that the LMD phenomenon is the last stage of the supply chain or delivery process, yet did not mention a common starting or finishing place for this process. Edwards et al. (2010) considered a local depot the starting point for LMD, while Wu et al. (2015) believed the starting point was a port or a consolidation centre, and Tipagornwong and Figliozzi (2014) applied a warehouse or a DC as the starting point of LMD. Although many of the definitions indicated the consumer's location as the finishing point for LMD, some definitions—such as those by Tipagornwong and Figliozzi (2014) and Gevaers (2013)—included other locations, such as final stores and collection centres.

Reviewing the literature indicated that previous studies have not used common terminology to address the LMD phenomenon. For example, Tipagornwong and Figliozzi (2014), Schliwa et al. (2015) and Allen et al. (2007) addressed LMD as the 'last mile supply chain', 'last mile logistics' and 'last mile solutions', respectively. Other studies, such as the research by Suksri et al. (2012), also referred to the 'last kilometre', rather than the 'last mile', in their studies. The use of different phrases for the same phenomenon and lack of agreement on definition and scope render LMD ambiguous and cause problems for communications among different stakeholders in this context. Based on this background, this study conducts a systematic literature review to collect, explore and analyse the extant literature to understand how the LMD phenomenon is addressed, named and defined by the literature. This study aims to demystify the LMD phenomenon and redefine LMD and its scope and structure.

### 2.1.2 Components of Last Mile Delivery

There have been limited studies to identify and classify LMD components. In one of the limited examples, Gevaers (2013) categorised the cost drivers of LMD into five characteristics, which were classified into various sub-characteristics:

1. consumer service, which has four sub-characteristics: time window, lead-time, frequency and return
2. security and delivery type, which is divided into four sub-groups: home delivery with and without a signature collection point and delivery boxes
3. geographical area and market density, which has two subcategories: density and pooling of goods

4. fleet and technology, which is divided into the type of delivery vehicle, information and communication, and technology/informatics sections
5. the environment, which has two categories: packaging and trade-off between time factors and environmental effects.

Studies in other disciplines mainly use an ontology approach to classify a concept. Although to date there has been no explicit contribution to LMD ontology in the literature, ontology is not new in the domain of logistics and supply chain management, which have a close relationship with LMD. Anand et al. (2012) proposed an ontology for city logistics, which is the closest ontology to the LMD context. They examined deliveries from end depots and retail premises to urban premises/homes by delivery vehicles, and these vehicles' return trips, alongside auxiliary logistics activities that influence city logistics performance. They focused on the macro parts of logistics in cities. Accordingly, they did not include operational aspects of logistics, such as the type of goods and retail premises, and some LMD aspects, such as pickup modes. In another study, Lian et al. (2007) proposed an ontology on logistics based on the situation of products and corresponding events. These events and situations were based on logistics processes and the transition of products. Leukel and Kirn (2008) employed the supply chain operation reference (SCOR) model to introduce a logistic ontology. Although their ontology modelled some logistics processes, such as packing and delivering, it had a relatively poor representativeness of goods transition and modifications of goods (e.g., place and time) in the logistics domain. However, all these previous efforts provide a good basis for building ontology in micro or macro logistics. LMD has both internal effects (such as cost) and external effects (such as pollution); thus, both micro and macro perspectives of logistics should be considered when building LMD ontology. This study introduces an LMD ontology that considers both the micro and macro perspectives of logistics. The proposed LMD ontology and related ontological analysis are presented in Section 4.3.

### 2.1.3 Problems and Solutions of Last Mile Delivery in the Real World

A wide range of initiatives have been applied in different cities around the world to improve LMD processes and decrease its negative aspects. The initiatives mainly target coping with some specific LMD difficulties, such as parking problems, environmental pollution, congestion and low cost performance. The parking problem has been addressed by certain initiatives. Delivery vehicle drivers have difficulty finding a space to park their vehicles for delivery purposes, especially in CBDs and downtown areas. To cope with this problem, as a practical example, Emporium Melbourne shopping centre has provided a booking facility for drivers who wish to deliver goods to the retailer stores in this shopping centre. Drivers can book a loading/unloading space for a specific time which allows them to be sure to have a parking space for both loading and unloading deliveries. Emporium receives 100 deliveries per day on average and, as a result of this initiative, delivery vehicles do not need to stay in the front of loading docks and block the street or drive around the CBD until they can find a space for loading and unloading (The City of Melbourne 2015).

Using bicycles or tricycles to conduct LMD is another solution that some companies have used to avoid generating environmental pollution during LMD processes. Cargone Couriers is a transport company in Melbourne that uses cargo bicycles to deliver goods around Melbourne CBD (The City of Melbourne 2015). This solution is not only a type of environmentally friendly transportation system, but also reduces parking difficulties in inner cities. Delivery people do not encounter difficulty finding parking places for loading and unloading of goods. Another solution applied in some cities, such as New York, London and Barcelona, is to limit the time of delivery to off-hours. Goods can be delivered during the evening or early in the morning, when there is less traffic in urban areas (The City of Melbourne 2015). This solution seeks to reduce traffic congestion and greenhouse gas emotions. Although this solution has positive effects on congestion, it increases the cost of delivery, as wages are generally higher during off-hours.

Some initiatives are related to operation and delivery processes, and seek to improve the performance of delivery processes. Delivery boxes (reception boxes) and collection centres (manned centre or parcel lockers) are two initiatives used to decrease the cost of delivery. Delivery boxes provide opportunities for carriers to decrease travelling distances and the number of delivery vehicles, which ultimately reduces the cost. Delivery boxes can be fixed and installed at customers' locations or can be portable and delivered and collected by the carrier (retailers). The receivers do not need to be available at the time of delivery for this mode of delivery. Consequently, carriers have more flexibility in the time of delivery, with a wider time window. For example, SOK is a Finnish retailing cooperative organisation that offers delivery boxes for its customers (Kämäräinen and Punakivi 2002). A collection centre that can be manned or unmanned is another initiative to facilitate delivery operations. In this initiative, receivers must visit a location near their home, such as a petrol station, to collect their own package. The package can be collected from a facility, such as a locker, or can be handed over by staff. This initiative can be used for both delivering and sending (collecting) goods. The Australia Post parcel lockers, Amazon lockers and TNT mobile depots are some examples of this initiative.

The different modes of delivery have their own advantages and disadvantages. Kämäräinen et al. (2001) compared four different modes of delivery: delivery at home (attended delivery), delivery using a delivery box (unattended delivery), pickup from a store and pickup from a collection centre or shared reception box. The results of their study indicated that unattended delivery using a delivery box has lower costs than the other options. This mode of delivery offers a wide delivery window, which can reduce the cost of delivery. They claimed that this mode can decrease the travelling distance by 50% compared with attended delivery. In a similar study, Al-nawayseh et al. (2013) compared three types of delivery points: delivery at home (attended delivery), pickup from a collection centre and pickup from a store. They used real data and considered distance, time and cost indicators to evaluate the LMD models. They found that pickup from a store was the best solution for online grocery retailers, among these three options. The results of their study support the previous study in that minimising delivery time will affect the cost.

Some initiatives are not limited to one individual company and involve a number of companies and stakeholders. An urban consolidation centre (UCC) is an initiative that requires the involvement of a wide range of companies, especially logistics service providers. This initiative has been used to tackle LMD problems in many cities around the world. UCCs often tend to have multiple objectives; however, the most common aims are reducing congestion, traffic disruption and vehicle emissions in urban areas. A UCC is a logistics facility for the first and last transportation of supply chains, which facilitates distribution and collection of goods in urban areas. UCCs split the goods transportation system in cities in two parts—inside the city and outside the city (Quak 2008). UCCs are known by various names, such as a public distribution depot, central goods sorting point, urban transhipment centre, shared-user urban transhipment depot, freight platform, cooperative delivery system, urban DC, city logistics scheme, logistics centre, pick-up drop-off location, offsite logistics support concept and freight village (Allen et al. 2007). Despite these different names, the following logistics activities can operate in a UCC: loading and unloading, cross-docking, consolidation, pre-retailing, warehousing, break bulk, transhipment from larger to smaller vehicles, goods return and waste collection services, and home delivery (Allen et al. 2007; Foltyński 2014; Scott Wilson Ltd 2010).

A UCC in Monaco presents a successful consolidation centre initiative. Quak (2008) distinguished that the provision of large subsidies from the government, strict regulation of trucks and characteristics of the city are the main reasons for this UCC's success. Despite the positive effects of UCC, many UCCs have not been successful and have closed within a few years (Quak 2008). The UCC in Leiden is an example of an unsuccessful UCC project. The UCC opened in 1997 and closed in 2002. Parcel delivery companies decided not to join the UCC, essentially because they were unwilling to collaborate with their competitors (Van Rooijen and Quak 2010). According to Schoemaker (2002), the main failure factors were the location of the UCC, lack of supportive policy, low traffic speed because of electric vehicles, low financial feasibility due to lack of volume of delivery. Van Rooijen and Quak (2010) investigated the results of establishing a new UCC in the Dutch city of Nijmegen, and concluded that the UCC had positive local effects on air pollution and noise because of fewer trucks entering the city centre and fewer kilometres being driven. The Nijmegen UCC focused on receivers, rather than carriers, and this concept increased the number of stores involved in the system, which resulted in an increasing volume of delivery.

As discussed thus far in this section, various LMD initiatives have been suggested and implemented in different cities around the world. Suksri et al. (2012) investigated the existing urban good movement initiatives and categorised them into five categories: operation, land use and infrastructure, environment, regulation and transportation. Generally, initiatives can be divided into two groups: initiatives that improve the current situation and initiatives that change the current situation. Quak (2008) investigated 106 initiatives in urban goods movement and classified the initiatives into 12 types that directly and indirectly affect the LMD processes. The types of initiatives that seek to improve the current situation include road pricing, licensing and regulation, parking and unloading, carrier cooperation, vehicle routing improvement and technological vehicle innovation. The types of initiatives that seek to change the current situation include consolidation centres, underground logistics systems, road infrastructure development, standardisation of load-units, transport auction and intermodal transport. Initiatives can be raised by public sectors, such as government authorities, and private sectors, such as logistics service providers. Holguin-Veras et al. (2015) investigated 54 initiatives related to public sectors and classified them into eight major groups as follows: infrastructure management; parking/loading area management; vehicle-related strategies; traffic management; pricing, incentives and taxation; logistical management; freight demand/land use management and stakeholder engagement.

Each initiative may involve one stakeholder or more than one specific stakeholder. Some initiatives, such as using delivery boxes, can be raised and conducted by one single company, yet other initiatives, such as UCCs, require the involvement and cooperation of various companies or stakeholders. However, there are limited LMD initiatives that require collaboration between different stakeholders. In this study, we introduce a new initiative that involves collaboration between competitors, including different third-party logistics (3PL) service providers and different retailers. In our proposed initiative, retailers and 3PLs share their empty running vehicles and DCs to improve delivery performance.

### 2.1.4 Structure of Last Mile Delivery

The LMD process can potentially be conducted by various structures. Reviewing the LMD literature indicates that limited research has been conducted thus far to describe the possible structure and distribution models of the LMD phenomenon. In one of the earliest studies, Chopra (2003) described a framework for designing the distribution network in a supply chain. He considered delivery mode and product flow as the two main decisions for designing a distribution network. According to his study, the decision maker should decide where consignments should be delivered to customers—to the customer location or to a pickup point. Moreover, decision makers have two choices for product flow—direct delivery or delivering via an intermediate location. Based on the choices for these two decisions, Chopra (2003) distinguished six distinct distribution networks for goods movement from the manufacturer to the end consumer:

- manufacturer storage with direct shipping
- manufacturer storage with direct shipping and in-transit merge
- distributor storage with package carrier delivery
- distributor storage with LMD
- manufacturer/distributor storage with customer pickup

- retail storage with customer pickup.

Chopra (2003) considered three owners for storage in a supply chain: manufacturer, distributor and retailer. The manufacturer/distributor/retailer warehouses indicate the start point of the product journey, which finishes at the customer location or a pickup point.

To extend the distribution model in a supply chain, Boyer et al. (2004) distinguished two key decisions: order preparation and delivery mode. They described that order preparation and collecting customer orders can occur in existing stores or in a centralised DC/warehouse. As with Chopra (2003), they considered delivery mode the key factor for designing a distribution model and described that decision makers should decide whether to deliver consignments to a customer's location or a pickup point. Based on the choices for these two decisions, decision makers have four strategies: semi-extended, fully extended, decoupled and centralised extended (see Figure 2.1). They described how these four strategies differ in four critical factors: customer convenience, delivery cost, collection efficiency and capital investment. They provided an overview of the advantages and disadvantages of these strategies to help decision makers select the best model for their LMD.

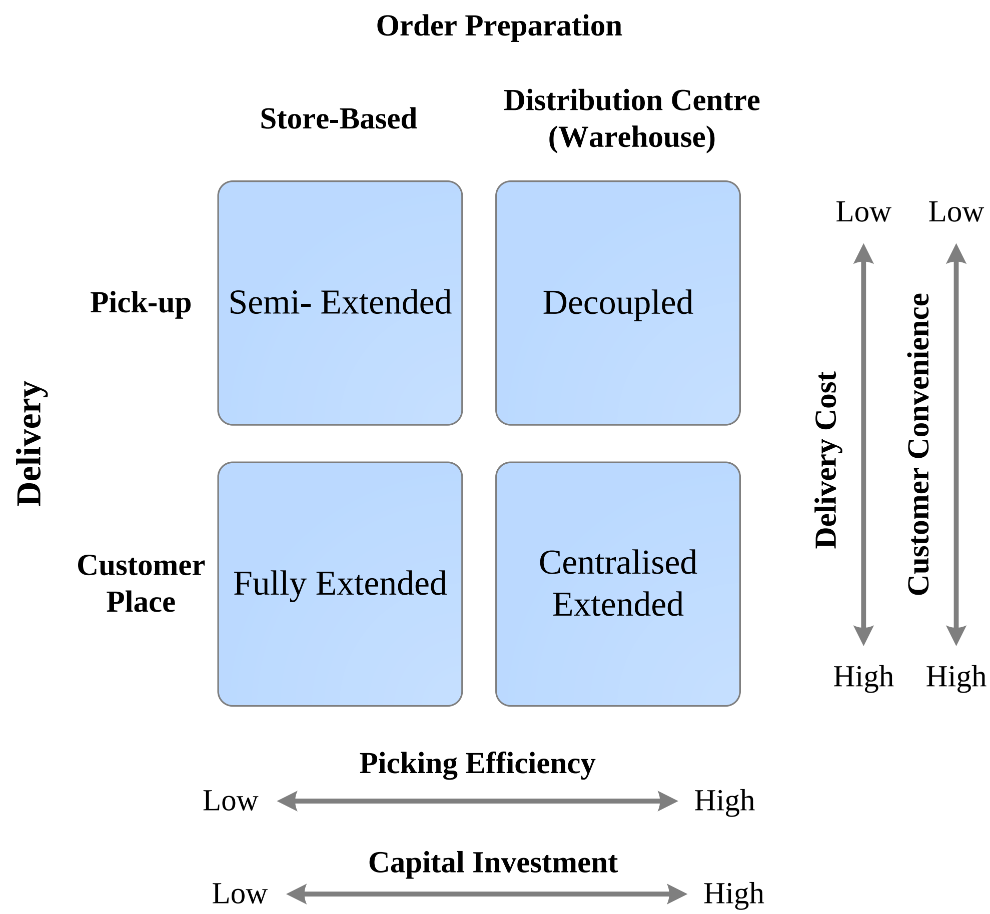



Figure 2.1: Different Stages of LMD (Boyer et al. 2004)

Gevaers (2013) summarised LMD options in the context of B2C, as illustrated in Figure 2.2. He classified LMD options based on four main factors: starting point, place of delivery, type of delivery and specific. According to Gevaers, the LMD process starts at a warehouse or collection location, such as a delivery hub, and consignments are delivered to the customer's home or collected from a specific warehouse/store or at a cluster point. Attended and unattended are the two types of home delivery, while reception box, collection point and post office are the three main types of cluster point. He also explained some specific aspects of each type of delivery. As with Boyer et al. (2004) and Chopra

(2003), this model considers delivery mode, but with more detail regarding reception options. Similar to Chopra, Gevaers (2013) did not emphasise order preparation.

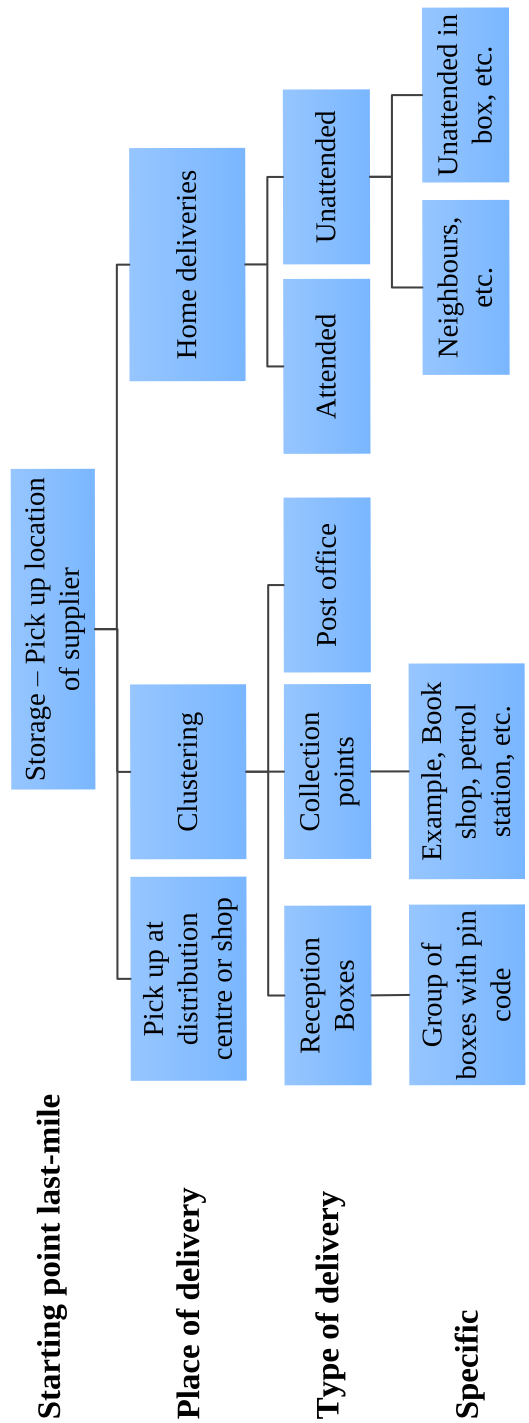



Figure 2.2: Delivery Methods in LMD (Gevaers 2013)

Jin and Srai (2015) investigated Chopra's (2003), Boyer et al.'s (2004) and Gevaers's (2013) studies and developed a typology for LMD from two typological building blocks: typological character and character state. They used a SCOR model to provide a candidate list for LMD typological characters. Based on the SCOR model, the source, make and delivery of information and goods flows were considered and all possible situations were tested. As a result, 46 different types of LMD were presented. Although this framework presented 46 different cases in LMD, there was no classification of positions and items. They classified LMD in an innovative manner using existing LMD structure in real cases and data from interviews. Although they sought to consider all classifications and eliminate duplicate cases, this classification did not cover all possible LMD structures.

Aized and Srai (2013) provided a conceptual planning approach to model an LMD system. They suggested using hierarchical modelling using the Petri net method. Their model included institutional, industrial and consumer layers that were connected through a hierarchical relationship. The model was practically suitable for routing planning of LMD in a geographical location. However, all the previous studies have failed to consider all potential forms of LMD structure. In this study, we define clear decision factors in LMD, which introduce more possible structures of LMD. Moreover, the previous studies focused on the structure of one distribution network, while, in this study, we focus on combining two or more distribution networks and introduce an LMD model with a coopetition strategy that contributes better delivery performance.

### 2.1.5 Stakeholders

Various stakeholders with different roles and interests are involved in LMD processes. Traditionally, stakeholders are divided into three groups based on their roles in the goods movement system: forwarders, carriers and receivers (Ogden 1992). Forwarders, carriers and receivers refer to the parties who respectively dispatch, transport and receive the consignments. Forwarders and receivers can be a business, consumer (Taniguchi et al. 2003) or representative of each of them. Retailers and suppliers are, respectively, examples of business receivers and business forwarders. A consumer or business can choose a representative to undertake their role in LMD processes. For example, a neighbour may receive a consumer's consignment, or a 3PL company may dispatch consignments from the last dispatch point on behalf of a business or consumer. Most authors consider these three stakeholders based on these classifications, yet may designate them different titles. For example, Anand et al. (2012) used the term 'shippers' instead of 'forwarders', Lindholm (2014) used 'consignors' instead of 'forwarders' and Suksri et al. (2012) used 'transport operators' instead of 'carriers'. The roles of these stakeholders are the main concerns for categorising the stakeholders, and these roles are related to their main operational activities, including dispatching, transporting and receiving. Although the roles are the main concern for categorising stakeholders in LMD, some authors do not follow this rule. For example, Anand et al. (2012) used the term 'retailers', instead of 'receivers', even though the retailer is just an example of a business receiver.

LMD is not limited to stakeholders who are dispatching, transporting and receiving—there are further stakeholders who have other roles in LMD processes. Developing regulations, procedures and restrictions are the roles of some stakeholders that affect LMD performance. The local government may introduce restricted entry of trucks into the city centre, tolls for car entrance to the city centre or restrictions on parking that affect LMD performance. This group of stakeholders is referred to by different titles. For example, they were called ‘administrators’ by Anand et al. (2012) and ‘decision makers’ by Stathopoulos et al. (2012).

Some stakeholders are not involved in LMD processes directly, but their behaviour will affect LMD process and they are also affected by the LMD process. Quak (2008) called this group ‘impactees’ and included residents, public shoppers and city visitors. This group may be affected by the negative aspects of LMD processes, such as congestion, noise and pollution, and their behaviour in travelling and purchasing will affect LMD performance. Ballantyne and Lindholm (2012) indicated more indirect stakeholders in LMD, including the drivers of the vehicles, vehicle manufacturers, trade associations, commercial organisations, landowners/property owners and public transport operators.

In conclusion, the direct stakeholders of LMD can be divided into five main groups: forwarders, carriers, receivers, developers and impactees. These five groups cover almost all roles of direct stakeholders in LMD. These groups have been referred to with different titles. For example, Quak (2008) included forwarders, carriers and receivers in one class, which he called ‘professional’. He distinguished three main stakeholders—governments, professionals and impactees—which covered all five main stakeholders. Suksri et al. (2012) divided stockholders into four major groups: residents, retailers/receivers, transport operators and government authorities. They referred to residents as impactees, transport operators as carriers and government authorities as developers. Suksri et al. even used an example of impactees—residents—to name a group of stakeholders.

Each stakeholder has their own interests. The main concerns of forwarders and receivers are generally costs, times of collection or delivery, the reliability of service and tracking information (Taniguchi et al. 2003). The cost of LMD is estimated to comprise between 13% and 75% of the total logistics cost (Gevaers 2013). Thus, reducing the cost of LMD has been an area of interest for the private sectors, those are running their businesses and forwarding and receiving goods. Cost refers to the price of delivery service for consumers (receivers), who tend to pay less for higher service quality. Dispatching or receiving goods within a specified time has become popular these days. Although picking up and delivering in a shorter time window is a tendency of forwarders and receivers, it increases the cost of LMD; thus, they must trade-off between their conflicting interests. Forwarders and receivers tend to have a reliable LMD service, which involves delivery without delay, trouble or damage (Taniguchi et al. 2003).

Cost is also the main concern for carriers. Carriers mainly try to minimise the cost of collecting and delivering goods to maximise their profits (Macário et al. 2008; Taniguchi et al. 2003). They need to provide a reliable service for customers with lower cost. They seek to deliver consignments within a designated period, yet often face difficulty in urban areas because of congestion and limited parking areas. Carriers expect adequate infrastructure for transport operations, which is the responsibility of public sectors involved in LMD, such as government authorities. Although carriers like to use large trucks to reduce their LMD cost, impactees do not like these types of vehicle because of noise, pollution and visual barriers. Impactees prefer minimum traffic congestion, noise, pollution and quiet and safe conditions on roads (Taniguchi et al. 2003). They wish to have pleasant living surroundings and space for parking (Macário et al. 2008).

## 2.2 Mathematical Models of Last Mile Delivery

To justify the new LMD initiatives and encourage decision makers to use them, it is necessary to quantify the consequences of these initiatives. Mathematical modelling in the form of optimisation modelling and simulation has widely been used in LMD to quantify and evaluate new initiatives and improve the performance of LMD processes—especially scheduling processes. Focusing on the practical applications of models in realistic cases, Taniguchi et al. (2012) stated that optimisation and simulation are the main models for evaluating initiatives in urban goods movement. Optimisation models provide optimal or near-optimal solutions to complex decision-making problems. As a result of the complexity of activities, the different and sometimes conflicting interests of stakeholders, and the variety of criteria and constraints, optimisation models are useful to integrate all LMD parameters and constraints into mathematical models. Optimisation models typically include vehicle routing and scheduling, multi-objective systems and intelligent agents. The current study deals with vehicle routing and multi-objective optimisation models. We briefly discuss the different types of these models in the following subsections.

### 2.2.1 Vehicle Routing Problems

Among all optimisation and simulation models, the vehicle routing problem (VRP) is the main practical problem in LMD and represents the cornerstone for optimisation of LMD schemes. VRP is described as the problem of finding the optimal set of routes of a fleet that are running to deliver goods to customers. VRP can be used for the problem of designing delivery routes from one dispatch point to a set of delivery points (see Figure 2.3). Some orders are assigned to each vehicle to be serviced to a set of delivery points in a specific sequence. It is assumed that vehicles are required to return to the dispatch point after completing their assigned job. The assignment and sequencing tasks of a vehicle indicate the vehicle's tour. A set of tours of all vehicles is known as a tour plan, which is considered a solution for VRP. The generation of a tour plan is based on the aims, which mathematically is known as the objective function. The main goal of the VRP is to find the optimal solution (tour plan) that results in the best value for objective function. VRP is categorised as a non-deterministic polynomial time hard (NP-hard) combinational optimisation problem, which means that it is not usually possible to find the optimal solution in a reasonable time (Lenstra and Rinnooy Kan 1981). Therefore, the goal of VRP is mainly to find a solution that results in an objective function value that is as close as possible to the optimal solution.

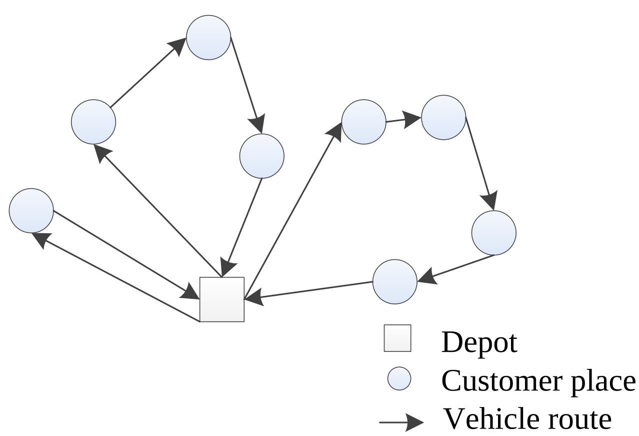



Figure 2.3: VRPs

The following variables, sets and parameters are defined in VRP:

*Variable*

$$x_{ij} = \begin{cases} 1 & \text{if and only if a vehicle travels directly from location } i \text{ to location } j \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ik} = \begin{cases} 1 & \text{if and only if vehicle } k \in K \text{ visits location } i \in V \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ijk} = \begin{cases} 1 & 1 \text{ if and only if vehicle } k \in K \text{ travels directly from } i \text{ to } j \\ 0 & \text{otherwise} \end{cases}$$

$$z_{ik} = \begin{cases} 1 & \text{if and only if vehicle } k \in K \text{ performs a pickup service at location } i \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ij}^{s} = \begin{cases} 1 & \text{if a second} - \text{level vehicle starting at satellite } s \text{ and going from } i \text{ to } j \\ 0 & \text{otherwise} \end{cases}$$

$$R_{ik} = \begin{cases} 1 & \text{if deliver to customer } j \text{ in consolidation with satellite } s \\ 0 & \text{otherwise} \end{cases}$$

*Sets*

*R: set of customers, {1, …, R}*

*V: set of nodes,* $R \cup \{0,R+1\}$

$V_S$ : set of satellites

K: set of vehicles

$L$ = set of linehaul customers

$B$ = set of backhaul customers

*Parameters*

$C_{ij}$: travel cost between nodes

$$\bar{C}_{ij} = \begin{cases} c_{ij} & if\ i \leq n\ and\ j \leq n \\ c_{i-n,j} & if\ i \geq n+1\ and\ j \leq n, j \neq i-n \\ c_{i,j-n} & if\ i \leq n\ , j \geq n+1, \quad i \neq j-1 \\ c_{i-n,j-n} & if\ i \geq n+1\ , j \geq n+1 \\ 0 & if\ j = i-n\ or\ i = j-n \end{cases}$$

*C: capacity of vehicle*

$Q_k$: capacity of vehicle *k*

$d_{ij}$: distance between *i* and *j*

$d_i$: delivery demand at *i*

$[a_i , b_i]$: A time window in location *i*

$w_{ik}$: the service starting time at customer *i* by vehicle *k*

*E:* the earliest possible departure time from the depot

*L:* the latest possible arrival time to the depot

$S_i$: the service time at *i*

$S_{ik}$: service time for *k* at *i*

$t_{ij}$: travel time between *i* and *j*

$t_{ijk}$: travel time between *i* and *j* for vehicle *k*

$T_k$: maximum route time for vehicle *k*

$u_{ik}$: upper bound on the total pickup demand accumulated in vehicle *k* on leaving *i*

$v_{ik}$: upper bound on the total delivery demand remaining in vehicle *k* on leaving *i*

$q_{ij}$: distance between *i* and *j*

$p_i$: pickup requests at *i*

*D*: maximum distance of a tour.

$D_s$: consignments passing through satellite *s*

$M_s$: cost of loading and unloading each consignment at satellite *s*

In the VRP, $R = \{1, \ldots, R\}$ defines the set of $R$ customer requests; $V = R \cup \{0, R+1\}$ represents a set of nodes that includes customer requests and the depot, denoted by node 0 at the start of tours and node $R + 1$ at the end of tours; and $K = \{1, \ldots, K\}$ defines the set of $K$ vehicles. $C_{ij}$ with $i, j \in V$ represents the travel cost between nodes. In the VRP, the solution consists of a tour plan represented by a set of binary variables, $X = \{x_{ij}\}$ $(i,j \in V, i \neq j)$, and equals 1 if and only if a vehicle travels directly from location $i$ to location $j$. The VRP is defined by the following mathematical model, proposed by Ferrucci (2013):

$$\text{Min z} = \sum_{i \epsilon V} \sum_{j \epsilon V} C_{ij} \, . \, x_{ij} \qquad \text{Equation 2.1}$$

Subject to:

$$(1) \; \forall \, i \in \text{R:} \sum_{j \in \{V \setminus i\}} x_{ij} = 1 \qquad \text{Equation 2.2}$$

$$(2) \; \forall \, i \in \text{R:} \sum_{i \in \{V \setminus j\}} x_{ij} = 1 \qquad \text{Equation 2.3}$$

$$(3) \; \sum_{i \in R} x_{0i} = k \qquad \text{Equation 2.4}$$

$$(4) \; \sum_{i \in R} x_{0i} = k \qquad \text{Equation 2.5}$$

$$(5) \; \forall \, \text{S} \subset \text{R}, 2 \leq |\text{S}| \leq \text{R} - 2 : \sum_{i \epsilon S} \sum_{j \epsilon \{V \setminus S\}} x_{ij} \geq 1 \qquad \text{Equation 2.6}$$

Equation 2.1 presents the objective function, which aims to minimise the total travelling cost. Constraints 1 and 2 ensure that each customer request is served exactly once.

Constraints 3 and 4 limit the vehicles to leaving and returning to the depot exactly once. Constraint 5 prevents sub-tours in the vehicle tours.

2.2.1.1 Vehicle Routing Problem Variants

Several variants of VRP exist to cope with different problem assumptions. In this section, we discuss the main variants and their most important formulations.

*Capacitated Vehicle Routing Problem (CVRP)*

In this type of VRP, vehicles are supposed to have limited capacity in carrying goods. CVRP is like un-capacitated VRP; however, in CVRP, each request $i \in R$ has a demand, $d_i$ and all vehicles have the same capacity ($C$). CVRP is formulated the same as VRP, except Constraint 5 (Equation 2.6) is replaced by Equation 2.7:

$$\forall \mathrm{S} \subset \mathrm{R}\,, 2 \leq |\mathrm{S}| \leq \mathrm{R} - 2 : \sum_{i \epsilon S} \sum_{j \epsilon \{V \setminus S\}} x_{ij} \geq r(S) \qquad \text{Equation 2.7}$$

The two-indexed formulation of VRP and CVRP has some drawbacks and does not allow modelling in more complex situations. For example, tour attributes—such as vehicle arrival times at the customer’s location—cannot be combined. A three-indexed formulation can be defined to overcome these problems (Toth and Vigo 2002). In this formulation, $X = \{x_{ijk}\}$ is a binary variable and equals 1 if and only if vehicle $k \in K$ travels directly from $i$ to $j$. Moreover, $Y = \{y_{ik}\}$ is defined as a binary variable that equals 1 if and only if vehicle $k \in K$ visits location $i \in V$. CVRP can be formulated as follows, as proposed by Toth and Vigo (2002):

$$\text{Min } z = \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} C_{ij} \, . \, x_{ijk}$$ Equation 2.8

Subject to:

$$(1) \ \forall \ i \in \text{R}: \sum_{k \in K} y_{ik} = 1$$ Equation 2.9

$$(2) \ \sum_{k \in K} y_{0k} = k$$ Equation 2.10

$$(3) \ \forall k \in K, i \in V: \sum_{j \in V} x_{ijk} = \sum_{j \in V} x_{jik} = y_{ik}$$ Equation 2.11

$$(4) \ \forall k \in K: \sum_{i \in V} d_i \, . \, y_{ik} \leq \text{C}$$ Equation 2.12

$$(5) \ \forall \ \text{S} \subseteq \text{R}, \text{h} \in \text{S}, \text{k} \in \text{K}: \sum_{i \in S} \sum_{j \notin S} x_{ijk} \geq y_{hk}$$ Equation 2.13

Equation 2.8 presents the objective function. Constraint 1 ensures that each customer request is serviced by one vehicle. Constraint 2 ensures that the depot is included in the vehicle tours. Constraint 3 ensures only one vehicle reaches and leaves a node. Constraint 4 limits the capacity of vehicles and Constraint 5 eliminates sub-tours.

*Vehicle Routing Problem with Time Window (VRPTW)*

In this type of VRP, a time window is assigned to each customer. A time window in location $i \in R$ can be defined as $[a_i , b_i]$, and means that deliveries/pickups must occur in specific time slots. Time windows are divided into two categories: hard time window and soft time window. In a hard time window, the vehicles cannot be at the customer location after the end of the time window. This can be shown by $\forall i \in R: w_{ik} \leq b_i$, where $w_{ik}$ is the service starting time at customer $i$ by vehicle $k$. The vehicle can be at the customer location before the time window and wait. In the case of a soft time window, the vehicle can be at the customer location after the end of the time window, but some additional penalties will be charged.

The following formulas show VRPTW in the case of a hard time window. In VRPTW, in addition to VRP and CVRP notations, $E$ is the earliest possible departure time from the depot, and $L$ is the latest possible arrival time to the depot. $S_i$ is the service time at $i$ and $t_{ij}$ is the travel time between $i$ and $j$:

$$\text{Min z} = \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} C_{ij} \,.\, x_{ijk} \qquad \text{Equation 2.14}$$

Subject to:

$$(1)\ \forall i \in R \sum_{j \in V} \sum_{k \in K} x_{ijk} = 1 \qquad \text{Equation 2.15}$$

$$(2)\ \forall k \in K \sum_{j \in V} x_{0jk} = 1 \qquad \text{Equation 2.16}$$

$$(3)\ \forall k \in K, h \in R: \quad \sum_{i \in V} x_{ihk} - \sum_{j \in V} x_{hjk} = 0 \qquad \text{Equation 2.17}$$

$$(4)\ \forall k \in K: \sum_{i \in V} x_{i,R+1,k} = 1 \qquad \text{Equation 2.18}$$

$$(5)\ \forall \text{ k} \in \text{K}, i \in V, j \in V: \quad x_{ijk}\left(w_{ik} + S_i + t_{ij} - w_{jk}\right) \leq 0 \qquad \text{Equation 2.19}$$

(6) $\forall$ k $\in$ K, $i \in V$:   $a_i \leq w_{ik} \leq b_i$   Equation 2.20

(7) $\forall$ k $\in$ K:   $E \leq w_{0k} \leq L$   Equation 2.21

(8) $\forall$ k $\in$ K :   $\sum_{i \in R} d_i \sum_{j \in V} x_{ijk} \leq C$   Equation 2.22

(9) $\forall$ k $\in$ K, $i \in V, j \in V$:   $x_{ijk} \in \{0,1\}$   Equation 2.23

Equation 2.14 presents the objective function. Constraint 1 limits the allocation of each customer to one vehicle route. Constraints 2, 3 and 4 determine the flow of each vehicle. Constraints 5 to 8 ensure schedule feasibility and the meeting of capacity limitations. Constraint 9 imposes binary conditions on the variables.

To increase customer satisfaction, companies try to offer shorter time windows for their delivery services. Having a short time slot for delivery increases customer satisfaction, yet also increases the cost of delivery. Thus, companies must trade-off between these two issues. Therefore, finding a suitable time window is a challenging issue in LMD. Agatz et al. (2010) investigated how time windows can be adjusted to minimise delivery cost. They presented two fully-automated approaches that generated optimal delivery time slots based on marketing and operational considerations.

*Vehicle Routing Problem with Backhauls (VRPB)*

This type of VRP deals with both delivery and pickup of goods at customer locations. Vehicles are required to deliver goods, which is known as linehauling, and are required to collect goods, which is known as backhauling. In VRPB, $L = \{1, \ldots, n\}$ defines the set of $n$ linehaul customers, and $B = \{1, \ldots, m\}$ defines the set of $m$ backhaul customers. $A = L$

$\cup B \cup \{0\}$ represents a set of nodes and includes linehaul and backhaul customer requests and the depot denoted by node *0*. $K = \{1, \ldots, K\}$ defines the set of $K$ vehicles and $Q_k$ denotes the capacity of vehicle $k$. $C_{ij}$ with $i, j \in A$ represents the travel cost between nodes. In VRPB, the solution consists of a tour plan represented by a set of binary variables, $X = \{x_{ijk}\}$ $(i,j \in A, i \neq j, k \in K)$, and equals 1 if and only if vehicle $k$ directly travels from location $i$ to location $j$. The VRP is defined by the following mathematical model, proposed by WA et al. (2012):

$$\text{Min } z = \sum_{i \in A} \sum_{j \in A} \sum_{k \in K} C_{ij} \,.\, x_{ijk}$$ Equation 2.24

Subject to:

$$(1)\ \forall i \in \{A \backslash 0\}, \qquad i \neq j, \sum_{j \in A} \sum_{k \in K} x_{ijk} = 1$$ Equation 2.25

$$(2)\ \forall j \in \{A \backslash 0\}, \qquad i \neq j, \sum_{i \in A} \sum_{k \in K} x_{ijk} = 1$$ Equation 2.26

$$(3) \sum_{j \in A} \sum_{k \in K} x_{0jk} = K$$ Equation 2.27

$$(4) \sum_{i \in A} \sum_{k \in K} x_{i0k} = K$$ Equation 2.28

$$(5)\ \forall\, \text{k} \in \text{K}: \quad \sum_{i \in L} \sum_{k \in K} d_i \,.\, x_{ijk} \leq Q_k$$ Equation 2.29

$$(6)\ \forall\, \text{k} \in \text{K}: \quad \sum_{i \in L} \sum_{k \in K} f_i \,.\, x_{ijk} \leq Q_k$$ Equation 2.30

(7) $\forall k \in K, j \in \{L \cup B\}$: $\sum_{i \in A} x_{ijk} - \sum_{h \in A} x_{jhk} = 0$ Equation 2.31

(8) $\forall k \in K, i \in A$: $\sum_{j \in A} x_{ijk} - \sum_{h \in A} x_{hik} = 0$ Equation 2.32

(9) $\forall S \subseteq \{2,3, \dots, n+m\}$: $\sum x_{ijk} \leq |S| - 1$ Equation 2.33

(10) $\sum_{i \in B} \sum_{j \in L} \sum_{k \in K} x_{ijk} = 0$ Equation 2.34

Equation 2.24 presents the objective function of VRPB. Constraints 1 and 2 limit the allocations of each customer to one vehicle route. Constraints 3 and 4 ensure that an equal number of vehicles leave and return the depot. Constraints 5 and 6 ensure the meeting of the vehicle capacity limitations in both linehaul and backhaul. Constraints 7 and 8 ensure route continuity. Constraint 9 prevents sub-tours in the vehicle tours. Finally, Constraint 10 ensures the precedence of linehaul to backhaul services.

*Vehicle Routing Problem with Simultaneous Pickup and Delivery (VRPSPD)*

This type of VRP is an extension of VRPB. In VRPB, all linehauling services are managed to be conducted before backhauling services, while, in VRPSDP, backhauling services can be conducted before linehauling services. In VRPSPD, we assume there are *n* customers, *i* represents the vertex *i* for delivery services, and *n* + *i*, which is related to pickup services. $\bar{C}_{ij}$ donates the cost between customers *i* and *j*, and is calculated as:

$$\bar{C}_{ij} = \begin{cases} c_{ij} & if\ i \leq n\ and\ j \leq n \\ c_{i-n,j} & if\ i \geq n+1\ and\ j \leq n, j \neq i-n \\ c_{i,j-n} & if\ i \leq n\ , j \geq n+1, \quad i \neq j-1 \\ c_{i-n,j-n} & if\ i \geq n+1\ , j \geq n+1 \\ 0 & if\ j = i-n\ or\ i = j-n \end{cases}$$

The following notations are considered for the formulation of VRPSPD:

- $u_{ik}$: upper bound on the total pickup demand accumulated in vehicle $k$ on leaving $i$
- $v_{ik}$: upper bound on the total delivery demand remaining in vehicle $k$ on leaving $i$
- $q_{ij}$: distance between $i$ and $j$
- $d_i$: delivery demand at $i$
- $p_i$: pickup requests at $i$
- $D$: maximum distance of a tour.

In VRPSPD, $K = \{1, \ldots, K\}$ defines the set of $K$ vehicles and $Q_k$ donates the capacity of vehicle $k$. The solution consists of a tour plan represented by a set of binary variables, $X = \{x_{ijk}\}$ $(i,j \in \{0,1,2\ldots,2n\}, i \neq j, k \in K)$, and equals 1 if and only if a vehicle directly travels from location $i$ to location $j$. Moreover, $Y = \{y_{ik}\}$ is defined as a binary variable that equals 1 if and only if vehicle $k \in K$ performs a delivery at location $i$. $Z = \{z_{ik}\}$ is also defined as a binary variable and equals 1 if and only if vehicle $k \in K$ performs a pickup service at location $i$. CVRSPD can be formulated as follows, as proposed by Hoff et al. (2009):

$$\text{Min } z = \sum_{i=0}^{2n} \sum_{j=0}^{2n} \sum_{k=1}^{K} \bar{C}_{ij} \, . \, x_{ijk} \qquad \text{Equation 2.35}$$

Subject to:

$$(1)\ \forall k \in K, \sum_{j=0}^{2n} x_{0jk} = 1 \qquad \text{Equation 2.36}$$

$$(2)\ \forall k \in K, \mathrm{i} \in \{0,1,\ldots,2n\} \quad \sum_{j=0}^{2n} x_{ijk} = \sum_{j=0}^{2n} x_{jik} \qquad \text{Equation 2.37}$$

(3) $\forall$ i $\in \{0,1,\ldots,2n\}$, $\sum_{j=0}^{2n}\sum_{k=1}^{K} x_{ijk} = 1$ Equation 2.38

(4) $\forall k \in K, \quad u_{0k} = 0$ Equation 2.39

(5) $\forall k \in K, \quad v_{0k} = \sum_{i=1}^{n} d_i\, y_{ik}$ Equation 2.40

(6) $\forall$ k $\in$ K, i $\in \{0,1,\ldots,2n\}$, $0 \leq u_{ik} + v_{ik} \leq Q_k$ Equation 2.41

(7) $\forall$ k $\in$ K, i $\in \{0,1,\ldots,2n\}$, j $\in \{1,\ldots,2n\}$ $u_{jk} \geq u_{ik} + p_j\, z_{jk} - (1 - x_{ijk})Q_k$

Equation 2.42

(8) $\forall$ k $\in$ K, i $\in \{0,1,\ldots,2n\}$, j $\in \{1,\ldots,2n\}$ $v_{jk} \geq v_{ik} + d_j\, y_{jk} - (1 - x_{ijk})Q_k$

Equation 2.43

(9) $\forall$ k $\in$ K, i $\in \{0,1,\ldots,2n\}$, j $\in \{1,\ldots,2n\}$ $x_{ijk} \leq y_{ik} + z_{ik}$ Equation 2.44

(10) $\forall$ k $\in$ K, i, j $\in \{0,1,\ldots,2n\}$ $x_{ijk} \in \{0,1\}$ Equation 2.45

(11) $\forall$ k $\in$ K, i $\in \{1,\ldots,n\}$ $y_{ik} \in \{0,1\}$ Equation 2.46

(12) $\forall$ k $\in$ K, i $\in \{n+1,\ldots,2n\}$ $z_{ik} \in \{0,1\}$ Equation 2.47

Equation 2.35 presents the objective function of VRPSPD. Constraint 1 limits $K$ vehicles from leaving the depot. Constraint 2 ensures that the same vehicle enters and leaves each customer. Constraint 3 limits the allocation of each customer to one vehicle route. Constraints 4 and 5 impose delivery and pickup service from the depot. Constraint 6 ensures the load of the vehicle does not exceed the vehicle capacity. Constraints 7 and 8 ensure that the upper limits of delivery and pickup are not exceeded in each customer location. Constraint 9 ensures that, if there is no delivery or pickup in a location, no vehicle is allocated to it. Constraints 10, 11 and 12 impose binary conditions on the variables.

*Multi-depot Vehicle Routing Problem (MDVRP)*

Goods can be dispatched from different depots in this type of VRP. Certain requests may be considered for delivering goods from a specific depot. In MDVRP, there are $m$ depots and $n$ nodes, which include depots and customer locations. $K = \{1, \ldots, K\}$ defines the set of $K$ vehicles and $p_k$ denotes the capacity of vehicle $k$. The solution consists of a tour plan represented by a set of binary variables, $X = \{x_{ijk}\}$ $(i,j \in \{1,2,\ldots m,\ldots,n\}, i \neq j, k \in K)$, and equals 1 if and only if vehicle $k$ directly travels from location $i$ to location $j$.

The following notations are considered for the formulation of MDVRP:

- $T_k$: maximum route time for vehicle $k$
- $d_i$: demand at $i$
- $S_{ik}$: service time for $k$ at $i$
- $t_{ijk}$: travel time between $i$ and $j$ for vehicle $k$
- $d_{ij}$: distance between $i$ and $j$
- $D$: maximum distance of a tour.

MDCVR can be formulated as follows, as proposed by Pathumnakul (1996):

$$\text{Min } z = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{K} d_{ij} \,.\, x_{ijk} \qquad \text{Equation 2.48}$$

Subject to:

$$(1)\ \forall j \in \{m+1, \dots, n\}, \sum_{i=1}^{n} \sum_{k=1}^{K} x_{ijk} = 1$$ Equation 2.49

$$(2)\ \forall i \in \{m+1, \dots, n\}, \sum_{j=1}^{n} \sum_{k=1}^{K} x_{ijk} = 1$$ Equation 2.50

$$(3)\ \forall\, k \in K, h \in \{1, \dots, n\}, \sum_{i=1}^{n} x_{ihk} - \sum_{j=1}^{n} x_{hjk} = 0$$ Equation 2.51

$$(4) \forall k \in K, \qquad \sum_{i=1}^{n} d_i \ \left(\sum_{j=1}^{n} x_{ijk}\right) \le Q_k$$ Equation 2.52

$$(5) \forall k \in K, \qquad \sum_{i=1}^{n} S_{ik} \sum_{j=1}^{n} x_{ijk} + \sum_{i=1}^{n} \sum_{j=1}^{n} t_{ijk} \,.\, x_{ijk} \le T_k$$ Equation 2.53

$$(6)\ \forall k \in K, \qquad \sum_{i=1}^{m} \sum_{j=m+1}^{n} x_{ijk} \le 1$$ Equation 2.54

$$(7)\ \forall k \in K, \qquad \sum_{i=m+1}^{n} \sum_{j=1}^{m} x_{ijk} \le 1$$

$$(8)\ \forall\ \mathrm{k} \in \mathrm{K}, \mathrm{i}, \mathrm{j} \in \{1, \dots, n\} \quad x_{ijk} \in \{0,1\}$$ Equation 2.55

Equation 2.48 presents the objective function of MDVRP, which minimises the total distance. Constraints 1 and 2 ensure each node is covered by only one vehicle. Constraint 3 imposes route continuity. Constraint 4 ensures the load of the vehicle does not exceed the vehicle capacity. Constraint 5 imposes time constraints. Constraints 6 and 7 ensure the number of available vehicles is not exceeded. Constraint 8 imposes a binary condition on the variable.

*Multi-echelon Vehicle Routing Problem*

Multi-echelon VRP is an extension of the classical VRP and deals with the situation in which goods are not directly carried between depots and customer locations, and need to pass through intermediates depots called ‘satellites’. This system has also been used in some transportation systems during the past decade. Some examples of multi-echelon distribution systems in different cities around the world include grocery and hypermarket product distribution, spare parts distribution in the automotive market, e-commerce and home delivery services, and newspapers and press distribution. Multi-echelon distribution systems have become more popular in large cities, where it is important to keep large vehicles out of the city centre and use small environmentally friendly vehicles to provide LMD or collecting services. In multi-echelon VRP, the overall transportation network is divided into more than one level, as follows:

- the level that connects the depots to the first-level satellites
- the level that connects two satellites
- the level that connects satellites to customer locations.

Each level has its own vehicles, and the goods are transferred from the previous level vehicles to the next level vehicles at satellites. Two-echelon VRP is the most common version of multi-echelon VRP, involving just two levels. At the first level, vehicles travel from a depot to a subset of satellites, and return to the origin depot. At the second level, vehicles travel from satellites to a subset of customers, and return to the origin satellites (see Figure 2.4). In the case of delivery, goods travel from depots to customers through intermediate satellites. In the case of pickup, goods travel in the opposite direction and are carried from customers to depots through intermediate satellites. Some networks also mix pickup and delivery tours to increase efficiency.

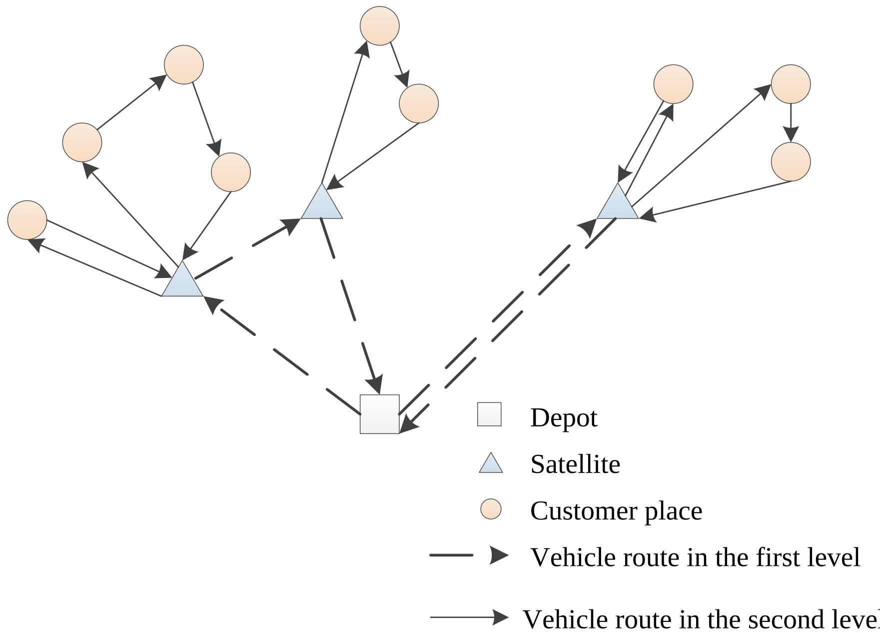



Figure 2.4: Two-echelon VRPs

In multi-echelon VRP, in addition to the travelling cost between two nodes in each echelon, the handling operation costs (including loading and unloading costs) in each satellite need to be taken in account in the objective function. The objective function for the two-echelon VRP can be defined as follows (Gonzalez-Feliu et al. 2008):

$$\text{Min } z = \sum_{i \in V_O \cup V_S} \sum_{j \in V_O \cup V_S} C_{ij} \cdot x_{ij} + \sum_{i \in V_O \cup V_C} \sum_{j \in V_O \cup V_C} \sum_{s \in V_S} C_{ij} \cdot y_{ij}^{s} + \sum_{k \in V_S} M_s \cdot D_s$$

Equation 2.56

In multi-echelon VRP, $V_O = \{V_O\}$ defines the set of depots, $V_S = \{V_{S1}, \ldots, V_{Sns}\}$ represents the set of satellites and $V_C = \{V_{C1}, \ldots, V_{Cnc}\}$ defines the set of customers. $C_{ij}$ represents the travel cost between nodes $i$ and $j$. In multi-echelon VRP, $x_{ij}$ is an integer variable representing the number of first-level vehicles using arc (*i*,*j*). $y_{ij}^{s}$ is a binary variable in the second-level echelon and equals 1 if a second-level vehicle follows a route starting at satellite *s* and going from node *i* to node *j*, and 0 otherwise. $M_s$ presents the cost of loading and unloading each consignment at satellite *s*. $D_s$ represents the consignments passing through each satellite *s*, and is calculated by Equation 2.57:

$$\forall \text{ s } \in \text{V}_S : \quad \text{D}_s = \sum_{j \in V_C} d_i \,.\, R_{sj} \qquad \text{Equation 2.57}$$

In Equation 2.57, $d_i$ represents the demand of customer *i* and $R_{sj}$ is a binary variable that equals 1 if the consignment is delivered to customer *j* in consolidation with satellite *s*.

Similar to VRP, multi-echelon VRP has different variants. In fact, the variants of VRP are also applicable for multi-echelon VRP, such as two-echelon capacitated VRP, two-echelon capacitated VRP with time windows, and two-echelon VRP with pickup and delivery.

#### 2.2.1.2 Objective Functions in Vehicle Routing Problems

Various objective functions can be considered for a VRP according to the considered application. Each objective function can also be combined with other objective functions. The following objectives are often used in VRPs.

*Minimising Travel-dependent Parameters*

Operative travel cost ($c_{ij}$), travel distance ($d_{ij}$) and travel time ($t_{ij}$) are some travel-dependent parameters that can be minimised in a VRP.

*Minimising Number of Used Vehicles*

The aim of this function is to minimise the number of vehicles used in a VRP. This function is mainly combined with other functions, such as travel distance and travel time.

*Minimising Sum of Tour Duration*

This objective function minimises the total time that all assigned vehicles take to conduct all required services. Scheduling aspects are considered when the time window is considered.

*Minimising Completion Time*

This objective function aims to minimise the time point at which the last vehicle in the operation finishes the job.

*Minimising Lateness Cost*

This function is applicable in the case of a soft time window, where lateness is allowed. The aim of this function is to minimise the penalty costs of lateness, which include both variable and fixed costs.

*Minimising Number of Un-serviced Customers*

This function is applicable in the case of a hard time window, where a late service is not allowed. To minimise the number of un-serviced customers, the operation aims to provide service for as many customers as possible within the time window.

*Minimising Customer Inconvenience and Request Response Time*

Using lateness cost, this function aims to minimise customer inconvenience. The maximum request response time for the services can be considered in the model to calculate and minimise lateness cost, which minimises customer inconvenience.

Moreover, service time is also used to evaluate customer inconvenience. Service time is often calculated based on travelling time. The waiting time for goods at dispatching points is not considered in service time calculation because of the assumption of VRP that all vehicles are dispatched from the depot at the same time. However, the waiting time must be considered in some cases, such as MDVRP, multi-echelon VRP and when using a collaboration strategy. Lead-time is more important when using a collaborative and multi-echelon model. Goods may wait longer to be collected at dispatch points in a collaborative model, compared with a non-collaborative model. In addition, waiting time in satellites needs to be considered in multi-echelon cases.

#### 2.2.1.3 Solution Methods for Vehicle Routing Problems

To solve VRP, various exact and heuristic solution methods have been developed, as discussed below.

*Exact Solution Methods*

Exact solution methods find an optimal solution for a VRP in a finite time. Branch-and-bound is a common class of exact solution methods in VRP. Some approaches—such as tree-search, branch-and-cut and branch-and-price—have also been developed to determine an optimal solution by examining fewer nodes and involving less computational effort.

*Heuristic Solution Methods*

Heuristic solution methods seek to find good solutions quickly. These methods generally provide approximate solutions when the classic solutions fail to provide exact solutions in reasonable time. Construction heuristics and improvement heuristics are two main approaches in heuristics solution methods. Construction heuristics generate tour plans, while improvement heuristics improve existing solutions. Simultaneous and successive are two approaches used in construction heuristics. In the simultaneous approach, the assignment and sequencing of requests are performed simultaneously, while, in the successive approach, assignment and sequencing are conducted consecutively. Improvement heuristics can be categorised into classic improvement heuristics and meta-heuristics. Classic improvement heuristics rely on the local optimum. An existing tour plan is improved until no better solution can be found in the neighbourhood in this approach. The meta-heuristics concept aims to overcome local optima to find a better solution in other areas with feasible solutions. A wide range of meta-heuristics have been developed. The most popular meta-heuristics in VRP include variable neighbourhood descent, simulated annealing, tabu search, greedy randomised adaptive search procedure (GRASP), ant colony optimisation, memetic algorithms and genetic algorithms (Ferrucci 2013).

#### 2.2.1.4 Application of Vehicle Routing Problems in Last Mile Delivery

A wide range of VRPs have been established and investigated, both in academia and the industry, to evaluate and predict LMD schemes (Souza et al. 2014). For example, an initiative implemented in some cities, such as London, states that, instead of delivery drivers needing to drive and find parking for each individual customer, customers can be clustered, and drivers can park the vehicle in one place for each cluster and deliver the goods to all customers in the cluster. Drivers can walk or use other types of delivery vehicles, such as bicycles, to complete the delivery process. To avoid increasing delivery time, this model suggests using more delivery people per vehicle. De Grancy (2015) investigated this idea and considered it as VRP with time windows and multiple service workers, and compared it with VRPTW. The study introduced a stochastic cluster to cluster the customers, and then used a route algorithm to find the optimum route. These two stages were linked by using ant colony optimisation meta-heuristics. The results of his investigation showed that the new initiative potentially mitigated both cost and environmental effects at the same time.

### 2.2.2 Multi-objective Optimisation

Optimisation seeks one or more solutions to optimise one or more specified objectives while satisfying all given constraints. If one objective is considered in the optimisation model, it is called single-objective optimisation. If there is more than one objective, it is known as multi-objective optimisation. In other words, in a multi-objective optimisation problem, two or more objectives need to be optimised simultaneously.

Two general approaches exist for multi-objective optimisation. In the first approach, individual objectives are combined into one objective, or objectives are moved to the constraints set, except one objective. A single objective can be made by using some methods, such as weighted sum method and utility theory. The problem with this approach is to find proper weights or utility functions. In the case of moving objectives to the constraints set, it is necessary to determine the value for each moved objective. This causes some problems because these values can be arbitrary. However, both cases present a single solution. The Pareto optimum approach is the second general approach. This approach presents a set of solutions that are non-dominated with respect to each other. A solution does not belong to a Pareto-optimal set—also known as a Pareto front or Pareto frontier—

when there is an alternative feasible solution that improves at least one criterion without reducing any other criteria.

#### 2.2.2.1 Multi-objective Optimisation Application in Last Mile Delivery

Single-objective optimisation has been widely used in the LMD context. Minimising cost, customer inconvenience and environmental effects are the most common objectives that have been separately addressed by the LMD mathematical models. The number of vehicles and travelling distance are generally used to calculate cost indicators (see, e.g., Chinh et al. 2016; Muñoz-Villamizar et al. 2015). Travelling distance, fuel consumption rate and emission factors are some parameters considered to calculate environmental effects (see, e.g., Zambuzi et al. 2016). Service time and time window have been mainly used to address customer satisfaction in LMD mathematical models (see, e.g., Lim et al. 2016). Cost, service time, environmental effects and social effects have been optimised separately in the presented LMD mathematical models. Some limited studies, such as the work by Handoko et al. (2016), have used multi-objective optimisation models to optimise more than one objective functions (indicators). Although cost and service time indicators have been investigated in many mathematical models, the extant literature has failed to introduce a mathematical model that optimises them simultaneously. As such, the current study uses multi-objective optimisation to evaluate LMD models and simultaneously optimise cost and service time (in the form of lead-time) indicators.

## 2.3 Coopetition: Collaboration with Competitors

Strategic collaboration between firms, especially between competitors, is now a ubiquitous phenomenon. Collaboration can occur when at least two parties share their efforts to reach a certain objective. Thomas (1992) defined collaboration as an attempt to fully satisfy the concerns of the parties involved in the exchange to achieve an integrative settlement. Hence, parties seek to achieve their own goals by considering a win–win approach. There are a variety of forms of collaboration within a supply chain, which can be grouped into two main categories: (i) vertical, which can include collaboration with customers, internally (across functions) and with suppliers, and (ii) horizontal, which can include collaboration with competitors, internally and with non-competitors (Barratt 2004) (see Figure 2.5). Horizontal collaboration is formed based on a specific type of relationship between companies. According to Bengtsson and Kock (1999), there are four types of horizontal relationship:

1. coexistence: a relationship without any economic exchange and dependent goals
2. cooperation: tight bonds with common goals
3. competition: an action–reaction pattern relationship with the same or comparable suppliers and groups of clients
4. coopetition: a relationship with stipulated joint goals during cooperation.

Coopetition—a simultaneous cooperation and competition relationship—is considered an appropriate strategy in a competitive environment. Research confirms that more than half of collaborations occur between companies working in the same industry—or competitors (Harbison and Pekar 1998). Competitors' goals and objectives can be incorporated in a win–win manner because, through this strategy, all parties involved are rewarded for their achievements and share limited resources to overcome challenges together (Deutsch et al. 2011). Several economic and strategic factors arise in coopetition relationships. Some factors that companies consider in coopetition relationships include reducing cost, risk and uncertainties regarding innovations; strengthening market position; transferring competitive advantages; and increasing flexibility (Luo 2007).

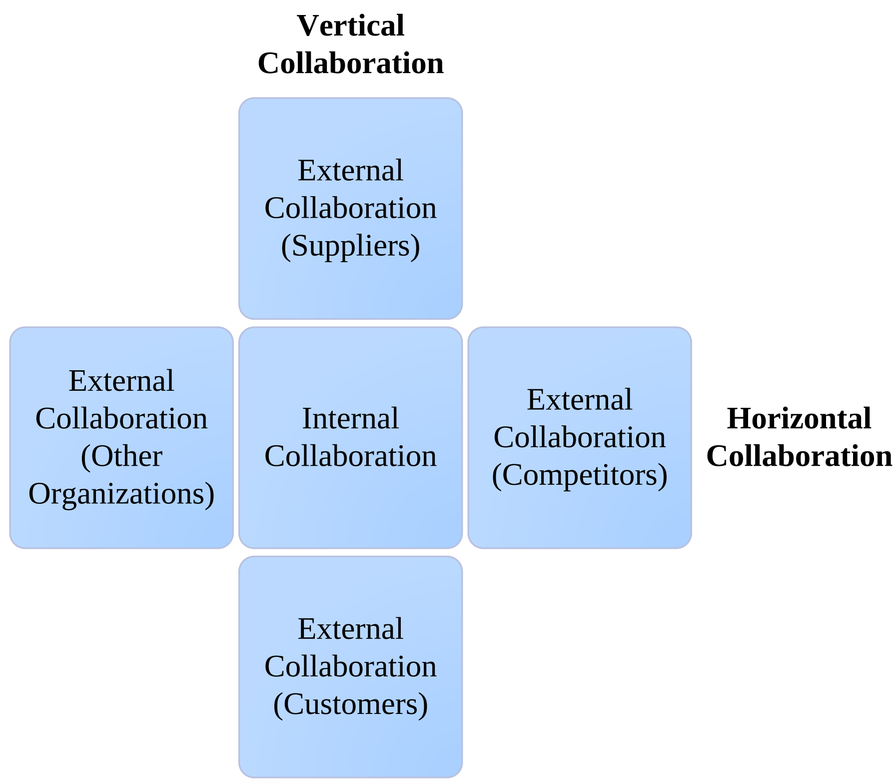



Figure 2.5: Forms of Collaboration (Barratt 2004)

Once a coopetition between companies is established, the cooperation and competitive elements may change over time. According to Luo (2007), the cooperation element in coopetition will increase when the competitive threats from other players outside the collaboration are increased. Companies also tend to have more cooperation when value chain integration, intuitional hazards and inter-organisational attachments are increased. On the other side, the competition element in coopetition will increase when the companies' competitive goals overlap, industry competition solidifies and/or resource interdependence between the companies decreases. Based on these factors, the intensity of cooperation and competition that occurs simultaneously can be explained by four situations: contending situation, isolating situation, partnering situation and adapting situation (see Figure 2.6). A contending situation refers to a situation in which competition is high and cooperation is low. To respond to this situation, companies may emphasise intelligence gathering, niche filling or position jockeying as strategic tactics. A contending situation is likely to occur in oligopoly markets (Malnight 2001). Under an isolating situation, companies compete and cooperate at a low level. Companies may follow domain specialisation, scale expansion and vertical integration as their strategic tactics. A partnering situation exists when companies strongly cooperate with others, and competition is low. Synergy extension, value sharing and attachment enhancement are the possible strategic tactics that companies can apply in a high cooperation and low competition situation. An adapting situation occurs when both competition and cooperation are at a high level. Boundary analysis, loose coupling and strategic balance are the strategic tactics that companies in this situation may consider.

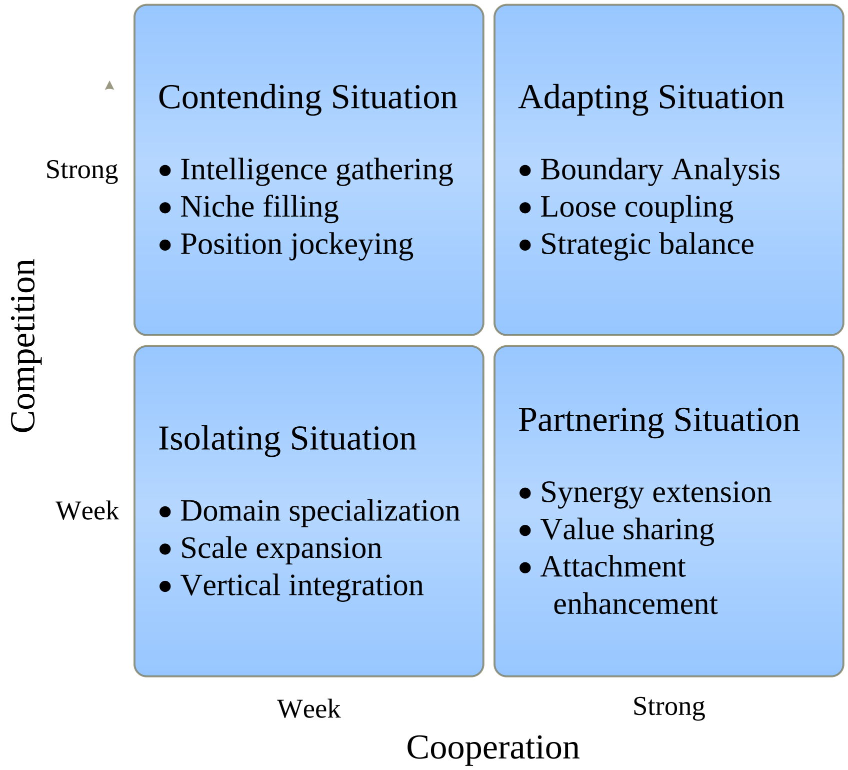



Figure 2.6: Intensity of Coopetition (Luo 2007)

Horizontal collaboration in a coopetition relationship has become increasingly popular in recent years, especially among logistics service providers. Logistics service providers seek to overcome the negative effects of LMD via joint goals, such as improving service quality and reducing cost and environmental effects. Gonzalez-Feliu and Salanova (2012, p. 175) discussed different material and immaterial resources shared among transport companies during a collaboration. These resources can be of varying nature, and may include logistics facilities, vehicles, planning and optimisation methods, logistics and transportation information. The literature theoretically proves the quantitative benefits of collaboration in LMD. Krajewska et al. (2008) showed that collaboration between two carriers yields a 10% reduction in the number of vehicles and almost a 13% reduction in routing costs. The collaborative LMD model that Muñoz-Villamizar et al. (2015)

presented offered more cost reduction (25%) and generated a 10% improvement in vehicle use.

### 2.3.1 Barriers and Success Factors of Coopetition

Although it has been theoretically proven that collaboration in LMD is a successful strategy, there are major barriers to it succeeding in practice (Quak 2008). Low rate of willingness to collaborate with a competitor is one of the major barriers to successful LMD collaboration (Quak 2008). Lindawati et al. (2014) investigated the factors that influence stakeholders' decisions to participate in LMD collaboration initiatives. They focused on the outcomes of the initiatives and examined the factors that motivate and hinder stakeholders with regard to participating in LMD collaboration initiatives, and found that the expected benefits (motivation) and competitive intelligence risks (barrier) influence the participation decision. Quak (2008) distinguished more potential success factors that should be implemented to enable collaborative initiatives, as follows:

- ensure that the companies do not lose their identity
- include the total social costs
- attain financial support from the public sector
- include all relevant parties in the initiative
- make all gains clearly visible
- appeal to the carrier's environmental and social reputation.

Irrespective of the barriers, there are some successful examples of collaborative schemes in the LMD context. One of the earliest successful collaborations among competitors occurred between Dutch sweets manufacturers. In 1993, eight competing

Dutch sweets producers agreed to share their DCs to increase the efficiency of their delivery processes. This horizontal collaboration agreement—called Zoetwaren Distributie Nederland (ZDN)—has proven successful and still exists. The companies supply a total of 250 DCs, and a hired logistics service provider consolidates and delivers the goods of all eight companies to their customers. Reducing transportation costs and improving customer service were the main results of this collaboration (Cruijssen et al. 2007). Irrespective of the successful and unsuccessful collaborative cases, horizontal collaboration in city logistics—specifically in LMD—is still at an early stage (Krajewska et al. 2008). Only a few models and initiatives of horizontal collaboration have been developed in the LMD context. Most of these models are seeking to reduce the cost of LMD, while some important indicators—such as lead-time—have not been considered by researchers or in practice.

### 2.3.2 Mathematical Modelling Application in Collaborative Last Mile Delivery

Collaboration has been considered a solution strategy in some studies in the field of LMD. These studies mainly used mathematical optimisation models to compare collaborative LMD models and non-collaborative LMD models. For example, Muñoz-Villamizar et al. (2015) suggested a collaborative LMD model and considered CVRP and multi-depot CVRP using mixed-integer linear programming (MILP) to optimise and evaluate collaborative and non-collaborative LMD scenarios. In their collaborative scenario, companies shared trucks, routes and customers to reduce their cost, number of necessary vehicles and environmental effects. In the non-collaborative scenario, each company defined the routing of its vehicles to deliver goods at delivery points. In the collaborative scenario, each demand was first allocated to one of the coalition companies based on minimising the total allocation distances, and then the routes were optimised for each set of allocations. The travelled distance was considered the objective function to be minimised; however, indirectly, travel time, vehicle use, carbon emissions, number of routes and service level could be evaluated in both scenarios. In other words, although this study employed a single-objective optimisation approach, other metrics could be evaluated based on the main objective.

In another study, Chinh et al. (2016) suggested using a collaborative model for delivering goods, using different assumptions and solutions than in the model presented by Muñoz-Villamizar et al. (2015). In Muñoz-Villamizar et al.'s model, the goods were similar and each logistics service provider could take the goods from its stock and deliver to customers belonging to other providers. Therefore, transportation between DCs was not needed. In Chinh et al.'s (2016) model, the goods to be delivered were different. Hence, to deliver the goods of other companies, vehicles needed to travel to the logistics service provider's DC to collect the goods. Chinh et al. considered VRP to develop their mathematical model, and the routes were optimised based on the shortest path, using a ruin-and-recreate algorithm. They used real data of three logistics providers in Singapore. The results showed that the proposed collaborative model decreased the cost, time of service, number of vehicles and total distance. They also investigated a situation in which companies were not interested in full collaboration, and wished to deliver their own goods first and then deliver the goods of other companies. The research indicated that the last scenario also decreased indicators in comparison with a non-collaborative scenario. Although the results of the partial collaboration scenario were not as good as those of the full collaboration scenario, the level of improvement was very similar. Moreover, Chinh et al. argued that the last scenario was more practical in real situations.

## 2.4 Summary

This chapter has reviewed the literature in the LMD context and investigated the coopetition strategy in general and specifically in the LMD context. Section 2.1 focused on the LMD phenomenon and investigated how this phenomenon has been studied thus far. First, we reviewed how LMD is defined by previous studies and discussed why these definitions do not present the phenomenon perfectly. Various initiatives and solutions have been suggested and conducted in different cities around the world. We reviewed these initiatives and solutions, and discussed their objectives and results. We then investigated different types of stakeholders participating in the LMD phenomenon and discussed their interests and priorities.

Some studies have used mathematical modelling to improve LMD performance. In Section 2.2, we reviewed the mathematical models explored in the LMD context. We also reviewed the main performance indicators addressed by the mathematical models of the previous literature, and discussed the gaps in these models. In Section 2.3, we reviewed the coopetition strategy, and discussed the concepts of this strategy and its applications in the LMD context and related contexts.

# Chapter 3: Research Methodology and Application

Research involves defining a problem, introducing research questions and hypotheses, and collecting and analysing data to address the questions and hypotheses. The aim of this chapter is to describe the process of this research and explain the methodologies and methods employed in accordance with the research objective and questions described in Chapter 1. First, Section 3.1 presents the research design, and discusses the purpose and approaches applied in this study. It explains how both qualitative and quantitative approaches were considered to conduct this research, and how this study was categorised as descriptive and experimental research. This study used several approaches and methods to collect, analyse and interpret data. Section 3.2 discusses the data collection methods, and describes why they were chosen. Section 3.3 presents the data analysis methods, and describes the procedures followed to conduct each method. At the end of this chapter, a summary of the chapter is presented.

## 3.1 Research Design

The main objective of this study included demystifying the LMD phenomenon and developing an LMD initiative by using coopetition strategy to improve delivery performance. This study comprised three main research questions to address the objective. RQ1 aimed to demystify the LMD phenomenon, RQ2 related to developing an LMD initiative with a coopetition strategy, and RQ3 examined how different factors can affect the coopetition model. RQ1 was divided into four sub-questions. Each research question was investigated separately; however, they were related to each other, and the outcomes of each question/sub-question were used in other questions. Figure 3.1 shows how the research questions related to each other. In RQ1a, the phrases addressing the LMD

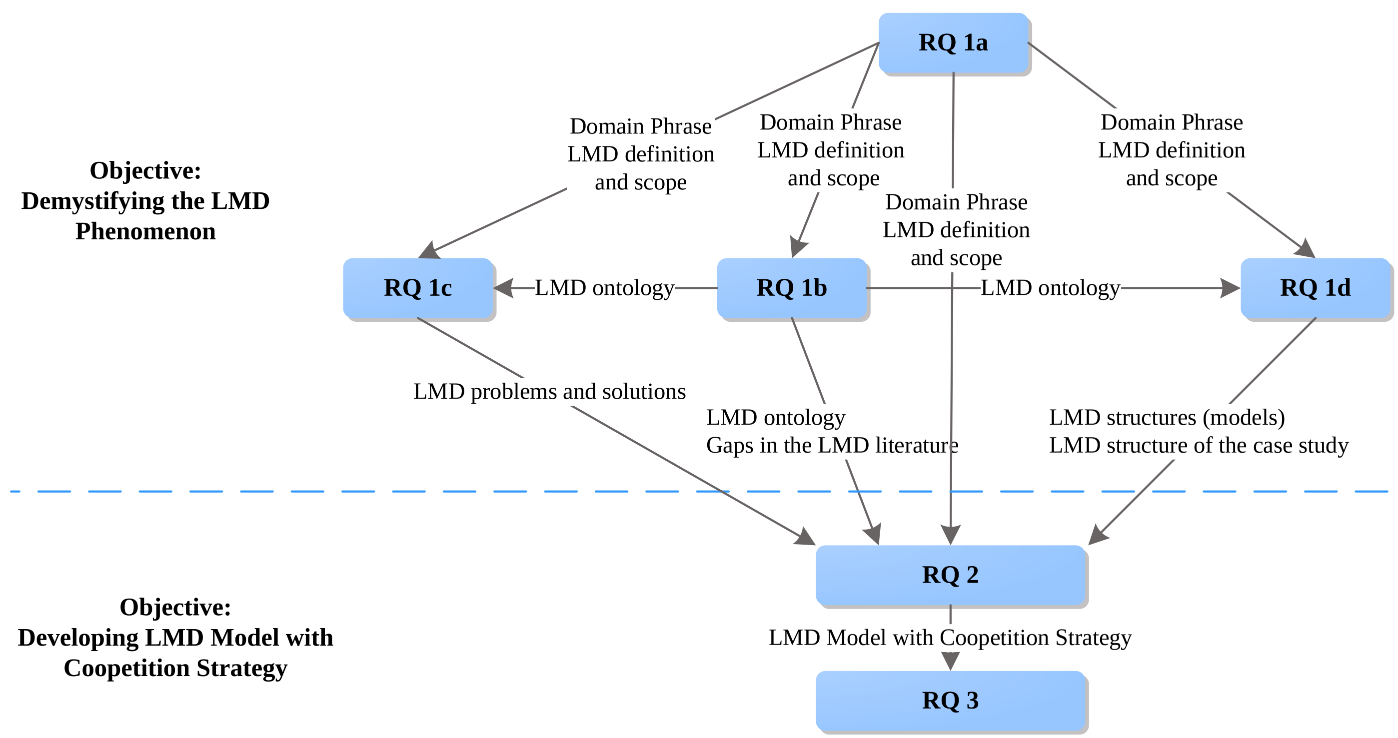



Figure 3.1: Relationships between Research Questions

phenomenon were first investigated by reviewing the literature. The domain phrase addressing the phenomenon was extracted from this research question and used throughout the research. Then, the definition and scope of LMD presented by the literature were investigated and clearly redefined, and used as the basic concept in all other research questions. In RQ1b, the components of LMD were classified based on the ontology concept. Moreover, in this research question, the literature was mapped based on the proposed LMD ontology to identify how research has been covered in the LMD context. These outputs were used in RQ2 when an initiative was developed to improve the LMD performance. The LMD ontology, as the outcome of RQ1b, was also used in RQ1c and RQ1d. The proposed LMD ontology was used in RQ1c to explore possible problems and solutions of LMD. In RQ1c, the structures of LMD were proposed based on the LMD ontology framework. After that, the proposed structures were used to examine the structure of LMD in a real case study. In RQ2, all outputs of RQ1 were first used to develop an LMD model with a coopetition strategy. Following this, the proposed LMD model was evaluated with mathematical models. Finally, RQ3 examined how changes in some factors could affect the results of LMD models with and without cooperation.

To address each research question, this study considered a specific methodology, approach and method. The approaches, purposes and methods were selected based on the nature of each research question. Table 3.1 presents a summary of the process of this research. The purposes of conducting research are classified in the following categories: exploration, description, explanation, action, evaluation and evoke/provoke (Leavy 2017). Although most research falls into one category, many researchers use more than one category. Two categories were used to address the different research questions of this study: descriptive and experimental.

Table 3.1: Research Process

| Objective | Research Question | Purpose | Approach | Data Sources | Data Collection | Data Analysis |
|---|---|---|---|---|---|---|
| Demystifying the LMD phenomenon | RQ1a | Descriptive research | Qualitative | Literature | Systematic literature review | Descriptive statistics, content analysis |
| | RQ1b | Descriptive research | Qualitative | Literature | Systematic literature review | Ontology, ontological analysis |
| | RQ1c | Descriptive research | Qualitative | Literature | Systematic literature review | Ontology |
| | RQ1d | Descriptive research | Qualitative | Case study | Semi-structured interview | Ontology, case study |
| Developing LMD with coopetition strategy | RQ2 | Experimental research | Quantitative | Random data and case study | Semi-structured interview, probability sampling and secondary data | Modelling, case study |
| | RQ3 | Experimental research | Quantitative | Random data | Probability sampling | Sensitivity analysis |

Descriptive research is a type of research to systematically describe a situation or phenomenon (Isaac and Michael 1995, pp. 45-7). Descriptive research aims to describe attributes, behaviours or phenomena. It usually does not address 'why/when' questions and is mainly suitable for 'what' questions. This approach was used to address the first research question (RQ1a, RQ1b, RQ1c and RQ1d). In RQ1, the aim was to describe the LMD phenomenon in terms of terminology, definition and scope, problems and solutions, components and structure.

Experimental research aims to examine the effects of treatment on some outcomes (O'Dwyer and Bernauer 2013). In experimental research, implementation of a treatment for one group is compared with a group not receiving the treatment. RQ2 and RQ3 were categorised as experimental research. In RQ2, the LMD models with a coopetition strategy were developed and compared with the LMD model without coopetition. The applicability of the LMD model with coopetition in a real case study was also examined in this research question. In RQ3, the effects of some factors on LMD models with and without cooperation were examined.

Qualitative, quantitative, mixed-methods, art-based and community-based participatory research are the five main approaches to research (Leavy 2017). The qualitative approach is mainly categorised as an inductive approach for building knowledge (Leavy 2017) and refers to the meanings, concepts, definitions and descriptions of things (Tran 2016). A qualitative approach is suitable when the objective is related to exploring or explaining. In this study, we aimed to explore and explain the LMD phenomenon. Therefore, a qualitative approach was considered for RQ1. The quantitative approach relies on deductive reasoning approaches and seeks to discover new knowledge by simplifying complexity (O'Dwyer and Bernauer 2013). Quantitative approach is about counting and measuring things, and distils complex phenomenon into simple representatives, such a mathematical equation or model. In RQ2 and RQ3, a quantitative approach was considered to simplify and investigate the coopetition strategy in LMD by developing and evaluating LMD models in the form of mathematical models.

## 3.2 Data Collection

There are various methods and tools for collecting quantitative and qualitative data. In this study, a literature (document) review, interviews, probability sampling and secondary data methods were applied to gather data. The data needed for RQ1a, RQ1b and RQ1c were gathered by collecting the relevant documents, which included journals and conference articles. A semi-structured interview was conducted to collect the data needed to address RQ1d. For RQ2, random data were generated, alongside using real data from a case study (secondary data). For RQ3, the same random data generated in RQ2 were used.

### 3.2.1 Types of Data

In both qualitative and quantitative research, the collected data provide the basis for answering the research questions. There are different types of data in both qualitative and quantitative research, depending on the nature of the problem and research area. Flick (2017) categorised qualitative data in three groups: verbal, ethnographic and material data. Verbal data are mainly produced in interviews and focus groups. Ethnographic data are produced with ethnographic approaches, such as observation, ethnography and videography. Material data come from documents, images, media and sounds. In contrast, widely accepted categories for quantitative data scales are nominal, ordinal, interval and ratio. In the nominal scale, values (typically numbers) are assigned to the attribute data, which is ‘in name only’ to make differences between them. Ordinal scales are used to rank the ordered data. Ordinal scales do not commonly have equal intervals. Interval scales are similar to ordinal scales, yet have equal intervals. Ratio scales have all the qualities of ordinal and interval scales; however, in addition, a zero in this scale means the absence of the attribute. The score in this scale provides the rank order, amount of the attribute and distance between the attributes.

To answer RQ1a, RQ1b and RQ1c, we used material data in the form of documents (including books, journals and conference articles) to investigate the LMD terminology, redefine the LMD definition and scope, and classify the LMD components. Both paper-based and computer-based documents were considered, which included both text and extra-textual elements, such as pictures, graphs and diagrams embedded in the documents. To answer RQ1d, we used verbal data from interviews. Finally, we used a mix of all types of quantitative data—including nominal, ordinal, interval and ratio data—to answer RQ2 and RQ3.

### 3.2.2 Systematic Literature Review

The principal aim of a systematic literature review is to access and map the existing body of knowledge and develop reliable knowledge (Tranfield et al. 2003). We conducted a systematic literature review to determine how the literature defines and addresses LMD, and to explore the components of LMD. Following the guidance of Denyer and Tranfield (2009), we conducted a literature review in four key steps:

- Step 1: question formulation
- Step 2: locating studies
- Step 3: study selection and evaluation
- Step 4: analysis, using results and reporting.

These steps enabled us to collect, explore and analyse the extant literature to gather basic knowledge about LMD.

**Step 1:** This systematic literature review explored different phrases, definitions and components of LMD. To establish the focus of this literature review, three main questions were formulated as follows:

- What is the domain phrase addressing LMD? (refers to RQ1a)
- How is LMD defined by the literature? (refers to RQ1a)
- What are the components of LMD and how they are addressed by the literature? (refers to RQ1b)

**Step 2:** This step aimed to locate as many studies as possible that were relevant to the review questions. To access as many relevant studies as possible, we needed to define appropriate search terms. The initial review of some relevant studies in the field (including books and articles) revealed that many phrases starting with 'last mile' or 'last kilometre' (or 'kilometer') were used to address the phenomenon. Therefore, using 'last mile' and 'last kilometre' as search terms could provide most related studies in this field. An initial review of the relevant papers also indicated that 'home delivery' and 'home shopping' addressed the phenomenon in some studies. Therefore, we considered 'home delivery' and 'home shopping' as the second group of search terms. Moreover, this phenomenon has been addressed by various articles in related subjects, such as 'city logistics' and 'urban freight'. Investigating articles in the relevant subjects also depicted how related subjects addressed the phenomenon. Thus, alongside 'last mile' and 'last kilometre', the second group of search terms included 'home delivery' and 'home shopping', and the third group of search terms included 'city logistics', 'urban logistics' and 'urban freight'.

We collected all related journal or conference papers related to the LMD phenomenon by using the first group of search terms in the title, abstract and keywords in major databases, including Elsevier (www.sciencedirect.com), Emerald (www.emeraldinsight.com), Springer (www.springerlink.com) and Informs (https://www.informs.org), and library services, including ProQuest (www.proquest.com) and Scopus (www.scopus.com). All irrelevant articles were screened by reviewing the title and abstract of each paper.

**Step 3:** In this step, the relevance of each study was investigated to determine whether it addressed the review questions. The relevant articles were identified by reviewing the title and abstract of each paper. Given that the same phrase with different application is used in telecommunication and humanitarian fields, it was necessary to delete irrelevant articles. The citations (including the title, abstract and keywords) and the whole text of articles were downloaded and exported to the EndNote software. One article could be presented by various databases; thus, EndNote software was used to avoid duplication. Following this, all papers and citations were exported to NVivo (Version 10) for analysing and reporting purposes.

**Step 4:** In this step, the collected literature was analysed for three purposes:

- to find the domain phrase of LMD phenomenon (see the results in Section 4.1)
- to discover the definition and scope of LMD by conducting content analysis (see the results in Section 4.2)
- to explore how the literature addressed LMD components by using ontological analysis (see the results in Section 4.3.5).

### 3.2.3 Interview

Interviews are one of the most common methods for data collection and are a very rich source of data when undertaken properly. In the interview method, the detailed information can be collected, which helps to analyse the problem properly. Interviews are conducted in three main forms based on the level of structure: structured, semi-structured and open. In structured interviews, questions are established in advance and the interviewees answer them one by one. In this type of interview, the respondents provide the same set of answers, which makes analysis simple. A semi-structured interview is a type of structured interview combined with open-ended questions, and is particularly useful for discovering the views of a person towards an issue and exploring more complicated research questions (Fraenkel et al. 1993; Miles and Gilbert 2005). Both semi-structured and open interviews provide opportunities for both the interviewer and interviewees to develop a new conversation around the topic. In semi-structured interviews, interviewers bring some topics or questions, yet interviewees can lead the conversation. In open interviews, there are no questions prepared in advance, and it is unknown how the interview will proceed.

Interviews can be conducted in different ways, such as face-to-face, via telephone, via email and via video conferencing. In this research, we conducted face-to-face semi-structured interviews to determine how LMD was conducted in an urban area and determine possible solutions for collaboration in the form of a coopetition relationship. The data collected by these interviews were used to address RQ1d and RQ2. In RQ1d, we first developed LMD structures based on the proposed LMD ontology. We then considered the proposed structures and information gathered by interviews to determine the structure of LMD in a case study. We selected the semi-structured interview because, in this form, we could discuss our proposed structures with the participants, as well as discussing other possible structures not included in our proposed LMD structure. The city of Melbourne was used as the case study in this research; therefore, the researchers had the chance to conduct face-to-face interviews with local logistics managers working in this city. In RQ2, these interviews provided suggestions that helped us develop collaborative LMD initiatives with a coopetition relationship.

#### 3.2.3.1 Interview Questions

This study aimed to determine the current situation of LMD and opportunities to improve the LMD system based on a coopetition strategy between competitors. The definition of LMD redefined in RQ1a and the proposed LMD ontology developed in RQ1b were used to formulate the interview questions. The interview questions were formulated based on eight subjects: LMD structure, consignment (freight), dispatch point, vehicle, delivery point, dispatching and delivery facilities, scheduling, and collaboration. The interview questionnaire is presented in Appendix A. Depending on the role of the organisation, some interview questions were changed or not applicable. For example, interviewees from shopping centres may not be able to answer some questions regarding the dispatching process of their receiving goods.

#### 3.2.3.2 Sampling Procedure

To attain better results, different types of LMD stakeholders were interviewed in this study. We sought to involve three major LMD stakeholders in the interview process: senders, carriers and receivers. Thus, the interviews included 3PL service providers as carriers, shopping centres as receivers, and retailers as both senders and receivers. Senior managers in the logistics and supply chain sectors were targeted to be involved in the interviews. We focused on the main logistics service providers, retailers and shopping centres in the city of Melbourne. Rahman (2011) presented a list of the main 3PLs working in Australia, and these were considered as potential companies to be involved in the interviews. Moreover, a quick survey of local shops in Melbourne CBD provided a list of the 3PLs working in Melbourne CBD. The results of this quick survey were consistent with the list of top 3PL firms considered by Rahman (2011). The senior managers from major department stores were also targeted to be interviewed to obtain retailers' insights. Moreover, senior managers from the major shopping centres in the city of Melbourne were targeted for interview. Table 1.1 presents a list of the main shopping centres in Melbourne CBD and their detailed information.

#### 3.2.3.3 Pre-testing and Questionnaire Validation

The interview questionnaire was discussed with two senior academics and based on their suggestion some changes were made.  They suggested to add few scheduling questions and change some questions in collaboration section. One interview was conducted based on the prepared questionnaire and the process and questionnaire were reviewed by the senior academics. The questionnaire was revised based on the comments and finalised.

#### 3.2.3.4 Conducting Interviews

Once the questionnaire was finalised, an email containing the invitation letter and the RMIT University consent form (Appendices B and C, respectively) was sent to interviewees to confirm their participation. The interviews were scheduled and conducted. Each interview was recorded and transcribed. The current structure of LMD in each organisation was extracted based on the interviewees' answers. A conceptual form of the suggested collaborative LMD model was developed based on the results of the interviews.

### 3.2.4 Probability Sampling (Data Generation)

To examine the mathematical models in RQ2 and RQ3, we needed to have instances. Given that our model was a new model, we needed to generate the instances. Thus, we generated random data for the parameters of the model. We explain the parameters and random selection of data in more detail in Section 5.3.1.

### 3.2.5 Secondary Data of the Case Study

The mathematical models in RQ2 were also examined by using the real data from a case study. We considered Melbourne as the single case study, and collected data from a retail sector working in this city. We collected the related information from two logistics service providers (two competitors) and one retailer working in this city. The parameters and types of data needed to evaluate the models are explained in Section 5.3.1.

## 3.3 Data Analysis

We conducted descriptive analysis, content analysis, ontology, case study, mathematical modelling and sensitivity analysis to analyse the data collected and generated in the data collection process. Some simple descriptive statistics were used to address RQ1a. Moreover, content analysis was also conducted in RQ1a to analyse LMD definitions and scope. In RQ1b, the ontology concept was applied to classify LMD components and investigate the LMD literature. In RQ1c, LMD ontology was used to extract problems and solutions for LMD. In RQ1d, LMD structures were developed based on the proposed LMD ontology. The information gathered during the interview process was then used to depict the LMD structure of the case study. A modelling method was used to examine the coopetition strategy in LMD and compare it with the situation without coopetition in RQ2. Both random and real case study data were used to investigate the coopetition strategy in this research. Finally, sensitivity analysis was used to examine the effects of various factors on the proposed LMD with and without coopetition in RQ3.

### 3.3.1 Content Analysis

Content analysis is a method for investigating texts in a systematic manner to determine the meaning embedded in texts (Leavy 2017). Although content analysis is a time-consuming method, it can be conducted for both quantitative and qualitative operations. Content analysis categorises data that can be analysed by using statistical methods (quantitative content analysis) or by using qualitative methods (qualitative content analysis). Daniel and Harland (2017) discussed three different content analysis approaches for categorising data: conventional, directed and summative. In conventional content analysis, data categories are generated directly from the data. In directed content analysis, data are categorised based on predetermined categories generated from sources other than the data. In a summative approach, the researchers identify keywords from the texts and analyse them to generate initial concepts. Once initial and key concepts are identified, the categories can be developed through further investigation.

In RQ1a, qualitative content analysis with a conventional approach was considered. Given that there are various phrases and definitions for LMD in literature, to understand its meaning, it is critical to investigate all related phrases and definitions. All journal and conference articles collected in the systematic process explained in Section 3.2.2 were reviewed manually and screened based on whether they offered a definition for LMD or related phrases. All definitions of LMD or alternative phrases were extracted from the articles. The definitions were manually investigated and the main structure of LMD definitions was categorised. Each definition was then coded based on the generated categories. The definition and scope of the LMD phenomenon were redefined based on interpretation of the categories and codes.

### 3.3.2 Ontology and Ontological Analysis

Researches usually begin with an assumption about a phenomenon that does not have a fixed definition or even expert agreement. Daniel and Harland (2017) suggested using ontology in the early stage of research to clarify the phenomenon and elucidate the personal preferences and conceptions of the phenomenon. In the current study, we found the definition, scope, structure and components of LMD to be unclear. We used ontology and ontological analysis to demystify the LMD phenomenon. In fact, we considered the ontology concept to extract and classify LMD components. The proposed LMD ontology was then used to analyse and map how the extant literature addresses LMD components. We used all the journal and conference articles collected in the systematic process explained in Section 3.2.2 to develop LMD ontology and conduct the ontological analysis.

To address RQ1b, we first developed an LMD ontology hierarchy that included all components of LMD and their interrelationships. We then used the proposed LMD ontology hierarchy to map how the literature addresses various components of LMD. To address RQ1c, we developed an LMD ontology framework to determine possible problems and solutions with regard to LMD. The proposed LMD ontology hierarchy was used to develop LMD structures, which related to RQ1d.

#### 3.3.2.1 Defining Last Mile Delivery Ontology Hierarchy

An ontology defines common vocabularies that provide a common understanding of the structure of information in a field. Following the instruction introduced by Noy and McGuinness (2001), we developed an LMD ontology hierarchy in this study. We first defined the domain and scope of LMD ontology. Then, along with existing classifications and components of LMD, important terms were extracted from the related articles collected in the systematic process explained in Section 3.2.2. According to Noy and McGuinness (2001), the extracted terms can be one of the three following components of the ontology concept: (i) classes or concepts in a domain; (ii) slots, features or attributes of the concepts; and (iii) facets, values and restrictions on the slots.

To categorise the terms that were determined to be a class, we used a process approach in the form of a turtle diagram. A turtle diagram is an effective tool for describing different aspects of processes. Using the turtle diagram, we linked six main elements to the core processes: what, who, how, how much, input and output. Following this rule, the LMD classes and class hierarchy were identified. This approach aimed to answer the following questions:

- What are the processes and sub-processes of LMD?
- What resources are needed to conduct LMD?
- Who is involved in LMD?
- How should the LMD process be conducted?
- Which indicators are monitoring LMD?
- What are the inputs and outputs of LMD?

Following this, the remaining terms were considered as slots and facets of the recognised LMD classes.

#### 3.3.2.2 Developing Last Mile Delivery Ontology Framework

Ontology can help break down a problem into its component dimensions to capture its complexity with natural language (Ramaprasad and Papagari 2009). Using some specified verbs, prepositions and conjunctions between the classes and slots of the proposed LMD ontology hierarchy, we developed an ontology framework to indicate problems, solutions and structures of LMD. The set of all combinations across classes and/or slots was determined in the form of sentences to describe the problems, solutions and structures of LMD, which addressed RQ1c and RQ1d.

#### 3.3.2.3 Ontological Analysis

The proposed LMD ontology hierarchy was used to analyse the LMD literature and investigate how components of LMD were addressed by previous studies. All papers obtained in the systematic literature review explained in Section 3.2.2 were used in this analysis. The LMD ontology hierarchy was built in NVivo (Version 10) software by creating one node for each class/slot. All papers were then exported to NVivo (Version 10) software and each paper was manually investigated and allocated to the corresponding classes/slots.

### 3.3.3 Case Study

Case study enables researchers to study complex phenomenon within a specific context. Yin (2009, p. 18) defined the case study research method as ‘an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not evident; and in which multiple sources of evidence are used'. A lot of details can be collected via case study method, that cannot be obtained easily by other methods. However, the findings cannot be easily generalised to the wider context. A case study can be used when research focuses on 'how' or 'why' questions. In this study, we used the case study approach to answer RQ1d and RQ2. In RQ1d, we investigated the LMD structure of the retailer sector in Melbourne's urban area as a single case study. According to Yin (2009), a single case study is considered when the research is conducted in one environment with a unique situation and there are limitations to completing multiple case studies. The LMD network in the city of Melbourne was considered as a single case study in this research. However, to investigate the structure of LMD in the city of Melbourne, we considered six different companies in our research. We also considered three companies of these six companies to examine the LMD models in RQ2. The case study was conducted to explore the structure of LMD in the retail sector of Melbourne's urban area and confirm that the LMD model with coopetition succeeded in a real situation and could be considered a useful solution for LMD.

#### 3.3.3.1 Case Selection

RQ1d emphasised understanding the structure of LMD in the retail sector in an urban context. Understanding the structure of LMD in urban areas requires a deep investigation of the various stakeholders working in those areas. This involves research in a wide range of locations (cities) and companies. To make this study practically manageable, we narrowed the research to one urban area and six different companies working in the retail sector in this area. We limited our research to the city of Melbourne and selected four main logistics service providers, one main retailer working in Melbourne, and one holding company owning four large shopping centres in Melbourne.

We selected Melbourne as the case study for the following reasons:

- Melbourne has been one of the most liveable cities in the world for a couple of years. Understanding the LMD structure of this city could be a benchmark for our study and for other researchers.
- The city of Melbourne aims to improve the LMD process in the city to reduce the negative environmental aspects of LMD. The City of Melbourne Council has already started to investigate LMD in the city centre. The results of our study will provide useful information for the city.
- The information was accessible to the involved researchers because they were living in Melbourne.
- Many large logistics companies and large retailers are working in this city, and the results of this study will provide reasonable information for them to improve their delivery process.

RQ2 evaluated LMD models with and without coopetition strategy, using both random data and data from the case study. Three of six companies considered in RQ1c were considered in RQ2. The data from two logistics service providers (two competitors) and one retailer working in Melbourne were also considered in RQ2. To simplify the calculation and because of limitations in data collection, we were unable to consider all six companies.

### 3.3.4 Modelling

A model is defined as 'a conceptual/mathematical/numerical description of a specific physical scenario, including geometrical, material, initial, and boundary data' (Thacker et al. 2004). A model can simplify a complex situation and helps to improve our understanding of the situation. Conceptual, mathematical and computer modelling were developed in this study to describe and evaluate coopetition in LMD. A conceptual model describing coopetition in LMD was developed based on the results from the interviews, content analysis and ontological analysis. To evaluate the results, the conceptual model was translated into mathematical models in the form of MILP. Then, computational models were developed based on the mathematical model to optimise the performance and evaluate the model. Computer codes were developed to solve the equations prescribed in the mathematical models.

#### 3.3.4.1 Conceptual Model

A conceptual model is the collection of assumptions, algorithms, relationships and data that describe the reality of interest (Paez 2008; Thacker et al. 2004). Considering the definition and scope of LMD, problems and solutions extracted from the LMD ontology framework, and results of the ontological analysis, the collaborative opportunities—especially with competitors—were reviewed with skilled managers during the interviews. Focusing on using empty running vehicles for return trips, possible collaborative models were discussed, and a new model was developed. A simple flowchart was used to depict the conceptual form of the LMD model with coopetition.

#### 3.3.4.2 Mathematical Modelling

The mathematical model is the mathematical equations, boundary values, excitations, initial conditions and other modelling data needed to describe the conceptual model (Paez 2008; Thacker et al. 2004). There are different types of mathematical models, but this study used optimisation modelling in the form of mixed-integer programming. To evaluate the performance of the collaborative LMD model in different indicators, we considered multi-objective optimisation. The current scenario (without coopetition) and collaborative scenarios (with coopetition) were defined and presented with a mathematical model. Cost, lead-time and travelling distance were the main indicators for evaluating and comparing different scenarios. Only cost and lead-time were considered in the scenarios with coopetition to optimise the performance of the model. A scenario without coopetition and two scenarios with coopetition were defined in this study.

#### 3.3.4.3 Computer Modelling

Computer modelling is the numerical implementation of the mathematical model, usually in the form of numerical discretisation, solution algorithms and convergence criteria (Paez 2008; Thacker et al. 2004). An accurate computational model captures the features of the mathematical model to guarantee positive validation results. The proposed LMD model with coopetition strategy was classified as NP-hard. As such, the exact solution methods became highly time-consuming as the problem instances increased in size. The model had two objectives (cost and lead-time) and it was not possible to identify a single solution that simultaneously optimised both objectives; thus, an algorithm was needed to provide a large number of alternative solutions that were on or near the Pareto-optimal front. A genetic algorithm (GA) is the most popular and well-suited algorithm for solving multi-objective optimisation problems (Konak et al. 2006). There are many variations of multi-objective GA in the literature. Non-dominated Sorting GA (NSGA II) is one of the most well-known and credible algorithms used in many applications, and its performance has been tested in several comparative studies (Konak et al. 2006). Therefore, as a result of the combinatorial nature of the model and the efficiency of GA in solving combinatorial multi-objective problems, we developed NSGA II, as a GA-based approach, to solve the proposed LMD model with coopetition strategy. The computational model and solution algorithm (NSGA II) were developed in MATLAB software.

### 3.3.5 Sensitivity Analysis

Sensitivity analysis is defined as 'the study of how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input' (Saltelli et al. 2008). Sensitivity analysis investigates how solutions are affected by changes to the model's components. In RQ3, sensitivity analysis was conducted to determine the influence of different variables on the LMD performance. The effects of variables included in the model were investigated to determine how facilities and resources could affect the results.

## 3.4 Ethical Consideration

Ethical considerations are important aspects of a research and address the interests of participants in the research. Ethical matters affirm that the interests of participants are not compromised or taken for granted. Since this research involved collecting data from individuals in the interview process, ethical considerations are needed.

This study followed the guidelines outlined by the RMIT Business College Human Advisory Network (BCHEAN). The ethics considerations have been approved by the BCHEAN committee. The approval letter is shown in Appendix D. According to BCHEAN, this research is categorized as a 'negligible or low risk' research.

## 3.5 Summary

This chapter has described the process of the research. First, Section 3.1 described the relationships between the research questions and explained how the outputs of each research question were used in the other research questions. We explained the purposes and approaches considered for each research question. A qualitative approach was considered for RQ1, while a quantitative approach was considered for RQ2 and RQ3. Section 3.2 detailed the data collection methods used in this research, and explained the procedure and detailed information for conducting the systematic literature review and interviews. We also discussed how we collected secondary data and generated random data for mathematical models. Moreover, we discussed the types of data used in this study. Section 3.3 presented this study's data analysis methods, and detailed the ontology, case study, modelling and sensitivity analysis methods.

# Chapter 4: Last Mile Delivery Definition, Scope, Components and Models

This chapter presents the analysis and findings of our research conducted to demystify the LMD phenomenon. We explore the terminology, meaning, scope structures, problems, solutions and components of LMD in theory, and investigate the structures of LMD in practice by focusing on the city of Melbourne. First, Section 4.1 investigates the literature in the LMD context and extracts the phrases used by the literature to address the LMD phenomenon. We use some simple statistics to decide on the dominant phrase used to address this phenomenon. In Section 4.2, through conducting content analysis, we investigate the extant definitions of LMD. The results of the content analysis lead us to redefine LMD and its scope. Section 4.3 discusses how we use the ontology concept to demystify LMD components. All details of LMD ontology—including classes, slots and facets—are discussed and presented. Later in this section, we develop and present an LMD ontology framework from which the problems, solutions and structures can be extracted. This section also shows how the LMD literature addresses different components of LMD and visualises the gaps. Based on LMD ontology and the proposed definition of LMD, we develop LMD structures, which are presented in Section 4.4. The proposed LMD structures are examined in a real situation by conducting some interviews in Melbourne cities. The related analysis and results are described in Section 4.5. Finally, a summary of the chapter is presented in Section 4.6.

## 4.1 Phrases Addressing the Last Mile Delivery Phenomenon

The literature uses various phrases with a combination of 'last mile' or 'last kilometre' and terms such as logistics, delivery and freight. Following the instructions explained in Section 3.2.2, we located 248 articles. Using NVivo (Version10), 'last mile' and 'last kilometre' terms were searched among the whole text of all 248 papers to find all phrases addressing the LMD phenomenon. We found 106 articles (out of 248) using either 'last mile' or 'last kilometre' in their text. Developing a word tree indicated how 'last mile' and 'last kilometre' were combined with other words (see Figures 4.1 and 4.2). Using NVivo, the texts of the 106 articles were investigated and sentences that included 'last mile' or 'last kilometre' were collected, and the five words before and five words after the phrase 'last mile' or 'last kilometre' were collected and then classified and presented as word trees for 'last mile' and 'last kilometre'.

Through reviewing the word trees for 'last mile' and 'last kilometre', we developed a list of phrases addressing the LMD phenomenon. Delivery, problem, distribution, supply chain, solution, transport, operation, freight and collection are the main words joined last mile/ last kilometre to make phrases addressing the LMD phenomenon. Table 4.1 displays the number of articles using each phrase in the whole text. It demonstrates that the phrase 'last mile delivery' was used in 44 of 248 articles, making it the most commonly used phrase in this context. 'Last mile logistics' was the second-most commonly used phrase, found in 20 articles. Based on statistics, 'last mile delivery' was the dominant phrase, and was subsequently used in this study to address the phenomenon.

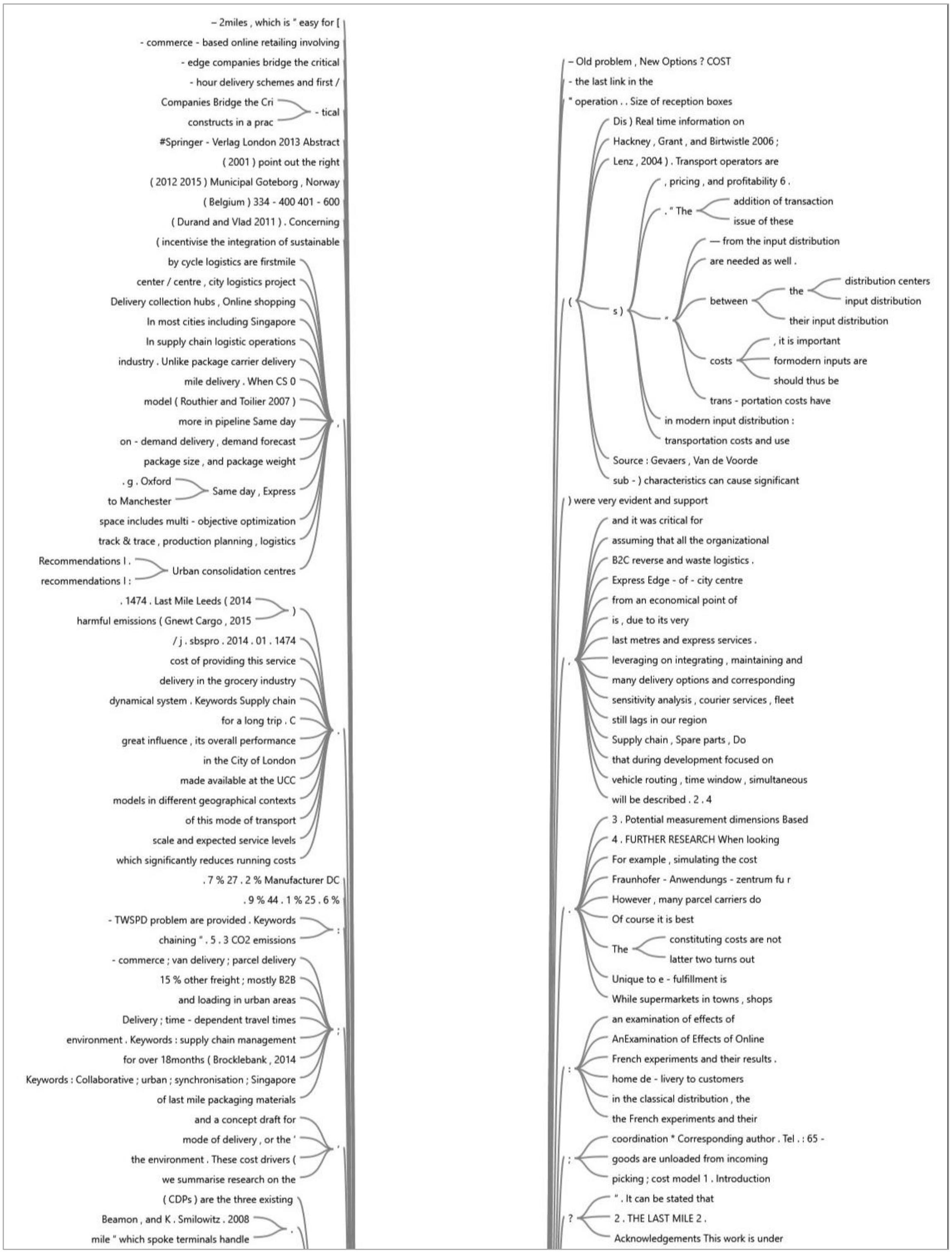




Figure 4.1a: Word Tree for ‘Last Mile’ in the Whole Text of All Articles (Part 1)

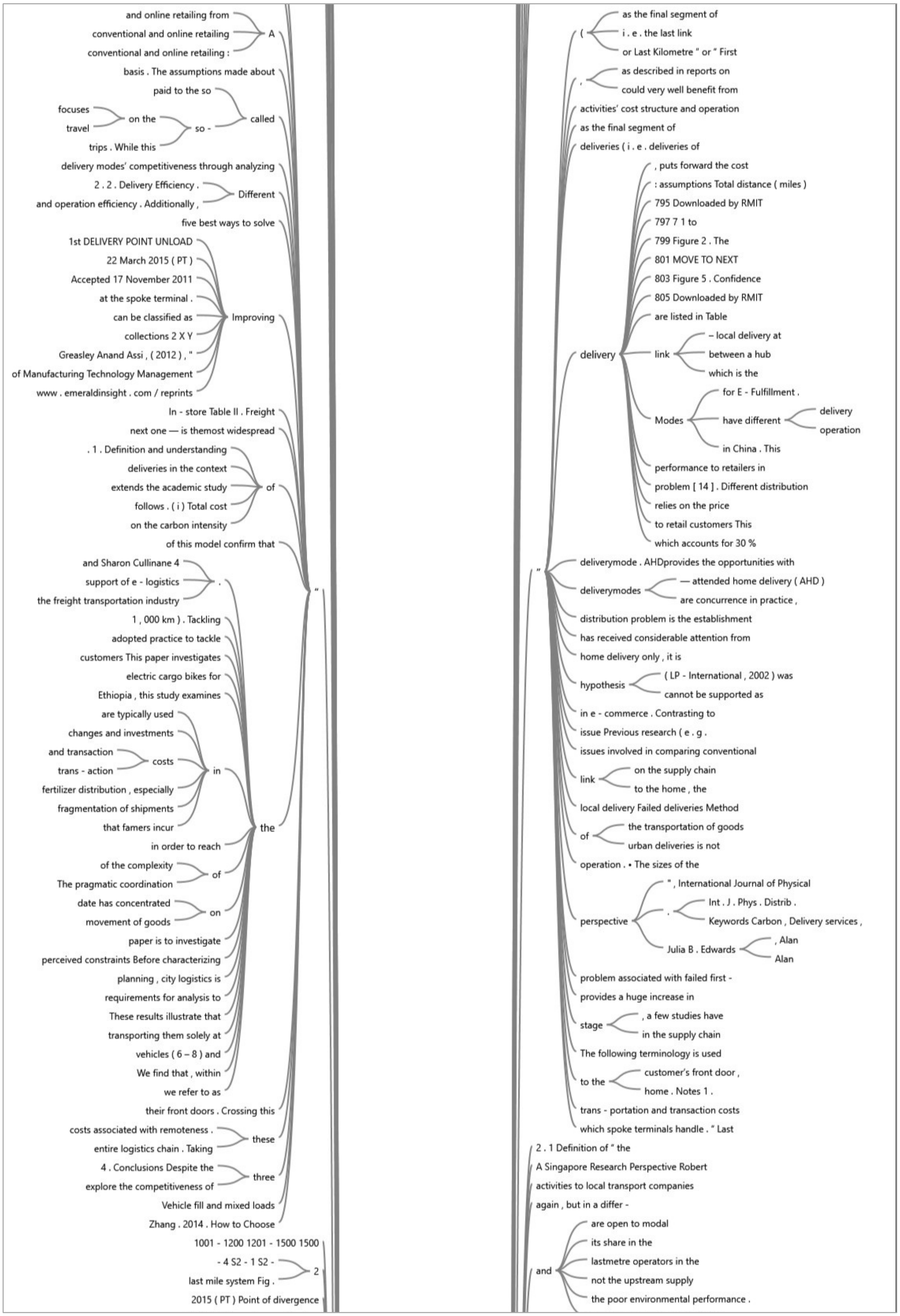



Figure 4.1b: Word Tree for ‘Last Mile’ in the Whole Text of All Articles (Part 2)

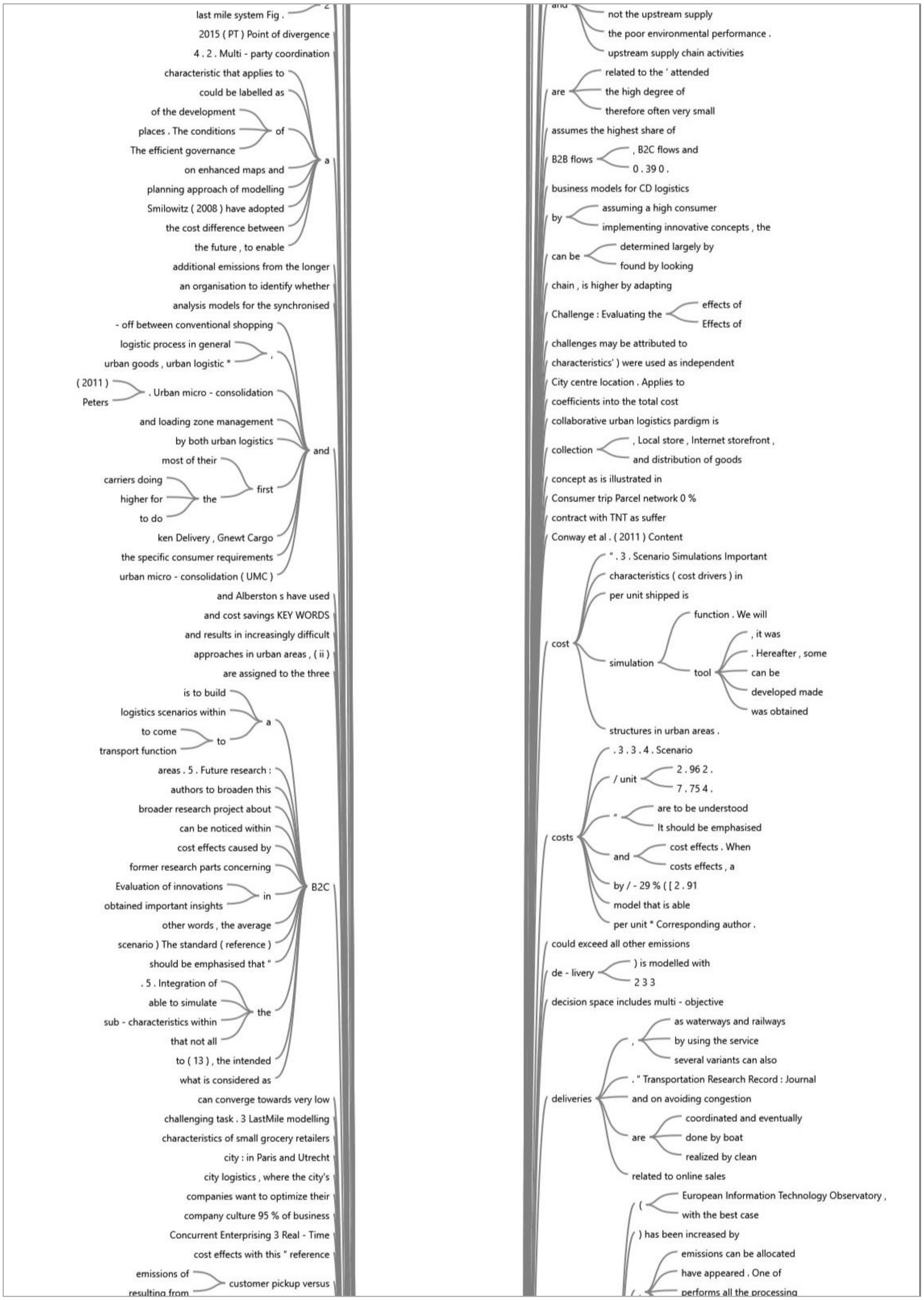


Figure 4.1c: Word Tree for 'Last Mile' in the Whole Text of All Articles (Part 3)

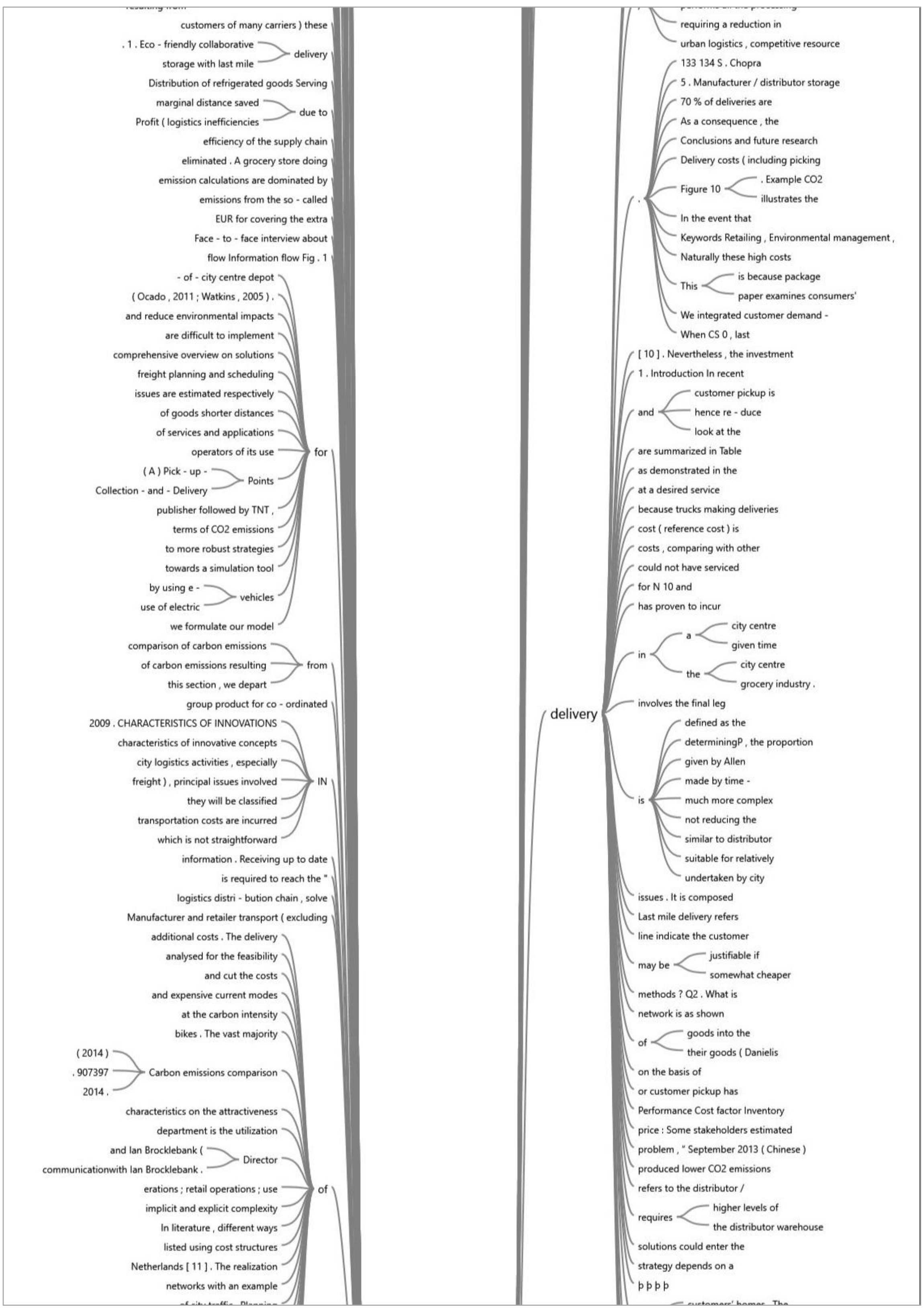


Figure 4.1d: Word Tree for ‘Last Mile’ in the Whole Text of All Articles (Part 4)

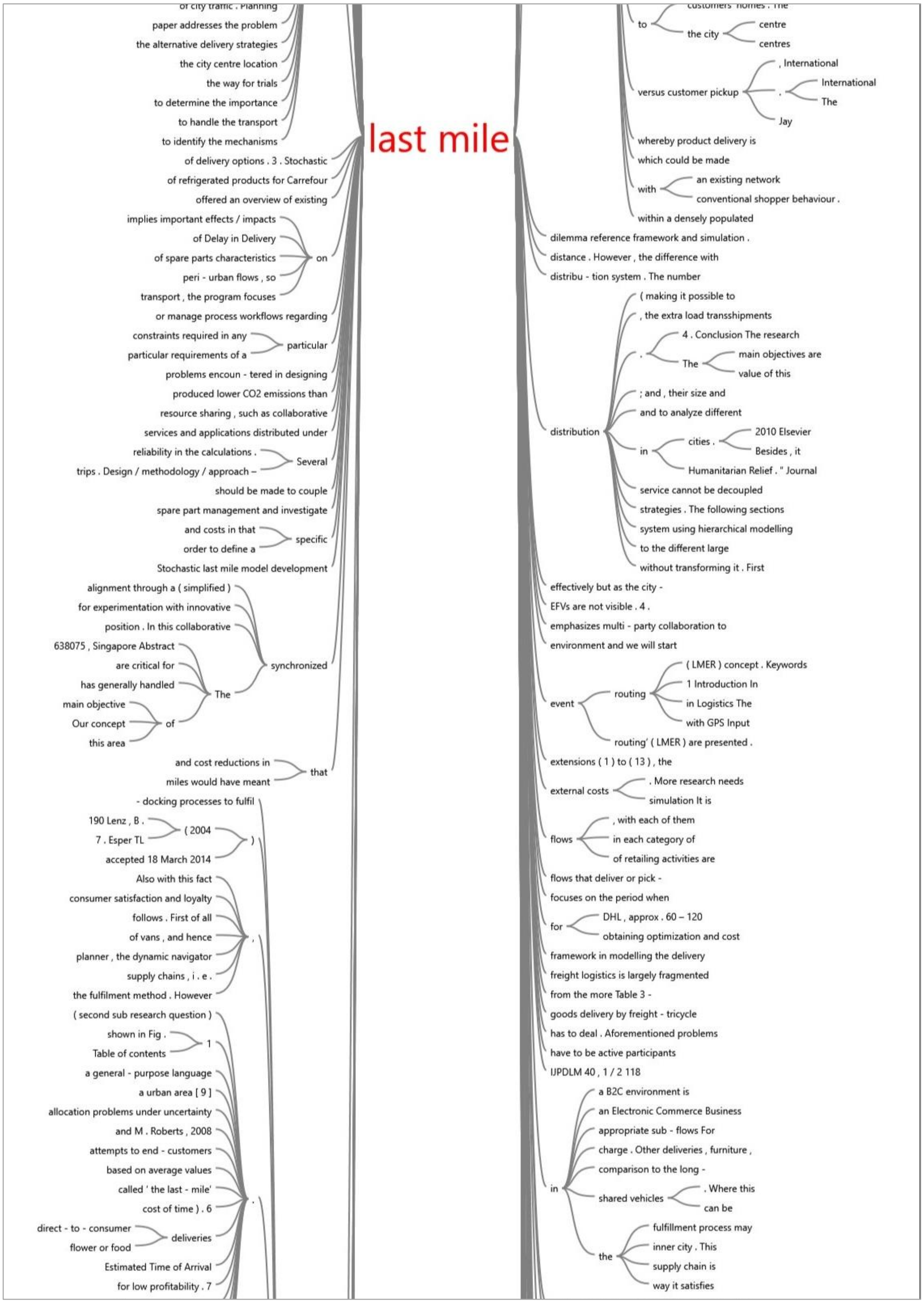



Figure 4.1e: Word Tree for ‘Last Mile’ in the Whole Text of All Articles (Part 5)

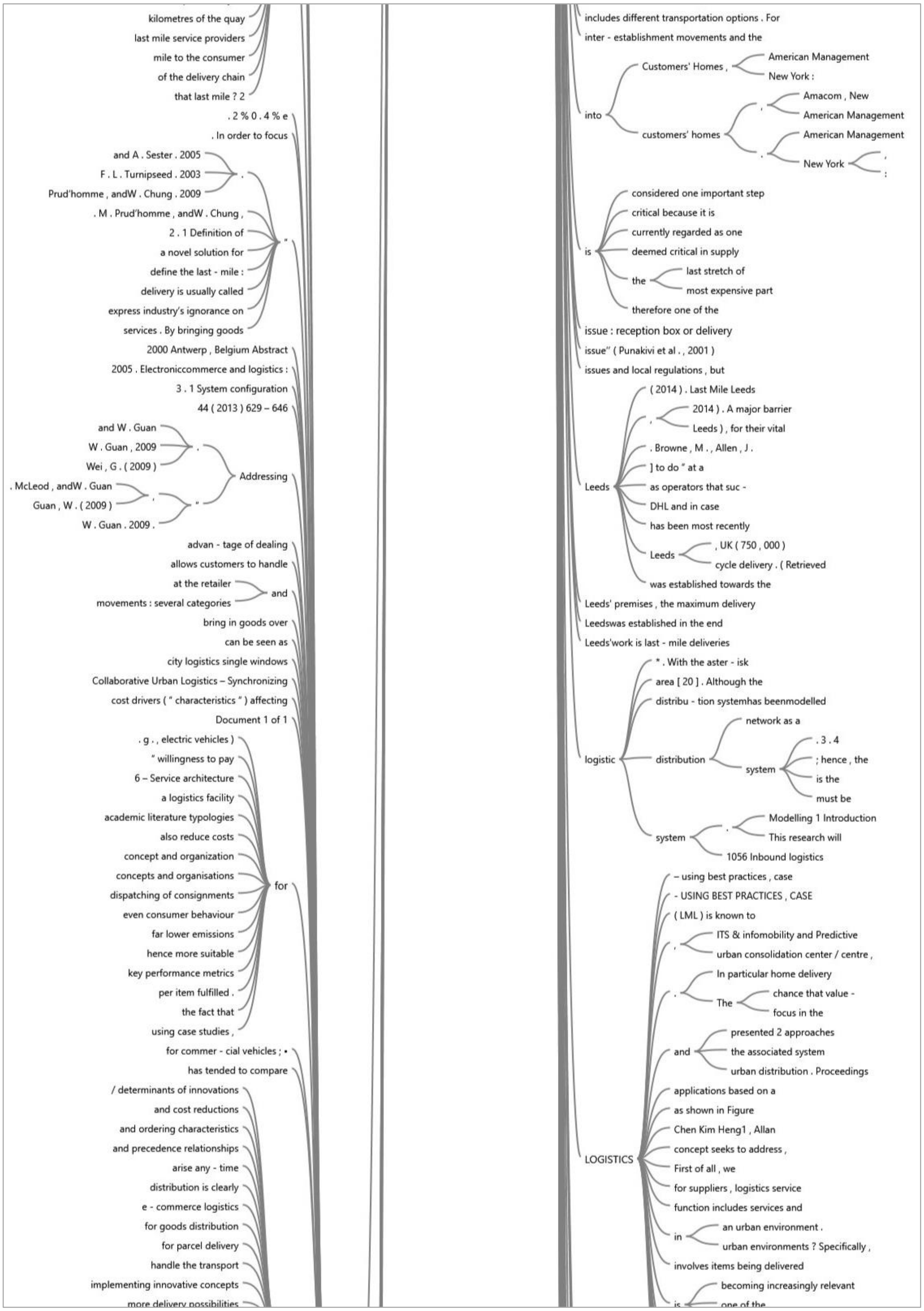


Figure 4.1f: Word Tree for 'Last Mile' in the Whole Text of All Articles (Part 6)

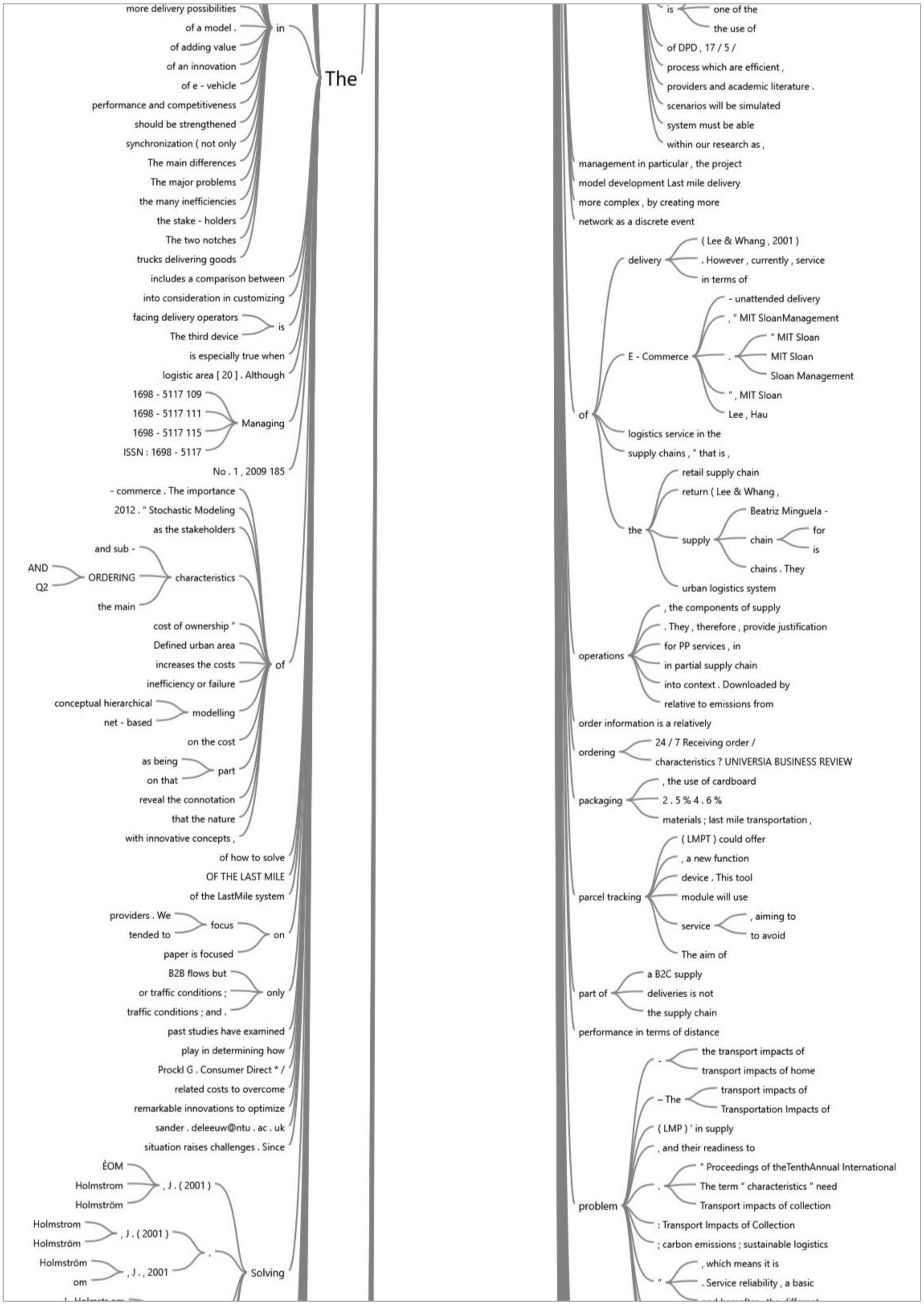


Figure 4.1g: Word Tree for ‘Last Mile’ in the Whole Text of All Articles (Part 7)

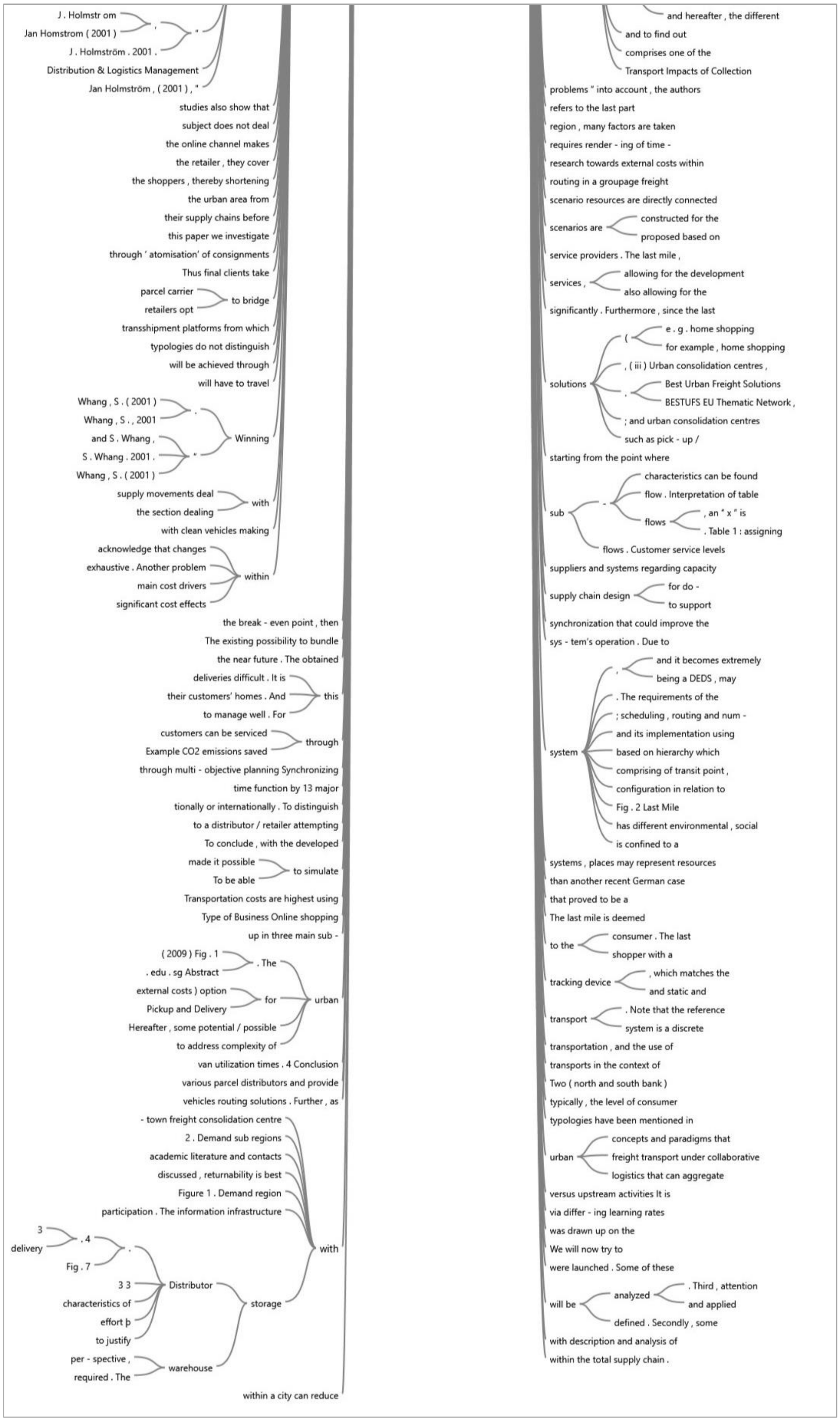



Figure 4.1h: Word Tree for 'Last Mile' in the Whole Text of All Articles (Part 8)

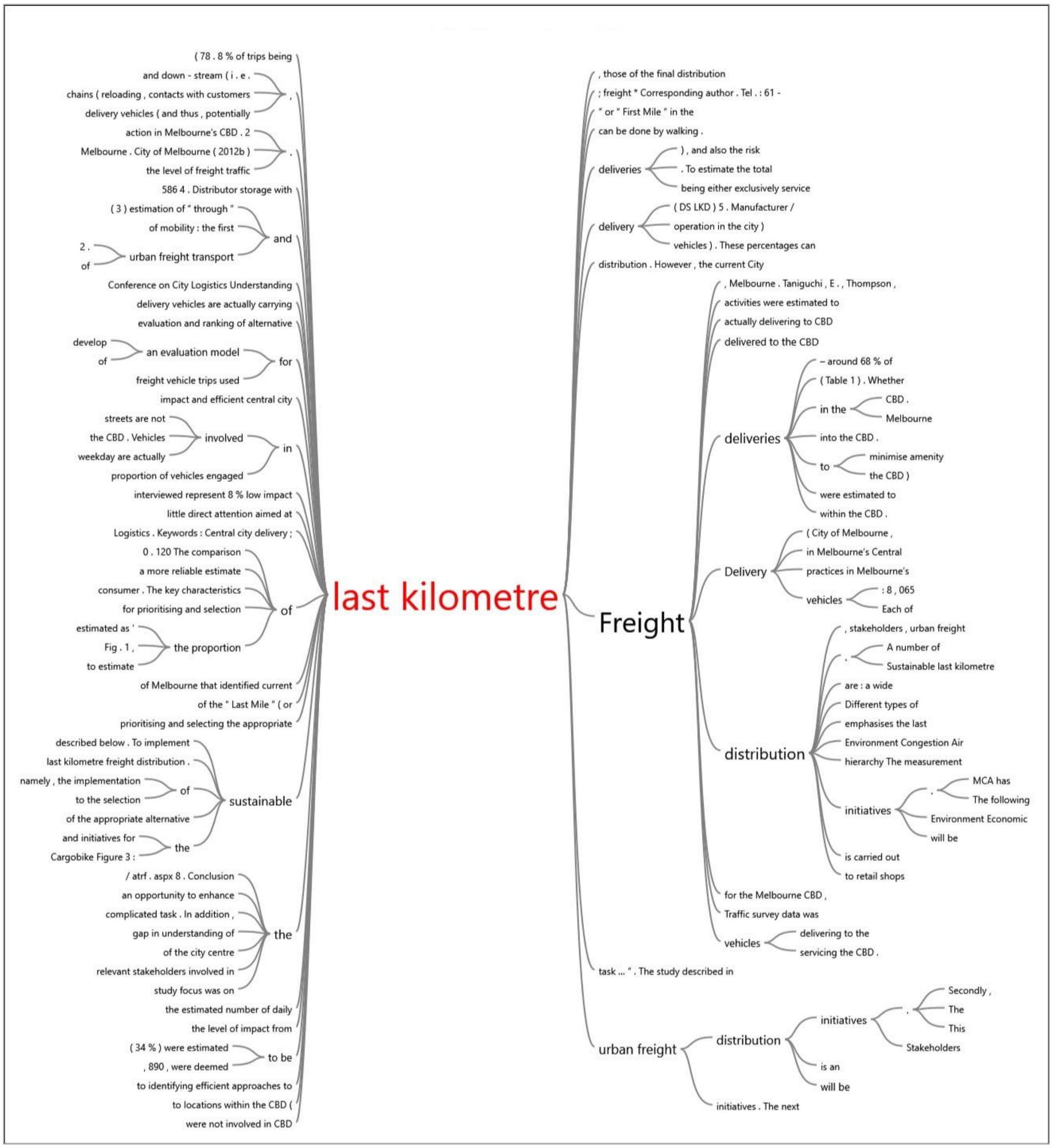



Figure 4.2: Word Tree for ‘Last Kilometre’ in the Whole Text of All Articles

Table 4.1: Frequency of Papers Using Specific Phrase in Whole Text

| Phrases | Search Term | | | | | | | All Terms |
|---|---|---|---|---|---|---|---|---|
| | **City Logistics** | **Urban Logistics** | **Urban Freight** | **Home Delivery** | **Home Shopping** | **Last Mile** | **Last Kilometre** | |
| Last mile delivery | 8 | 6 | 8 | 13 | 2 | 24 | 0 | 44 |
| Last mile logistics | 7 | 4 | 6 | 4 | 0 | 12 | 0 | 20 |
| Last mile problem | 0 | 0 | 1 | 11 | 0 | 9 | 0 | 15 |
| Last mile distribution | 4 | 3 | 4 | 2 | 0 | 6 | 0 | 13 |
| Last mile supply chain | 0 | 0 | 0 | 4 | 1 | 9 | 0 | 9 |
| Last kilometre | 3 | 2 | 4 | 0 | 0 | 2 | 2 | 8 |
| Last mile solution | 7 | 0 | 4 | 0 | 0 | 1 | 0 | 7 |
| Last mile transport | 2 | 0 | 1 | 1 | 0 | 5 | 0 | 7 |
| Last mile operation | 0 | 0 | 1 | 5 | 0 | 2 | 0 | 6 |
| Last mile freight | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 2 |
| Last mile collection | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 2 |
| Last mile/kilometre (all) | 31 | 15 | 28 | 37 | 4 | 44 | 2 | 106 |

## 4.2 Last Mile Delivery Definition and Scope

Given that various phrases and definitions for LMD exist in literature, to understand its meaning, it was critical to investigate all related phrases and definitions. Through reviewing the studies collected systematically (explained in Section 3.2.2), we identified a total of 21 definitions of LMD, which are presented in Table 4.2.

Table 4.2: Summary of Definitions for ‘Last Mile’ and Related Phrases

| Def. No. | Author/s | Phrase Used | Definition |
|---|---|---|---|
| 1 | Morganti et al. (2014b, p. 23) | Last mile | ‘The final segment of the supply chain’ |
| 2 | Gevaers (2013, p. 8) | Last mile | ‘The last mile is the last stretch of a B2C parcel delivery to the final consignee who has to take reception of the goods at home or at a cluster/collection point’ |
| 3 | Aized and Srai (2013, p. 1) | Last mile | ‘Last mile is the last part of the supply chain for the direct-to-consumer market’ |
| 4 | Minguela-Rata and De Leeuw (2013, p. 104) | Last mile | ‘The last link in the supply chain to the consumer’ |
| 5 | Woodard (2013, pp. 8, 18) | Last mile | ‘Last mile is the final portion of goods movement in which the package is delivered to the intended recipient’ |
| 6 | Edwards et al. (2010, p. 104) | Last mile | ‘Last mile as the last link in the supply chain to the home’ |
| 7 | Souza et al. (2014, p. 426) | Last mile delivery | ‘Last mile delivery is the last leg in a supply chain whereby the consignment is delivered to the (final) recipient’ |
| 8 | Lewandowski (2014, p. 184) | Last mile delivery | ‘The delivery process is a part of supply chain at the last link, from last warehouse to recipient’ |
| 9 | Edwards et al. (2010, p. 103) | Last mile delivery | ‘Last mile delivery as deliveries of goods from local depots to the home’ |
| 10 | Chopra (2003, p. 133) | Last mile delivery | ‘Last mile delivery refers to the distributor/retailer delivering the product to the customer’s home instead of using a package carrier’ |
| 11 | Wu et al. (2015, p. 498) | Last mile logistics | ‘The final stage to deliver freight to urban customers from the port or consolidation centers in a city’ |
| 12 | Schliwa et al. (2015, p. 52) | Last mile logistics | ‘Last mile logistics involves items being delivered from a depot or hub a short distance to their final destination’ |
| 13 | Aized and Srai (2013, p. 1) | Last mile logistics distribution system | ‘Last mile logistic distribution system is the final step in business-to-customer supply chain’ |
| 14 | Scott et al. (2009, p. 3) | Last mile Logistics | ‘Last mile Logistics is the critical, final phase of supply-chain management where goods move from a supplier to a customer’ |
| 15 | Tipagornwong and Figliozzi (2014, p. 77) | Last mile of supply chains | ‘The movement of goods from a distribution center or warehouse to final stores and customers’ |
| 16 | Kull et al. (2007, p. 409) | Last mile supply chain | ‘Last mile supply chain is a portion of the supply chain delivering products directly to the consumer’ |
| 17 | Muñoz-Villamizar et al. (2015, p. 263) | Last mile urban freight transport | ‘The last link of complex supply chains involving numerous stakeholders’ |

| | | | |
|---|---|---|---|
| 18 | Suksri et al. (2012, p. 2) | Last kilometre freight distribution | 'Last kilometer freight distribution is the last link of the supply chain that delivers goods to retailers in urban areas' |
| 19 | Morganti (2011, p. 42) | Last food mile | 'Last food mile refers to the physical distribution of food occurring in the last part of food supply chain. It refers to the final delivery of perishable goods to urban food outlets' |
| 20 | Xu et al. (2008, pp. 20-5) | Last mile of online shopping | 'The last mile of online shopping is the home delivery logistics in e-commerce' |
| 21 | Allen et al. (2007, p. 41) | Last mile solutions | 'Last mile solutions are the logistics element of the fulfillment process within consumer e-commerce transactions (both B2C and C2C), other remote purchases from mail order, direct selling and television shopping companies, and deliveries from retail outlets' |

Investigating all definitions indicated that these definitions basically addressed some or all following categories: main process/theme, function, commodity, coming from (whom and where) and going to (whom and where). Table 4.3 displays the ways the definitions address these categories. Almost all definitions explained that this phenomenon refers to the last phase (stage) of the main process. Over 50% (12) of the definitions considered the supply chain as the main process. Delivery, movement, logistics and distribution were the four functions used in these definitions. Delivery and movement, respectively, with 13 and three replications, were the most common functions in the existing definitions. There was no relationship between the function used in a definition and the phrase used. For example, it was expected that 'last mile logistics' definitions would use logistics functions, but they used delivery and movement functions, while the 'last mile online shopping' and 'last mile solution' definitions used both logistics and delivery functions. It is notable that all LMD definitions used the delivery function. Different words were used for commodities, but 'goods' was the most popular word. The definitions did not emphasise common places for conducting functions (both from and to).

They considered various locations, such as ports, consolidation centres and warehouses, as the last point where the final movement of goods would begin in a supply chain. This point is called the ‘last dispatch point’ in this study. In addition, the definitions considered various places—such as stores, homes and cluster/collection points—as the location where the goods were delivered to the consignee. This point is called the ‘delivery point’ in this study.

Table 4.3: Structure of Definitions for 'Last Mile' and Related Phrases

| Def. No. | Phrase | Sequence | Main Process/Theme | Function | Commodity | From (Where) | From (Whom) | To (Where) | To (Whom) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Last mile | The final segment | Supply chain | | | | | | |
| 2 | Last mile | The last stretch | Parcel delivery | Delivery | Parcel/goods | | Business | Home/cluster/collection point | Consumer/final consignee who has to take reception of the goods |
| 3 | Last mile | The last part | Supply chain | | | | | | Direct-to-consumer market |
| 4 | Last mile | The last link | The supply chain | | | | | | Consumer |
| 5 | Last mile | The final portion | Goods movement | Delivery/movement | Package | | | | Intended recipient |
| 6 | Last mile | The last link | Supply chain | | | | | Home | |
| 7 | Last mile delivery | The last leg | Supply chain | Delivery | Consignment | | | | (Final) recipient |
| 8 | Last mile delivery | The last link | A part of supply chain | Delivery | | Last warehouse | | | Recipient |
| 9 | Last mile delivery | | | Delivery | Goods | Local depots | | Home | |
| 10 | Last mile delivery | | | Delivery | Product | | | Customer's home | |
| 11 | Last mile logistics | The final stage | | Delivery | Freight | Port/consolidation centres in a city | | | Urban customers |
| 12 | Last mile logistics | | | Delivery | Items | Depot/hub a short distance | | Final destination | |
| 13 | Last mile logistic distribution system | The final step | Supply chain | | | | Business | | Customer |
| 14 | Last mile logistics | The critical, final phase | Supply chain management | Movement | Goods | | Supplier | | Customer |
| 15 | Last mile of supply chains | | | Movement | Goods | DC/warehouse | | Final stores | Customers |
| 16 | Last mile supply chain | A portion | Supply chain | Delivery | Products | | | | Consumer |
| 17 | Last mile urban freight transport | The last link | Complex supply chains | | | | | | |
| 18 | Last kilometre freight distribution | The last link | Supply chain | Delivery | Goods | | | | Retailers in urban areas |
| 19 | Last food mile | The last part/the final delivery | Food supply chain | Delivery/ distribution | Food/perishable goods | | | Urban food outlets | |
| 20 | Last mile of online shopping | The home delivery logistics | E-commerce | Delivery/logistics | | | | Home | |
| 21 | Last mile solutions | The logistics element | The fulfilment process within consumer e-commerce transactions/remote purchases | Delivery/logistics | | Retail outlets | Business/ consumer | | Consumer |

To attain a clearer view of the LMD definition and scope, it was necessary to review the whole order fulfilment process. According to Campbell and Savelsbergh (2006), customer orders are fulfilled in three steps: (i) order capture and promise, (ii) order sourcing and assembly (order preparation) and (iii) order delivery. In the first step, customers place orders in different ways, such as online, by phone or in person (Chopra 2003). The ordered products do not have any physical movement in this step. In the second step, the products of each order are collected from shelves and packed. Specific products are allocated to a specific customer order, which is called 'consignment' in this study. The location in which consignments are prepared for a specific customer order is called the 'preparation point' in this study. The consignments are ready to begin their delivery journey at the order 'preparation point'. In the third step, the consignment starts its delivery journey from the preparation point, and may pass different places to be delivered to the customer. The place at which delivery occurs is called the 'delivery point' in this study. Thus, the delivery journey starts at the 'preparation point' and finishes at the 'delivery point'. The delivery journey from the 'preparation point' to 'delivery point' can be undertaken directly or through one or more intermediate facilities where storing, merging and consolidation activities are performed (Boyer et al. 2004). The indirect delivery journey is commonly called 'multi-echelon transportation', where each echelon refers to one level of the distribution network (Cuda et al. 2015). Each echelon has two nodes, and dispatching and delivery actions occur in the first and second nodes, respectively. LMD is the last echelon of the delivery journey and starts from the 'last dispatch point', where the last dispatch action is conducted, and finishes at the 'delivery point'.

Based on this background, this study introduces a definition for LMD to clarify all aspects of this phenomenon. This definition includes B2B, B2C and C2C contexts:

> LMD is the last transportation of a consignment in a supply chain from the last dispatch point to the delivery point where the consignee receives the consignment.

Instead of using the terms ‘goods/freight/product’ or ‘customer/consumer’, this definition uses the terms ‘consignment’ and ‘consignee’, respectively. In reference to the consignment definition of ‘a batch of goods destined for or delivered to someone’ (Oxford Dictionaries 2019) and the consignee definition of ‘the person or company to whom goods or documents are officially sent or delivered’ (Cambridge Dictionary 2019), the terms ‘consignment’ and ‘consignee’ explain the LMD situation in a clearer manner.

The first echelon of the delivery journey is also an important stage in the delivery context. The first echelon is the main part of the return and collection process, which was also addressed by some previous studies (see Schliwa et al. 2015; Souza et al. 2014). This stage of the delivery journey is called ‘first mile delivery’ in this study. ‘First mile delivery’ is the first transportation of consignment, which starts at the ‘preparation point’. In the direct delivery journey, LMD starts at the ‘preparation point’. Hence, the ‘last dispatch point’ and ‘preparation point’ are the same in the direct delivery journey. In the direct delivery journey, LMD and ‘first mile delivery’ are the same.

The LMD process is completed when the consignee receives the consignment; however, this does not mean that the consignment has no more transportation after that. There is extra transportation for a consignment to reach its final destination when the delivery point is distant from the consignee’s location. For example, a consumer may collect his or her consignment from a retail store and bring it home in his or her private car. This transportation is not within the scope of LMD, but should not be ignored because consignees travel to the delivery point to collect their consignment. Xu et al. (2008) called this activity ‘last mile collection’ and defined it as a collection from certain convenient locations that are close to the customer’s house or workplace. This transportation of consignment is called ‘after last mile delivery’ in this study and is defined as the collection and transportation of a consignment from the delivery point to the consignee’s location. In the same manner, all transportation before LMD from the preparation point to the last dispatch point is considered ‘before last mile delivery’ (see Figure 4.3).

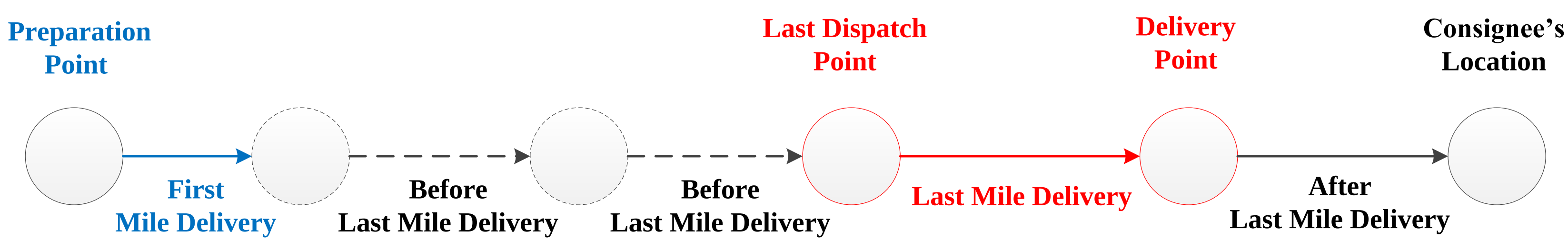



Figure 4.3: Different Stages of LMD

## 4.3 Hierarchy of Last Mile Delivery: An Ontological Approach

To demystify the LMD phenomenon, this study used an ontology approach. We followed the instruction introduced by Noy and McGuinness (2001) to develop the LMD ontology hierarchy. First, we defined the scope of ontology. Second, we extracted all terms potentially describing LMD dimensions from the related articles. Finally, we classified all relevant terms based on the ontology approach.

### 4.3.1 Scope of Last Mile Delivery Ontology

Considering the proposed LMD definition, the LMD process was limited to all issues regarding the transportation of consignments from the last departure point to the 'delivery point' where the consignee receives the consignments. This ontology focuses on the transportation process and does not include the process of making or preparing orders. This ontology is limited to logistics activities in B2B and B2C contexts. Hence, return processes and logistics activities in the context of C2C and consumer-to-business (C2B) are not within the scope of this ontology.

### 4.3.2 Enumerating Related Terms and Phrases

Through reviewing the extant literature in the fields of LMD, city logistics and home delivery (explained in Section 3.2.2), we listed all related terms and phrases without worrying about the overlap between the concepts they represented and relationships among them. These terms and phrases were investigated and classified in the next step.

### 4.3.3 Last Mile Delivery Ontology Hierarchy

According to Noy and McGuinness (2001), the extracted terms can be considered one of the three following components of the ontology concept: (i) classes or concepts in a domain; (ii) slots, features or attributes of the concepts; and (iii) facets, values or restrictions on the slots. We investigated all extracted terms one by one and considered whether it was a class, slot or facet. The classes, slots and facets were sorted hieratically and all together present the LMD ontology hierarchy, which is shown in Figure 4.4 and Appendix E. The class hierarchy, slots and facets are shown in black, red and blue fonts, respectively, in this figure. The hierarchy of classes are indicated by numbering. The slots are on the right side of the related classes. The facets are underneath the related slots.

#### 4.3.3.1 Last Mile Delivery Ontology Classes

Some of the extracted terms were found to be classes that related to the concept of LMD. There are three possible approaches to classify terms recognised as classes: top-down, bottom-up and combination (Noy and McGuinness 2001). We used the top-down approach in this study. Therefore, we first recognised and classified the terms at the top level, and then attached the other terms to the top level as subclasses.

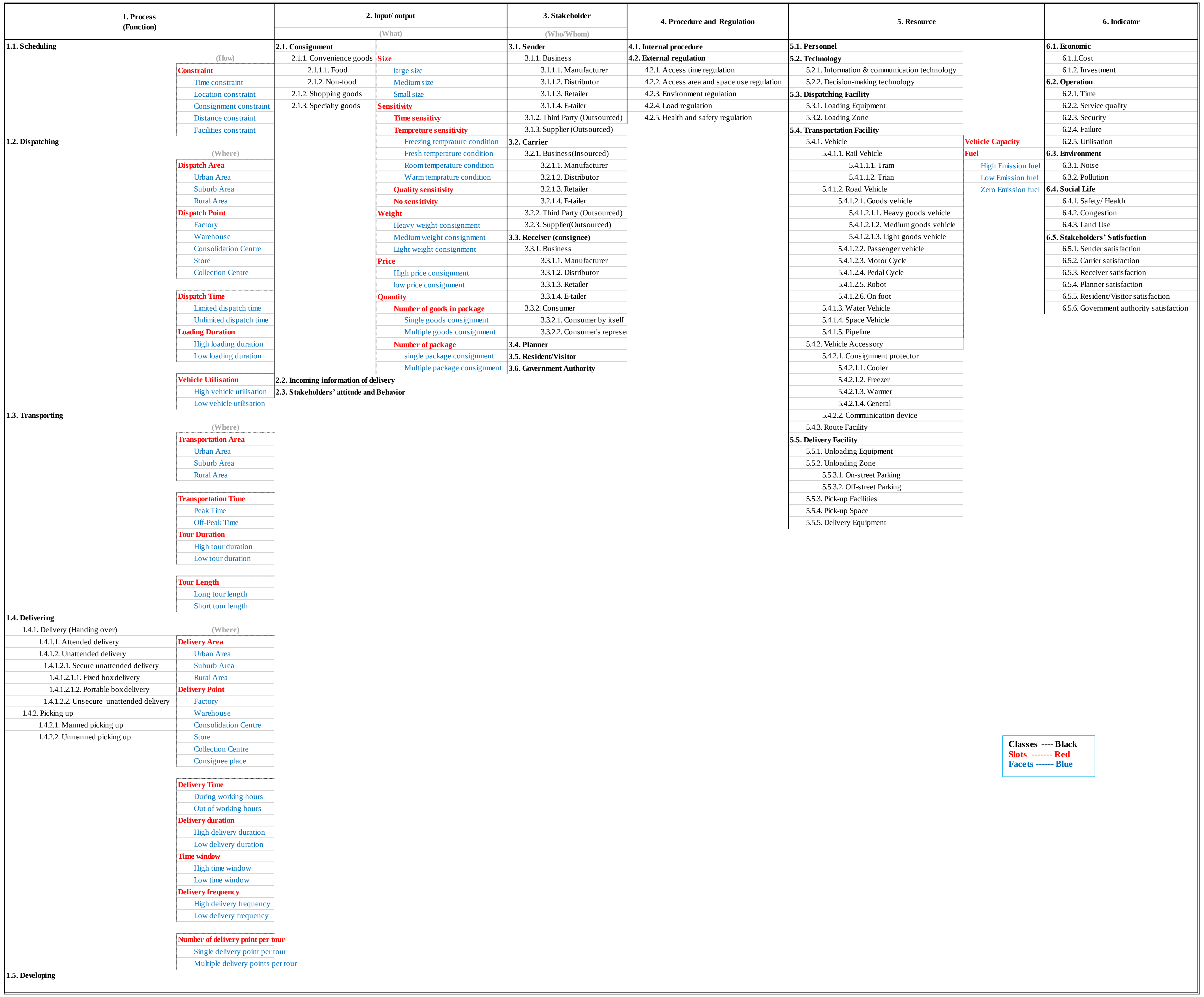


Figure 4.4: LMD Ontology Hierarchy

To categorise the top level of classes, we used a process approach in the form of a turtle diagram. According to the process approach and turtle diagram, any process can be described by its owners (stakeholders), the resources needed to conduct the process, the procedures and regulations that should be followed, the indicators that measure the process performance, the inputs that are converted to outputs, and the support processes that support the core process. Following the process approach and turtle diagram, we considered *process*, *input*, *output*, *stakeholder*, *procedure and regulation*, *resource* and *indicator* as the main (first-level) classes of the LMD ontology (see Figure 4.5). Using this structure, other extracted terms realised as classes were attached to these classes. All classes of LMD ontology are shown in black in Figure 4.4.

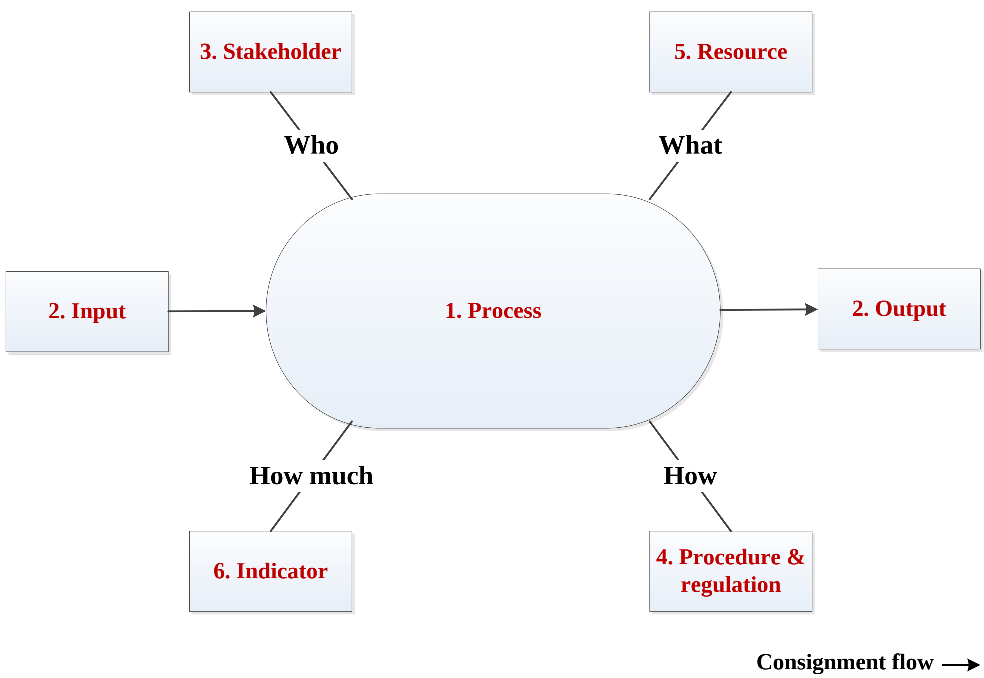



Figure 4.5: Main Classes of LMD Based on Process Approach

*Process*

Focusing on the consignment movement, there are four core processes in the LMD: *scheduling*, *dispatching*, *transporting* and *delivering*. *Scheduling* is the first step of LMD processes, and generates a schedule for the whole process of LMD. *Dispatching* from the last dispatch point is considered the kick-off for the movement of the consignment in the LMD context. During the *transporting* process, the consignment is moved from the last dispatch point to the delivery point, where the consignment is delivered to the consignee within the *delivering* process. In addition, *developing* is considered a support process that facilitates other LMD processes.

The delivering process can be conducted in two modes, which are also called ‘reception modes’: (i) the *delivery mode* (also called ‘home delivery’), in which consignments are delivered to the *consignee's location*, and (ii) the *picking-up* mode, in which the consignments are collected from a place away from the *consignee's location. Delivery mode* can occur at the consignee's location with or without attendance of consignee or his/her representative (Kämäräinen et al. 2001). There are two choices for *unattended delivery mode*: *secured unattended delivery mode* and *unsecured unattended delivery mode* (McKinnon and Tallam 2003). The carrier can leave the consignment in front of the consignee's door, which is an unsecured mode, or can use delivery boxes for unattended delivery, which is secured. Delivery boxes can be fixed at a delivery place (such as a customer's garage or home yard) or can be portable (Punakivi et al. 2001). In the case of *picking-up mode*, the consignee or consignee's representative can collect the consignment from a *delivery point*. *Picking-up mode* (also called ‘out home delivery’) (Durand and Gonzalez-Feliu 2012) can be manned or unmanned (Visser et al. 2014). A shared reception box is a common feature used for *unmanned picking-up mode* (Punakivi and Tanskanen 2002).

*Input and Output*

*Input* is transferred to *output* during the core processes, which include a set of interrelated or interacting activities. *Input* can be tangible or intangible (Corrie 2004). There are both tangible and intangible *inputs* to the LMD process. *Consignment* is a tangible input and *information of delivery* and *stakeholders' attitude and behaviour* are two intangible inputs in the LMD process. The same classification is applicable to the output of LMD. A delivered *consignment* is considered the tangible output and *information of delivery* and *stakeholders' attitude and behaviour* are also intangible outputs of LMD delivery.

Thirumalai and Sinha (2005) divided consignment into three *type*s: *convenience goods*, *shopping goods* and *specialty goods*. *Convenience goods* refer to the type of goods that consumers usually purchase frequently, immediately and with minimal effort. Groceries, home supplies and office supplies are some examples of convenience goods. *Convenience goods* can also be divided into *food* and *non-food* groups. *Shopping goods*, such as ready-to-wear men's, women's and children's apparel, are goods that consumers characteristically compare based on factors such as suitability, quality, price and style during the selection and ordering stage. Consumers invest special effort to order *specialty goods*. Computers and wedding dresses are two examples of *specialty goods*.

*Stakeholders*

Various *stakeholders* with different interests are involved in LMD processes. Different classifications have been proposed for LMD stakeholders in the literature. For example, Suksri et al. (2012) divided stakeholders into four major groups—residents, retailers/receivers, transport operators and government authorities—while Macário et al. (2008) divided stakeholders into six groups: residents, visitors, estate managers/developers, retail, shippers/carrier/retail and business. We considered the extant classifications and classified LMD stakeholders based on the LMD processes. The main stakeholders in LMD are those parties who conduct the LMD processes. Therefore, we defined the *planner*, *sender*, *carrier* and *receiver*—who conduct scheduling, dispatching, transporting and delivering processes, respectively—as the main stakeholders in the LMD context. In addition, *government authorities* may develop regulations and policies that directly or indirectly affect LMD processes. Thus, we considered *government authority* a stakeholder in LMD as well. In addition, the performance of LMD will affect people who are living, working and visiting in the operating areas. Thus, we also considered *residents and visitors* as stakeholders in LMD.

The *sender* dispatches and the *carrier* transports and delivers consignments from the last dispatch point to the delivery point. Considering the scope of this ontology, a *business* (including a *manufacturer*, *distributor* [wholesaler], *retailer* and *e-tailer*) can dispatch, transport and deliver consignments by itself or can outsource the dispatching process to its *suppliers* or other parties (*third party*) (Nuzzolo and Comi 2014a, 2014b). The *receiver* can be a *business* or *consumer*. *Consumers* can receive the consignment themselves or introduce a representative to receive the consignment on their behalf. Delivering a consignment to a neighbour is an example of delivering a consignment to a *consumer's representative*.

*Procedure and Regulation*

There are two groups of restrictions that should be followed by supply chains during LMD processes: internal and external (Browne and Gomez 2011). Internal restrictions are procedures that refer to policies, strategies and instructions that clarify the way of conducting different processes in LMD, and are usually created by internal stakeholders of a supply chain, including the sender, carrier, planner and receiver (in the case of business). *Internal procedures* encompass all LMD core processes, including scheduling, dispatching, transporting and delivering, and may differ in different supply chains. External restrictions are regulations that refer to policies and procedures introduced by government authorities to organise and manage goods movements within cities. These *external regulations* and policies can relate to *access time*, *access area and space use*, *load*, *environment* and *health and safety* (Benjelloun et al. 2010; Browne et al. 2007; Quak 2008). *Access time regulation* refers to specific periods for deliveries or transporting, while *access area and space use* refer to gaining permission to use specific areas and spaces for transporting, loading, unloading and delivery operations. *Load regulation* refers to limitations regarding load, such as weight and size. *Environment regulation* refers to limits on negative environmental effects, while *health and safety regulation* refers to limits on affecting the health and safety of anyone directly or indirectly involved in or affected by LMD processes (Benjelloun et al. 2010; Browne et al. 2007; Quak 2008).

*Resources*

Various *resources* are needed to conduct LMD processes. These *resources* are provided by different stakeholders in LMD. For example, *dispatching facilities* and *transportation facilities* are provided by senders and carriers, and *road facilities* are provided by government authorities. As well as the different stakeholders who provide the resources, there are different types of resources in LMD: *personnel*, *technology*, *dispatching facilities*, *transportation facilities* and *delivery facilities.*

*Personnel* refer to people who are involved in LMD *processes*. *Personnel* can be part of LMD *stakeholders*, including a *planner*, *sender*, *carrier*, *receiver* (*business*) or *government authority*. *Technology* refers to hardware and software resources and the intelligence embedded therein. *Information and communication* and *decision-making technologies* are two groups of technology in the LMD context (Benjelloun et al. 2010). *Information and communication technologies* are used for information flow and communicating between different actors during LMD processes. *Decision-making technologies* are used by decision makers for various proposes, such as scheduling, planning, designing, analysing, controlling and managing in LMD. Although vehicles can be considered a technology resource, we classified them as part of *transportation facilities*.

A supply chain requires facilities for dispatching consignments from the last dispatch point. *Loading equipment* and *loading zone* are the two main facilities required to conduct the dispatching process. There are three main groups of facilities for conducting transportation activities in an LMD context: *vehicle, vehicle accessory* and *route facilities*. Vehicles use *rail*, *roads*, *water*, *space* and *pipelines* for moving consignments during

LMD. Vehicles using rail can be divided into two groups: *train* and *tram*. *Goods vehicles*, *passenger vehicles* (including omnibuses), *motorcycles* and *pedal cycles* are different types of road vehicles (Australian Government 2005). Moreover, *robots* have been considered by some companies, such as Domino's (2017) in Australia, as a future delivery vehicle. In addition, consignments can be moved and delivered to consignees while carriers complete the job by walking (Cherrett et al. 2012). Although *passenger vehicles*, including omnibuses, are designed for carrying passengers, they may also be used for delivering goods. For example, many passenger cars are used for delivering fast food to customer's locations. *Goods vehicles* can be divided into *light*, *medium* and *heavy goods vehicles* (Australian Government 2005).

Consignment protectors—including a *cooler*, *freezer*, *warmer* and other *general* devices—installed in vehicles to protect consignments are a kind of *vehicle accessory* that may be used in LMD processes. Moreover, vehicles may use some *communication devices*, such as a global positioning system, during the transport process, which is also a type of *vehicle accessory*. *Route facilities* refer to infrastructure and facilities that are needed for the movement of vehicles during the *transporting process* in LMD. Equipment and space are two resources that may also be needed to facilitate unloading and delivery/pickup activities. Consignment is delivered to consignees at the consignees' location or collected at a place away from the consignee's location. Some facilities may be needed during delivery of the consignment to the consignee's location, such as delivery boxes. Some spaces and facilities, such as temporary storage and shared boxes, are needed to facilitate collection activities. Thus, delivery facilities can be divided into five groups: *unloading equipment*, *unloading zone*, *pickup facilities*, *pickup space* and *delivery* *equipment*. An *uploading zone* can be divided into two different zones: *off-street parking* (such as a private garage or driveway) and *on-street parking* (along the curb of streets).

*Indicators*

Each stakeholder has their own interests in the LMD context. *Indicators* can help measure, monitor and manage the coverage level of stakeholders' interests. Considering sustainable development, Patier and Browne (2010) categorised urban movement indicators into three classical groups: economic, social and environmental. Nuzzolo and Comi (2014c) added safety to these three groups, while Suksri et al. (2012) believed that 'operation' is the fourth indicator of LMD. Concluding different categorisations, we considered *economic*, *operation*, *environment*, *social* and *stakeholder's satisfaction* as the five aspects of performance in LMD. We considered safety a subclass of the social indicator.

#### 4.3.3.2 Slots and Facets

While the classes describe concepts in the LMD phenomenon, slots describe the property of classes, and facets describe the value of slots. Most of the related terms extracted from the literature were used to develop the classes and subclasses of LMD. All slots and facets are presented in red and blue, respectively, in Figure 4.3. Using the remaining terms, we defined slots and facets for some classes of the LMD ontology. No slots were recognised for the *stakeholder*, *procedure and regulation* or *indicator* classes. To simplify the ontology framework, we present an enumerated facet type, which specifies a list of the specific allowed values of the slots. We excluded other value-type facets, including number, Boolean (yes/no), instance and string.

*Process_ Scheduling*

Constraints are the characteristics of the *scheduling* process. A schedule is generated to deliver consignments based on time, location, consignment, distance and facility constraints. The source of *time constraints* can be inside or outside a supply chain. Off-peak delivery regulation is an example of a time constraint dictated from outside the supply chain. *Location constraints* refer to any locational limitations that should be considered during LMD scheduling. The condition and nature of consignments, such as size and weight, will affect the schedule process. This type of constraint, which is called *consignment constraints*, may affect the number of replenishments and vehicle utilisation rate. As a result of certain issues, such as drivers' working hours and geographical situations, the length of delivery trip may be limited. These types of limitations are known as *distance constraints*. The capacity of vehicles and loading and unloading facilities are some examples of *facility constraints* that will also affect schedule process.

*Process_ Dispatching*

*Dispatch area*, *dispatch point*, *dispatch time*, *loading duration* and *vehicle utilisation* are five characteristics of the dispatching process. The last dispatch point can be a *factory*, *warehouse*, *consolidation centre (or DC)*, *store* or *collection centre* where a consignment is respectively produced, stored, merged with other consignments or awaiting collection. *Dispatch points* can be located in *urban*, *suburban* and *rural areas*. The definition of each area can be different in each city. For example, the French National Institute for Statistics and Economic Studies defined an *urban area* as a set of municipalities made up of an urban centre, where the distance between buildings is equal to or less than 200 metres (Morganti et al. 2014a). *Dispatch time* refers to the time in which the *dispatching* process occurs, and can be *limited* to a specific time during a day or week, or can also be *unlimited*. *Loading duration* refers to the time taken to load the consignment, which can be a short or long time. *Vehicle utilisation* is another slot of the *dispatching* process that refers to the manner of loading and using the capacity of a vehicle. *Vehicle utilisation* is usually shown by the percentage of vehicle capacity usage and can be simply grouped into high and low rates.

*Process_ Transporting*

*Transportation area*, *transportation time*, *tour duration* and *tour length* are the slots of the *transporting* process. Similar to *dispatch area*, the transportation of a consignment can occur in *urban*, *suburban* and *rural areas.* Transportation can occur in *peak time* or *off-peak time* (Ehmke and Campbell 2014; Tozzi et al. 2013). *Off-peak time* differs in different cities and can be during the night, day or both (Casey et al. 2014). *Tour duration* refers to the total time for a round trip from the last dispatch point to one or more delivery points (Herrel 2014). *Tour length* is considered another transporting attribute in the context of distance (Tipagornwong and Figliozzi 2014). A tour includes multiple trips, which both begin and almost end at the last dispatch point. A trip is a movement between two consecutive delivery points (Chen 2014, p. 31).

*Process_ Delivering*

*Delivery area*, *delivery point*, *delivery time*, *delivery duration*, *time window*, *delivery frequency* and *number of delivery points per tour* are the characteristics of the *delivering process*. The delivering process can be conducted anywhere, including *urban*, *suburban* and *rural areas*. Consignments are delivered to consignees at the *delivery point*, which can be a *factory*, *warehouse*, *consolidation centre/DC*, *collection centre*, *store* or *consignee's location*. The number of delivery points during a delivery tour (round trip) is considered a characteristic of the delivery process. A tour with one delivery point is called a direct tour, and with more than one delivery point is known as a peddling tour (Chen 2014). Thus, a *single delivery point per tour* or *multiple delivery points per tour* can be allocated to a delivery tour. In the time context, the delivering process is determined by *delivery time* and *delivery duration*. Delivery activity can be conducted *during working hours* or *outside working hours*. *Delivery duration* refers to the time taken to conduct delivering activities, such as unloading and contacting the consignee (Ljungberg and Gebresenbet 2004). In addition, the *time window* is a criterion in the delivering process that refers to a pre-specified time period in which consignees are expected to receive service (Boyer et al. 2009). The *time window* can be set before the LMD processes (during order capturing) or during scheduling and transporting processes. The frequency of delivery to a particular delivery point is also considered a characteristic of the delivery process that affects LMD. *Delivery frequency* can be calculated in different ways, such as the number of deliveries to a particular delivery point per day or week; however, in general, it can be divided into high and low rates.

*Input/Output_ Consignment*

The characteristics of a *consignment* are divided into five main slots: *size, sensitivity*, *weight*, *price* and *quantity*. The dimensions (*size*) of a *consignment* affect the carrying process and were considered a characteristic of consignments in some previous studies, such as the work by Xu and Hong (2013). Three values are considered for this slot: large, medium and small. A consignment is considered medium sized if the consignment can be moved by one person in one attempt. A consignment is considered small if more than one consignment can be moved by one person in one attempt. Otherwise, it is considered a large consignment (Alho and de Abreu e Silva 2015).

*Sensitivity* refers to the level of sensitivity of consignment to time, temperature and quality during the whole process of LMD. A *time-sensitive consignment* can originate in two ways: (i) the value of the consignment itself decreases over time and (ii) the consumer not receiving the consignment at a given time disrupts the operation of a system or company. For example, fresh vegetables or fresh bakery products grow stale after a time; therefore, their intrinsic value decreases considerably or becomes zero (Figliozzi 2006). Some consignments cannot be stored, transported or delivered in ordinary (normal) conditions and require specific equipment to keep them in a special condition. For instance, some foods (such as frozen meat) need to be kept frozen during transportation or delivery, and a freezer or special packaging is needed. Allegre and Paché (2014) divided products delivered to stores based on temperature: dried (room temperature), fresh (+2°C) and frozen (-18°C) products. In addition, some goods need to be delivered warm or hot—at higher than room temperature. Therefore, consignments can be divided into four groups based on their *temperature sensitivity*: *frozen*, *fresh*, *room temperature* and *warm*. Some consignments are vulnerable, and their quality is sensitive. For example, fragile consignments should be transported and moved carefully. The quality of this group of consignments will decrease if a specific concern is not applied during the LMD processes. Any consignment can have some or none of these three types of sensitivities. Thus, we can have four different types of consignment with different sensitivities: *time sensitive*, *temperature sensitive*, *quality sensitive* and *insensitive*.

*Weight*, as one of the consignment characteristics, can have three values: light, medium and heavy. Similar to *size*, a consignment that can be moved by one person is considered a *medium weight consignment*. It is considered a *light weight consignment* if more than one consignment can be moved by one person in one attempt. Otherwise, it is considered a *heavy weight consignment* (Alho and de Abreu e Silva 2015; Macário 2013).

*Consignment price* is an important factor that determines how LMD should be conducted. Xu and Hong (2013) claimed that consignment *price* has a significant effect on consignees' willingness to select a pickup service. The *price* of a consignment can attain different values; however, in a simple classification, it can be divided into two groups: *high-price consignment* and *low-price consignment* (Xu and Hong 2013).

A consignment includes one good or a batch of goods delivered to consignees. *Quantity* refers to both the *number of goods per package* and the *number of packages* handled in one delivery. A *consignment* can have single or multiple packages or goods (Ljungberg and Gebresenbet 2004).

*Resource_ Transportation Facility_ Vehicle*

*Vehicles as a transportation facility resource* can have different *capacity* and *fuel*. *Capacity* is defined by the maximum weight (kilogram or tonne) or volume (cubic metre) that can be carried. Each vehicle requires *fuel*, which is classified into three groups from the perspective of sustainability. *Fuel* can generate *high*, *low* or *zero emissions*.

### 4.3.4 Last Mile Delivery Ontology Framework

Ontology can help break down a problem into its component dimensions to capture its complexity with natural language (Ramaprasad and Papagari 2009). Using specified verbs, prepositions and conjunctions between the classes and slots of the LMD ontology hierarchy presented in Section 4.3 (Figure 4.4), we developed an ontology framework to indicate problems, solutions and structures for LMD. This ontology framework is shown in Figure 4.6 and Appendix F. Figure 4.6 is similar to Figure 4.4; however, in Figure 4.6, a column that includes verbs, prepositions and conjunctions is added to each class and slot. Each combination of classes (including slots) with the specified verbs, prepositions and conjunctions makes a sentence to describe problems, solutions or structures of LMD. Numerous combinations (sentences) can be made within all levels of classes and slots, but many of the combinations may be irrelevant or meaningless. However, the combinations can present problems, solutions or structures of LMD. The following combinations are some examples that describe LMD problems:

- *'Transporting_ within_ urban area_ during_ peak time_ using_ goods vehicle_ with_ high emission fuel_ increase_ pollution'*
- *'Attended delivery_ during working hours_ to_ consumer _ increase_ failure'*
- *'Dispatching_ with_ low vehicle use_ by_ carrier_ increase_ cost'*
- *'Developing_ access area and place use regulation_ by_ government authority_ for_ delivering_ at_ urban area_ using_ heavy goods vehicle_ affect_ congestion_ and_ land use indicator'* (to enable a clear sentence, we changed the order of some terms).

The following sentences are examples that present potential solutions, initiatives and valuable insights regarding LMD:

- *'Unmanned picking up _ at_ collection centre_ by_ consumer _ decrease_ cost'*

- *'Transporting _ consignment_ within_ urban area_ using_ train_ decrease_ congestion'*
- *'Transporting_ and_ delivering_ by_ third-party carrier_ increase_ use indicator'*

This ontology framework helps decision makers develop and redesign LMD processes. Examining the LMD ontology framework from different perspectives—such as place, time and facilities—reveals different possible LMD structures that can be chosen by decision makers. For example, the following combinations introduce different LMD structures through the place perspective:

- *'Dispatching_ from_ factory_ and_ fixed box delivery_ at_ consignee location'*
- *'Dispatching_ from_ consolidation centre_ and_ manned picking up _ at_ collection centre'*.

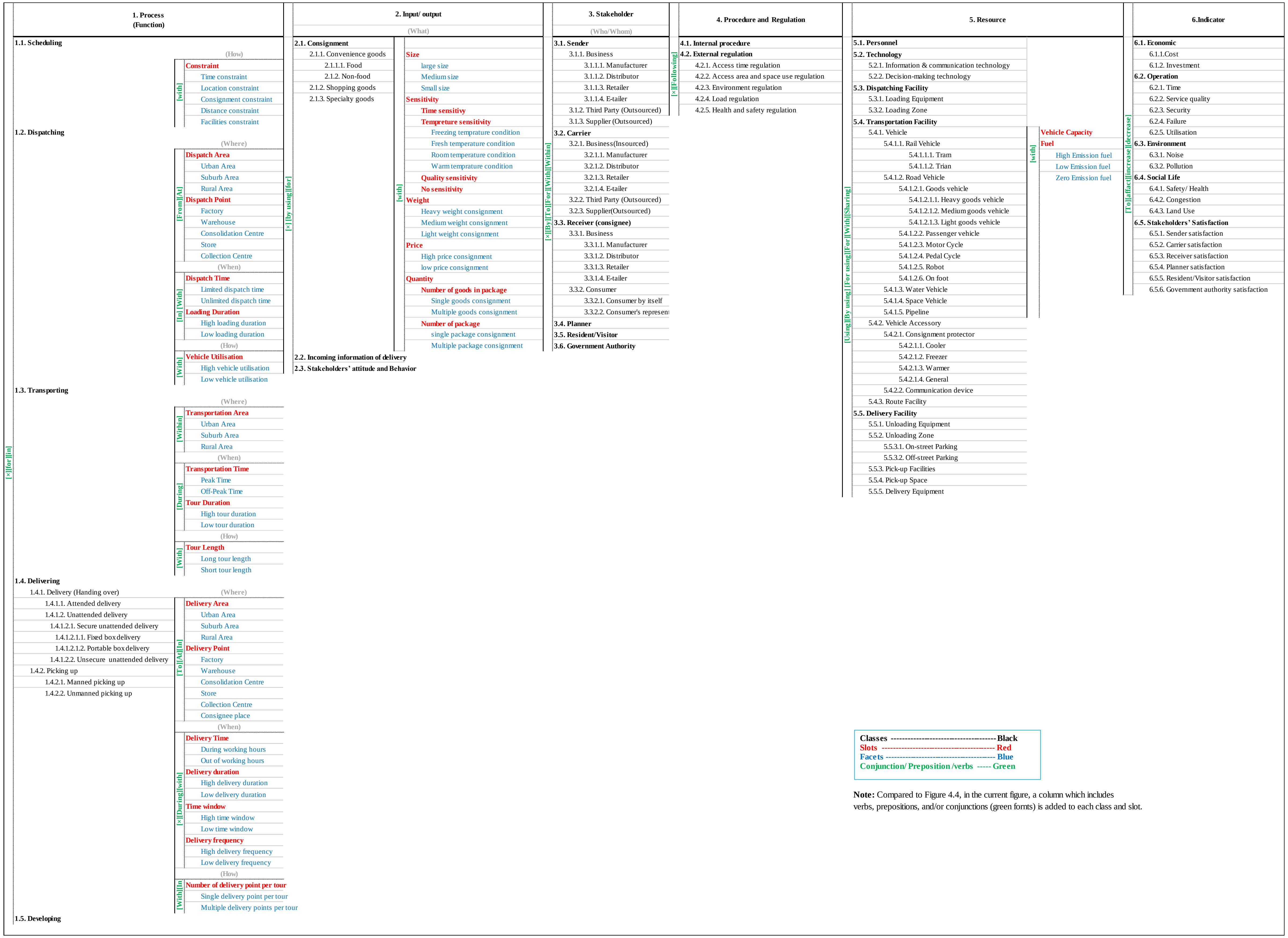



Figure 4.6: Ontological Framework on LMD

### 4.3.5 Last Mile Delivery Ontological Analysis

We used the proposed LMD ontology to analyse the LMD literature and investigate how different components of LMD were addressed by previous studies. We focused on the studies that directly addressed the LMD phenomenon. Therefore, following the instructions explained in Section 3.2.2, we considered ‘last mile’, ‘last kilometre’, ‘home delivery’ and ‘home shopping’ as search terms, which were labelled as the first and second search groups in Section 3.2.2. We sought the search terms in the titles, abstracts and keywords, and found 93 journal and conference papers up to mid-2015, and imported them to NVivo software. The LMD ontology hierarchy was created in NVivo by defining each class/slot as a node. Each paper was manually investigated and allocated to the corresponding classes/slots (nodes) in NVivo software. Each paper could address one or more classes of LMD ontology. All parent classes/slots were automatically tagged when a paper addressed a class/slot.

Matrix X shown in Appendix G indicates how each article addressed different classes in the first level of the LMD ontology, in which $x_{ij} = 1$ if article $i$ addressed class $j$ and $x_{ij} = 0$ otherwise. This matrix is a two-mode matrix with article and class modes. Similar matrices were prepared for other levels of LMD classes (see Appendix H). Using Matrix X, Matrix S was constructed to show the number of classes addressed by each article in which $s_i = \sum_j x_{ij}$. Each level has its own matrix S (see Appendices I and J). Figure 4.7 indicates how the articles addressed the first and second levels of classes of the LMD ontology. It indicates that *process* and *indicator* were the most popular components of LMD for researchers. Between different processes of LMD, *delivery* was investigated in more articles. The articles addressed *economic* and *operation indicators* more than the other indicators. *Procedures/regulation* and *stakeholders* were two subjects not investigated widely by researchers. A limited number of articles (five of 93) addressed *procedures/regulation. Planners, visitors* and *government authorities* were investigated less than the other groups of stakeholders.

| | | | | | |
|---|---|---|---|---|---|
| 1. Process | 93 | 2. Input | 52 | 3. Stakeholder | 39 |
| 1.1. Scheduling | 31 | 2.1. Consignment | 44 | 3.1. Sender | 21 |
| 1.2. Dispatching | 40 | 2.2. Incoming informatio | 4 | 3.2. Carrier | 13 |
| 1.3. Transporting | 44 | 2.3. Stakeholders' attitu | 20 | 3.3. Receiver (consignee) | 28 |
| 1.4. Delivering | 80 | | | 3.4. Planner | 0 |
| 1.5. Developing | 16 | | | 3.5. Resident/Visitor | 2 |
| | | | | 3.6. Government Authority | 5 |
| 4. Procedure & regulatic | 5 | 5. Resource | 50 | 6. Indicator | 81 |
| 4.1. Internal procedure | 1 | 5.1. Personnel | 2 | 6.1. Economic | 53 |
| 4.2. External regulation | 4 | 5.2. Technology | 11 | 6.2. Operation | 55 |
| | | 5.3. Dispatching Facility | 3 | 6.3. Environment | 19 |
| | | 5.4. Transportation Faci | 32 | 6.4. Social Life | 9 |
| | | 5.5. Delivery Facility | 12 | 6.5. Stakeholders' Satisfac | 14 |

Figure 4.7: Numbers of Articles Addressing Each Class of the LMD Ontology (First and Second Levels)

## 4.4 Last Mile Delivery Structures

Based on the LMD definition introduced in Section 4.2, the 'last dispatch point' and 'delivery point' are two critical locations in LMD that form the structure of LMD. Moreover, although the 'preparation point' is not part of LMD, it affects both the last dispatch point and delivery point. To design an LMD structure, decision makers need to decide where the order preparation, last dispatch and delivery actions occur:

- The **preparation point** is where the order preparation action is conducted. The goods of each order are collected from shelves and packed. In other words, the goods are allocated to specific orders and form consignments in this place.

- The **last dispatch point** is where the last dispatch action is conducted, and the consignments are dispatched directly to the delivery point.
- The **delivery point** is where the delivery action is conducted. The delivery action can occur in two different forms: pickup mode or handover mode. Pickup mode is conducted far from the consignee's location, while handover mode occurs at the consignee's location.

According to the proposed LMD ontology, there are various choices for these three decision factors (see Table 4.4). Order preparation, last dispatch and delivery can occur in six different locations along a distribution network:

1. The **factory** refers to the place where goods are produced. Order preparation, last dispatch and collection can occur directly from this location.
2. An **intermediate warehouse** refers a facility where goods are stored, and is located somewhere between the factory (manufacturing facility) and customer. The intermediate warehouse may belong to a manufacturer, distributor or retailer.
3. A **DC/consolidation centre** refers to a place where various consignments are consolidated and accumulated before distribution. While storage is the main function of a normal warehouse, DCs focus on product movement, rather than storage (Langevin and Riopel 2005). According to our classification, there is no storage function in a DC and the prepared orders are just consolidated for specific areas or 'delivery points'.
4. A **store (shop)** refers to a place where goods are displayed for sale. Stores usually require a level of stock for displaying and selling purposes, which enables stores to conduct the order preparation function.

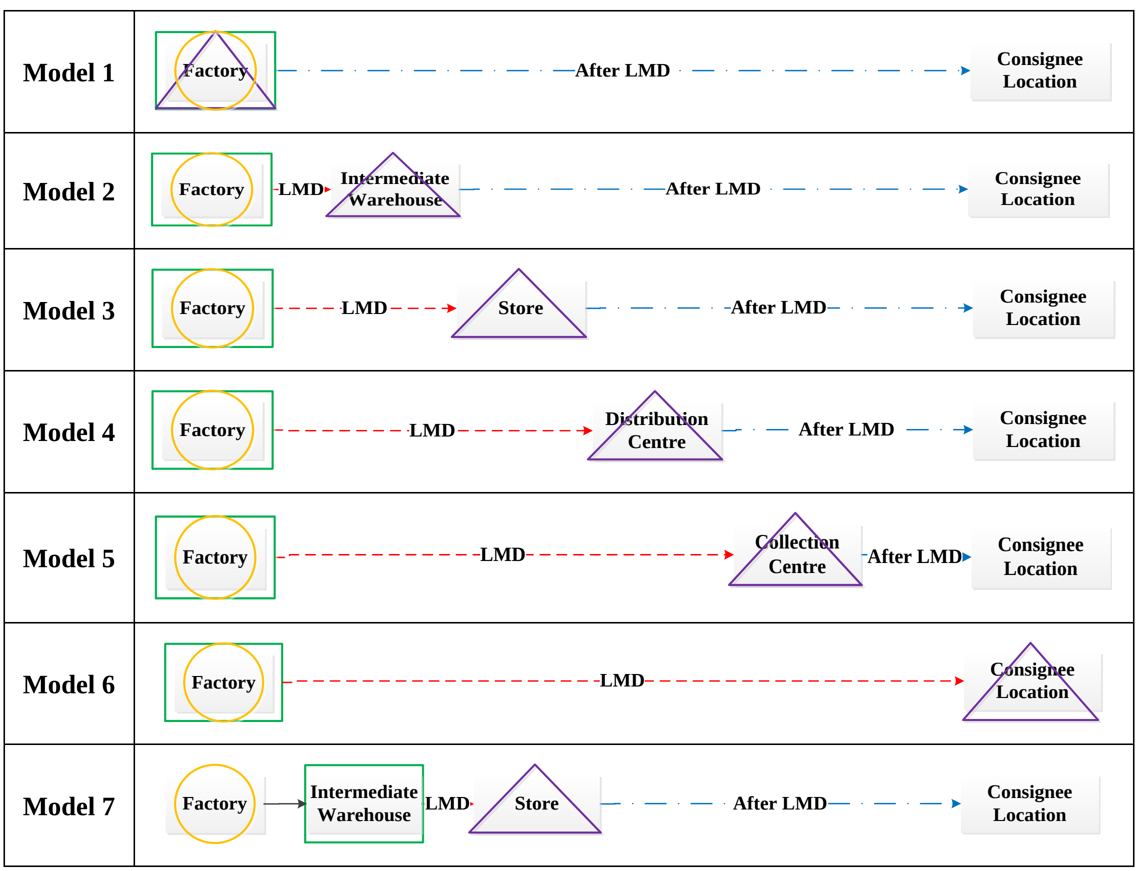
5. A **collection centre (pickup centre)** refers to a facility where consignments await collection by consignees or their representatives. It is assumed that this place is separate from the consignee's location. Although factories, warehouses, stores and DCs are potentially collection centres, these places are not considered collection centres in our classification. Post offices, petrol stations and parcel lockers are some examples of collection centres.
6. The **consignee's location** is the place where the consignee is assumed to have or use consignments.

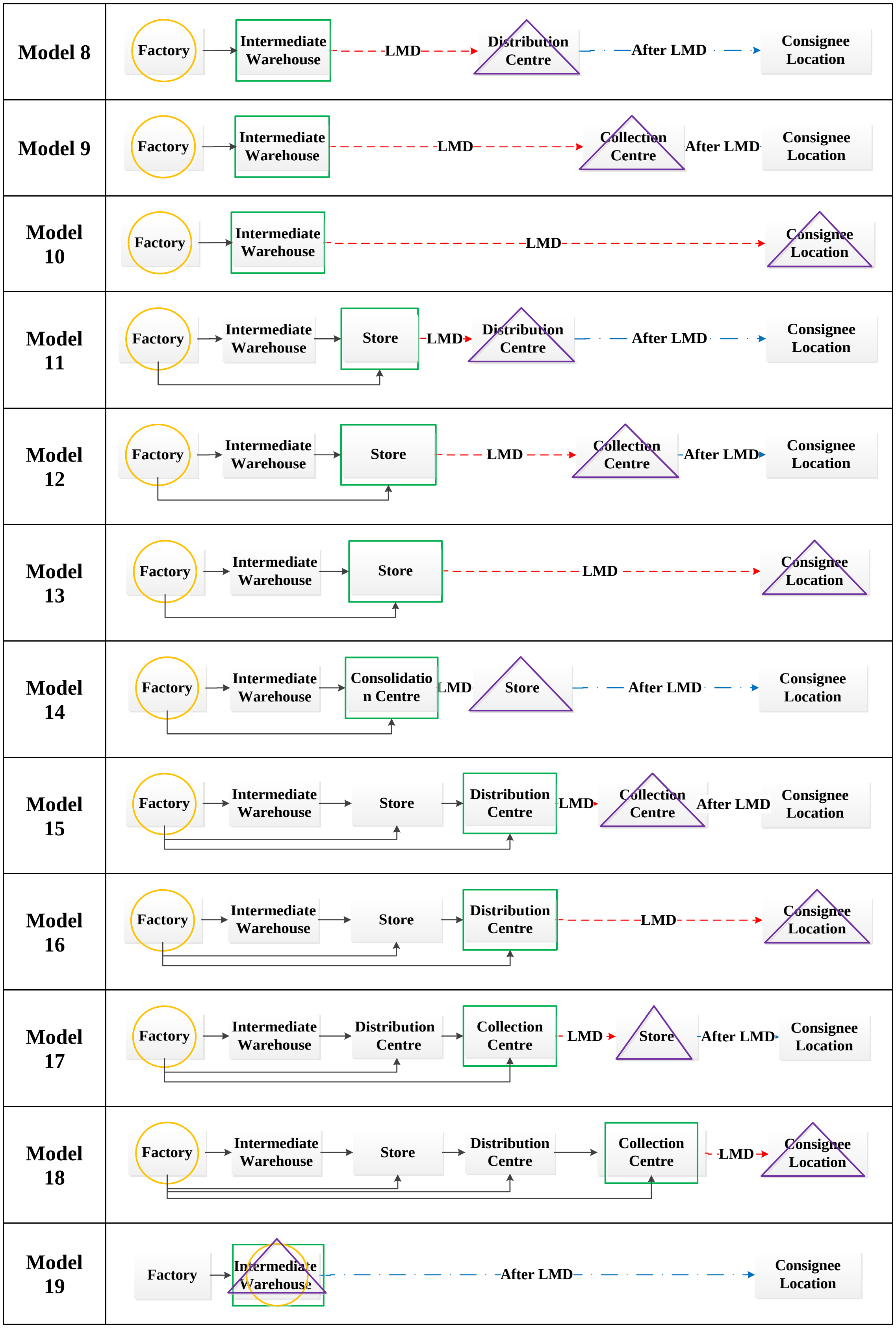
Table 4.4: Different Choices of Last Mile Delivery

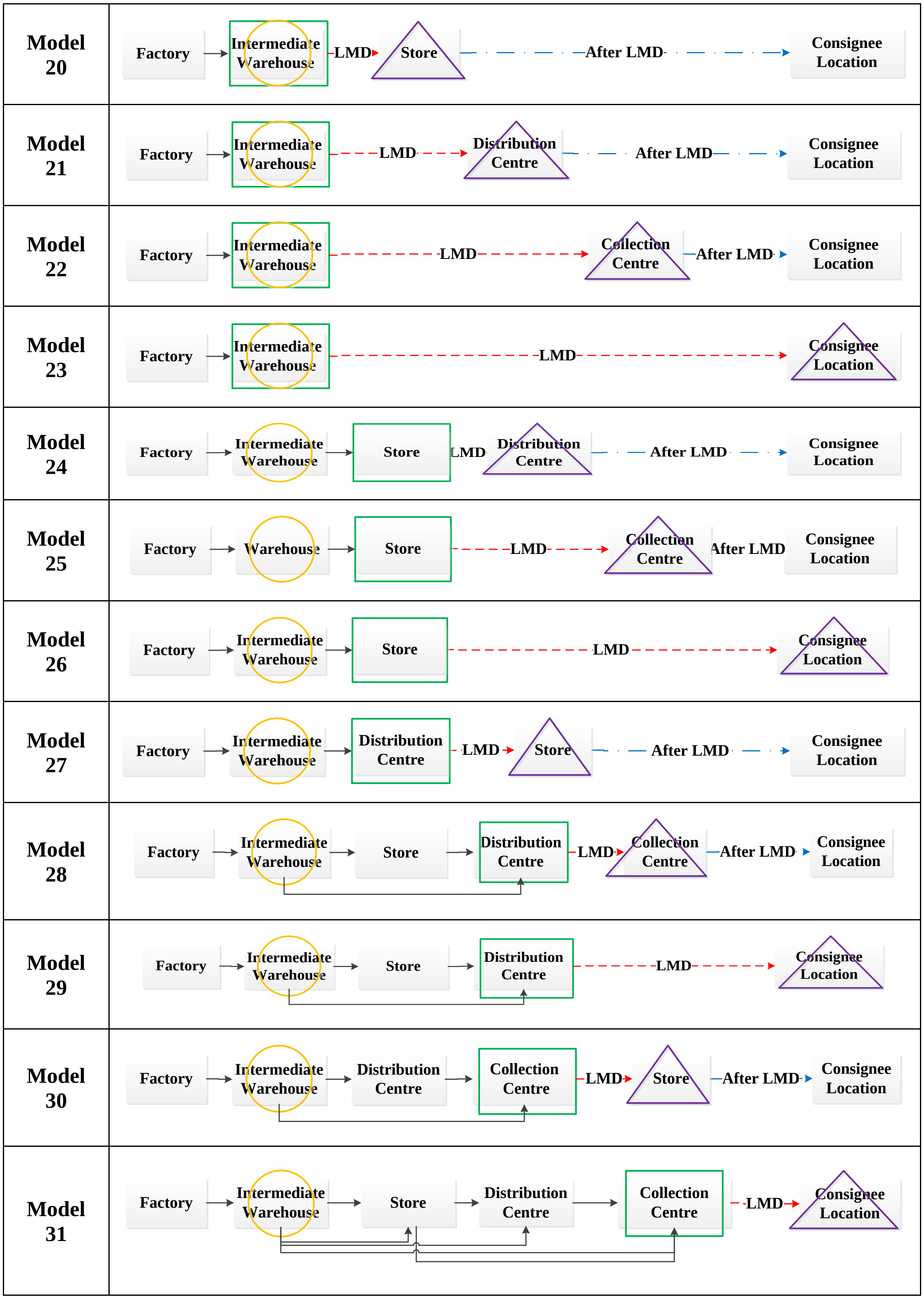
| | **Preparation Point** | **Last Dispatch Point** | **Delivery Point** | |
|---|---|---|---|---|
| | | | **Pickup Mode** | **Handover Mode** |
| Factory | √ | √ | √ | |
| Intermediate warehouse | √ | √ | √ | |
| Store | √ | √ | √ | √ |
| DC | | √ | √ | |
| Collection centre | | √ | √ | |
| Consignee location | | | | √ |

Order preparation can logically occur where the goods are available for collection and packing; thus, a holding inventory function is needed in these locations. Therefore, order preparation can occur in a factory, warehouse or store. As discussed, a consignment is sent to the consignee directly from order preparation points or indirectly from intermediate facilities. Thus, the last dispatch point can be a factory, warehouse, store, DC or collection centre. Delivery activity can occur at any location of a distribution network, including a factory, warehouse, DC, store, collection centre or consignee's location. There are two forms of delivery in LMD: pickup mode and handover mode. During pickup mode, consignees travel to an allocated place that is distant from their location and collect the consignment. In handover mode, carriers deliver the consignment to the consignee's location. A consignee can be a business or consumer; thus, a consignee's location can be a place such as a house, office or shop.

Based on the different choices in order preparation point, last dispatch point and delivery point, we developed 40 potential distinct LMD structures, as shown in Figure 4.8. These models indicate how the last physical movement of goods can occur during a distribution network. Each model has its own advantages and disadvantages. Selection of the appropriate model depends on a wide range of factors, such as cost, customer convenience and lead-time, which were beyond the scope of this study. However, some models may be more popular in a specific industry or circumstance.




Model 8
Factory
Intermediate Warehouse
LMD
Distribution Centre
After LMD
Consignee Location
Model 9
Factory
Intermediate Warehouse
LMD
Collection Centre
After LMD
Consignee Location
Model 10
Factory
Intermediate Warehouse
LMD
Consignee Location
Model 11
Factory
Intermediate Warehouse
Store
LMD
Distribution Centre
After LMD
Consignee Location
Model 12
Factory
Intermediate Warehouse
Store
LMD
Collection Centre
After LMD
Consignee Location
Model 13
Factory
Intermediate Warehouse
Store
LMD
Consignee Location
Model 14
Factory
Intermediate Warehouse
Consolidation Centre
LMD
Store
After LMD
Consignee Location
Model 15
Factory
Intermediate Warehouse
Store
Distribution Centre
LMD
Collection Centre
After LMD
Consignee Location
Model 16
Factory
Intermediate Warehouse
Store
Distribution Centre
LMD
Consignee Location
Model 17
Factory
Intermediate Warehouse
Distribution Centre
Collection Centre
LMD
Store
After LMD
Consignee Location
Model 18
Factory
Intermediate Warehouse
Store
Distribution Centre
Collection Centre
LMD
Consignee Location
Model 19
Factory
Intermediate Warehouse
After LMD
Consignee Location


Model 20
Factory
Intermediate Warehouse
LMD
Store
After LMD
Consignee Location
Model 21
Factory
Intermediate Warehouse
LMD
Distribution Centre
After LMD
Consignee Location
Model 22
Factory
Intermediate Warehouse
LMD
Collection Centre
After LMD
Consignee Location
Model 23
Factory
Intermediate Warehouse
LMD
Consignee Location
Model 24
Factory
Intermediate Warehouse
Store
LMD
Distribution Centre
After LMD
Consignee Location
Model 25
Factory
Warehouse
Store
LMD
Collection Centre
After LMD
Consignee Location
Model 26
Factory
Intermediate Warehouse
Store
LMD
Consignee Location
Model 27
Factory
Intermediate Warehouse
Distribution Centre
LMD
Store
After LMD
Consignee Location
Model 28
Factory
Intermediate Warehouse
Store
Distribution Centre
LMD
Collection Centre
After LMD
Consignee Location
Model 29
Factory
Intermediate Warehouse
Store
Distribution Centre
LMD
Consignee Location
Model 30
Factory
Intermediate Warehouse
Distribution Centre
Collection Centre
LMD
Store
After LMD
Consignee Location
Model 31
Factory
Intermediate Warehouse
Store
Distribution Centre
Collection Centre
LMD
Consignee Location

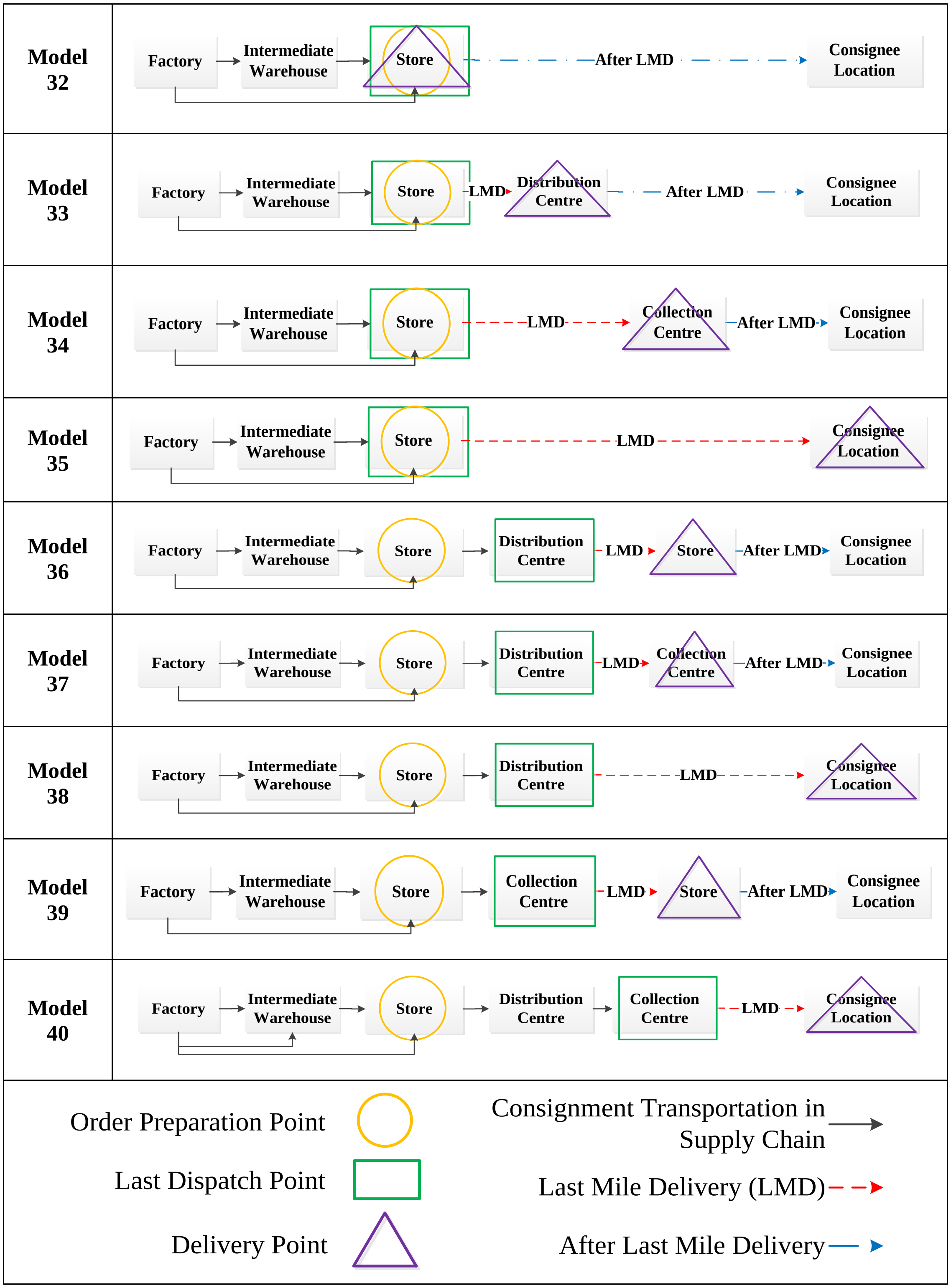



Figure 4.8: LMD Models

Our investigation of one of the largest department stores in Australia indicated that the store adapted Model 14 to deliver goods to its stores (B2B) and used Model 38 to deliver parcels (online orders) to customers (B2C). All goods going to stores for selling and display purposes were prepared at manufacturer (supplier) facilities and transported to a regional DC, where the goods were distributed to all stores in the same region. The factory, DC and store were the order preparation point, last dispatch point and delivery point, respectively, which indicated Model 14. Parcels were prepared at selected stores by store staff and delivered to customers by a carrier. The carrier transported all consignments to a central DC and, from there, the consignments were sent to local DCs, where the last dispatch activity occurred. Therefore, stores, DCs and the consignee's location were the order preparation point, last dispatch point and delivery point of this structure, which indicated Model 38.

Click-and-collect is a very popular marketing channel these days and is offered by many retailers. In this process, parcels are prepared at stores where customers can collect their orders. Click-and-collect corresponds with Model 32; however, in some cases, the products are not available at the customer's most convenient store. Therefore, the order needs to be prepared at another store and transported to the selected store for collection. In this case, click-and-collect may refer to Models 39, 36 or 32.

According to the proposed definition, LMD does not exist when the last dispatch point and delivery point are the same. In Models 1, 19 and 32, the last dispatch point and delivery point are the same location; thus, there is no LMD.

## 4.5 Last Mile Delivery Structures: Case of Melbourne City

Logistics service providers and retailers as the sender, carrier and receiver are the main stakeholders involved in delivering goods to businesses and private customers in the city of Melbourne. In Melbourne, between September 2016 and January 2017, we conducted six in-depth, semi-structured, face-to-face interviews of 60 to 75 minutes in duration. We aimed to involve all three major LMD stakeholders—senders, carriers and receivers—in the interview process. The semi-structured interviews were conducted with six senior managers from four major logistics service providers (as senders and carriers), one main retailer working in the city of Melbourne (as a sender and receiver) and one holding company owning four large shopping centres in the city of Melbourne (as a receiver). We also conducted four separate visiting tours to see the current processes and facilities in two 3PLs, one retailer and one shopping centre. Table 4.5 anonymously lists all interviewees with their background information. The results of the interviews depicted the structure of LMD in the retail sector in the city of Melbourne.

Table 4.5: Interviewees' Profiles

| Participant Firm | Type of Firm | Interviewee | Position | Experience | Education |
|---|---|---|---|---|---|
| Case 1 | 3PL | Participant 1 | Senior manager | More than 11 years of managerial experience in logistics services | Post-graduate |
| Case 2 | 3PL | Participant 2 | Head of department | More than 11 years of managerial experience in logistics services | Post-graduate |
| Case 3 | 3PL | Participant 3 | Senior manager | More than 11 years of managerial experience in logistics services | Graduate |
| Case 4 | 3PL | Participant 4 | Senior manager | More than 20 years of managerial experience in logistics services | Graduate |
| Case 5 | Retailer | Participant 5 | General manager | More than 11 years of managerial experience in logistics services | Post-graduate |
| Case 6 | Shopping centre | Participant 6 | General manager | 17 years of experience in the retail property sector | Graduate |

### 4.5.1 Last Mile Delivery Structure in Case 1 (3PL)

Case 1 was a major Australian logistics company that had been operating in Australia for more than a century. This company served domestic and international markets with a wide range of services, such as parcel and courier, freight transport and warehouse services. This company worked in both B2B and B2C sectors. This company had three types of LMD: (i) delivery via 3PL warehouse, (ii) delivery via a retailer warehouse with dedicated vehicles and (iii) parcel delivery. In the first structure, the company stored products and, from its own warehouse, dispatched them to retailers' stores when orders were placed. Each vehicle dispatching from the warehouse could serve one or more than one store (delivery point), which could be in different locations. Moreover, this company had mini hubs in some major shopping centres, which were used to receive and deliver consignments of several retailers in the shopping centre. Local personnel in the hubs used trollies to deliver the consignments from the hub to retailers' stores in the shopping centre (see Figure 4.9). This structure corresponds with Model 20 explained in Section 4.4.

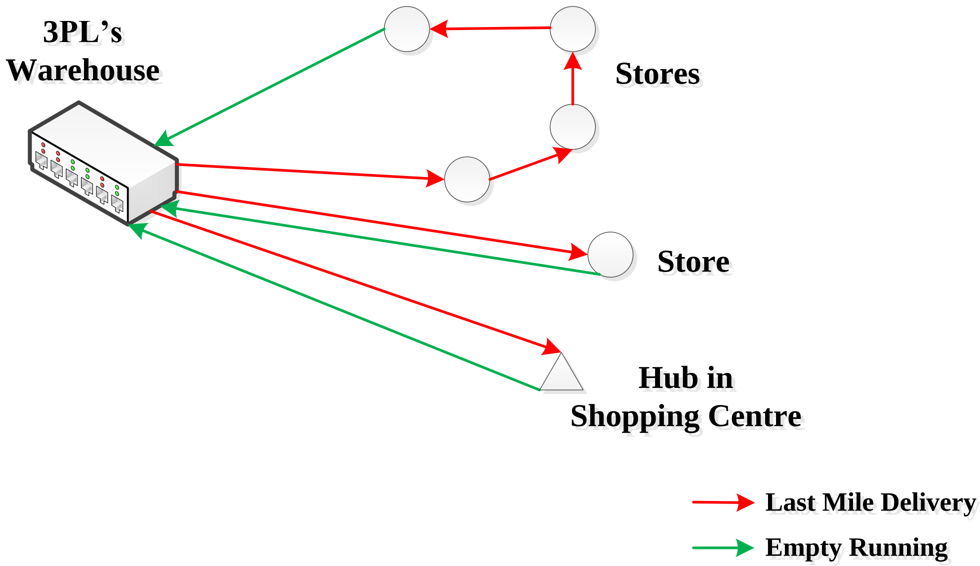



Figure 4.9: LMD in Case 1 (3PL)—Delivery via 3PL Warehouse

The second structure was the same as the first, except consignments were dispatched from the retailer's DCs or warehouses (see Figure 4.10). In this case, vehicles were fully dedicated to the retailers. Vehicles could serve one store or a group of retail stores. This structure corresponds with Models 7, 14, 20 and 27 explained in Section 4.4.

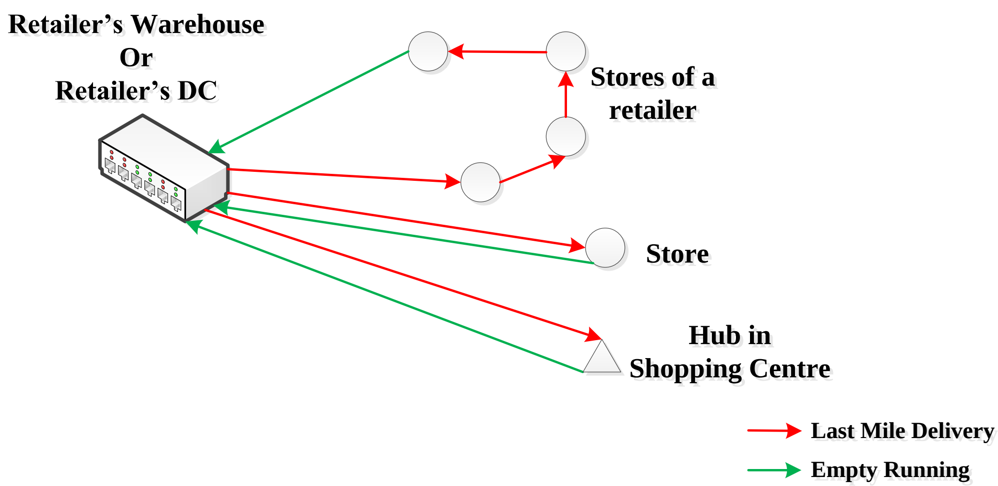



Figure 4.10: LMD in Case 1 (3PL)—Delivery via Retailer's DCs or Warehouses

In the third structure, parcels for the whole of Melbourne were sent to a consolidation centre (Figure 4.11). Parcels were collected by vehicles from the 3PL's local DCs, 3PL's warehouse, retailer's warehouses, retailer's DCs or retailer's stores, and brought to a consolidation centre (collection cycle or 'first mile delivery'). Consignments were consolidated and dispatched from this centre to different delivery points (LMD). The utilisation rate of vehicles collecting parcels from stores in the 'first mile delivery' was between 20% and 30%, while this rate was 80% to 100% in LMD. This structure corresponds with Models 14, 16, 27, 29, 36 and 38 explained in Section 4.4.

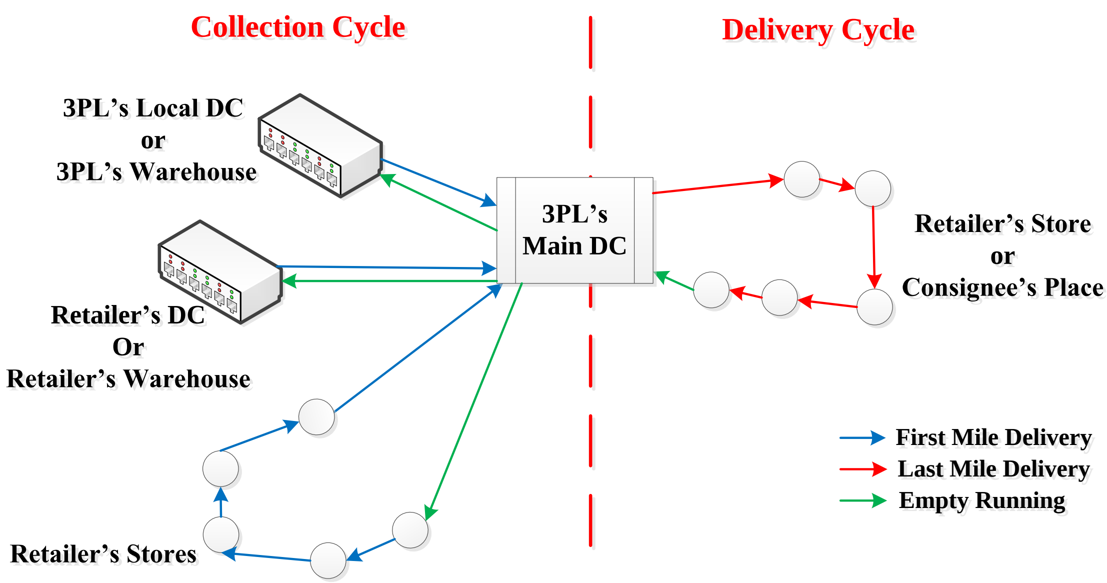



Figure 4.11: LMD in Case 1 (3PL)—Parcel Delivery Structure

### 4.5.2 Last Mile Delivery Structure in Cases 2 and 3 (3PLs)

Cases 2 and 3 (3PLs) involved Australia's largest retail network and delivered to more than 10 million addresses across Australia every day. Parcel delivery in the B2C and C2C sectors was the main service in these 3PLs. In the B2C sector, vehicles ran from the 3PL's local DCs in each area to the whole of Victoria to collect parcels in their specified zone (see Figure 4.12). Depending on volume, a vehicle could travel to one or several points to collect parcels. Light goods vehicles were usually used to collect parcels; however, for retailers with higher volume, larger vehicles with a direct tour were allocated. Suitable vehicles were allocated depending on the volume and loading/unloading limitations at stores. Regardless of the destination, all parcels were sent by larger vehicles to the 3PL's main DC, where all parcels were sorted and consolidated based on their destination zone. The parcels were then sent to the 3PL's local DCs by medium or heavy goods vehicles. All coming and going vehicles in the 3PL's main DC were medium or heavy goods vehicles and did not use light goods vehicles in this centre. The parcels were sorted based on destination addresses and streets, and delivered by light goods vehicles (vans). All collection and delivery tours in the 3PL's local DCs had one empty run in their initial or return trips. This structure corresponded with Models 29 and 38 described in Section 4.4.

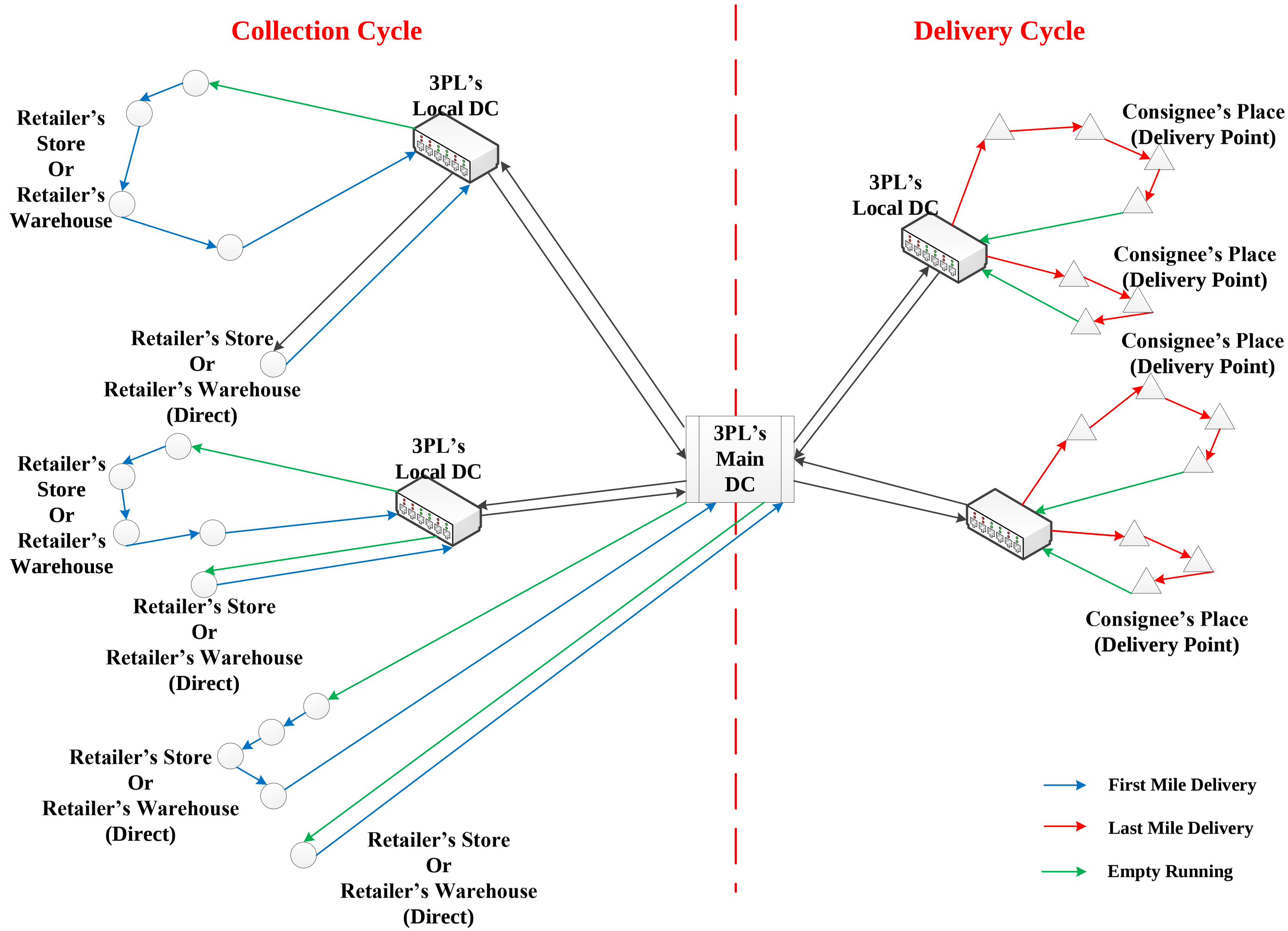



Figure 4.12: LMD in Cases 2 and 3 (3PL)—Parcel Delivery Structure

### 4.5.3 Last Mile Delivery Structure in Case 4 (3PL)

Case 4 (3PL) was also one of the largest 3PL businesses in Australia. This 3PL only worked in the B2B sector; thus, there was no parcel delivery service in this company. The structures of LMD in this 3PL were similar to 3PL Case 1's structure. This company followed two structures: via 3PL's warehouses or via retailer's DCs or warehouses (see Figures 4.13 and 4.14).

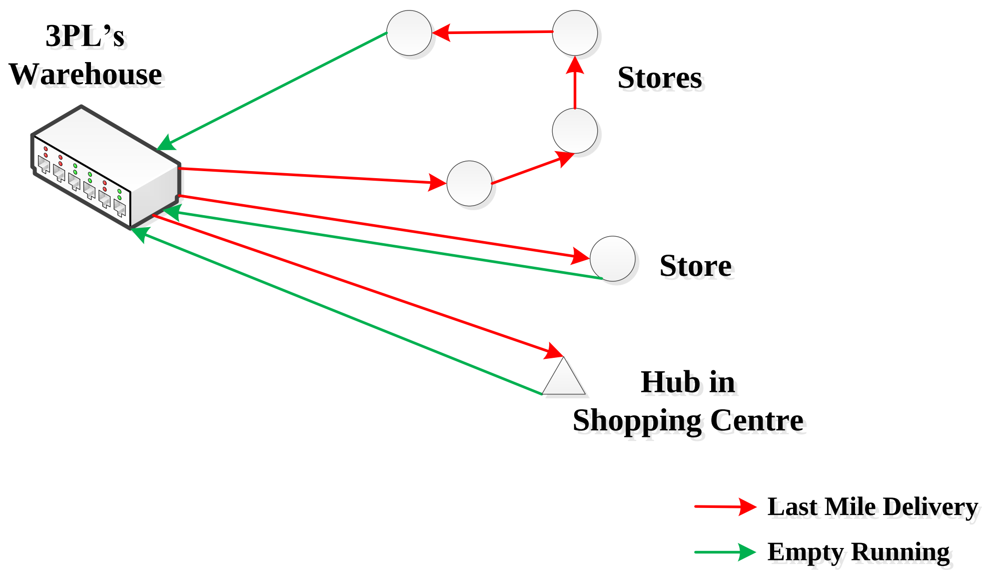



Figure 4.13: LMD in Case 4 (3PL)—Via 3PL's Warehouse

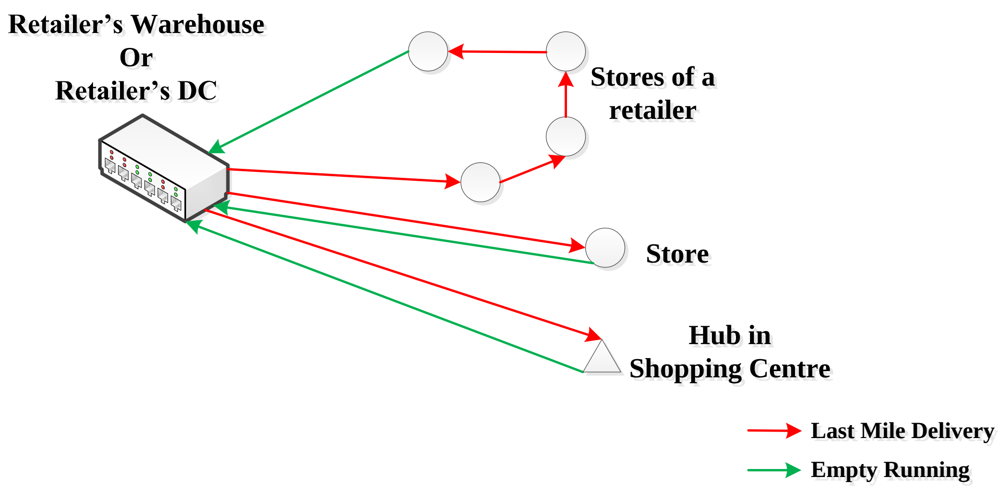



Figure 4.14: LMD in Case 4 (3PL)—Via Retailer's DCs or Warehouse

### 4.5.4 Retailer's Last Mile Delivery Structure (Case 5)

This study considered one of the main retailers in Australia and Melbourne's CBD. This retailer has more than 50 stores across Australia and is one of the most popular department stores in Melbourne CBD. This retailer supplies its products from around 1,200 local and global suppliers. This retailer was using two different structures to deliver goods from suppliers to the retailer's Victorian stores (B2B sector). In the first structure, which included about 80% of deliveries, the retailer used a DC to cross-dock goods from different suppliers. All goods came to a retailer's DC and were sorted and consolidated based on stores' demand (see Figure 4.15). The goods were dispatched using dedicated light and medium goods vehicles. The vehicles belonged to 3PL Case 4 and were dedicated to this retailer according to an agreement. All vehicles usually had a direct tour from the DC to the store. It was rare to serve more than one store in each tour, but this could happen during quiet seasons. The rate of vehicle utilisation was near 100%, but most vehicles came back empty to the DC. All stores were served by at least one vehicle per day. The store located in the Melbourne CBD was usually served by between five and eight vehicles per day. As a result of limitations in store docks, this retailer could not use larger vehicles to reduce the number of running vehicles. Vehicles could carry a maximum of 10 or 12 pallets in each trip. The first delivery structure of this retailer corresponded with Models 14 and 27 described in Section 4.4.

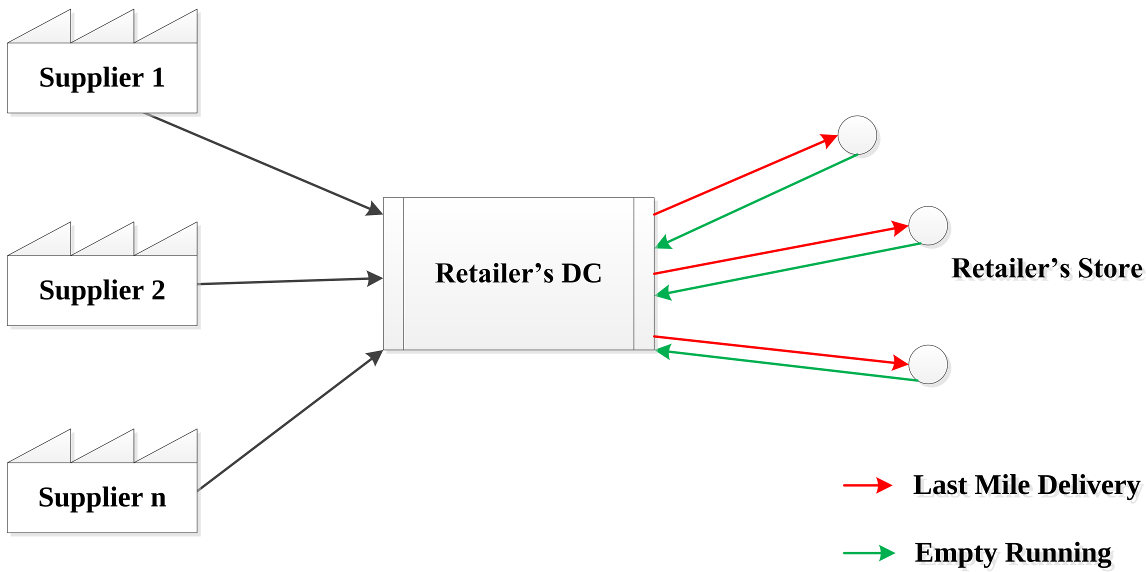


Figure 4.15: LMD in Case 5 (Retailer)—Via Retailer's DCs

In the second structure, the retailer's suppliers delivered their goods directly to the retailer's stores. These products did not pass the retailer's DCs (see Figure 4.16). Suppliers could use a 3PL to complete their delivery or use their own vehicles and distribution system. The first delivery structure of this retailer corresponded with Models 3, 7, 14, 17, 20, 27, 30, 36 and 39 described in Section 4.4.

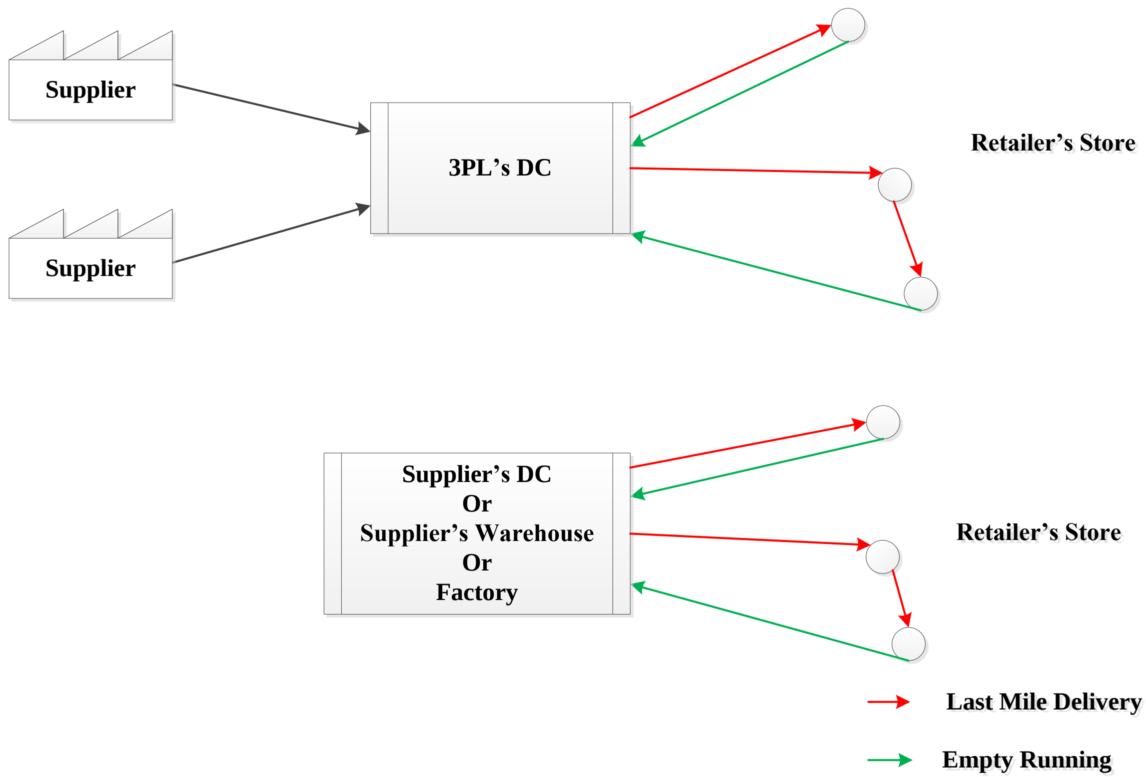



Figure 4.16: LMD in Case 5 (Retailer)—From Supplier's Network

## 4.6 Summary

This chapter has discussed the output of content analysis, ontological analysis and interviews that we completed to demystify the LMD phenomenon. According to our investigation, 'last mile delivery' is the dominant phrase for addressing the LMD phenomenon. Through conducting a content analysis on LMD definitions, the definition and scope of LMD were redefined. In this chapter, we have presented an LMD ontology and discussed possible problems, solutions and structures that can be extracted from the proposed LMD ontology framework. Our ontological analysis of the extant LMD literature indicated that previous researchers have not thoroughly examined LMD stakeholders and LMD procedures. Using the proposed LMD ontology and the proposed definition, we developed LMD structures and introduced 40 different structures (models) based on the location of conducting preparation, dispatching and delivery processes. Through using these models and conducting interviews with logistics managers in Melbourne, we depicted the structure of LMD in the retail sector in Melbourne city.

# Chapter 5: Last Mile Delivery Model Development with and without Coopetition Strategy

The purpose of this chapter is to develop and examine LMD models with and without coopetition in the urban context. First, Section 5.1 presents and discusses conceptual LMD models with and without coopetition. The conceptual models are described in the form of scenarios with and without coopetition. In Section 5.2, we present mathematical models to evaluate the proposed scenarios. The assumptions and formulations of each scenario, including the formulation of objectives and constraints, are presented in detail. Then, in Section 5.3, we evaluate the proposed LMD scenarios using MATLAB software. To complete the computational tests, we required suitable sets of instances. Thus, we explain how we generated these instances, and then present the results of the computational tests. In Section 5.4, the LMD scenarios are examined using real data from a case study in Melbourne. Section 5.5 presents a summary of the results to provide an overview of the outcomes of the scenarios. Section 5.6 analyses the effects of changes in the main factors on the performance of the scenarios. Finally, Section 5.7 presents a summary of the findings related to clarification of LMD.

## 5.1 Conceptual Model of Last Mile Delivery with and without Coopetition Strategy

Based on the findings from demystifying LMD presented in Chapter 4, sharing empty running vehicles among competitors is a potential area for improving LMD performance. Considering this idea, we discussed with the interviewees ways to develop a model in LMD with a coopetition strategy. As discussed in Chapter 4, because of the loading and unloading limitations of shopping centres, 3PLs in the Melbourne urban area currently use small size vehicles to collect parcels from shopping centres and deliver them to their local DCs. The parcels are then picked up by larger vehicles and delivered to the 3PL's main DC. This network is called a '3PL network' in this research. Besides this network, numbers of vehicles travel between the retailer's DCs and shopping centres to deliver goods to retail stores at shopping centres. This network is called a 'retailer network' in this research. In this network, vehicles deliver goods to shopping centres and return empty to the retailer's DCs (see Figure 5.1). The LMD in this case is conducted in a B2B context. A retailer network can be operated by a 3PL or the retailer's own system. However, in our case study, a retailer network is conducted by a 3PL. This research investigates how cooperation between these networks can improve the delivery performance of both networks. We suggest that the empty running vehicles of the retailer network should complete the 'first mile delivery' of the 3PL network. Instead of 3PL network vehicles, the empty running vehicles of the retailer network can collect parcels and deliver them to the retailer's DCs without changing their routes (see Figure 5.2). The parcels are then collected by larger vehicles from the retailer's DCs and taken to the 3PL's main DC. In this study, transportation between the shopping centres and the 3PL's local DCs or the retailer's DCs is called the 'first echelon', and transportation from the 3PL's local DCs or retailer's DCs to the 3PL's main DC is called the 'second echelon'.

The proposed LMD model with coopetition can also be described by the proposed LMD ontology framework as 'Retailer_ delivering_ at_ store_ share_ Road vehicle_ with_ third party_ dispatching_ from_ store _ to decrease_ cost_ and_ time_ and_ increase_ use’ (see Section 4.3.4). To analyse the performance of the proposed LMD model with coopetition, we considered three scenarios:

- **Scenario I**, w**ithout coopetition strategy—current situation:** This scenario represents the current situation, where the 3PL network and retailer network work separately. Parcels are collected only by 3PL network vehicles from shopping centres (see Figure 5.1). These vehicles travel between the 3PL’s local DCs and shopping centres in a fixed time schedule, during business hours (9.00 am to 4.00 pm). Larger vehicles then carry parcels from the 3PL’s local DCs to the 3PL’s main DC in a fixed time schedule.
- **Scenario II**, **with coopetition strategy:** Instead of 3PL network vehicles, parcels are collected by retailer network vehicles in this scenario (see Figure 5.2). The retailer network vehicles leave shopping centres on a fixed time schedule, during business hours (8.00 am to 3.00 pm). Larger vehicles then carry parcels from the retailer’s DCs to the 3PL’s main DC in optimum time schedules.
- **Scenario III**, **with coopetition strategy—mixed model:** Parcels are collected by both retailer and 3PL network vehicles in this scenario (see Figure 5.2). The vehicles of both networks run their trips on a fixed schedule during business hours (8.00 am to 4.00 pm). Larger vehicles then carry parcels from the retailer’s DCs or 3PL’s local DCs to the 3PL’s main DC in optimum time schedules.

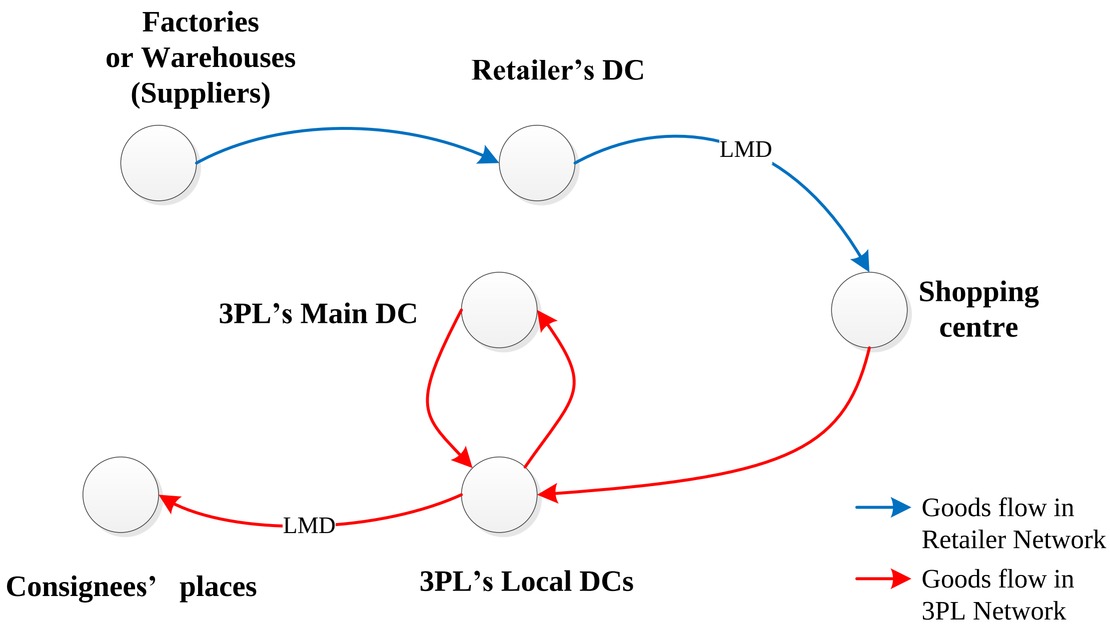



Figure 5.1: Retailer Network and 3PL Network—Scenario I, without Coopetition

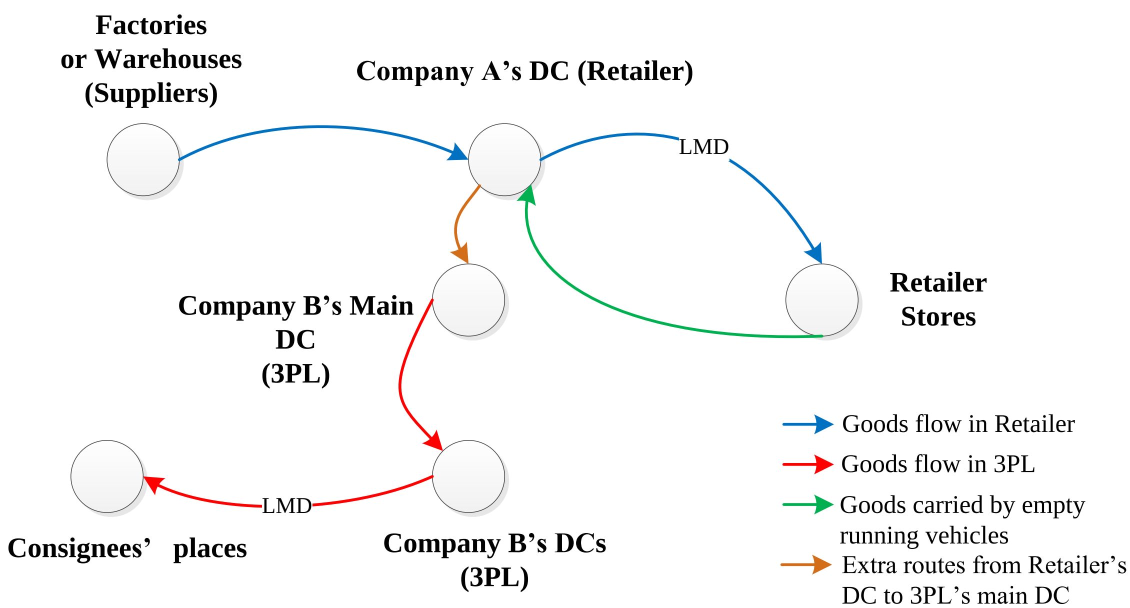



Figure 5.2: Retailer Network and 3PL Network—Scenarios II and III, with Coopetition

## 5.2 Mathematical Last Mile Delivery Model with and without Coopetition Strategy

We developed an LMD model with coopetition strategy and presented three scenarios to investigate the performance of the proposed model. To conduct the investigation, the proposed scenarios were formulated mathematically. Three main indicators—including cost, lead-time and travelling distance—were considered for all three proposed scenarios in this research. The cost indicator was calculated based on the number of vehicles and their travelling distance. Lead-time in this model was defined as the difference of the time between when a parcel is ready to be dispatched at a shopping centre and when the parcel is delivered to the 3PL's main DC. Besides cost and lead-time, the rate of total travelling distance can clearly depict the performance of each scenario. The total distance that all vehicles travel in both networks was defined as the total travelling distance indicator, which was an environmental indicator.

In the first scenario, each parcel passed an identified route to reach the 3PL's main DC. Therefore, cost, lead-time and total travelling distance indicators were calculated by following the current process. In the scenarios with coopetition, Scenarios II and III, there were various possible routes for each parcel. Multi-objective MILP was used to find the optimum routes. The mean cost of each parcel and mean lead-time of each parcel were considered two objectives of the optimisation program. Total travelling distance was then calculated for each optimum solution.

### 5.2.1 Model Assumptions

The following assumptions were considered for the three scenarios:

- Parcels were assumed to be ready for collection between 7.00 am and 3.00 pm. This time could differ for each parcel and depended on the preparation process. It was assumed that the preparation process of each retailer worked between 6.00 am and 3.00 pm and could prepare a specific number of parcels per hour. Therefore, the time that parcels were ready for collection at shopping centres followed a uniform distribution.
- The dispatching time of vehicles from shopping centres in both networks was fixed. Vehicles left shopping centres between 8.00 am and 3.00 pm.
- Parcels were allowed to be collected the next day.
- It was assumed that there was one DC for each retailer.
- Each 3PL's local DC served only one shopping centre; therefore, the number of 3PL's local DCs was equal to the number of shopping centres.

### 5.2.2 Model Formulation and Notations

Cost, lead-time and travelling distance were calculated to evaluate the performance of scenarios with and without coopetition. The following cost components were considered in each scenario:

- transportation cost in the 'first echelon': the distance between shopping centres and retailer's DCs or 3PL's local DCs, multiplied by the distance cost rate
- transportation cost in the 'second echelon': the distance between the retailer's DCs or 3PL's local DCs and 3PL's main DC, multiplied by the distance cost rate

- loading and unloading cost in the first echelon: the number of parcels, multiplied by the loading and unloading rate in the first echelon
- loading and unloading cost in the second echelon: the number of parcels, multiplied by the loading and unloading rate in the second echelon.

The transportation cost between two nodes was calculated by multiplying the distance between the origin and destination and the distance cost rate. In the first echelon, the origin was a shopping centre and the destination was a retailer's DC or 3PL's local DC. In the second echelon, the origin was a retailer's DC or 3PL's local DC and the destination was the 3PL's main DC. The transportation cost would be double in the case of round trips. Therefore, the total transportation cost in the first echelon or second echelon in each scenario was calculated by summing the transportation cost between each couple of nodes for which transportation occurred.

The loading and unloading cost was considered to calculate the whole system cost in each scenario. Each parcel needed to be loaded and unloaded in each node of the first echelon and second echelon. To simplify the calculation, a constant rate was considered for the loading and unloading cost of each parcel in each echelon. Therefore, the number of parcels multiplied by the loading and unloading rate determined the amount of loading and unloading cost in each echelon. To formulate the scenarios with and without coopetition, the following notations were considered.

5.2.2.1 Variables

To complete the calculations, binary variables were defined as follows:

$$x_{ijpk} = \begin{cases} 1 & \text{if } p^{th} \text{ parcel of shopping centre } i \text{ is carried to DC } j \text{ by } k^{th} \text{ vehicle} \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ijpv} = \begin{cases} 1 & \text{if } p^{th} \text{ parcel of shopping centre } i \text{ is carried from DC } j \text{ to 3PL main DC by } v^{th} \text{ vehicle} \\ 0 & \text{otherwise} \end{cases}$$

$$m_{ijk} = \begin{cases} 1 & \text{if } \sum_{p}^{n_{p_i}} x_{ijpk} > 0 \text{ (At least one parcel is carried by } k^{th} \text{ vehicle travelling from } i \text{ to } j\text{)} \\ 0 & \text{if } \sum_{p}^{n_{p_i}} x_{ijpk} = 0 \end{cases}$$

$$n_{jv} = \begin{cases} 1 & \text{if } \sum_{i}^{n_s} \sum_{p}^{n_{p_i}} y_{ijpv} > 0 \text{ (At least one parcel is carried by } v^{th} \text{ vehicle travelling from } j \text{ to 3PL's main DC)} \\ 0 & \text{if } \sum_{i}^{n_s} \sum_{p}^{n_{p_i}} y_{ijpv} = 0 \end{cases}$$

5.2.2.2 Sets

The following sets were considered in this problem:

*i*: shopping centres, $\{1,2, \ldots, n_s\}$

$n_s$ = number of shopping centres

*j*: DCs (retailer and 3PL), $\{1,2, \ldots, n_{RDC}, n_{RDC}+1, \ldots, n_{RDC} + n_{TRC}\}$

$n_{TDC}$ = number of 3PL's local DCs

$n_{RDC}$ = number of retailer's DCs

*k*: runs of vehicles from shopping centre *i* to DC *j*, $\{1,2, \ldots, n_{k_{ij}}\}$

$n_{k_{ij}}$ = number of runs (vehicles) from shopping centre *i* to DC *j* in the first echelon

*v*: runs of vehicle from *j* to the 3PL's main DC, $\{1,2, \ldots, n_{v_j}\}$

$n_{v_j}$ = number of runs (vehicles) from $j$ to 3PL's main DC in the second echelon

$p$: parcel (or pallet), $\{1, 2, \ldots, n_{p_i}\}$

$n_{p_i}$ = total number of consignments at $i$

5.2.2.3 Parameters

To conduct the calculations, the following parameters were considered in this problem:

$D1R_{ij}$ = distance between shopping centre $i$ and retailer's DC $j$ in the first echelon

$D1T_{ij}$ = distance between shopping centre $i$ and $j$ (3PL's local DC) in the first echelon

$D2Rj$ = distance between retailer's DC $j$ and 3PL's main DC in the second echelon

$D2Tj$ = distance between $j$ (3PL's local DC) and 3PL's main DC in the second echelon

$DCR1R$ = distance cost rate of retailer network vehicles in the first echelon (dollars per kilometre)

$DCR1T$ = distance cost rate of 3PL network vehicles in the first echelon (dollars per kilometre)

$DCR2R$ = distance cost rate of 3PL network vehicles leaving retailer's DCs in the second echelon (dollars per kilometre)

$DCR2T$ = distance cost rate of 3PL network vehicles leaving 3PL's local DC in the second echelon (dollars per kilometre)

$LoC1$ = loading and unloading cost in the first echelon (dollars per parcel)

$LoC2$ = loading and unloading cost in the second echelon (dollars per parcel)

$Cap1_{ijk}$ = capacity of the vehicle travelling from $i$ to $j$ in the $k^{th}$ run in the first echelon

$Cap2_{jv}$ = capacity of the vehicle travelling from $j$ to 3PL's main DC in the $v^{th}$ run in the second echelon

$T1_{ip}$ = time that $p^{th}$ parcel of shopping centre $i$ is ready to collect at the shopping centre

$T2_{ip}$ = time that $p^{th}$ parcel of shopping centre $i$ is received to selected DC in the first echelon

$T3_{ip}$ = time that $p^{th}$ parcel of shopping centre $i$ is received to 3PL's main DC

$T1Updated_{ip}$ = recalculating the time that $p^{th}$ parcel of shopping centre $i$ is ready to collect, but cannot be collected on the same day

$Du1_{ijk}$ = travelling duration of $k^{th}$ vehicle from shopping centre $i$ to DC $j$

$Du2_{jv}$ = travelling duration of $v^{th}$ vehicle from DC $j$ to 3PL's main DC

$DTime1_{ijk}$ = departure time of $k^{th}$ vehicle from shopping centre $i$ to DC $j$

$DTime2_{jv}$ = departure time of $v^{th}$ vehicle from DC $j$ to 3PL's main DC

### 5.2.3 Formulation of Scenario I

In the current situation, 3PL network vehicles travel from their local DC to the specified shopping centre to collect parcels. Each vehicle collects the parcels of a specified retailer based on a fixed time schedule. The maximum size of vehicles (vehicle capacity) is limited to the size of the shopping centre loading/unloading area. Parcels are then dispatched by larger vehicles from the 3PL's local DCs to the main DC in the late afternoon. The dispatching time of vehicles in both echelons (from the shopping centres and 3PL's local DCs) is fixed. The number of vehicles travelling between each couple of nodes in both echelons depends on the number of parcels and the capacity of vehicles, and is determined by 3PL. Customers may place their orders any time of a day; however, the time that the orders are ready to dispatch (*T1*) depends on the preparation process, which is assumed to operate during business hours. Given that vehicles leave shopping centres in a fixed time schedule, parcels that are prepared after the vehicles' departure time will be shipped the next day. Given that the capacity and number of vehicles are limited, some parcels cannot be shipped by the same-day vehicles and need to be shipped the next day.

Beside the 3PL network, retailer network vehicles travel from the retailer's DCs to the shopping centres to deliver goods to the retailer's shops and return to the retailer's DCs empty. Each vehicle has a direct round trip to a shopping centre. In this network, there is just one DC for each retailer, and it is assumed that these DCs are close to the 3PL's main DC. These vehicles travel between the retailer's DCs and the shopping centres based on a fixed time schedule during business hours. In this scenario, these vehicles are empty on their return trip and do not carry any parcels from the shopping centres to the retailer's DCs. The number of empty running vehicles ($n_{k_{ij}}$) travelling between each shopping centre and the retailer's DCs depends on the demand for the retailer's shops and can differ in different situations. The mean cost per parcel, mean lead-time and total travelling distance of this scenario are calculated as follows.

5.2.3.1 Mean Cost per Parcel Formula

Equation 5.1 formulates the total transport cost of the current situation, which includes the transport cost of the retailer's empty running vehicles, loading and unloading cost in the first echelon, cost of transporting parcels from the shopping centres to the 3PL's local DCs, loading and unloading cost in the second echelon, and cost of transporting parcels from the 3PL's local DCs to the 3PL's main DC:

Total cost of Scenario I

$$= \sum_{i=1}^{n_s} \sum_{j=1}^{n_{RDC}} \sum_{k=1}^{n_{k_{ij}}} (D1R_{ij} * DCR1R) + \sum_{\substack{i=1 \\ j=i+n_{RDC}}}^{i=n_s} \sum_{k=1}^{n_{k_{ij}}} (2 * D1T_{ij} * DCR1T)$$

$$+ \sum_{j=1+n_{RDC}}^{n_{RDC}+n_{TDC}} \sum_{v=1}^{n_{v_j}} (2 * D2T_{ij} * DCR2T) + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC1 + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC2$$

Equation 5.1

The first part of Equation 5.1 shows the current cost of empty running vehicles in the retailer network. The second and third parts of this equation show the cost of transporting parcels in the 3PL network in the first echelon and second echelon, respectively. The number of 3PL vehicles travelling between each couple of nodes in the first echelon and second echelon ($n_{k_{ij}}$ *and* $n_{v_j}$, respectively) is determined based on the number of parcels, $n_{p_i}$, and capacity of related vehicles ($Cap1_{ijk}$ and $Cap2_{jv}$), and is calculated by Equations 5.2 and 5.3:

$$n_{k_{ij}} = n_R * \left\lceil \frac{n_{p_i}}{(Cap1_{ij1} * n_R)} \right\rceil \quad i \in \{1, \ldots, n_s\} \text{ and } j \in \{n_{RDC} + 1, \ldots, n_{RDC} + n_{TDC}\}$$

Equation 5.2

$$n_{v_j} = \left\lceil \frac{n_{p_j}}{Cap2_{j1}} \right\rceil \; j \in \{n_{RDC} + 1, \ldots, n_{RDC} + n_{TDC}\}$$

Equation 5.3

It is assumed that each 3PL's local DC supports just one shopping centre in this scenario. Therefore, $n_{TDC}$ is equal to $n_s$ in this scenario.

To calculate the mean cost per parcel, the total cost is divided by the total number of parcels (see Equation 5.4):

Mean cost of Scenario I

$$= \left( \begin{array}{c} \sum_{i=1}^{n_s} \sum_{j=1}^{n_{RDC}} \sum_{k=1}^{n_{k_{ij}}} (D1R_{ij} * DCR1R) + \\ \sum_{\substack{i=1 \\ j=i+n_{RDC}}}^{i=n_s} \sum_{k=1}^{n_{k_{ij}}} (2 * \ D1T_{ij} * DCR1T) + \\ \sum_{j=1+n_{RDC}}^{n_{RDC}+n_{TDC}} \sum_{v=1}^{n_{v_j}} \left(2 * \ D2T_{ij} * DCR2T\right) \ + \\ \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC1 + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC2 \end{array} \right) \Bigg/ \sum_{i=1}^{n_s} n_{p_i} \qquad \text{Equation 5.4}$$

### 5.2.3.2 Mean Lead-time Formula

The lead-time of each parcel is defined as the difference between the time when a parcel is ready to dispatch at a shopping centre (*T1*) and the time that the parcel is delivered to the 3PL's main DC (T3) (see Equation 5.5). Some parcels are ready after the departing time of the last vehicle leaving the shopping centre; therefore, they cannot be shipped the same day. To calculate the real lead-time of parcels shipped the next day, *T1Updated* was calculated and used instead of *T1* (see Equation 5.6). The parcels shipped the next day should wait a maximum of 24 extra hours to be collected. The same problem occurs for some parcels on the previous day. Therefore, vehicles should ship some parcels that could not be shipped on the previous day. We assumed that the number of parcels from the previous day was equal to the number of parcels that would be shipped the next day. Considering this assumption, *T1* was updated using Equation 5.7. In this way, the system considered all parcels that could be shipped in the same day and those that could not be shipped on the previous day, which is the same as considering all parcels prepared during the business hours of a specific day.

T3 directly depends on the arrival time of vehicles to the 3PL's main DC in the second echelon. The T3 of each parcel is equal to the arrival time of the related vehicle to the 3PL's main DC. Therefore, the T3 of each parcel was calculated by summation of the departure time of the related vehicle from the 3PL's local DCs (*DT2*) and the travelling time of the vehicle to reach the 3PL's main DC (*Du2*) (see Equation 5.8). Equation 5.9 shows the summation of the lead-time of all parcels in more detail. To calculate the mean lead-time, the total lead-time is divided by the total number of parcels/pallets (see Equation 5.10):

$$Lead\ time_{ip} = T3_{ip} - T1_{ip} \qquad \text{Equation 5.5}$$

$$Lead\ time_{ip} = T3_{ip} - T1Updated_{ip} \qquad \text{Equation 5.6}$$

$$T1Updated_{ip} = \begin{cases} \mathrm{T1_{ip}} - 24\ \text{hours} & \text{if the parcel cannot be shipped on the same day} \\ \mathrm{T1_{ip}} & \text{if the parcel can be shipped on the same day} \end{cases} \qquad \text{Equation 5.7}$$

$$T3_{ip} = DTime2_{i1} + Du2_{i1} \qquad \text{Equation 5.8}$$

$$\text{Total lead time} = \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} DTime2_{i1} + Du2_{i1} - T1Update_{ip} \qquad \text{Equation 5.9}$$

$$\text{Mean lead time} = \left( \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} DTime2_{i1} + Du2_{i1} - T1Update_{ip} \right) \Bigg/ \sum_{i=1}^{n_s} n_{p_i} \qquad \text{Equation 5.10}$$

5.2.3.3 Total Travelling Distance Formula

The total travelling distance of the whole system includes the entire distance that all vehicles travel in the first echelon and second echelon in both the 3PL network and retailer network. The total distance includes round trips, except for the retailer network in the first echelon. The main trips of the retailer network vehicles, which handle B2B LMD and are conducted from the retailer's DCs to shopping centres, are not considered in the calculation. Equation 5.11 shows the calculation of total travelling distance in Scenario I. The first part shows the travelling distance of the retailer network in the first echelon and the second part indicates the travelling distance of the 3PL network in the first echelon. The last part calculates the travelling distance in the second echelon, which is related to the 3PL network:

$$\text{Total travelling distance} = \sum_{i=1}^{n_s}\sum_{j=1}^{n_{RDC}}\sum_{k=1}^{n_{k_{ij}}} D1R_{ij} + \sum_{\substack{i=1 \\ j=i+n_{RDC}}}^{i=n_s}\sum_{k=1}^{n_{k_{ij}}}(2 * D1T_{ij}) + \sum_{j=1+n_{RDC}}^{n_{RDC}+n_{TDC}}\sum_{v=1}^{n_{v_j}}(2 * D2T_{ij}) \qquad \text{Equation 5.11}$$

The mean travelling distance per parcel is also calculated according to Equation 5.12:

$$\text{Mean travelling distance} = \left( \begin{array}{c} \sum_{i=1}^{n_s}\sum_{j=1}^{n_{RDC}}\sum_{k=1}^{n_{k_{ij}}} D1R_{ij} + \\ \sum_{\substack{i=1 \\ j=i+n_{RDC}}}^{i=n_s}\sum_{k=1}^{n_{k_{ij}}}(2 * D1T_{ij}) + \\ \sum_{j=1+n_{RDC}}^{n_{RDC}+n_{TDC}}\sum_{v=1}^{n_{v_j}}(2 * D2T_{ij}) \end{array} \right) \Bigg/ \sum_{i=1}^{n_s} n_{p_i} \qquad \text{Equation 5.12}$$

5.2.3.4 Cost to 3PL

The 3PL cost includes all transporting and loading and unloading costs in both the first echelon and second echelon, except the empty running vehicle cost in the retailer network. 3PL cost calculations are shown in Equation 5.13:

$$\text{Cost to 3PL in Scenario I} = \sum_{\substack{i=1 \\ j=i+n_{RDC}}}^{i=n_s} \sum_{k=1}^{n_{k_{ij}}} (2 * D1T_{ij} * DCR1T) + \sum_{j=1+n_{RDC}}^{n_{RDC}+n_{TDC}} \sum_{v=1}^{n_{v_j}} \left(2 * D2T_j * DCR2T\right) + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC1 + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC2 \quad \text{Equation 5.13}$$

5.2.3.5 Cost to Retailers

Retailers just pay for empty running vehicles in Scenario I. The total cost to the retailer network is calculated based on Equation 5.14. Equation 5.15 shows the cost to each retailer in Scenario I:

$$\text{Cost to retailers in Scenario I} = \sum_{i=1}^{n_s} \sum_{j=1}^{n_{RDC}} \sum_{k=1}^{n_{k_{ij}}} (D1R_{ij} * DCR1R) \quad \text{Equation 5.14}$$

$$\text{Cost to retailer } j \text{ in Scenario I} = \sum_{i=1}^{n_s} \sum_{k=1}^{n_{k_{ij}}} (D1R_{ij} * DCR1R) \quad j \in \{1, \dots, n_{RDC}\} \quad \text{Equation 5.15}$$

### 5.2.4 Formulation of Scenario II

In this scenario, the 3PL network and retailer network collaborate to improve their delivery indicators. Instead of 3PL network vehicles, parcels are collected from shopping centres by retailer network vehicles. The empty running vehicles of the retailer network ship parcels to the retailer's DCs without changing their fixed time schedule or defined routes. Retailer network vehicles can ship parcels that belong to other retailers. The parcels are then collected by larger vehicles from the retailer's DCs and shipped to the 3PL's main DC. Despite Scenario I, the departure time of vehicles in the second echelon is not fixed and occurs at an optimum time schedule considering lead-time and cost. Considering these assumptions, parcels can be delivered to the 3PL's main DC through various routes and time schedules. To determine the optimum routes and time schedule, this research used multi-objective mixed-integer programming. Considering mean cost and mean lead-time as two objectives, this model introduced the optimum route and time schedule.

**Objective 1:** Minimising mean cost of total system (Z1)

$$\text{Mean cost of Scenario II} = \text{Minimising}\left\{\left(\begin{array}{c}\sum_{i=1}^{n_s}\sum_{j=1}^{n_{RDC}}\sum_{k=1}^{n_{k_{ij}}}(D1R_{ij} * DCR1R) + \\ \sum_{j=n_{RDC}+1}^{n_{RDC}+n_{TDC}}\sum_{v}^{n_{v_j}} 2 * D2R_j * DCR2R * n_{jv} + \\ \sum_{i=1}^{n_s}\sum_{p=1}^{n_{p_i}} LoC1 + \sum_{i=1}^{n_s}\sum_{p=1}^{n_{p_i}} LoC2\end{array}\right) \Bigg/ \sum_{i=1}^{n_s} n_{p_i}\right\} \quad \text{Equation 5.16}$$

**Objective 2:** Minimising mean lead-time of delivering parcels (Z2)

Mean lead time of Scenario II

$$= \text{Minimising}\left\{\left(\sum_{i=1}^{n_s}\sum_{p=1}^{n_{p_i}}(T3_{ip} - T1Updated_{ip})\right)\Big/\sum_{i=1}^{n_s} n_{p_i}\right\}$$

$$= \text{Min}\left\{\left(\sum_{i=1}^{n_s}\sum_{p=1}^{n_{p_i}}\left(\left(\sum_{j=1}^{n_{TDC}}\sum_{v}^{n_{v_j}}(DTime2_{jv} + Du2_{jv}) * y_{ijpv}\right) - T1Updated_{ip}\right)\right)\Big/\sum_{i=1}^{n_s} n_{p_i}\right\}$$

Equation 5.17

Subject to:

$$(1)\ \sum_{j=1}^{n_{RDC}}\sum_{k=1}^{n_{k_{ij}}} x_{ipjk} = 1 \quad \exists\, \forall\, i \in \{1, \dots, n_s\}\ and\ p \in \{1, \dots, n_{p_i}\}$$

Equation 5.18

$$(2)\ \sum_{j=1}^{n_{RDC}}\sum_{v=1}^{n_{v_j}} y_{ipjv} = 1 \quad \exists\, \forall\, i \in \{1, \dots, n_s\}\ and\ p \in \{1, \dots, n_{p_i}\}$$

Equation 5.19

$$(3)\ \sum_{i=1}^{n_s}\sum_{p=1}^{n_{p_i}}\sum_{k=1}^{n_{k_{ij}}} x_{ipjk} = \sum_{i=1}^{n_s}\sum_{p=1}^{n_{p_i}}\sum_{v=1}^{n_{v_j}} y_{ipjv} \quad \exists\, \forall\, j \in \{1, \dots, n_{RDC}\}$$

Equation 5.20

$$(4)\ \sum_{p=1}^{n_{p_i}} x_{ipjk} \le Cap1_{ijk} * m_{ijk}$$

Equation 5.21

$$\exists\, \forall\, i \in \{1, \dots, n_s\}\ and\ j \in \{1, \dots, n_{RDC}\}\ and\ k \in \{1, \dots, n_{k_{ij}}\}$$

$$(5)\ \sum_{i=1}^{n_s}\sum_{p=1}^{n_{p_i}} y_{ipjv} \le Cap2_{jv} * n_{jv}$$

Equation 5.22

$$\exists\, \forall\, j \in \{1, \dots, n_{RDC}\}\ and\ v \in \{1, \dots, n_{v_j}\}$$

$$(6)\ \sum_{i=1}^{n_s}\sum_{p=1}^{n_{p_i}}\sum_{j=1}^{n_{RDC}}\sum_{k=1}^{n_{k_{ij}}} x_{ipjk} = \sum_{i=1}^{n_s}\sum_{p=1}^{n_{p_i}}\sum_{j=1}^{n_{RDC}}\sum_{v=1}^{n_{v_j}} y_{ipjv}$$

Equation 5.23

$$(7) \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} \sum_{j=1}^{n_{RDC}} \sum_{k=1}^{n_{k_{ij}}} x_{ipjk} = \sum_{i=1}^{n_s} n_{p_i}$$ Equation 5.24

$$(8) \sum_{j=1}^{n_{RDC}} \sum_{k=1}^{n_{k_{ij}}} (t1Updated_{ip} - DTime1_{ijk}) * x_{ipjk} \leq 0$$ Equation 5.25

$\exists \forall i \in \{1, \ldots, n_s\}$ $and$ $p \in \{1, \ldots, n_{p_i}\}$

$$(9) \sum_{j=1}^{n_{RDC}} \sum_{k=1}^{n_{k_{ij}}} \left(DTime1_{ijk} + Du1_{ijk}\right) * x_{ipjk} - \sum_{j=1}^{n_{RDC}} \sum_{v=1}^{n_{v_j}} DTime2_{jv} * y_{ipjv} \leq 0$$ Equation 5.26

$\exists \forall i \in \{1, \ldots, n_s\}$ $and$ $p \in \{1, \ldots, n_{p_i}\}$

$$(10) \frac{(\sum_i^{n_s} \sum_p^{n_{p_i}} \sum_k^{n_k} x_{ipjk})}{Cap2_{j1}} - \sum_v^{n_v} n_{jv} \leq 0 \qquad \exists \forall j \in \{1, \ldots, n_{RDC}\}$$ Equation 5.27

The Objective function 1 aims to minimise the mean cost of each parcel of the model with coopetition strategy (see Equation 5.16). The Objective function 2 also aims to minimise the mean lead-time of delivering parcels to the 3PL's main DC (see Equation 5.17). Constraints 1 and 2 (Equations 5.18 and 5.19) ensure each parcel is allocated to a vehicle in the first and second echelon, respectively. The balance between the quantity of incoming and outgoing parcels in each retailer's DC is ensured by Constraint 3 (Equation 5.20). Constraints 4 and 5 (Equations 5.21 and 5.22) ensure that the vehicle capacity in the first and second echelons is not exceeded. The balance between the parcel quantity of the first and second echelon is imposed by Constraint 6 (Equation 5.23). Constraint 7 (Equation 5.24) specifies the quantity of all parcels in the system. Constraints 8 and 9 (Equations 5.25 and 5.26) are related to time limitations. Constraint 8 ensures that the parcels allocated to the first-echelon vehicles have a departure time later than the time at which the parcel is ready. In the same way, Constraint 9 ensures that the parcels in the second echelon are allocated to vehicles that leave the retailer's DC after the parcel's arrival time. Constraint 10 (Equation 5.27) ensures that the minimum required numbers of vehicles are available in each retailer's DC.

#### 5.2.4.1 Cost to 3PL

Given that all parcels were collected from shopping centres by retailer network vehicles, the 3PL cost was limited to all transporting, loading and unloading costs of the second echelon. The calculations of the 3PL cost of Scenario II are presented in Equation 5.28:

$$\text{Cost to 3PL in Scenario II} = \sum_{j=1}^{n_{RDC}} \sum_{v=1}^{n_{v_j}} (2 * D2T_j * DCR2T) * n_{jv} + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC2 \qquad \text{Equation 5.28}$$

#### 5.2.4.2 Cost to Retailers

Given that all parcels were collected by the retailer network vehicles, the first echelon loading and unloading cost was added to the retailer cost. Therefore, retailers paid for their empty running vehicles and loading and unloading cost in the first echelon in Scenario II (see Equation 5.29). To calculate the cost to each retailer, it was necessary to know the number of parcels carried by each retailer, which can be indicated by $x_{ipjk}$ (see Equation 5.30):

Cost to retailers in Scenario II

$$= \sum_{i=1}^{n_s} \sum_{j=1}^{n_{RDC}} \sum_{k=1}^{n_{k_{ij}}} (D1R_{ij} * DCR1R) + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC1 \qquad \text{Equation 5.29}$$

Cost to retailer $j$ in Scenario II

$$= \sum_{i=1}^{n_s} \sum_{k=1}^{n_{k_{ij}}} (D1R_{ij} * DCR1R) + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} \sum_{k=1}^{n_{k_{ij}}} LoC1 * \ x_{ipjk} \quad j \in \{1, \dots, n_{RDC}\} \qquad \text{Equation 5.30}$$

### 5.2.5 Formulation of Scenario III

As with Scenario II, coopetition occurred between the 3PL network and retailer network in Scenario III. Despite Scenario II, parcels could be collected from shopping centres by both the retailer network and 3PL network vehicles. The parcels were then collected by larger vehicles from the retailer or 3PL's local DCs and shipped to the 3PL's main DC. 3PL network and retailer network vehicles left shopping centres in a fixed schedule time in this scenario. In the second echelon, vehicles left the 3PL's local DCs or retailer's DCs in an optimum time schedule considering cost and lead-time indicators. All other conditions were the same as Scenario II. In Scenario III, a parcel had more choices regarding the routes and time schedule. To determine the optimum routes and time schedule, this scenario used multi-objective mixed-integer programming. Considering mean cost and mean lead-time as two objectives, the model introduced the optimum route and time schedule. The objective functions for minimising the mean cost of each parcel and mean lead-time are shown in Equations 5.31 and 5.32, respectively. All constraints of Scenario II were applicable for Scenario III.

**Objective 1**: Minimising mean cost of total system (Z1)

Mean cost of Scenario III

$$= \text{Minimising} \left\{ \left( \begin{array}{c} \sum_{i=1}^{n_s} \sum_{j=1}^{n_{RDC}} \sum_{k=1}^{n_{k_{ij}}} (D1R_{ij} * DCR1R) + \\ \sum_{i=1}^{n_s} \sum_{j=1+n_{RDC}}^{n_{RDC}+n_{TDC}} \sum_{k=1}^{n_{k_{ij}}} \left(2 * \ D1T_{ij} * DCR1T\right) * m_{ijk} + \\ \sum_{j=1}^{n_{RDC}+n_{TDC}} \sum_{v}^{n_{v_j}} 2 * \ D2R_j * DCR2R * n_{jv} + \\ \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC1 + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC2 \end{array} \right) \Big/ \sum_{i=1}^{n_s} n_{p_i} \right\}$$ Equation 5.31

**Objective 2:** Minimising mean lead-time of delivering parcels (Z2)

Mean lead time of Scenario III

$$= \text{Min} \left\{ \left( \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} (( \sum_{j=1}^{n_{TDC}+n_{RDC}} \sum_{v}^{n_{v_j}} \left(DTime2_{jv} + Du2_{jv}\right) * y_{ijpv}) - T1Updated_{ip}) \right) \Big/ \sum_{i=1}^{n_s} n_{p_i} \right\}$$

Equation 5.32

5.2.5.1 Cost to 3PL

As with Scenarios I and II, all transporting and loading and unloading costs in the second echelon were considered parts of 3PL cost. Given that both 3PL network and retailer network vehicles could ship parcels in the first echelon in Scenario III, the transporting and loading and unloading costs in the first echelon depended on the selected route and could be allocated to the 3PL network or retailer network. The calculations of the 3PL cost of Scenario III are presented in Equation 5.33:

Cost to 3PL in Scenario III

$$= \sum_{i=1}^{n_s} \sum_{j=1+n_{RDC}}^{n_{RDC}+n_{TDC}} \sum_{p=1}^{n_{p_i}} \sum_{k=1}^{n_{k_{ij}}} LoC1 * x_{ijpk}$$

$$+ \sum_{i=1}^{n_s} \sum_{j=1+n_{RDC}}^{n_{RDC}+n_{TDC}} \sum_{k=1}^{n_{k_{ij}}} \left(2 * \ D1T_{ij} * DCR1T\right) * m_{ijk}$$ Equation 5.33

$$+ \sum_{j=1}^{n_{RDC}+n_{TDC}} \sum_{v=1}^{n_{v_j}} (2 * \ D2T_j * DCR2T) * n_{jv} \ + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} LoC2$$

5.2.5.2 Cost to Retailers

Beside empty running vehicle cost, retailers pay for loading and unloading cost if a parcel is collected by a retailer network. Therefore, the cost of loading and unloading in the first echelon depended on the route selection and could be allocated to each retailer or 3PL. Equations 5.34 and 5.35 display the cost to the retailer network and cost to each retailer in Scenario III, respectively:

Cost to retailers in Scenario III

$$= \sum_{i=1}^{n_s} \sum_{j=1}^{n_{RDC}} \sum_{k=1}^{n_{k_{ij}}} (D1R_{ij} * DCR1R) + \sum_{i=1}^{n_s} \sum_{j=1}^{n_{RDC}} \sum_{p=1}^{n_{p_i}} \sum_{k=1}^{n_{k_{ij}}} LoC1 * x_{ijpk}$$ Equation 5.34

Cost to retailer *j* in Scenario III

$$= \sum_{i=1}^{n_s} \sum_{k=1}^{n_{k_{ij}}} (D1R_{ij} * DCR1R) + \sum_{i=1}^{n_s} \sum_{p=1}^{n_{p_i}} \sum_{k=1}^{n_{k_{ij}}} LoC1 * \ x_{ipjk} \quad j \in \{1, \dots, n_{RDC}\}$$ Equation 5.35

## 5.3 Computational Test of the Last Mile Delivery Model with and without Coopetition Strategy

In this section, the presented LMD model with a coopetition strategy is analysed by using MATLAB software. To study the model and the proposed scenarios, it was necessary to have suitable sets of instances. Given that the proposed model has not been studied in the literature, there was no benchmark and it was necessary to build new sets of instances.

### 5.3.1 Construction of Instance Sets

The instances developed to evaluate the proposed model covered up to 10 shopping centres, 10 retailers and 90 pallets (each pallet included 100 parcels) for each shopping centre (900 pallets or 90,000 parcels in total). These limitations were considered based on the number of main shopping centres and main retailers trading in Melbourne. The related information was collected during the interview process presented in Sections 3.2.3 and 4.5. All instances were grouped in 18 sets based on the number of retailers and shopping centre and demand conditions (see Table 5.1). The number of shopping centres and number of retailers was set to two for the low rate, five for the medium rate and 10 for the high rate. Each retailer had five pallets (500 parcels) per day on normal days and nine pallets (900 parcels) per day on high-demand days.

Table 5.1: Instance Sets and Groups

| | | Number of Parcels | | | | | |
|---|---|---|---|---|---|---|---|
| | | Normal Days | | | High-demand Days | | |
| | | Number of Retailers | | | | | |
| | | **Low** | **Medium** | **High** | **Low** | **Medium** | **High** |
| Number of shopping centres | Low | Set 1 | Set 2 | Set 3 | Set 4 | Set 5 | Set 6 |
| | Medium | Set 7 | Set 8 | Set 9 | Set 10 | Set 11 | Set 12 |
| | High | Set 13 | Set 14 | Set 15 | Set 16 | Set 17 | Set 18 |

The instances were randomly generated to simulate different geographical locations for shopping centres, 3PL's local DCs, 3PL's main DC and retailer's DCs. The instances were generated according to the following parameters:

- Distance between shopping centres and DCs (3PL's local DCs $[D1R_{ij}]$ and retailer's DCs $(D1T_{ij}]$): The distance of each arc was randomly selected in the range of 15 to 70 kilometres.
- Distance between the 3PL's local DCs and 3PL's main DC $(D2T_j)$: The distance of each arc was randomly selected in the range of 20 to 70 kilometres.
- Distance between the retailer's DCs and 3PL's main DC $(D2R_j)$: It was assumed that the retailer's DCs were located near the 3PL's main DC; therefore, the distance of each arc was randomly selected in the range of five to 20 kilometres.
- Number of vehicles in the first and second echelon $(n_{k_{ij}}\ and\ n_{v_j})$: It was assumed that a maximum of two vehicles travelled between each shopping centre and the retailer's DC. The number of vehicles was set as one on normal-demand days and two on high-demand days. Retailer stores at shopping centres need more goods on high-demand days; therefore, more vehicles visit shopping centres on high-

demand days. The number of 3PL network vehicles in the first and second echelon was calculated based on the demand and capacity of vehicles (see the calculation of $n_{k_{ij}}$ $and$ $n_{v_j}$ in Section 5.2.2).

- Capacity of vehicles ($Cap1_{ijk}$ $and$ $Cap2_{jv}$): The capacity of vehicles for the first and second echelon was set to 10 and 28, respectively. It was assumed that the total capacity of retailer network vehicles departing from a shopping centre was equal to or more than demand in the shopping centre.
- Distance cost ($DCR1R, DCR1T, DCR2R$ $and$ $DCR2T$): The distance cost of transportation in both the 3PL and retailer network was set to \$1.2 per kilometre in the first echelon and \$1.6 per kilometre in the second echelon.
- Loading/unloading cost ($LoC1$ $and$ $LoC2$): The loading/unloading cost was set to \$1.00 for both the first and second echelon.
- Departure time of vehicles in the first echelon ($DTime1_{ijk}$): It was assumed that each retail network and 3PL network vehicle left the shopping centre between 8.00 am and 4.00 pm randomly.
- Time that a parcel is ready to dispatch at shopping centre ($T1_{ip}$): It was assumed that the order preparation process worked nine hours per day, from 6.00 am to 15.00 pm, and prepared a specific number of pallets per hour. The order preparation process of each retailer prepared one pallet per two hours on normal days and one pallet per hour on high-demand days.
- Travelling duration ($Du1_{ijk}$ $and$ $Du2_{jv}$): It was assumed that each vehicle travelled one kilometre per minute in both echelons; therefore, travelling duration depended on the distance between the origin and destination.

- Number of retailers and 3PL's local DCs ($n_{RDC}$ $and$ $n_{TDC}$): It was assumed that each retailer had only one DC; therefore, the number of retailer's DCs was equal to the number of retailers. Similarly, each 3PL's local DC served only one shopping centre, which meant that the number of 3PL's local DCs was equal to the number of shopping centres.

For each combination of number of shopping centres, retailers and parcels, two instances were created, for a total of 36 instances. A summary of the main features of the different sets is reported in Table 5.2. Column 1 reports the set of instances, while Column 2 presents the number of instances. Columns 3, 4 and 5 contain the number of shopping centres, retailers and pallets in each shopping centre, respectively. Given that each retailer had only one DC, Column 4 also indicates the number of retailer's DCs. Column 6 displays the number of 3PL's local DCs, which is equal to the number of shopping centres. The remaining columns display the value or rules of different parameters explained earlier in this section.

Table 5.2: Features of Sets of Instances

| Set No. | No. of Instances | $n_s$ | $n_{RDC}$ | $n_{p_i}$ | $n_{TDC}$ | $n_{k_{ij}}$ for retailers | $D1R_{ij}$& $D1T_{ij}$ & $D2R_j$ & $D2T_j$ | $DCR1R$ & $DCR1T$ | $DCR2R$ & $DCR2T$ | $Cap1_{ijk}$ | $Cap2_{jv}$ | $LoC1$ | $LoC2$ | $T1_{ip}$ | $DT1_{ij}$ | Transport Duration Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 2 | 2 | 5 | 2 | 1 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per 2 hours | Random | 1 min/km |
| 2 | 2 | 2 | 5 | 5 | 2 | 1 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per 2 hours | Random | 1 min/km |
| 3 | 2 | 2 | 10 | 5 | 2 | 1 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per 2 hours | Random | 1 min/km |
| 4 | 2 | 2 | 2 | 9 | 2 | 2 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per hour | Random | 1 min/km |
| 5 | 2 | 2 | 5 | 9 | 2 | 2 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per hour | Random | 1 min/km |
| 6 | 2 | 2 | 10 | 9 | 2 | 2 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per hour | Random | 1 min/km |
| 7 | 2 | 5 | 2 | 5 | 5 | 1 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per 2 hours | Random | 1 min/km |
| 8 | 2 | 5 | 5 | 5 | 5 | 1 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per 2 hours | Random | 1 min/km |
| 9 | 2 | 5 | 10 | 5 | 5 | 1 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per 2 hours | Random | 1 min/km |
| 10 | 2 | 5 | 2 | 9 | 5 | 2 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per hour | Random | 1 min/km |

| Set No. | No. of Instances | $n_s$ | $n_{RDC}$ | $n_{p_i}$ | $n_{TDC}$ | $n_{k_{ij}}$ for retailers | $D1R_{ij}$& $D1T_{ij}$ & $D2R_j$ & $D2T_j$ | $DCR1R$ & $DCR1T$ | $DCR2R$ & $DCR2T$ | $Cap1_{ijk}$ | $Cap2_{jv}$ | $LoC1$ | $LoC2$ | $T1_{ip}$ | $DT1_{ij}$ | Transport Duration Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 2 | 5 | 5 | 9 | 5 | 2 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per hour | Random | 1 min/km |
| 12 | 2 | 5 | 10 | 9 | 5 | 2 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per hour | Random | 1 min/km |
| 13 | 2 | 10 | 2 | 5 | 10 | 1 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per 2 hours | Random | 1 min/km |
| 14 | 2 | 10 | 5 | 5 | 10 | 1 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per 2 hours | Random | 1 min/km |
| 15 | 2 | 10 | 10 | 5 | 10 | 1 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per 2 hours | Random | 1 min/km |
| 16 | 2 | 10 | 2 | 9 | 10 | 2 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per hour | Random | 1 min/km |
| 17 | 2 | 10 | 5 | 9 | 10 | 2 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per hour | Random | 1 min/km |
| 18 | 2 | 10 | 10 | 9 | 10 | 2 | Random | $1.2/ km | $1.6/ km | 10 | 28 | $1/ pallet | $1/ pallet | 1 pallet per hour | Random | 1 min/km |

### 5.3.2 Proposed Solution and Algorithm

The proposed LMD model with coopetition strategy is categorised as a two-echelon VRP, which is classified as an NP-hard problem. This means it becomes highly time-consuming as the problem instances increase in size. The model has two objectives and, since it is not possible to have a single solution that simultaneously optimises both objectives, an algorithm is needed to provide a large number of alternative solutions lying on or near the Pareto-optimal front. GA is the most popular and well-suited algorithm for solving multi-objective optimisation problems (Konak et al. 2006). There are many variations of multi-objective GA in the literature. NSGA II is one of the most well-known and credible algorithms. It has been used in many applications and its performance has been tested in several comparative studies (Konak et al. 2006). Therefore, as a result of the combinatorial nature of the model and the efficiency of GA in solving combinatorial multi-objective problems, NSGA II, as a GA-based approach, was developed to solve the proposed LMD model with coopetition strategy.

GA is a randomised global search technique that can easily be adapted to various types of problems. Basically, the GA approach must have a good genetic representation of the problem, an initial population generator, an appropriate fitness function and genetic operators (such as crossover and mutation) to work effectively. In general, the algorithm is an iterative procedure that works as follows:

- Step 1: initial population construction—the initial population of chromosomes are randomly generated
- Step 2: reproduction—two parent chromosomes are selected

- Step 3: recombination—two offspring chromosomes are obtained from the parents using a crossover operator
- Step 4: mutation—a random mutation is applied to each offspring, with a small probability; Steps 2 to 4 are repeated $n$ times (irritation)
- Step 5: generation replacement—a new population of chromosomes is created by removing the worst solutions, which are replaced by the new offspring. In the NSGA II, the solutions are ranked based on a non-dominated sorting approach.

5.3.2.1 Genetic Representation

A binary representation was used for the genetic representation of the LMD model with coopetition strategy. Each chromosome in the genetic generation represented a candidate solution for the LMD with coopetition strategy. Each chromosome included the nodes (shopping centres, 3PL's local DCs and retailer's DCs), vehicles and parcels, which were shown by the $x_{ijpk}$ variable. Other variables were computed accordingly.

5.3.2.2 Initial Population Construction

The initial population size was set to 36 in this study. In the proposed methodology, the desired numbers of the initial feasible population were generated randomly. This initial population helped the algorithm be the ambassador for any vicinity of the search space.

5.3.2.3 Selection and Genetic Operator

Parents were randomly selected for crossover and mutation purposes. Crossover and mutation percentages were set to 0.7 and 0.5 in this study. In addition, the mutation rate was set to 0.1 for all runs. All single-point, double-point and uniform approaches were used for the crossover process considering a 0.2, 0.2 and 0.6 probability, respectively.

#### 5.3.2.4 Termination

The number of iterations was set to 2,000 to terminate the generational process.

### 5.3.3 Results of the Computational Test

To evaluate the performance of the proposed scenarios, 36 instances were examined in this study. This section presents the results of all instances in each scenario. Appendix K displays the value of indicators for each instance in the current situation (Scenario I). These values were calculated based on the formulation presented in Section 5.2.2. Appendices L and M present the results of the optimum solutions for every instance in Scenarios II and III, respectively.

To compare the three proposed scenarios, the cost and lead-time values of every instance are illustrated in one figure. Figures 5.3 to 5.20 display the mean cost per pallet and mean lead-time of the three scenarios for all instances. All non-dominated solutions (Pareto front) of Scenarios II and III are shown in these figures. Reviewing the results indicated that both Scenario II and III improved the performance of LMD in terms of cost and lead-time. All solutions presented by both Scenarios II and III offered lower cost than Scenario I. Except for three solutions presented by Scenario II and seven solutions presented by Scenario III, all solutions of Scenarios II and III improved lead-time. In both Scenario II and III, there was at least one solution in each instance that simultaneously offered better cost and lead-time than the scenario without coopetition strategy. Therefore, the proposed LMD model with coopetition strategy significantly improved the performance of LMD in terms of cost and lead-time simultaneously.

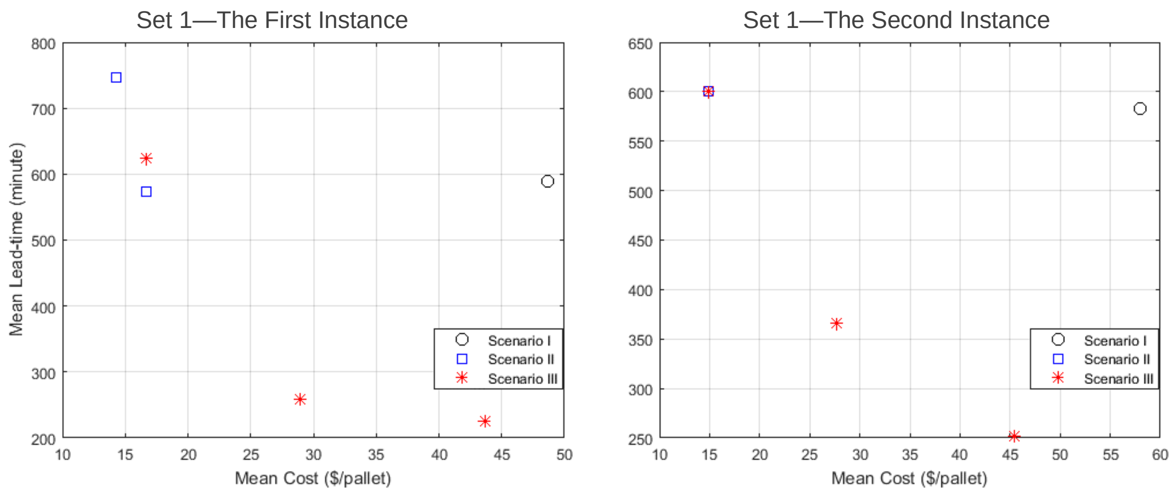



Figure 5.3: Pareto Fronts of the Scenarios—Set 1

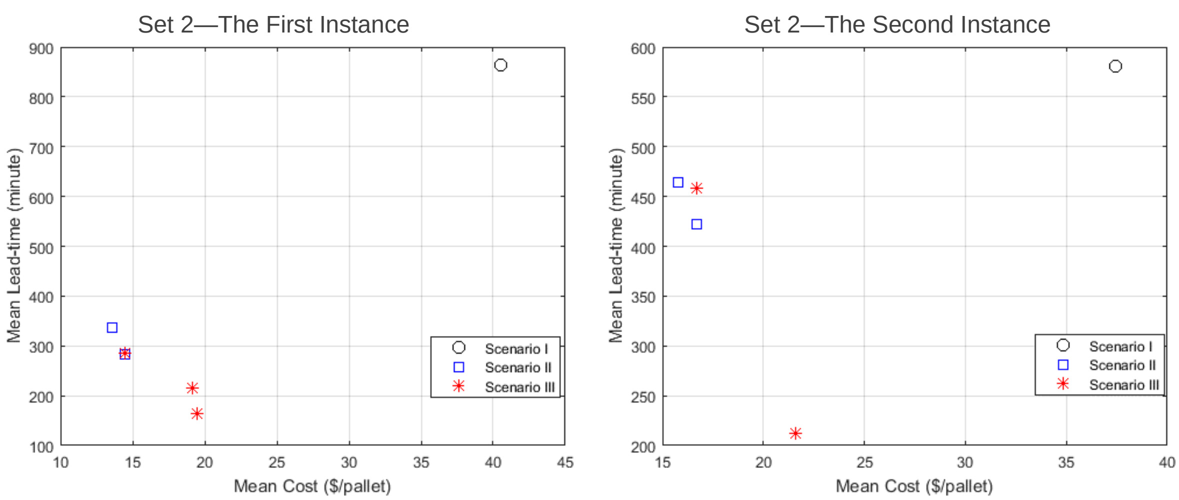



Figure 5.4: Pareto Fronts of the Scenarios—Set 2

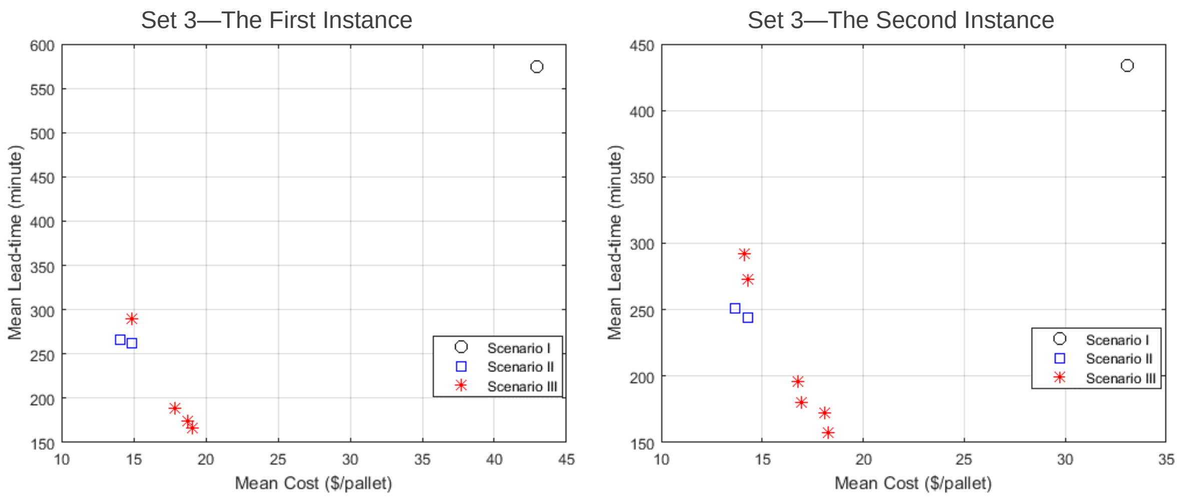



Figure 5.5: Pareto Fronts of the Scenarios—Set 3

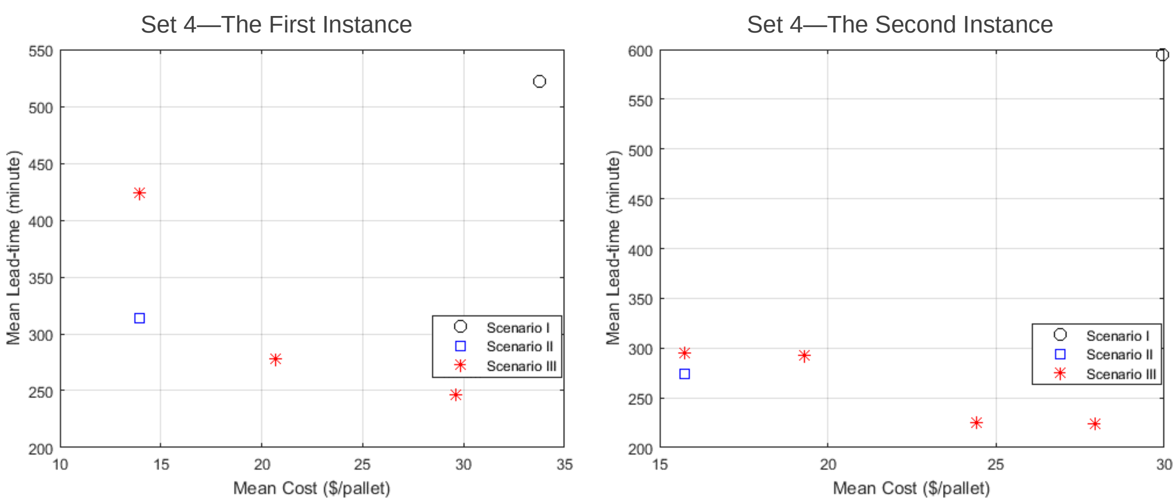



Figure 5.6: Pareto Fronts of the Scenarios—Set 4

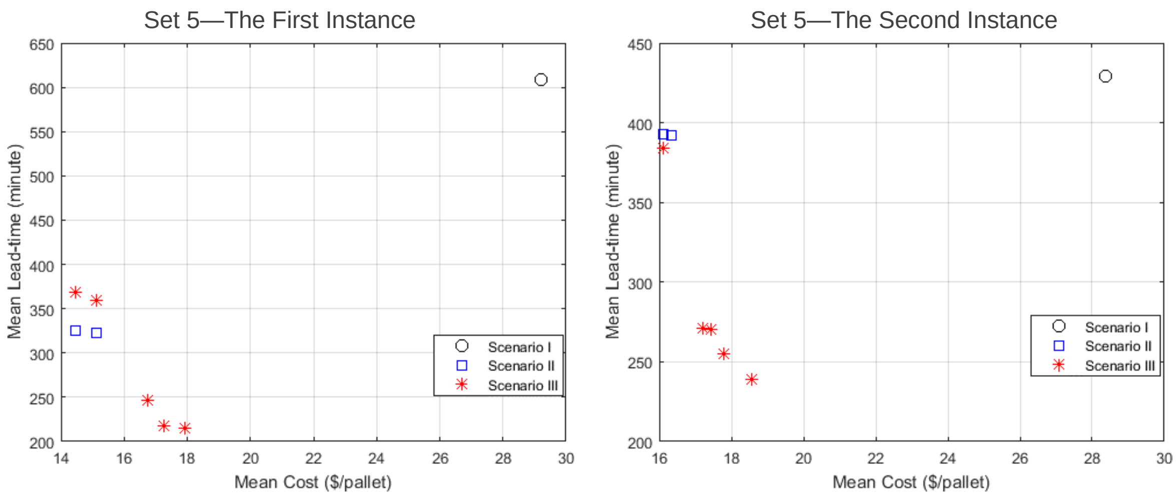



Figure 5.7: Pareto Fronts of the Scenarios—Set 5

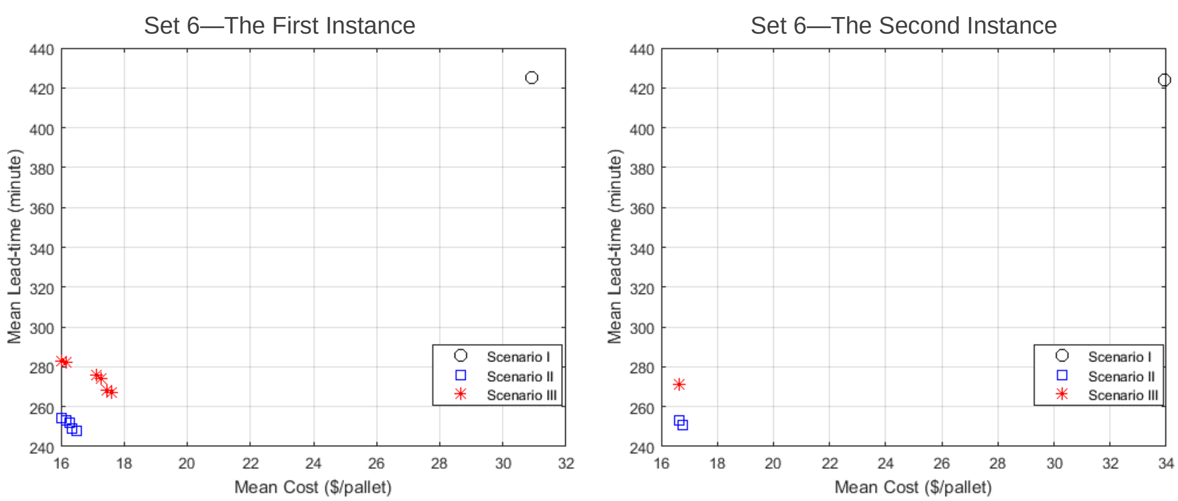



Figure 5.8: Pareto Fronts of the Scenarios—Set 6

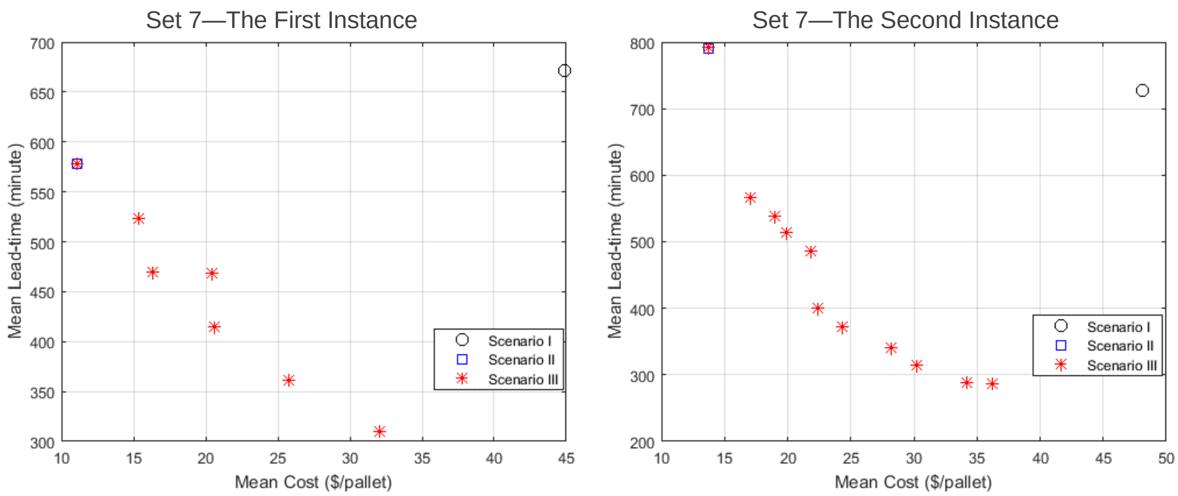



Figure 5.9: Pareto Fronts of the Scenarios—Set 7

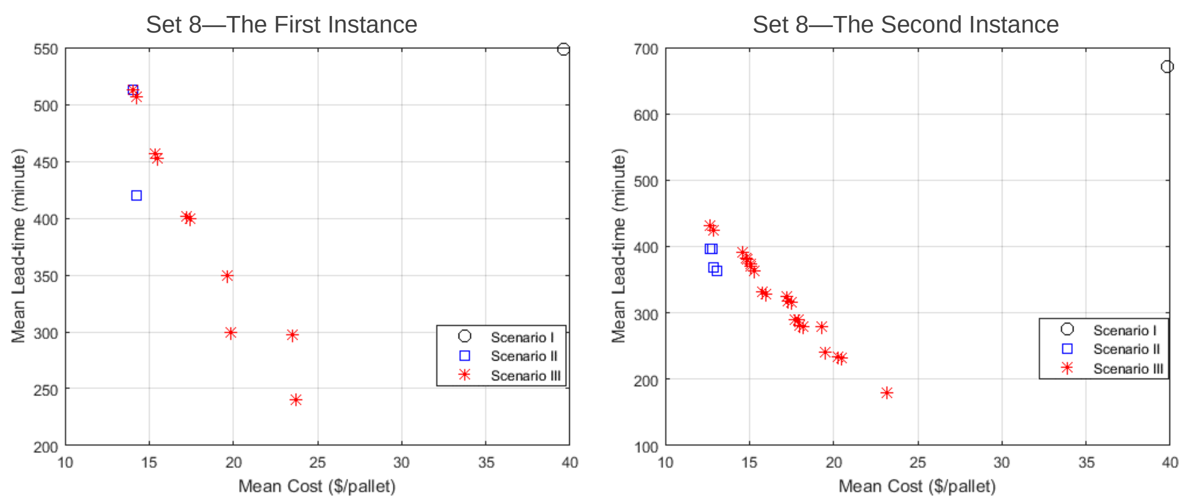



Figure 5.10: Pareto Fronts of the Scenarios—Set 8

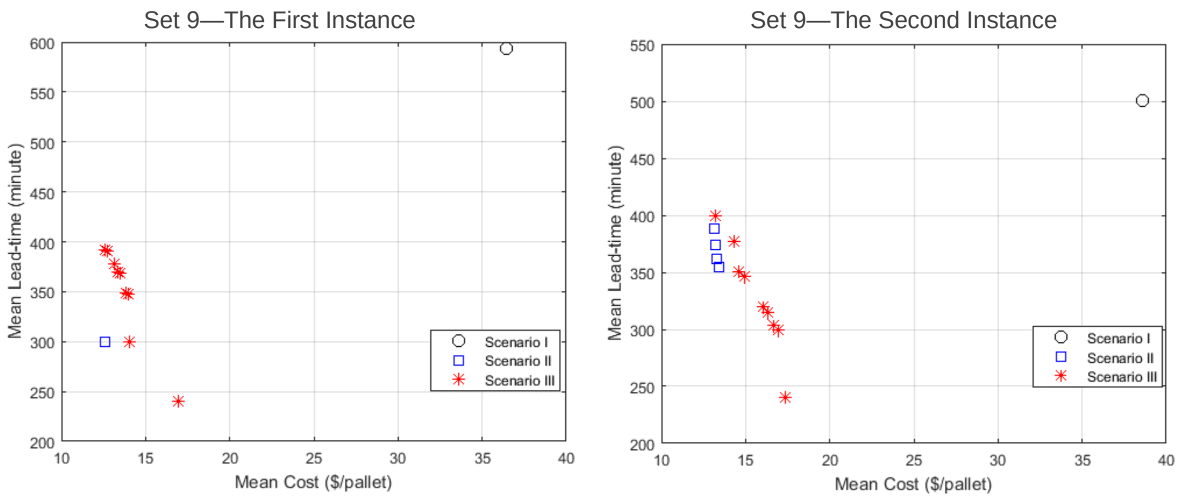



Figure 5.11: Pareto Fronts of the Scenarios—Set 9

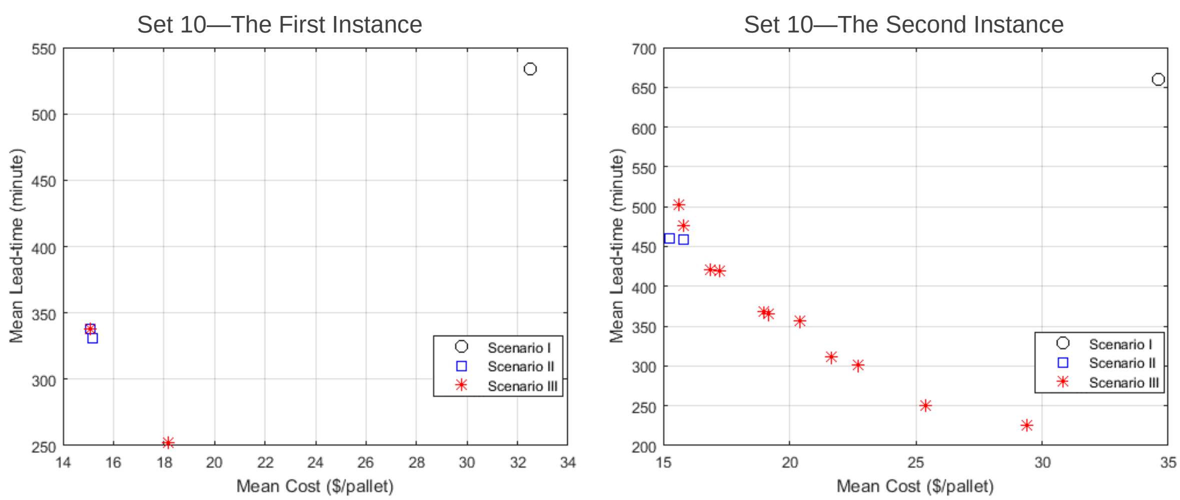



Figure 5.12: Pareto Fronts of the Scenarios—Set 10

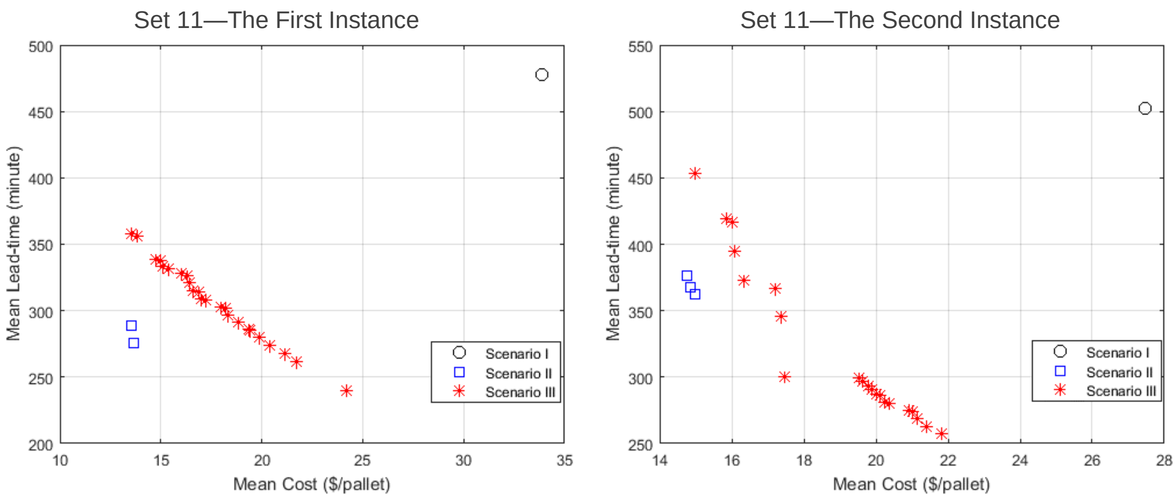



Figure 5.13: Pareto Fronts of the Scenarios—Set 11

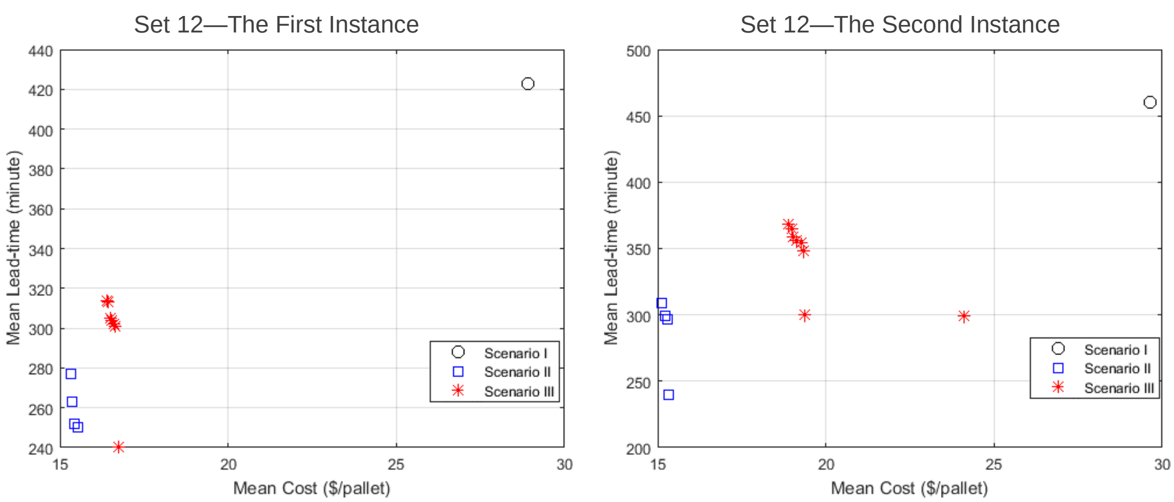



Figure 5.14: Pareto Fronts of the Scenarios—Set 12

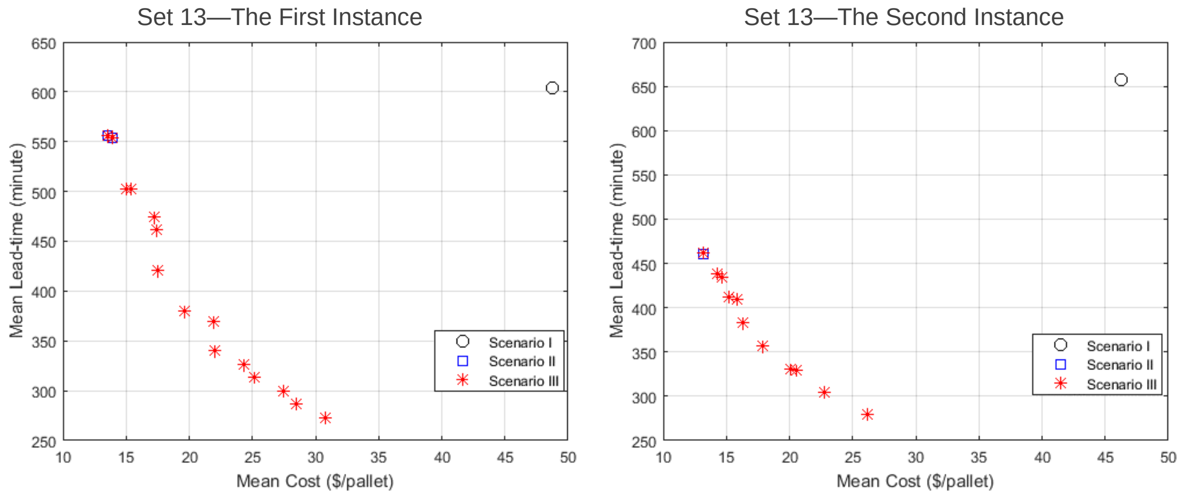



Figure 5.15: Pareto Fronts of the Scenarios—Set 13

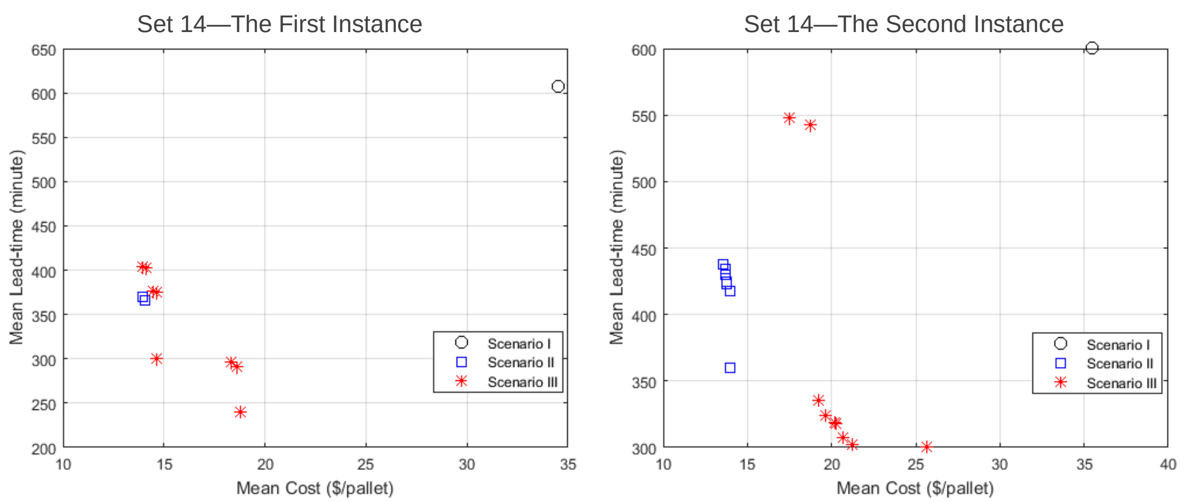



Figure 5.16: Pareto Fronts of the Scenarios—Set 14

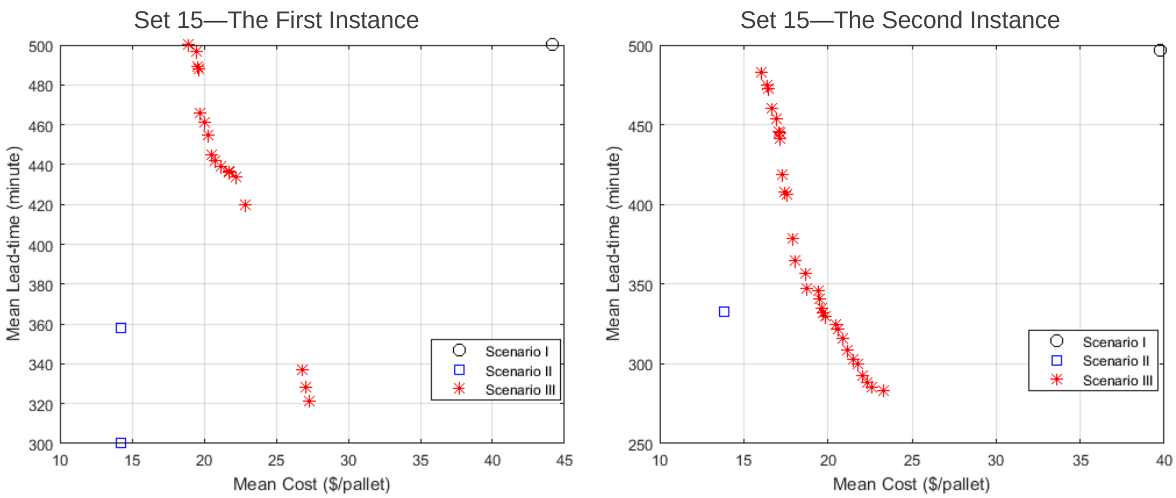


Figure 5.17: Pareto Fronts of the Scenarios—Set 15

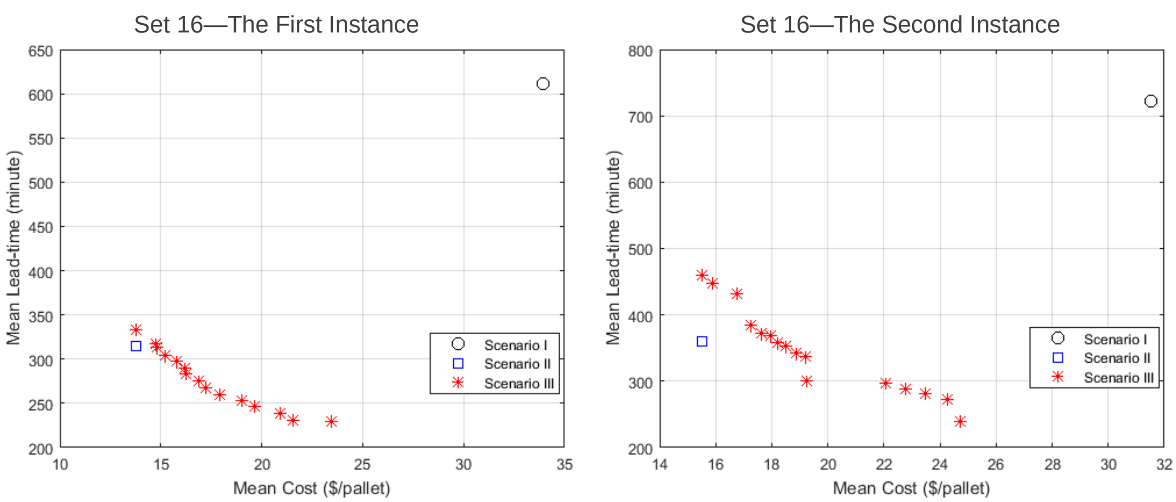


Figure 5.18: Pareto Fronts of the Scenarios—Set 16

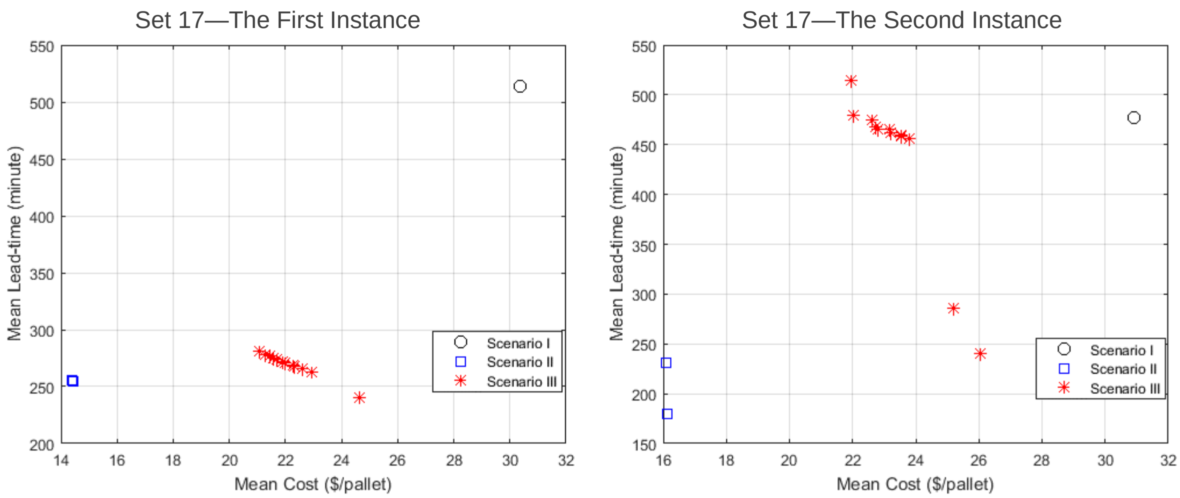



Figure 5.19: Pareto Fronts of the Scenarios—Set 17

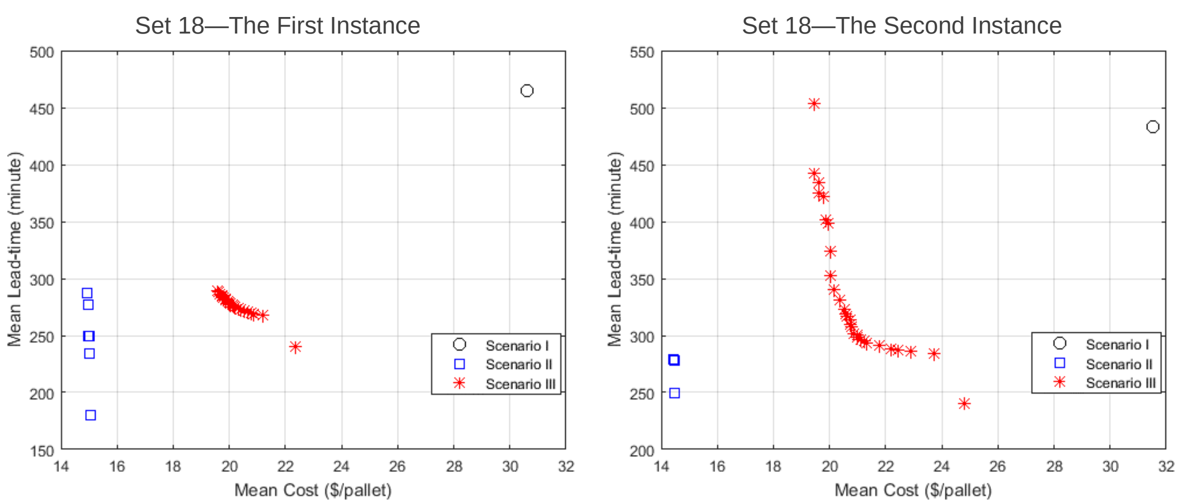



Figure 5.20: Pareto Fronts of the Scenarios—Set 18

Reviewing the Pareto front indicated that Scenario II generally improved the cost indicator more than Scenario III, while Scenario III improved the lead-time indicator more than Scenario II. Comparing the average cost and lead-time of the three scenarios also confirmed this finding. The average cost per parcel of the best cost solution of all instances in Scenario II was lower than that in Scenario III ($0.1436 and $0.1558 per parcel, respectively). Conversely, the average lead-time per parcel of the best lead-time solution of all instances in Scenario III was lower than that in Scenario II (243.75 and 356.22 minutes per parcel, respectively) (see Figure 5.21). Both scenarios had better results than Scenario I. The results also showed that Scenario II improved the mean travel distance more than Scenario III (0.0872 and 0.0986 kilometres per parcel, respectively).

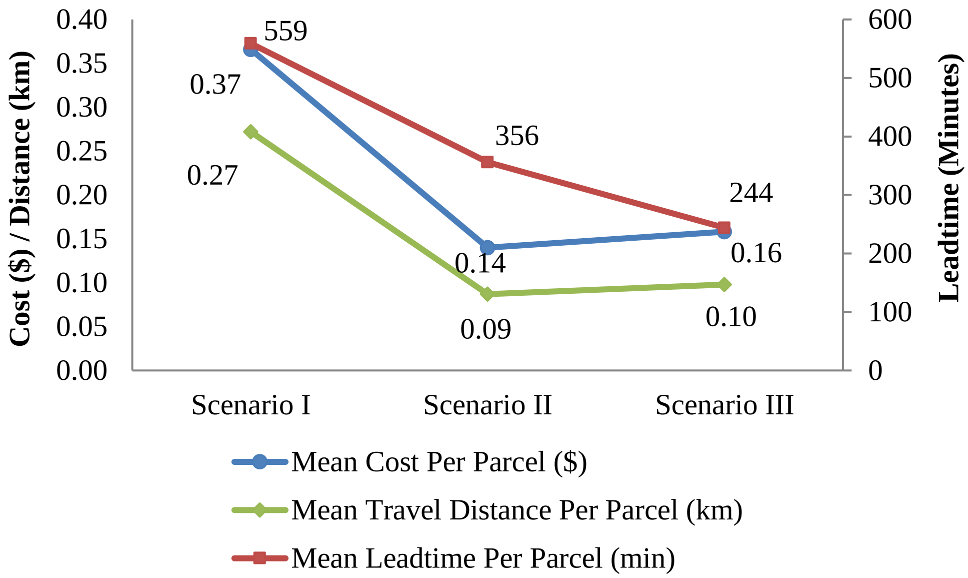



Figure 5.21: Comparison of the Results of Three Scenarios

Figure 5.22 compares the mean cost per parcel of each instance in the three scenarios. There were various solutions for each instance in Scenarios II and III, but the solution with the best mean cost per parcel is considered in this comparison. This figure indicates that the mean cost per parcel of the best solution for each instance offered by Scenario II was equal to or less than the relevant best solution offered by Scenario III. It also shows that, although the mean costs per parcel of the scenarios with coopetition strategy were significantly less than the scenario without coopetition strategy, the differences between Scenarios II and III were not high.

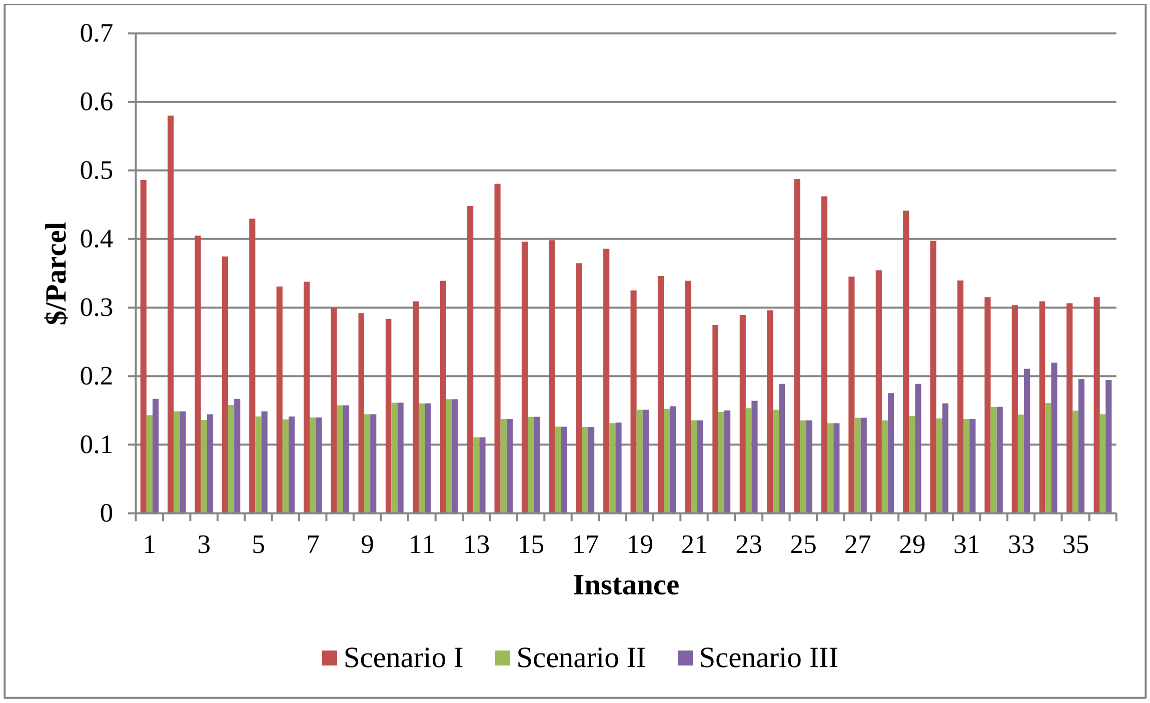



Figure 5.22: Best Cost Solutions of Each Instance

Figure 5.23 compares the three scenarios in terms of mean lead-time per parcel. For each instance, the solution with the best mean lead-time per parcel was considered in this comparison (in both Scenario II and III). Scenario III offered the best mean lead-time per parcel in the most instances. Scenario II offered the best results in mean lead-time per parcel in some instances such as instance numbers 11, 12, 24, 29, 34 and 35. Both Scenarios II and III offered better lead-time than Scenario I, with two exceptions. Scenario I had better lead-time results than Scenario II in instances 2 and 14, but they were not still good as the lead-time offered by Scenario III.

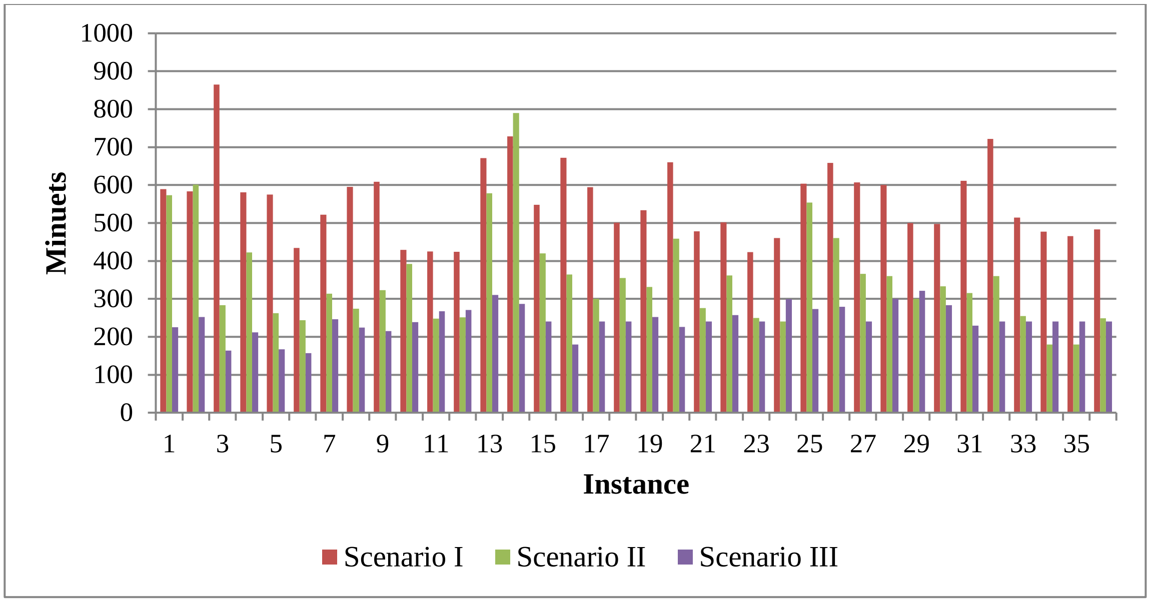



Figure 5.23: Best Lead-time Solutions of Each Instance

In addition, Scenario II generally improved the travelling distance indicator more than Scenario III. Figure 5.24 compares the three scenarios in terms of the mean travelling distance per parcel. This figure shows that Scenario II generally offered the lowest mean travelling distances. However, there were some exceptions. Scenario III provided better results in mean travelling distance per parcel in some instances, including instances 3, 6, 15, 17, 27, 31 and 32. However, both Scenario II and III significantly improved mean travelling distance in all instances compared with Scenario I.

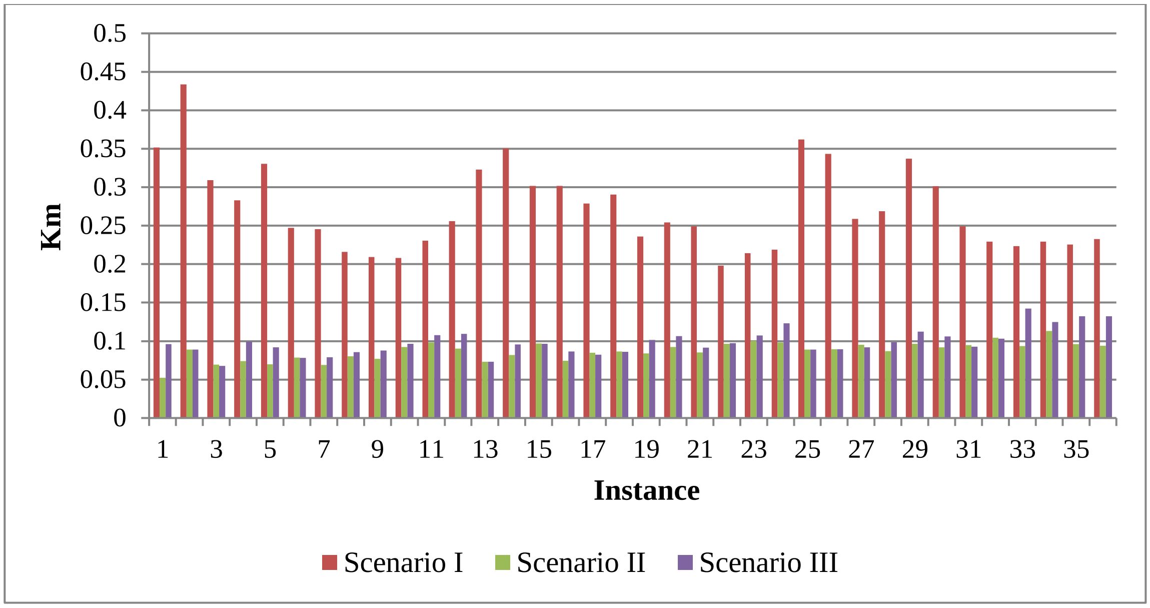



Figure 5.24: Best Total Travelling Distance Improvement of Each Instance

Scenarios with coopetition strategy decreased the number of vehicles needed for the whole system. Figure 5.25 compares the number of vehicles in each instance among the three scenarios. The numbers of vehicles needed for each instance in both Scenarios II and III were generally equal; however, in some cases, fewer vehicles were needed for each instance in Scenario II. The same pattern was applicable for utilisation rate in the three scenarios. Both Scenarios II and III significantly improved the utilisation rates in all instances (see Figure 5.26). The utilisation rates of Scenario II were equal to or higher than the utilisation rate in Scenario III.

Figure 5.27 shows the average utilisation rate and average number of vehicles operated in all three scenarios. It indicates that Scenario II used the lowest number of vehicles and had the highest utilisation rate. It shows that both coopetition models had better results for utilisation rate and the number of operating vehicles.

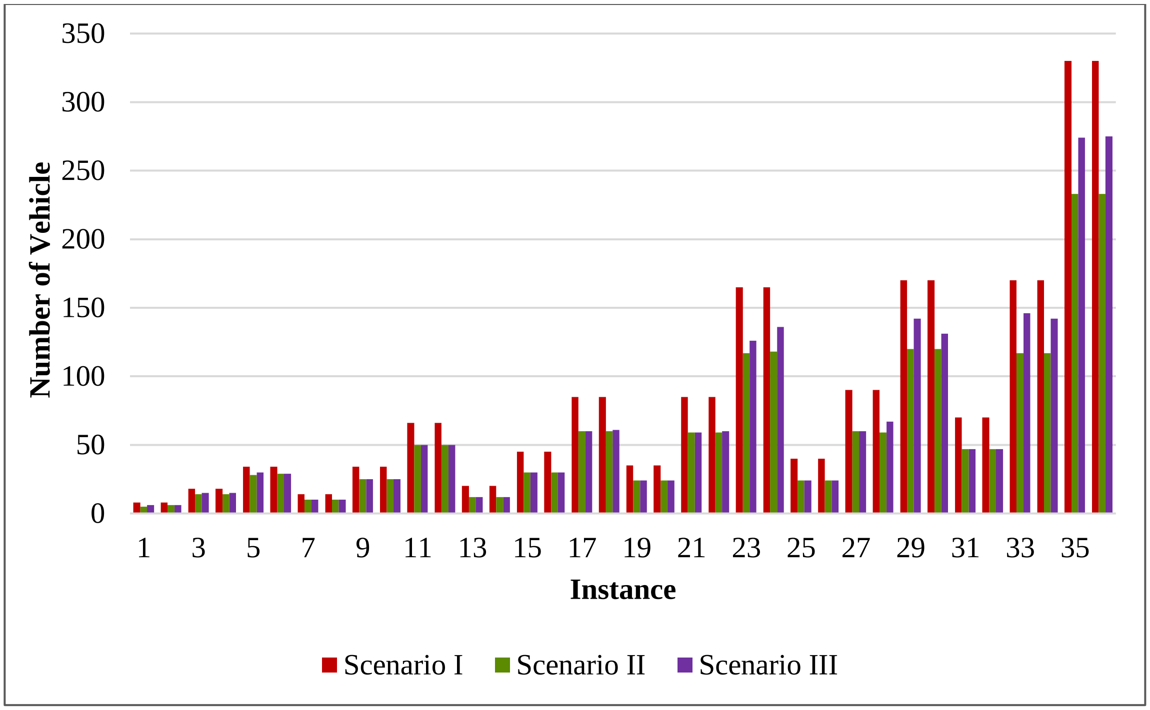



Figure 5.25: Number of Vehicles in Each Instance (Best Cost Solution)

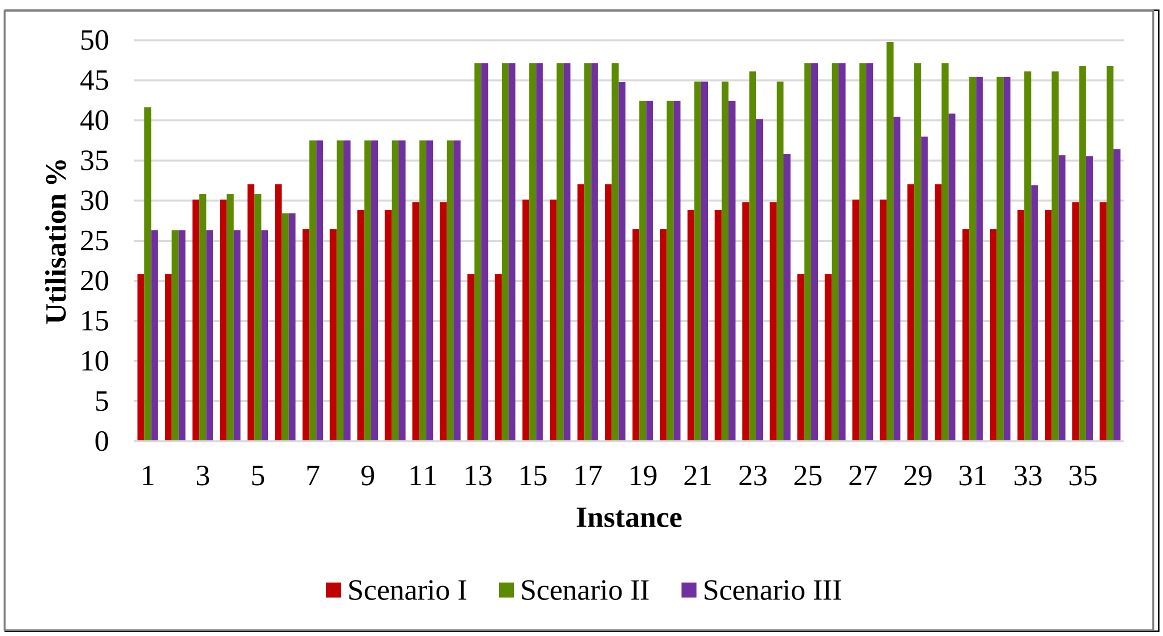



Figure 5.26: Utilisation Rate in Each Instance (Best Cost Solution)

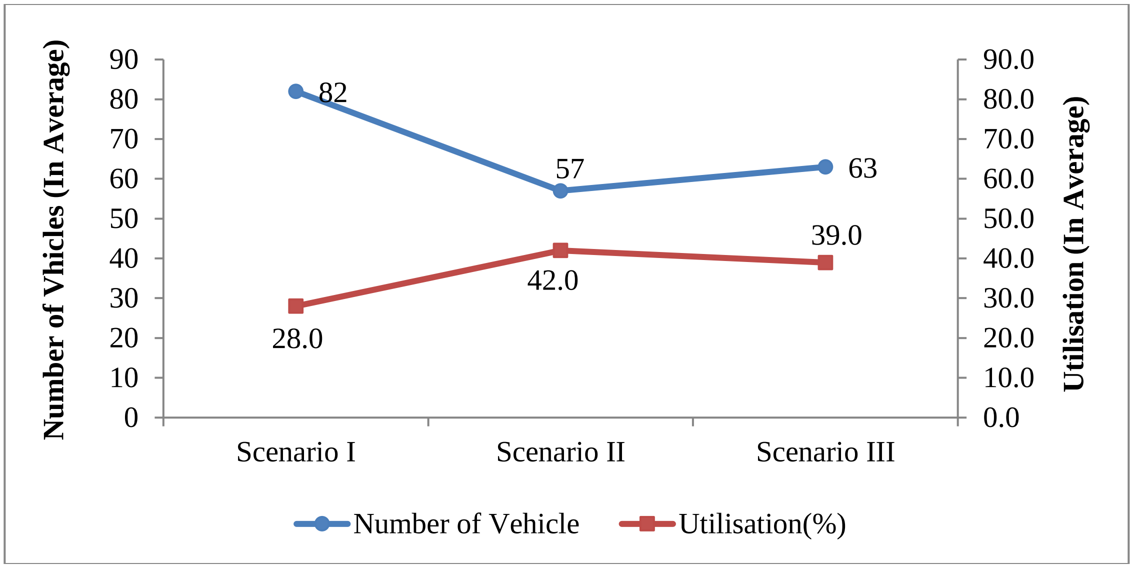



Figure 5.27: Comparison of Number of Vehicles and Utilisation Rates of Three Scenarios Using Random Instances (Best Cost Solution)

### 5.4 Case Study and Results

Through using data from a real case in the city of Melbourne, we examined the performance of the proposed LMD model with coopetition strategy. The case study included two 3PLs (two competitors) and one retailer that served six shopping centres. Cases 2, 4 and 5 discussed in Section 4.5 were involved in this research. Cases 2 and 4 were 3PLs and Case 5 was a retailer. Case 2 conducted 3PL network operations and Case 4 conducted retailer network operations related to the retailer (Case 5). The following information was considered for each parameter of the model:

- Distance between nodes $(D1R_{ij}, D1T_{ij}, D2T_j \ and \ D2R_j)$: The shortest pass between the real locations of each couple of nodes was obtained using Google Maps and considered as the related distance. These were the routes that the vehicles normally travelled.

- Number of vehicles in the first and second echelon ($n_{k_{ij}}$ $and$ $n_{v_j}$): The number of vehicles for each arc was obtained from the real data.
- Capacity of vehicles ($Cap1_{ijk}$ $and$ $Cap2_{jv}$): The real capacity of vehicles was considered in this case study. The capacity of each arc in the first echelon was different and varied between four and 28 pallets per vehicle. The capacity of each arc in the second echelon was fixed at 28.
- Distance cost ($DCR1R, DCR1T, DCR2R$ $and$ $DCR2T$): The distance cost of transportation in both the 3PL network and retailer network was set to \$1.2 per kilometre in the first echelon and \$1.6 per kilometre in the second echelon.
- Loading/unloading cost ($LoC1$ $and$ $LoC2$): The loading/unloading cost was set to \$1.00 for both the first and second echelon.
- Departure time of vehicles in the first echelon ($DTime1_{ijk}$): The departure times were considered based on the time schedule that was used in the real case.
- Time that a parcel is ready to dispatch at shopping centre ($T1_{ip}$): The preparation time of each parcel was obtained from the real situation. The preparation times varied from 6.00 am to 9.00 pm.
- Travelling duration ($Du1_{ijk}$ $and$ $Du2_{jv}$): It was assumed that each vehicle travelled one kilometre per minute in both echelons. Therefore, travelling duration depended on the distance between the origin and destination.
- Number of retailer's DCs and number of 3PL's local DCs ($n_{RDC}$ $and$ $n_{TDC}$): One retailer with one DC was operating in the system. There were six shopping centres in this case study, but the 3PL had four DCs to serve these shopping centres. Each

DC served one shopping centre, except one DC, which served three shopping centres.

The results of conducting the case study proved that the proposed LMD with coopetition strategy improved delivery performance in terms of cost, lead-time and travelling distance. Figure 5.28 displays the mean cost per pallet and mean lead-time per parcel of the current situation, alongside the non-dominated solutions of Scenarios II and III. The results show that the solution of Scenario II offered the lowest mean cost per pallet, while most of the solutions of Scenario III offered lower lead-time. Both Scenario II and III offered lower mean cost and mean lead-time than the current situation.

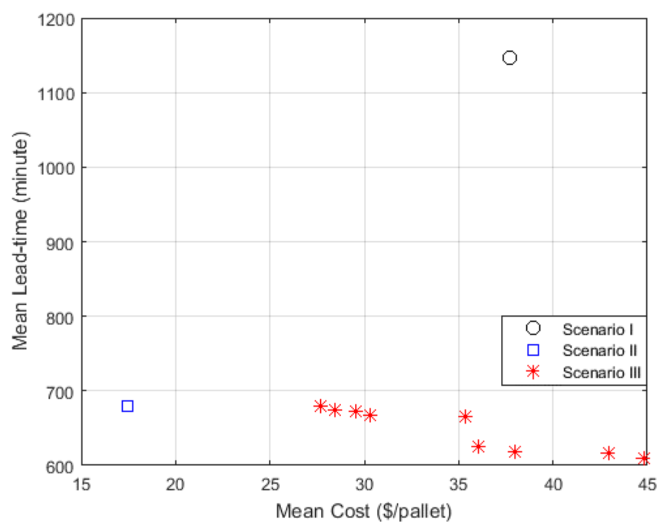



Figure 5.28: Pareto Fronts of All Three Scenarios—Case Study

The results of the case study corresponded with the results of the simulated instances. The average cost per parcel of both Scenarios II and III was less than Scenario I ($0.1748, $0.2765 and $0.3768 per parcel, respectively). As with the results from the instances, the average lead-time per parcel of the best lead-time solution in Scenario III was less than Scenario II (610 and 679 minutes per parcel, respectively) (see Figure 5.29). Both scenarios had better results than Scenario I. Despite the results of the instances, Scenario III improved mean travelling distance more than Scenario II in the real case (0.0921 and 0.1118 kilometres per parcel, respectively).

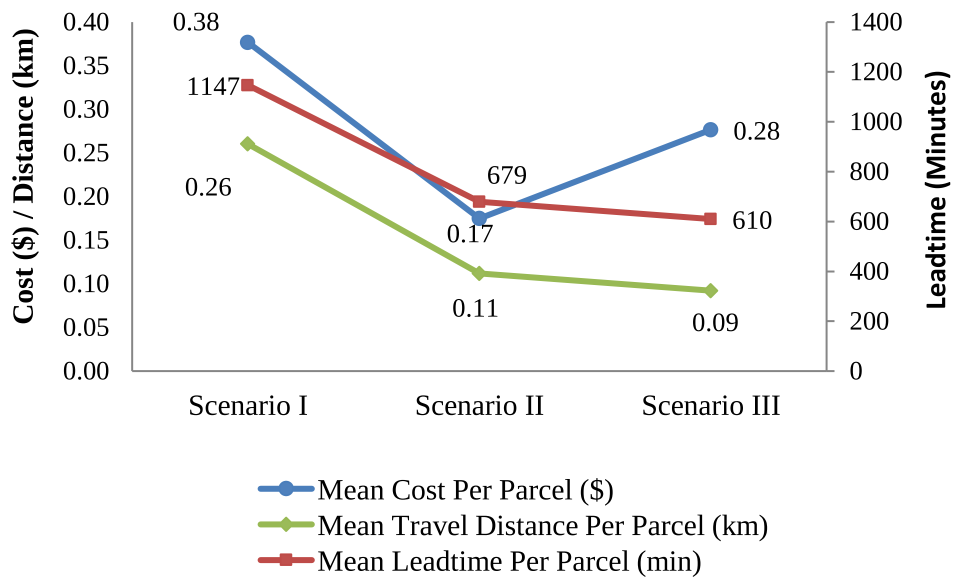



Figure 5.29: Comparison of Results of Three Scenarios Using Case Study Data

The results of the case study confirmed that the scenarios with coopetition strategy decreased the number of vehicles needed for the whole system and increased the utilisation rate. Figure 5.30 compares the number of vehicles and utilisation rate among the three scenarios in the case study. Despite the results from the instances, the numbers of vehicles and the utilisation rate for both Scenario II and III were the same.

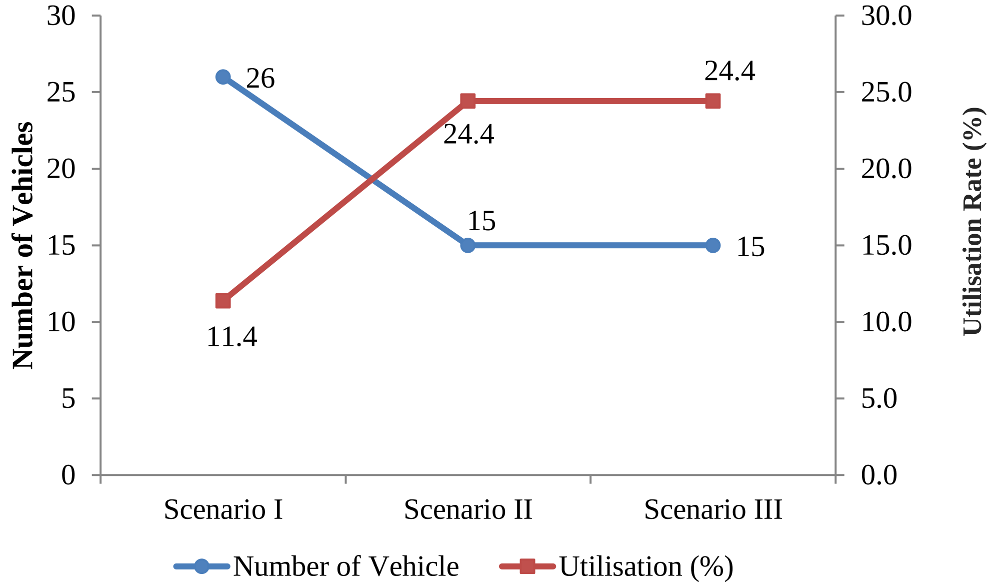



Figure 5.30: Comparison of Number of Vehicles and Utilisation Rates of Three Scenarios Using Case Study Data

### 5.5 Summary of the Results

This study investigated LMD models with and without coopetition strategy. Both cost and lead-time—as the LMD performance indicators included in the objective function—simultaneously decreased when coopetition was applied. The results showed that coopetition also significantly improved other aspects of LMD performance, including travelling distance, utilisation rate and number of vehicles (see Table 5.3). The scenarios with coopetition strategy decreased cost by around 60% considering random instance sets. Using the case study data, Scenario III reduced LMD cost by 26%, which was around half the cost reduction in the random instance sets. The scenarios with coopetition strategy were between 36% and 56% faster than the scenario without coopetition strategy in both random instances and the case study. The vehicles in scenarios with coopetition strategy travelled shorter distances to deliver parcels (between 57% and 66%) considering both random instances and the case study data. The results of the case study data showed a better utilisation rate for both coopetition scenarios than in the random instance results. The number of vehicles decreased in coopetition scenarios by between 30% and 42% considering instances and the case study data.

The results showed that both scenarios with coopetition strategy (Scenarios II and III) significantly improved the LMD performance, but Scenario II had slightly better results for cost and travelling distance, utilisation rate and number of vehicles based on the instance sets. In contrast, Scenario III provided better results in the lead-time indicator. These findings aligned with the case study data, except for travelling distance. The results showed that Scenario III had better traveling distance performance than Scenario II when using the case study data. Moreover, the performance of Scenarios II and III was the same in utilisation rate and the number of vehicles when the models were evaluated by case study data. Therefore, selecting the best scenario depends on the strategies and preferences of the network—if lead-time and quality of service are emphasised, it may be wiser to apply Scenario III; otherwise, Scenario II would be preferable. Either way, this study strongly recommends employing a coopetition strategy for LMD.

Table 5.3: Summary of Results

| Issue | Instance | Cost Reduction | Lead-time Reduction | Travelling Distance Reduction | Utilisation Rate Improvement | Vehicle Reduction |
|---|---|---|---|---|---|---|
| Scenario II compared with Scenario I | Random | 60% | 36% | 66% | 50% | 36% |
| | Case study | 55% | 40% | 57% | 114% | 42% |
| Scenario III compared with Scenario I | Random | 57% | 56% | 63% | 39% | 30% |
| | Case study | 26% | 46% | 64% | 114% | 42% |
| Scenario III compared with Scenario II | Random | -8% | 31% | -11% | -7% | -10% |
| | Case study | -64% | 10% | 18% | 0% | 0% |
| Best scenario | Random | Scenario II | Scenario III | Scenario II | Scenario II | Scenario II |
| | Case study | Scenario II | Scenario III | Scenario III | Scenarios II and III | Scenarios II and III |
| Is coopetition recommended? | | Yes | Yes | Yes | Yes | Yes |

### 5.6 Sensitivity Analysis

The sensitivity analysis investigated how the solutions were affected by the changes to the model's components. We conducted a sensitivity analysis to determine the effects of changes in the main factors on the performance of scenarios with and without coopetition strategy. We investigated the effects of changes in the number of retailers, number of shopping centres and number of parcels. We investigated how these changes affected cost, lead-time and utilisation rate, which can direct decision makers to make more suitable decisions.

#### 5.6.1 Sensitivity Analysis with Number of Retailers

This section investigates the effects of the number of retailers involved in the system on cost, lead-time and utilisation rate indicators in all three scenarios. There was no coopetition in Scenario I, and the retailer network and 3PL network worked separately.

The cost to the whole system decreased by around seven cents per parcel ($7.00 per pallet) on average when the number of retailers increased from a low to medium rate. This reduction did not continue when the number of retailers increased from the medium to high rate (see Figure 5.31). The cost increased a little (one cent per parcel on average) when the number of retailers increased from five to 10. However, it could not be concluded that the increase in the number of retailers always decreased the cost indicator in the scenario without coopetition strategy.

Increasing the number of retailers decreased the lead-time rate in this scenario. Delivering parcels from the shopping centres to the 3PL's main DC took 623 minutes on average when there were two retailers in the system, and 574 and 482 minutes when there were five and 10 retailers, respectively (see Figure 5.32). In other words, parcels reached the 3PL's main DC two hours and 21 minutes (141 minutes) sooner, an average, when the number of retailers involved in the system increased from two to 10. More parcels reached each 3PL's local DC when there were more retailers in each shopping centre. Therefore, more vehicles left from the 3PL's local DC to the main DC and, consequently, each parcel had more chances of being collected from local DCs, which decreased the delay time in the 3PL's local DCs.

The average utilisation rate did not change significantly by changes in the number of retailers (see Figure 5.33). It increased slightly (2%) when the number of retailers increased from two to five. The average utilisation rates were almost constant when the number of retailers increased from five to 10.

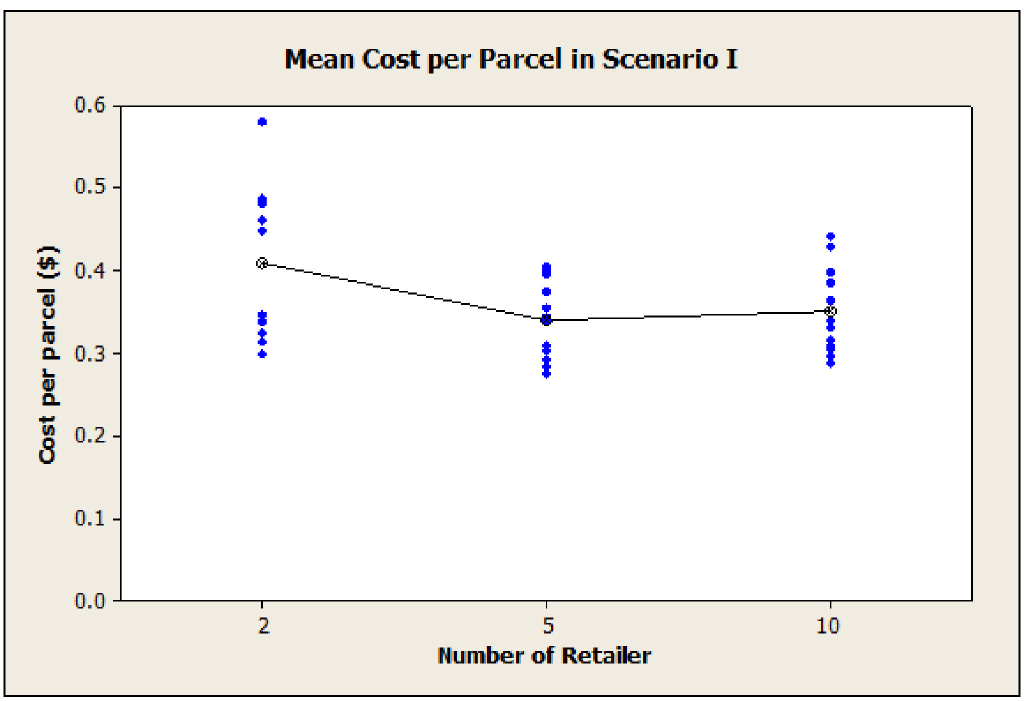



Figure 5.31: Effects of Number of Retailers on Cost in Scenario without Coopetition Strategy

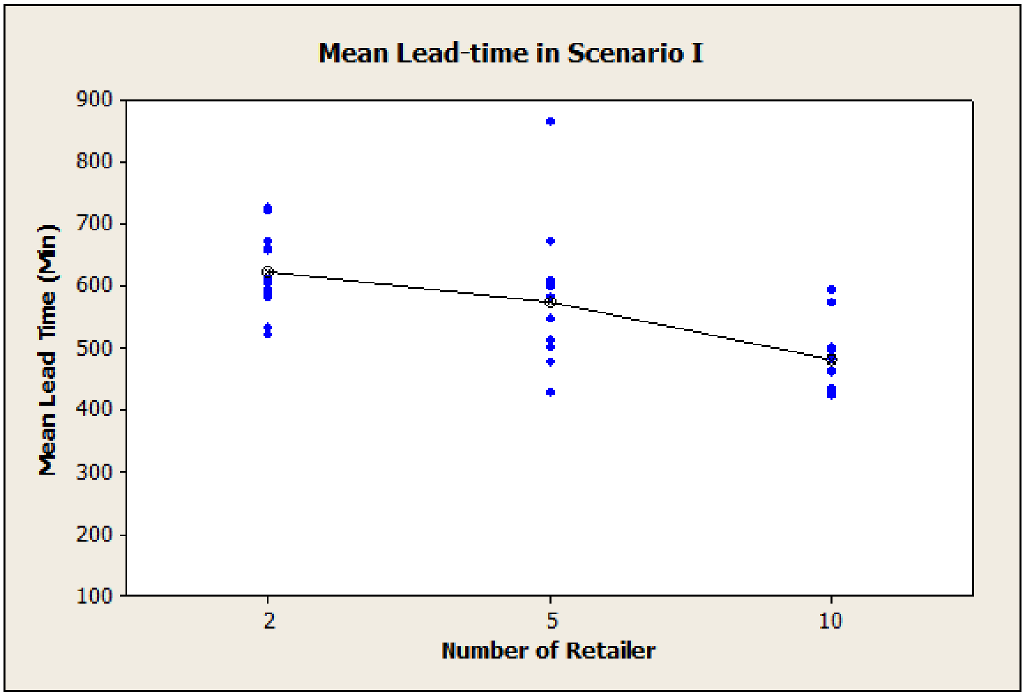



Figure 5.32: Effects of Number of Retailers on Lead-time in Scenario without Coopetition Strategy

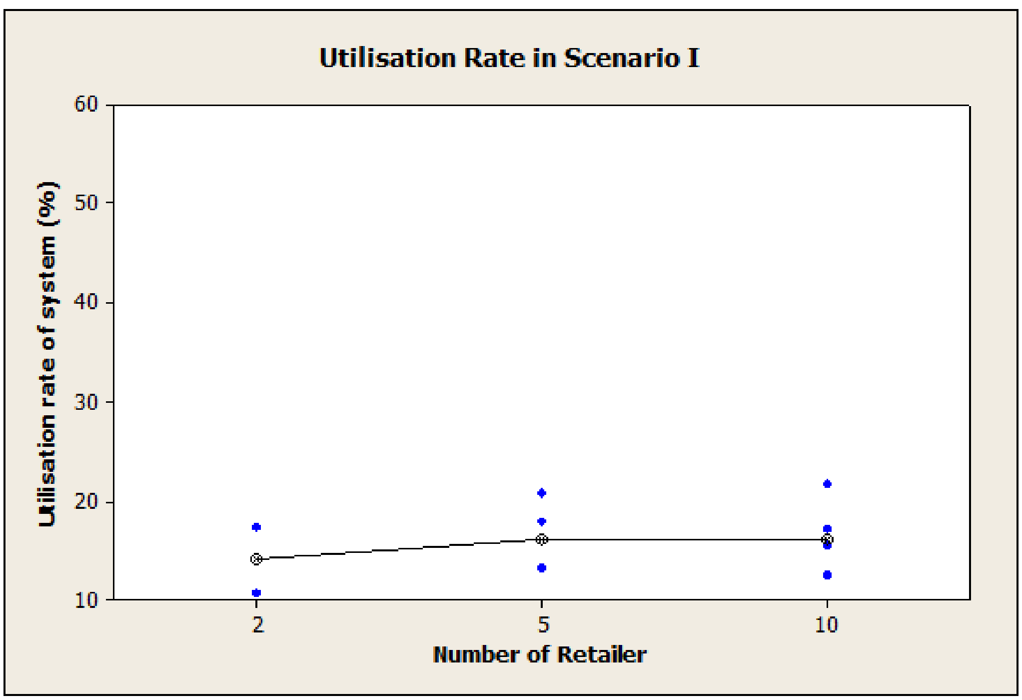



Figure 5.33: Effects of Number of Retailers on Utilisation Rate in Scenario without Coopetition Strategy

Figures 5.34, 5.35 and 5.36 display how the number of retailers involved in the models with coopetition strategy affected the cost, lead-time and utilisation indicators in Scenarios II and III. The mean cost per parcel of the whole system in both Scenario II and III remained almost steady when the number of retailers changed. The average cost changed less than one cent (0.33 cents per parcel) in Scenario II (see Figure 5.34). The cost changed around two cents per parcel on average by increasing the number of retailers in Scenario III.

The number of retailers had a significant effect on lead-time in Scenario II, yet had little effect in Scenario III. The mean lead-time of a parcel decreased to 134 and 200 minutes when the number of retailers changed from two to five and 10, respectively, in Scenario II (see Figure 5.35). In Scenario III, lead-time fluctuated around only 23 minutes on average.

The differences between the utilisation rates of cases with fewer and more retailers were not significant in Scenario II. The utilisation rates for all cases were around 45% (see Figure 5.36). In Scenario III, increasing the number of retailers decreased the utilisation rate very slightly (around 3%), which was not considered a significant change.

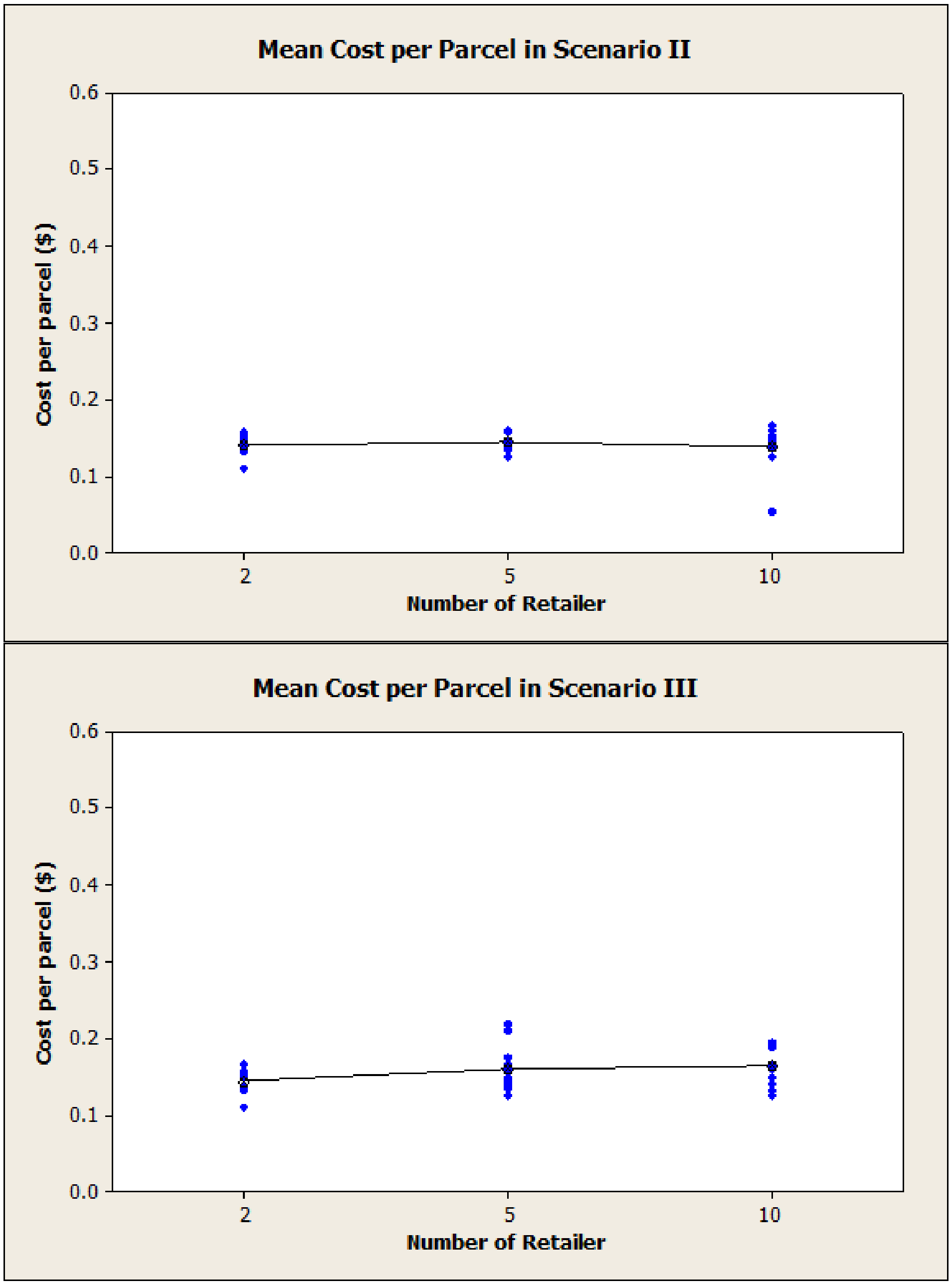



Figure 5.34: Effects of Number of Retailers on Cost in Scenarios with Coopetition Strategy

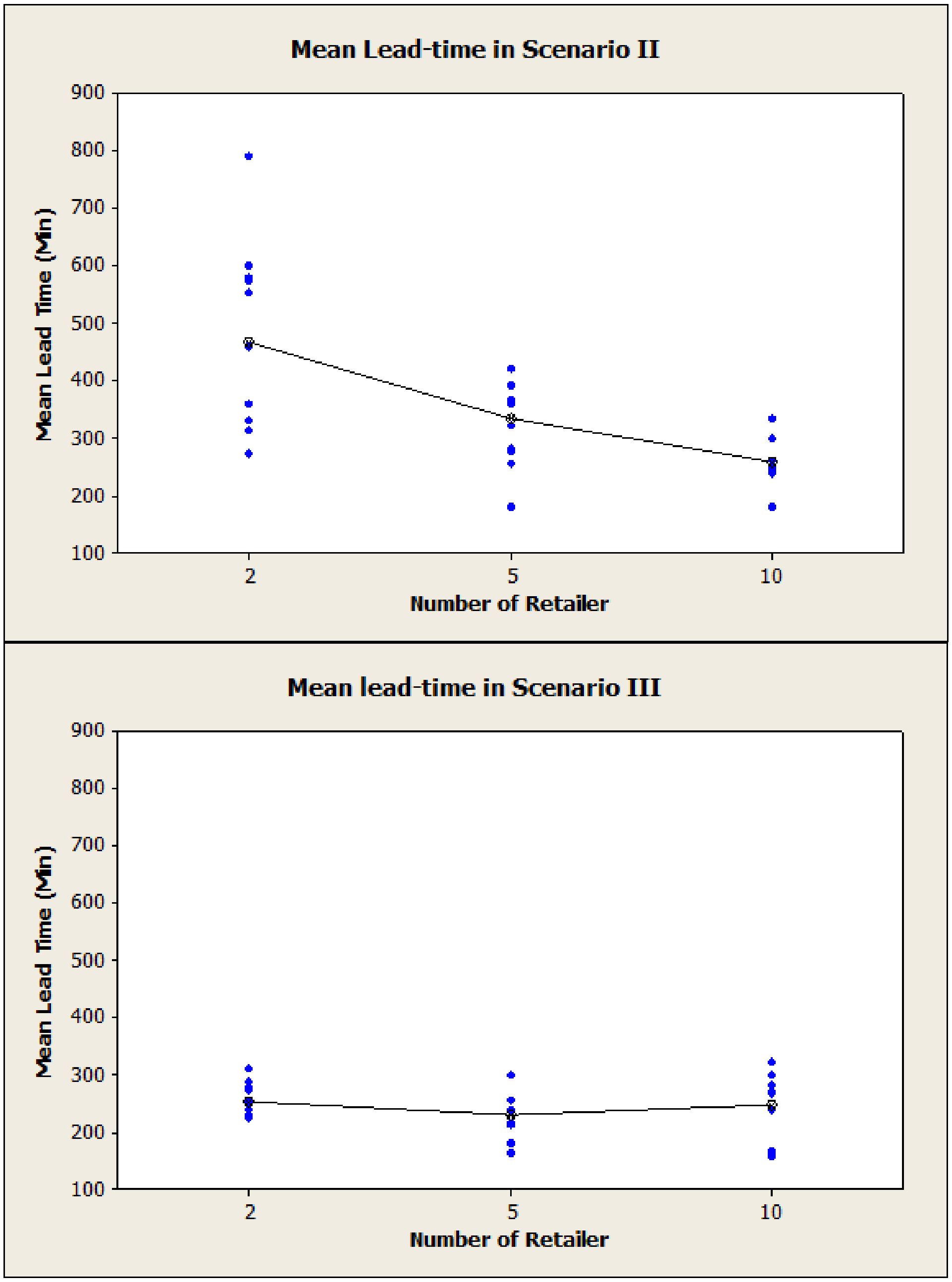



Figure 5.35: Effects of Number of Retailers on Lead-time in Scenarios with Coopetition Strategy

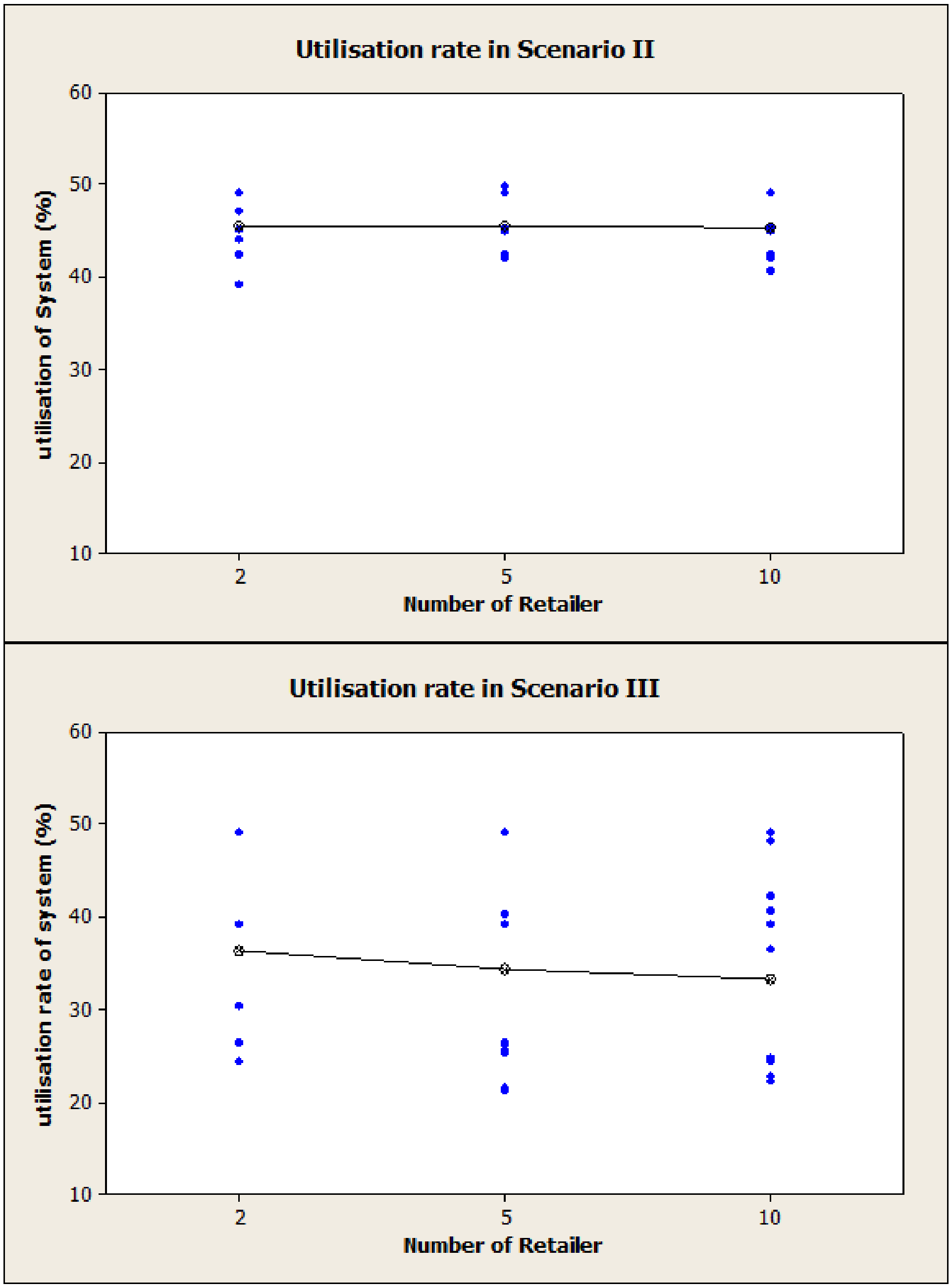



Figure 5.36: Effects of Number of Retailers on Utilisation Rate in Scenarios with Coopetition Strategy

### 5.6.2 Sensitivity Analysis with Number of Shopping Centres

This section investigates the effects of the number of shopping centres in the system on cost, lead-time and utilisation rate indicators in all three scenarios. Changes in the number of shopping centres did not significantly affect cost, lead-time or utilisation rate in Scenario I (see Figures 5.37, 3.38 and 5.39). The maximum changes in the mean cost per parcel were around one cent ($1.00 per pallet), in the mean lead-time per parcel were around 12 minutes, and in the utilisation rate were less than 2% when the number of shopping centres increased. As a result of the structure of the proposed model, this perception was reasonable. In the proposed model, it was assumed that each 3PL's local DC provided service for just one shopping centre. Therefore, each vehicle only collected goods from one shopping centre and the parcels could not be collected from different shopping centres by one vehicle. Therefore, the increase in the number of shopping centres could not affect the results.

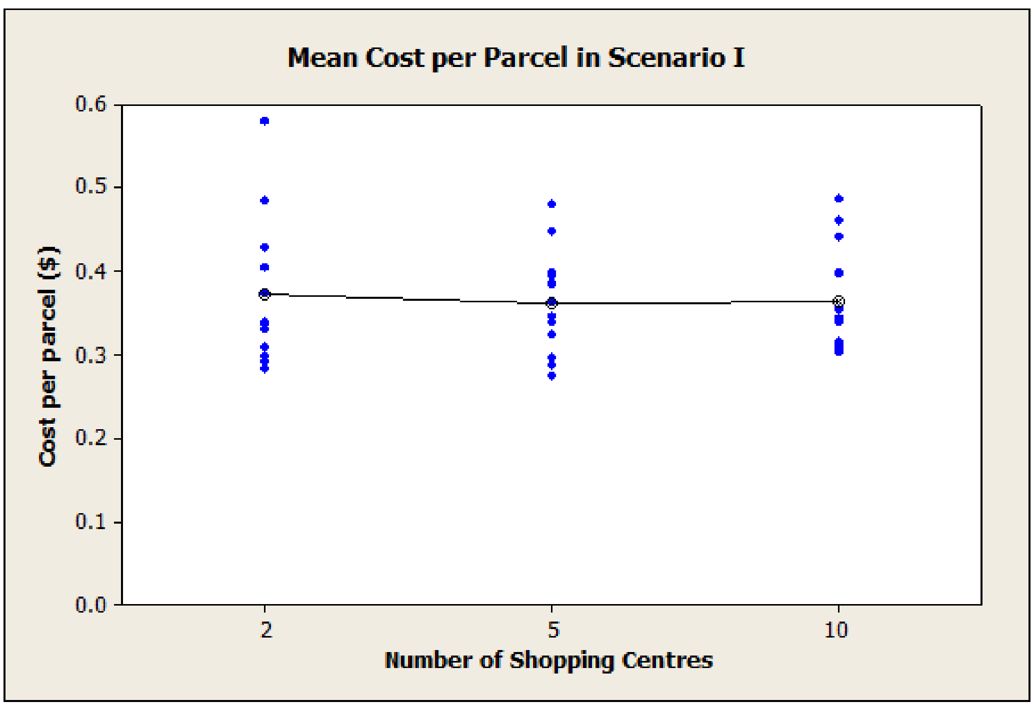


Figure 5.37: Effects of Number of Shopping Centres on Cost in Scenario without Coopetition Strategy

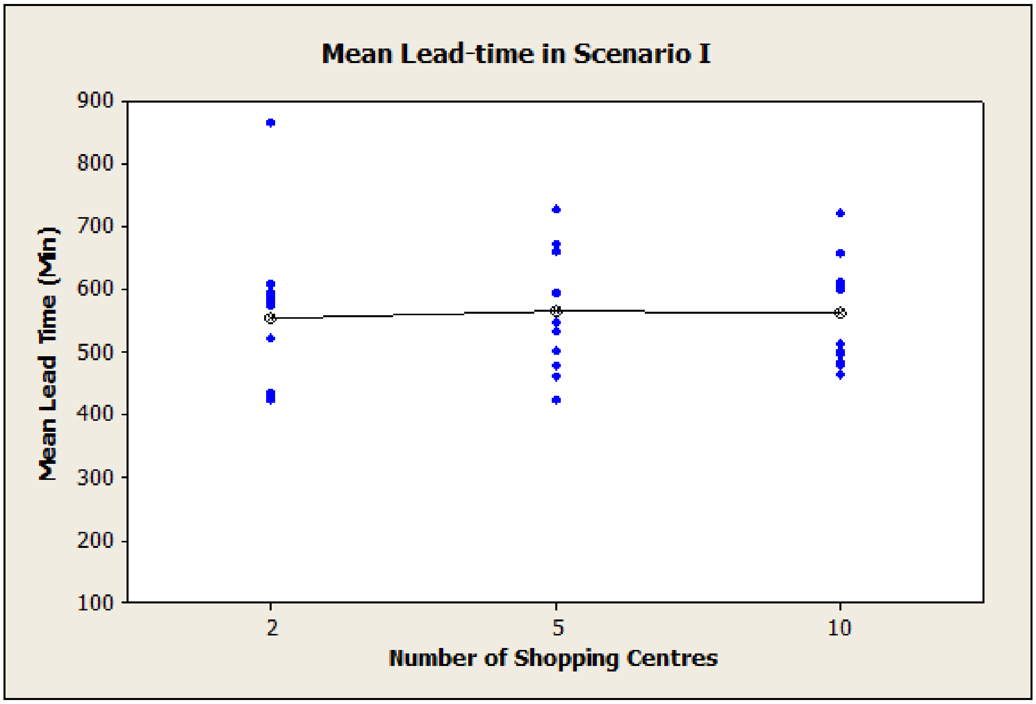



Figure 5.38: Effects of Number of Shopping Centres on Lead-time in Scenario without Coopetition Strategy

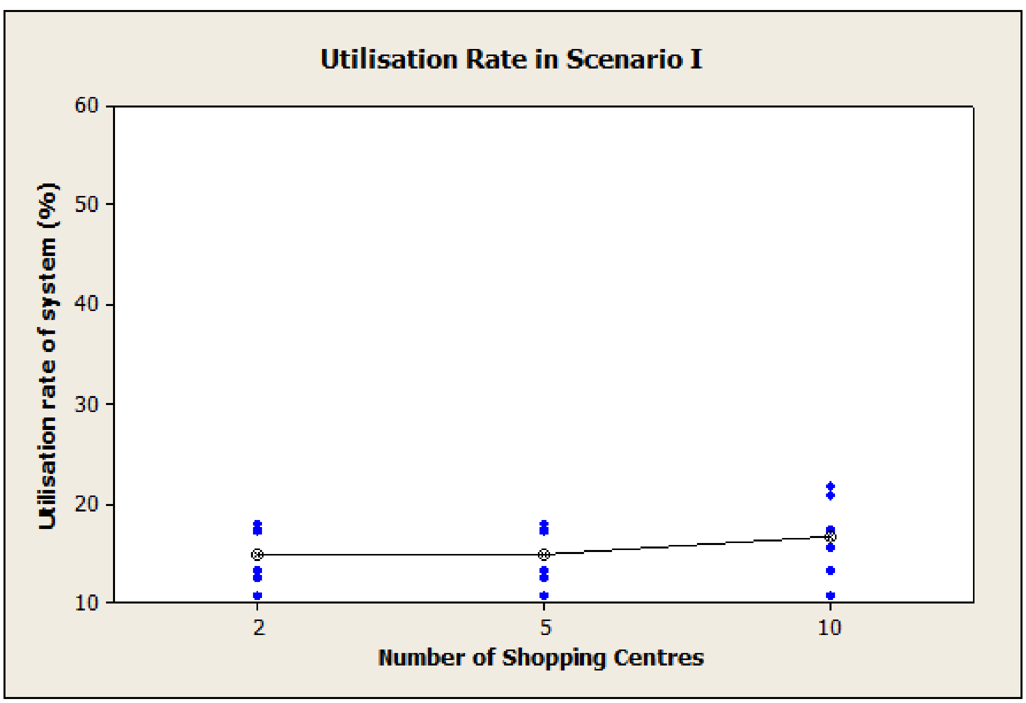



Figure 5.39: Effects of Number of Shopping Centres on Utilisation Rate in Scenario without Coopetition Strategy

There were limited fluctuations in the mean cost by changing the number of shopping centres involved in the models with coopetition strategy. The mean cost of parcels changed between one and three cents ($1.00 to $3.00 per pallets) by changing the number of shopping centres, which was not a significant change (see Figure 5.40). However, the best mean cost belonged to the medium number of shopping centres in both Scenarios II and III.

When more shopping centres were involved in the system, parcels needed more time to be delivered to the 3PL's main DC in Scenario III. It took 31 and 41 minutes more on average for parcels to be delivered to the 3PL's main DC when the number of shopping centres changed from two to five and 10, respectively (see Figure 5.41). This pattern was not applicable in Scenario II. The shortest mean lead-time per parcel occurred when high numbers of shopping centres were involved in the system, while the longest mean lead-time did not occur for the low number of shopping centres, and occurred when there were medium shopping centres in the system. The difference between the high and low amount of mean lead-time was about 67 minutes.

The utilisation rates slightly changed when the numbers of shopping centres increased in scenarios with coopetition strategy. In Scenario II, the rates increased by around 4% and 5% when the number of shopping centres increased from two to five and 10, respectively (see Figure 5.42). In Scenario III, the utilisation rate increased by around 4% when the number of shopping centres increased from two to five, yet fell slightly (around 3%) when the number of shopping centres increased from five to 10.

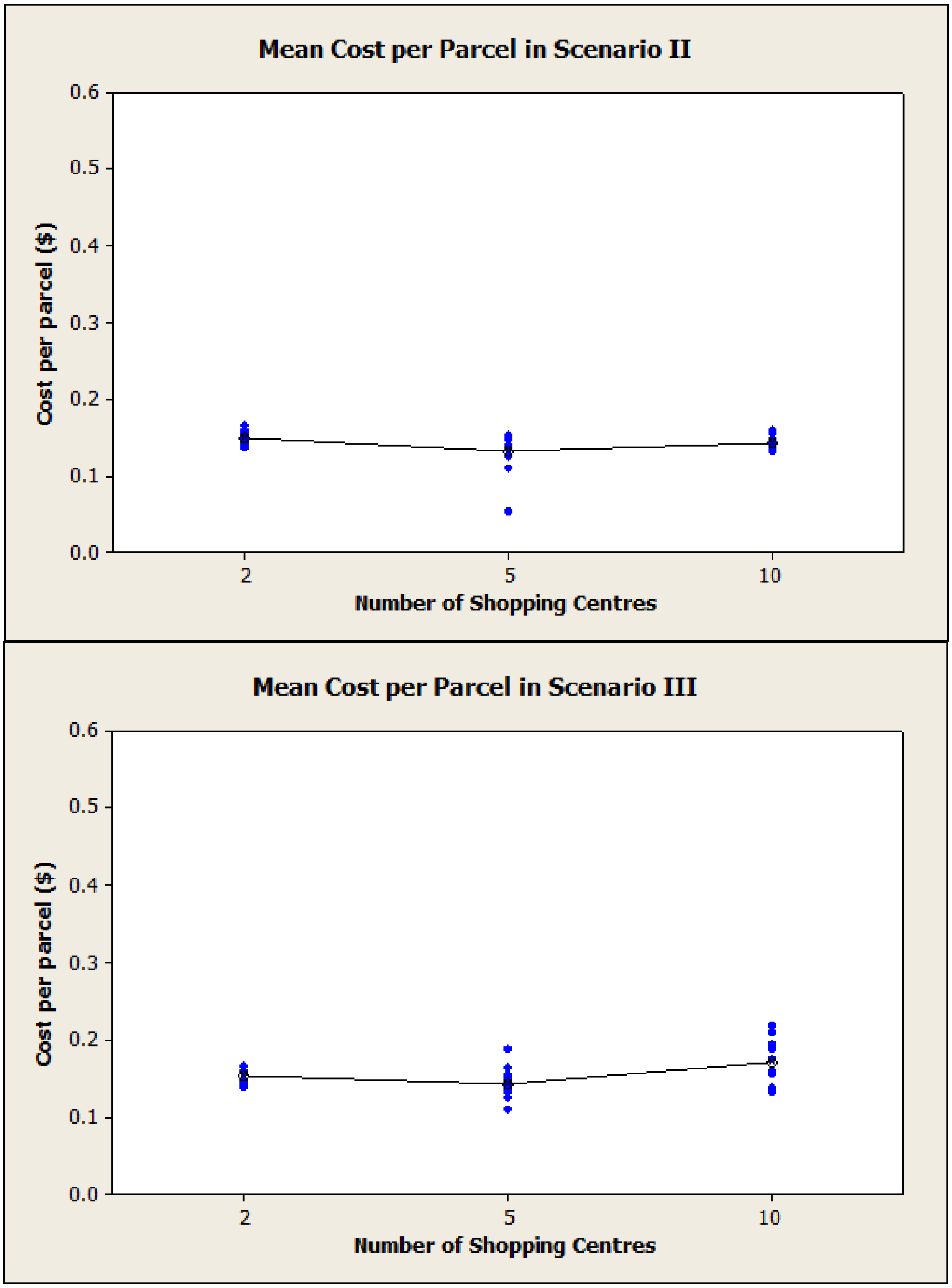



Figure 5.40: Effects of Number of Shopping Centres on Cost in Scenarios with Coopetition Strategy

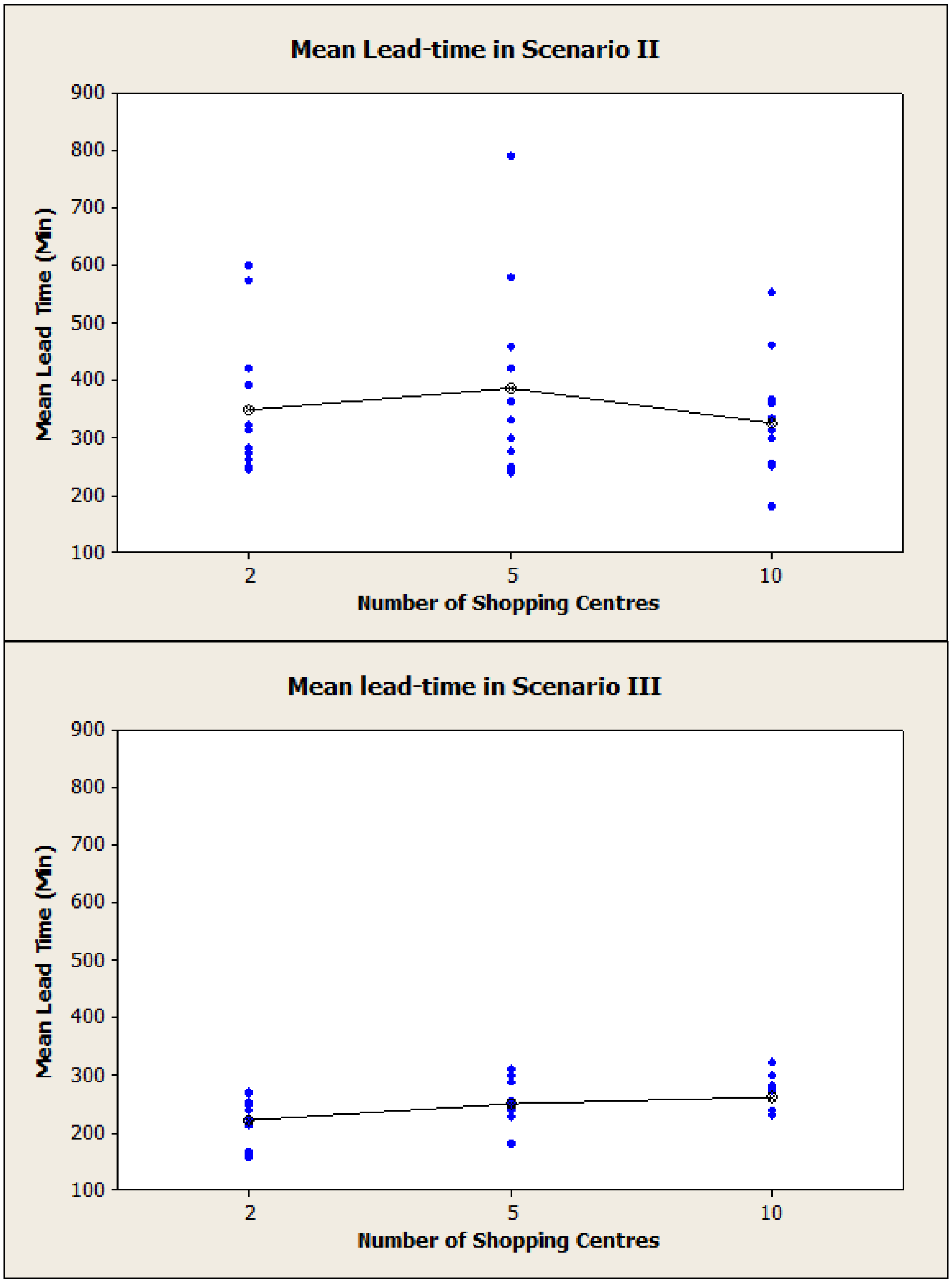



Figure 5.41: Effects of Number of Shopping Centres on Lead-time in Scenarios with Coopetition Strategy

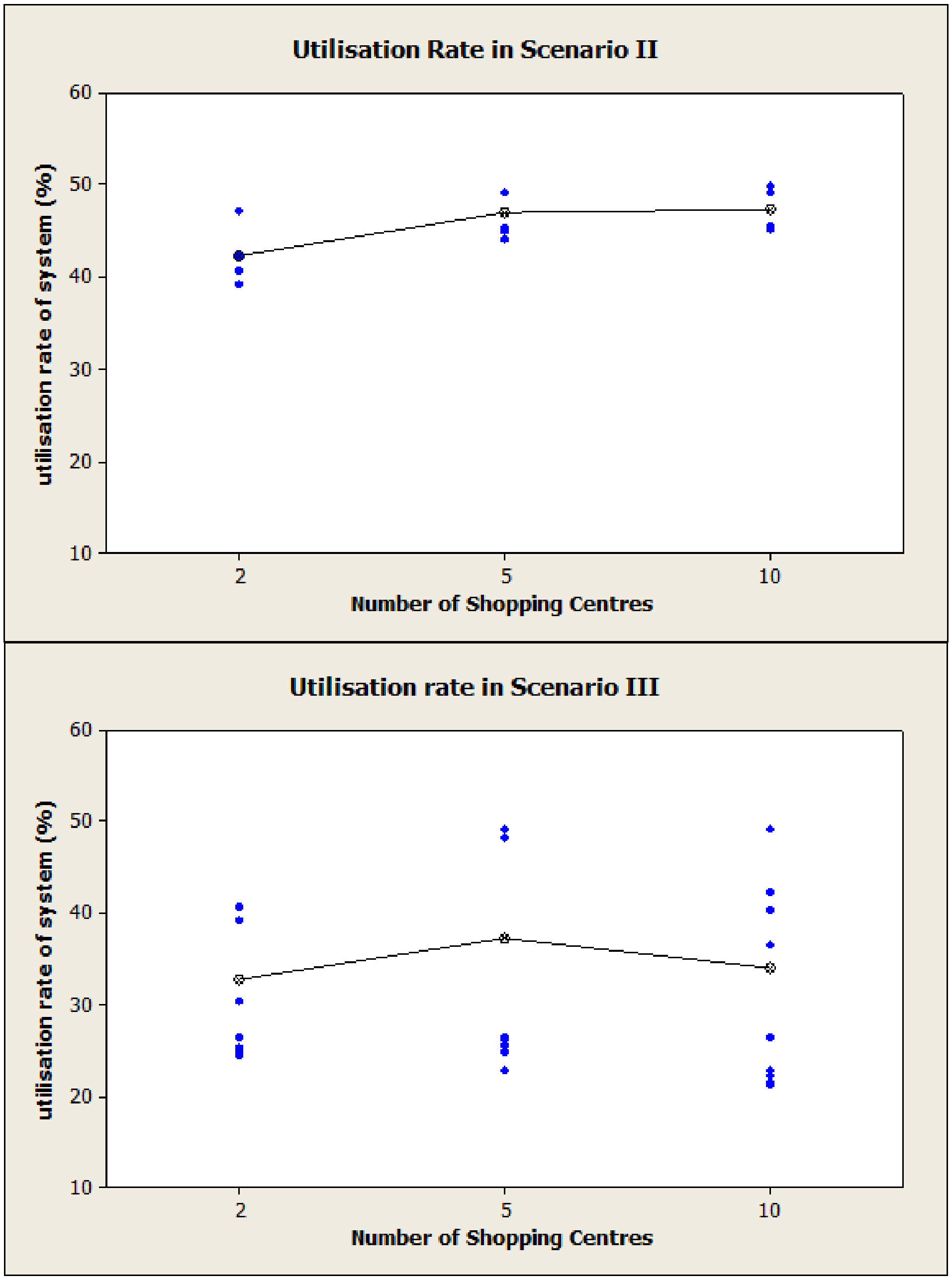



Figure 5.42: Effects of Number of Shopping Centres on Utilisation Rate in Scenarios with Coopetition Strategy

### 5.6.3 Sensitivity Analysis with Number of Parcels

This section investigates the effects of increasing the number of parcels in the whole system on the performance of the scenarios. The number of parcels significantly decreased the cost and lead-time and increased the utilisation rate in Scenario I. The mean cost of delivering each parcel on high-demand days was around 11 cents ($11.00 per pallet) less than the cost on normal days (see Figure 5.43). There were nine pallets (900 parcels) for each retailer in each shopping centre on high-demand days, and five pallets (500 parcels) on normal days. Compared with low-demand days, parcels were delivered to the 3PL's main DC around 82 minutes sooner, with around a 6% higher utilisation rate on high-demand days in the scenario without coopetition strategy (see Figures 5.44 and 5.45).

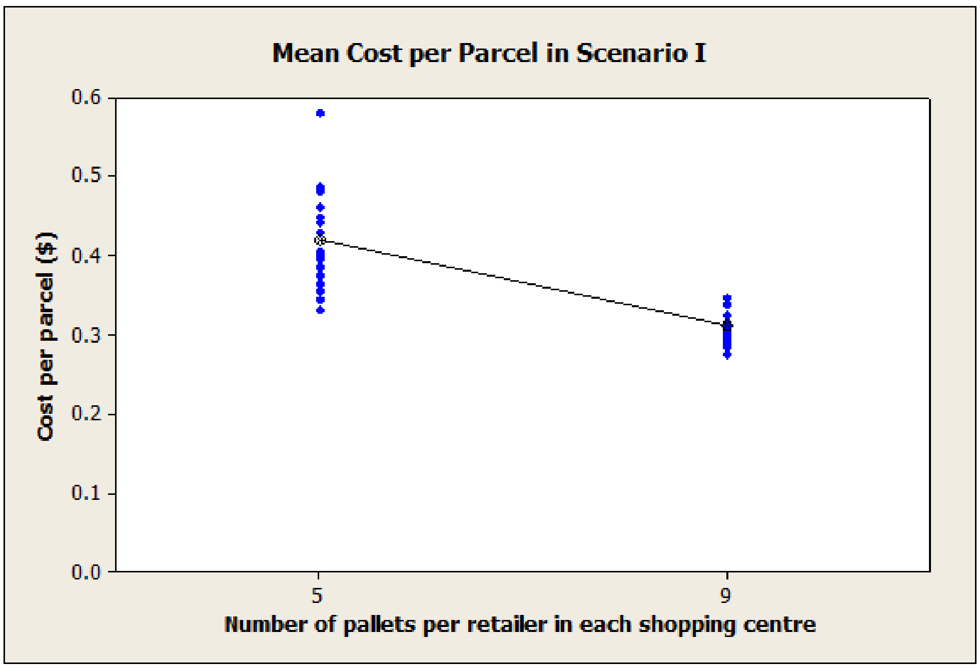



Figure 5.43: Effects of Number of Parcels on Cost in Scenario without Coopetition Strategy

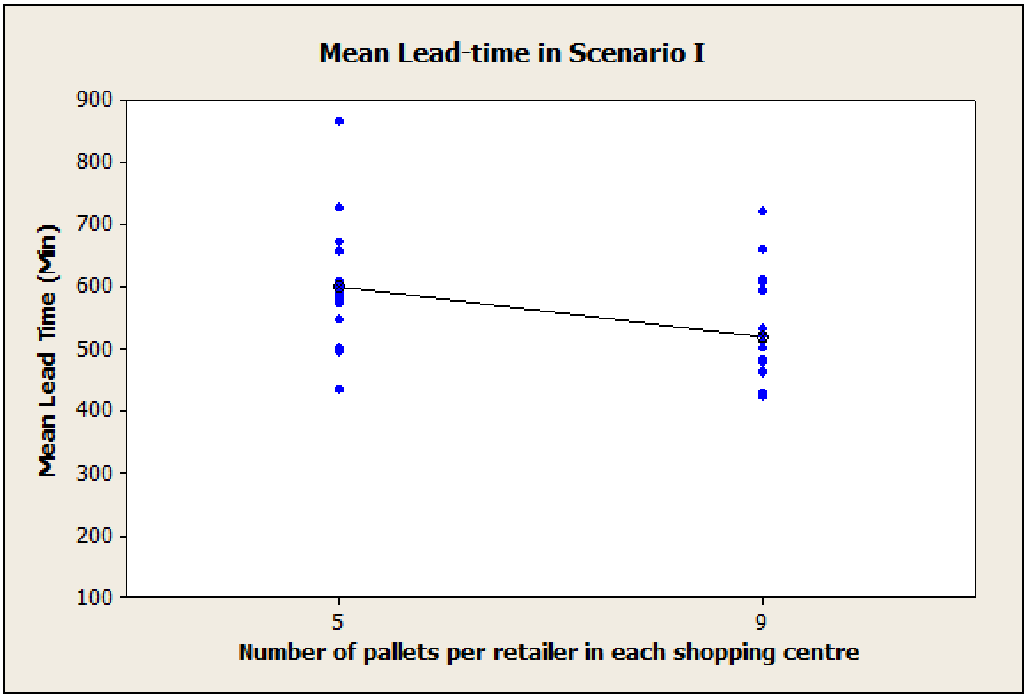


Figure 5.44: Effects of Number of Parcels on Lead-time in Scenario without Coopetition Strategy

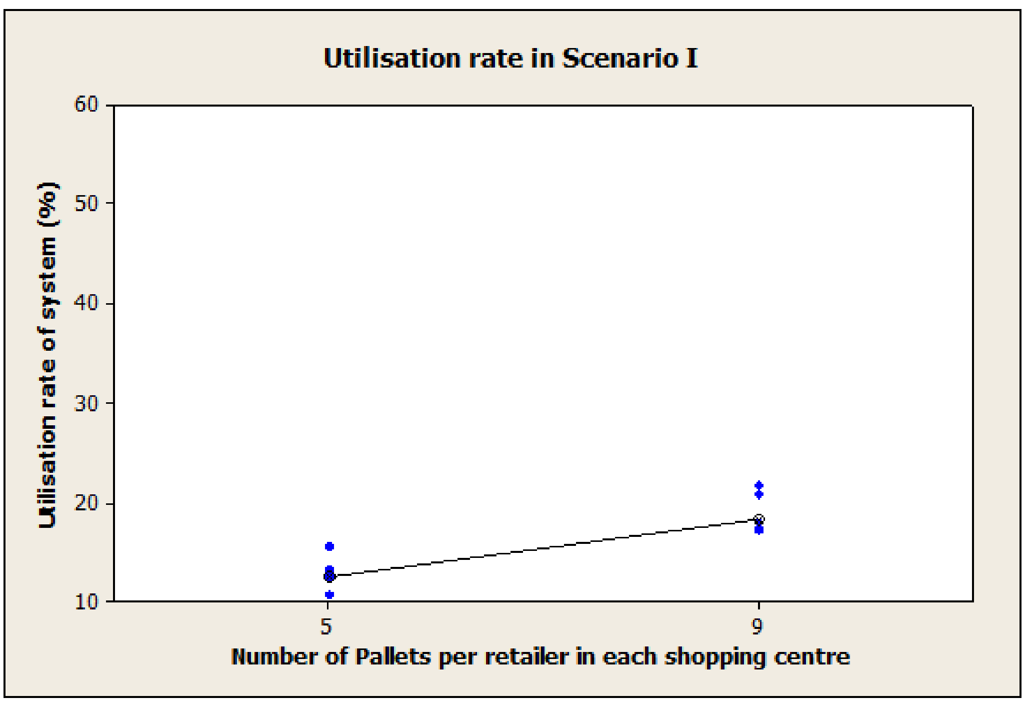


Figure 5.45: Effects of Number of Parcels on Utilisation Rate in Scenario without Coopetition Strategy

Unlike the system without coopetition strategy, cost increased very slightly in the scenarios with coopetition strategy when the number of parcels increased from five to nine pallets per retailer shopping centre. The increases were not significant (around $2.00 per pallet); however, unlike Scenario I, the cost is not decreased by increasing the number of parcels (see Figure 5.46).

Parcels reached the 3PL’s main DC around two hours sooner, on average, on high-demand days in comparison with normal-demand days in Scenario II. However, in Scenario III, the mean lead-time of parcels did not significantly change by changing the number of parcels (see Figure 5.47). The behaviour of utilisation rate was different in Scenarios II and III. The utilisation rate did not change significantly (around 2%) when the number of parcels increased from five to nine pallets per retailer shopping centre in Scenario II, while the utilisation rate on high-demand days was 20% less than the utilisation rate on normal days (see Figure 5.48).

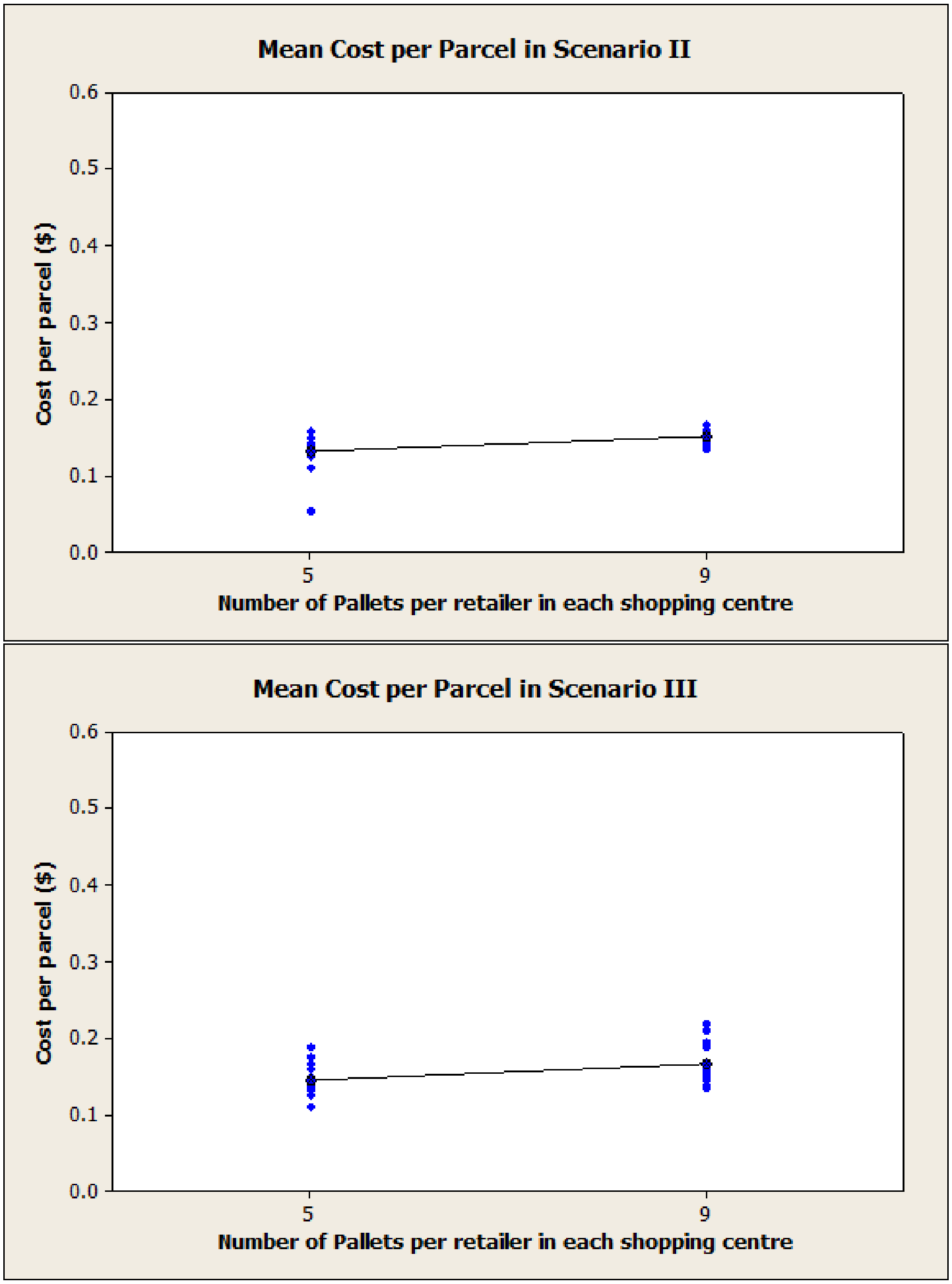



Figure 5.46: Effects of Number of Parcels on Cost in Scenarios with Coopetition Strategy

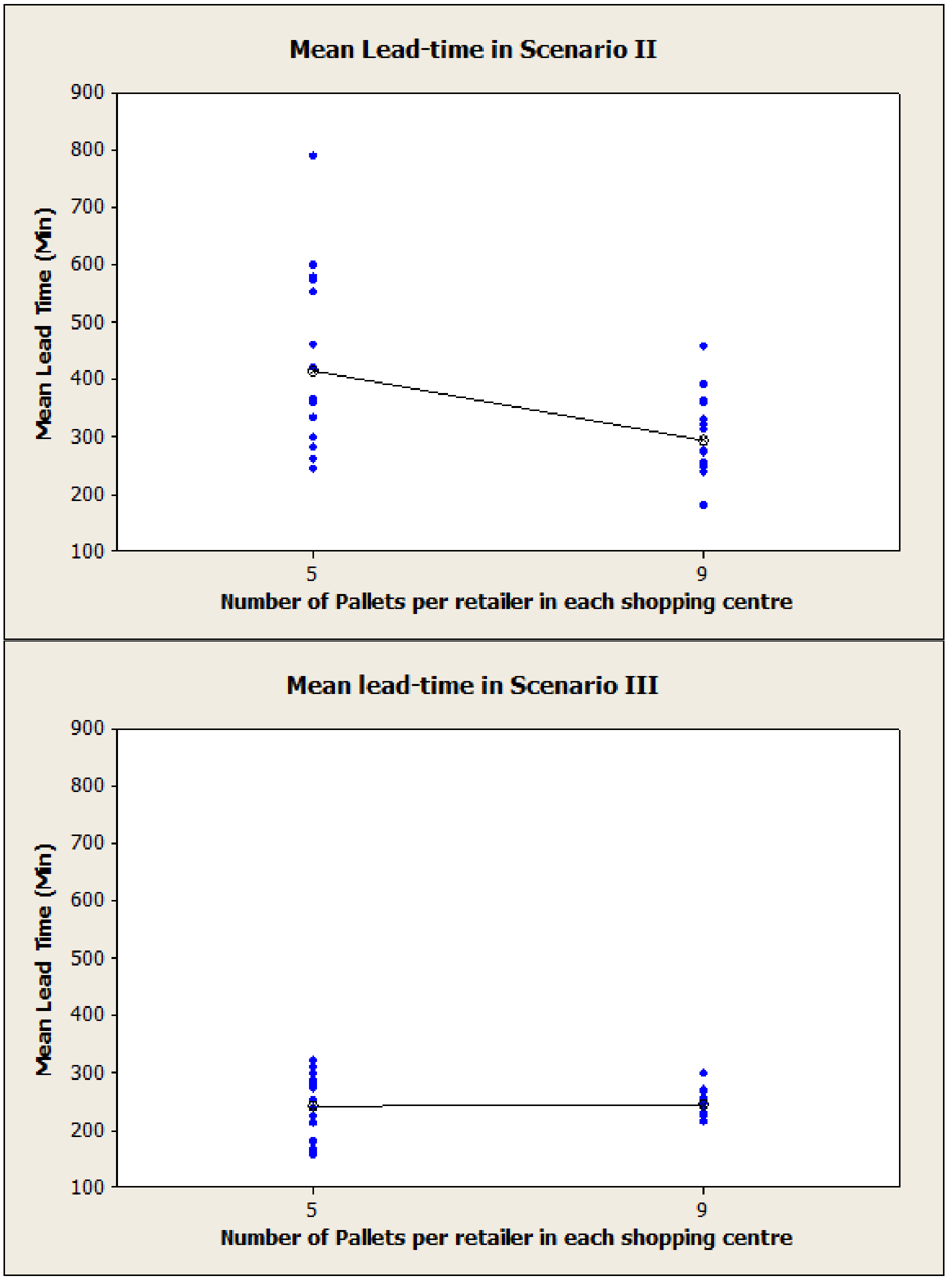



Figure 5.47: Effects of Number of Parcels on Lead-time in Scenarios with Coopetition Strategy

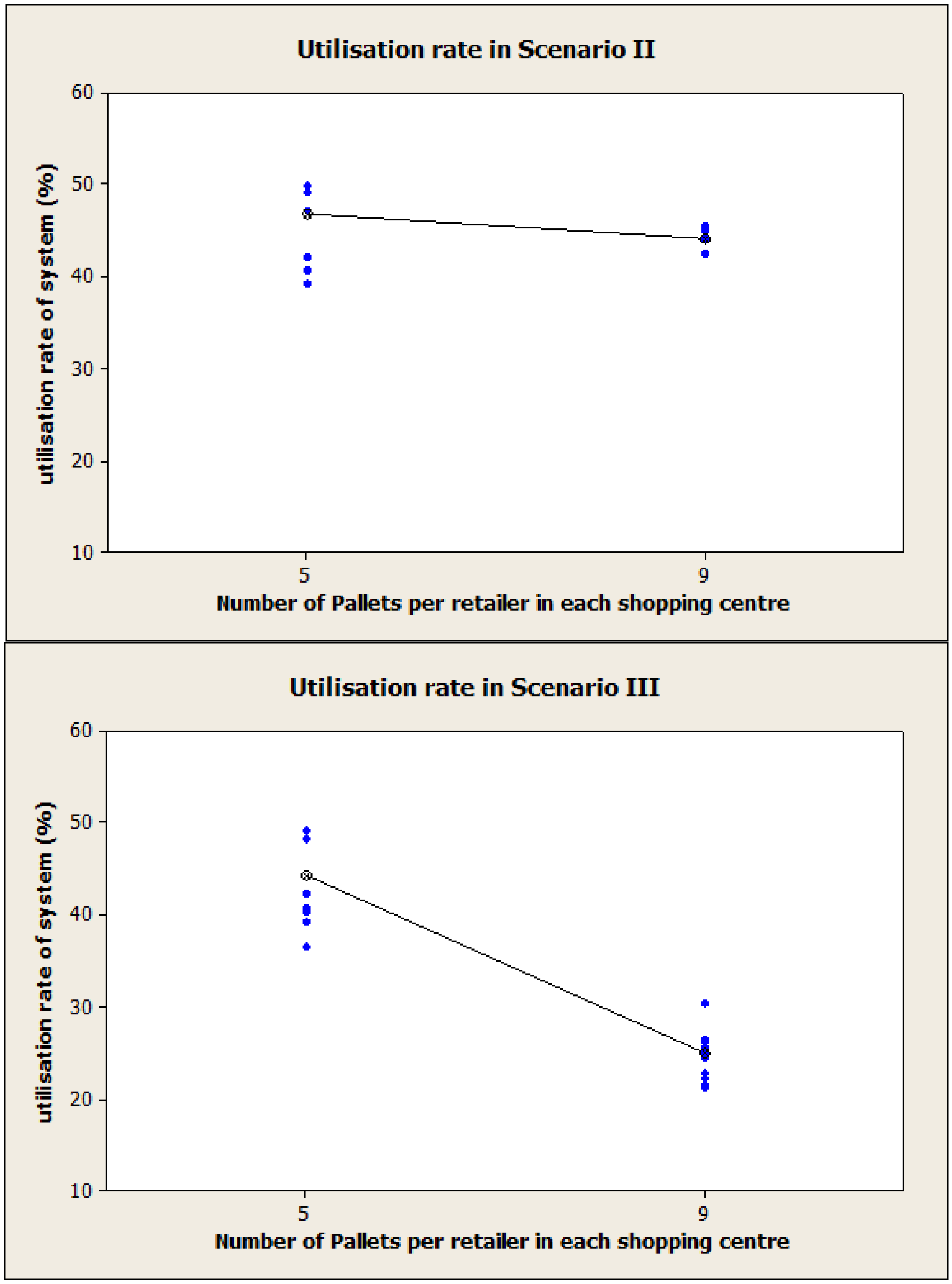



Figure 5.48: Effects of Number of Parcels on Utilisation Rate in Scenarios with Coopetition Strategy

### 5.6.4 Summary of Sensitivity Analysis

This chapter has investigated the behaviour of cost, lead-time and utilisation rates in the scenarios with and without coopetition strategy, based on changes in the number of retailers, shopping centres and parcels. A summary of this investigation is presented in Figure 5.49. Increasing the number of retailers significantly decreased the lead-time in Scenarios I and II. Increasing the number of shopping centres did not have strong effects on performance—it only slightly increased the lead-time of Scenario III and utilisation rate of Scenario II. Increasing the number of parcels significantly decreased the cost of Scenario I, lead-time of Scenarios I and II and utilisation rate of Scenario III. It also slightly increased the utilisation rate of Scenario I.

| | Cost | | | Lead-time | | | Utilisation Rate | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Scenario I** | **Scenario II** | **Scenario III** | **Scenario I** | **Scenario II** | **Scenario III** | **Scenario I** | **Scenario II** | **Scenario III** |
| Increase in number of retailers | ~ | ≅ | ≅ | ⇓ | ⇓ | ≅ | ≅ | ≅ | ≅ |
| Increase in number of shopping centres | ≅ | ≅ | ≅ | ≅ | ~ | ↑ | ≅ | ↑ | ~ |
| Increase in number of parcels per retailer shopping centre | ⇓ | ≅ | ≅ | ⇓ | ⇓ | ≅ | ↑ | ≅ | ⇓ |

~ Fluctuation
≅ Almost no change
↓ Slight decrease
⇓ Radical decrease
↑ Slight increase
⇑ Radical increase

Figure 5.49: Summary of Sensitivity Analysis Results

## 5.7 Summary

This chapter has presented the LMD models with and without coopetition, and calculated and compared the models' performance. This chapter also discussed how coopetition can affect LMD performance. To do so, two scenarios with a coopetition strategy and one scenario without a coopetition strategy were defined. Retailers and logistics service providers shared their empty running vehicles in the scenarios with coopetition strategy, and worked separately in the scenario without coopetition strategy. In the first scenario with coopetition strategy, all parcels were delivered only by the retailer's vehicle, while, in the second scenario with coopetition strategy, both the retailer's and 3PL's vehicles could complete the delivery. The proposed scenarios were discussed conceptually, and then the scenarios were translated into mathematical models.

The mathematical models facilitated calculation of the performance of scenarios and optimised them when there were different choices for delivering parcels. MILP in the form of multi-objective optimisation was considered to formulate the models. This chapter discussed how NSGA II was considered to optimise the performance. It was necessary to define the limitations of the model; therefore, the assumptions of the model were clearly discussed. To examine the model and calculate the performance of the scenarios, some instances were required as inputs. We explained the construction of the instance sets that we considered to examine the model. The performance of the proposed LMD model with coopetition strategy was presented, along with the performance of the model without coopetition strategy. The results indicated that coopetition improved the LMD performance, including cost, lead-time, travelling distance, utilisation rate and number of vehicles. The results revealed that the first scenario with coopetition strategy decreased cost and travelling distance and increased the number of vehicles more than did the second scenario; however, the opposite was the case for the lead-time indicator.

We also examined the model for a real case study of a retail sector network in Melbourne. The results of the case study confirmed our findings from the random data. At the end of this chapter, we completed a sensitivity analysis and examined how changes in the main factors of the model would affect the performance of the scenarios with and without a coopetition strategy. The major findings indicated that increasing the number of retailers, shopping centres and parcels would not have similar effects on cost, lead-time and utilisation rate in the different scenarios. The numbers of shopping centre did not significantly affect the results. Increasing the number of retailers or parcels decreased the lead-time of the scenario without a coopetition strategy and the first scenario with a coopetition strategy (Scenario II). Increasing the number of parcels also significantly decreased the cost of Scenario I and utilisation rate of Scenario III.

# Chapter 6: Discussion

In this chapter, we discuss the results and findings of this study. Section 6.1 discusses the LMD phenomenon and the determinants of LMD. Section 6.2 discusses the structure of LMD in an urban context. Section 6.3 compares the scenarios proposed for LMD with and without a coopetition strategy, and debates the results and conditions of each scenario. The reasons for the changes in the results in various situations are then discussed, and the implication conditions and concerns are also discussed. Finally, Section 6.4 presents a summary of the chapter.

## 6.1 Last Mile Delivery

Several transportations may occur to carry an order from the preparation point, where the order is prepared, to the delivery point, where the order is delivered. The phrase 'last mile' in LMD refers to the last step of transportation in these journeys. Before LMD, goods are carried from the preparation point to the last dispatch point, where LMD begins. Loading and unloading activities are part of all transportation, and the final loading and unloading occurs in LMD. Goods are loaded to vehicles at the last dispatch point of supply chains, and unloaded at the delivery point in the LMD process. Moreover, the term 'delivery' in LMD emphasises the delivery action of this phenomenon. Delivery will occur at delivery points after unloading action. Therefore, LMD is defined as *'the last transportation of a consignment in a supply chain from the last dispatch point to the delivery point where the consignee receives the consignment'*. LMD can occur in any supply chain, unless the preparation point and delivery point are the same. For example, when goods are purchased and collected from brick-and-mortar stores, as undertaken traditionally, there is no LMD because the order is prepared and delivered to the customer in one location. In this example, there is no LMD in the B2C context, whereas there is LMD in the B2B context. The store places orders for displaying or selling purposes, and the goods are prepared somewhere in the supply chain and delivered to the store. Thus, the preparation point and delivery point are different in this context, which means there is LMD. LMD is part of the purchasing process and can occur when the place of preparation is different from the place of delivery. Therefore, LMD can occur in any supply chain and is applicable in B2B, B2C, C2B, C2C and any other context.

The channels of placing orders are not considered a determinant of LMD. Customers may place their order in a face-to-face experience or via the internet or telephone. This does not determine whether LMD exists in a supply chain. For example, in the case of click-and-collect, consumers can place their order online and collect their order from the desired retailer's shop. If the order is prepared at the same shop where delivery occurs, there is no LMD.

LMD is the final transportation of goods in the supply chain boundary, but it may not be the last transportation of goods, as the goods may require extra transportation from the delivery point to the place in which they are actually used. After LMD occurs, transportations happen in pickup mode when the delivery point is distant from the consignee's location. According to our proposed LMD models, 28 of the 40 models are pickup modes that have after-LMD transportation.

## 6.2 Last Mile Delivery Structure

Different forms of LMD can be conducted in an urban context. The LMD transportation can begin from various places (last dispatch point), including factories, warehouses, stores, DCs and collection centres, and finish at the aforementioned places, in addition to the consignee's location. The orders (consignments) can be prepared in various places, including factories, warehouses and stores, which can be the same as the last dispatch point or a different location. Considering these decision factors—including preparation point, last dispatch point and delivery point—LMD can have 40 different structures (see Figure 4.8). The 3LPs and retailer investigated in this study used the LMD structure numbers 7, 14, 16, 20, 27, 29, 36 and 38 to conduct LMD in the retail sector in Melbourne.

Although LMD can start from various places, warehouses and DCs were the most common locations among the investigated companies working in Melbourne. In the retail sector, companies mostly started LMD from their own warehouses/DCs or those belonging to retailers. In the B2B context, the LMD process usually finished at stores, while, in the B2C context, it was finished at consignees' location. The companies investigated in this study mostly prepared the orders at a factory, warehouse or DC in the B2B context, while the orders were prepared at stores in the B2C context. Preparing orders at stores means the first mile delivery starts at stores. If first mile delivery starts from the store and LMD finishes at the store, this means that some vehicles travel to stores to deliver goods and some vehicles from other supply chains travel to stores to collect goods. This is a potential area to share vehicles among different supply chains working in the same area. We considered this opportunity to develop a collaborative LMD model.

## 6.3 Coopetition in Last Mile Delivery

In many cases, the size, weight and quantity of consignments going to a destination are less than the capacity of the allocated vehicle. Therefore, carriers consolidate several consignments that have the same or near destinations to decrease their cost. Using multi-delivery points per tour increases the utilisation rate and consequently decreases cost. As a result of delivery time constraints and limited consignments for delivery, carriers cannot have perfect consolidation. Moreover, the vehicles are mainly empty on their return trips, which affects the utilisation rate and cost. Coopetition and sharing of resources between carriers is a good solution that may increase the utilisation rate and reduce cost. We considered vehicles that were running empty on their return trips as a potential area for coopetition. Two or more carriers can collaborate to use the empty running vehicles on return trips when the delivery points of one carrier are the same as the preparation point (first dispatch point) of another carrier. To develop an LMD model with coopetition strategy, we divided the delivery networks of carriers working in an urban area into two groups: retailer network and 3PL network. In the retailer network, carriers transport goods from some DCs to retailers' shops located at shopping centres. In the 3PL network, carriers transport goods (parcels) from retailers' shops located at the same shopping centres to some DCs. The 3PL network uses the empty running vehicles on the return trips of the retailer network to conduct its first mile delivery transportations.

To describe the proposed model, evaluate its performance and compare it to the LMD without a coopetition strategy, three scenarios were developed in this study:

- Scenario I, without coopetition strategy—current situation
- Scenario II, with coopetition strategy
- Scenario III, with coopetition strategy—mixed model.

The performance of each scenario and the implementation concerns are described in the following sections.

### 6.3.1 Scenario I, without Coopetition Strategy—Current Situation

In the scenario without coopetition strategy, the retailer network and 3PL network worked separately. In this scenario, the 3PL network did not use the empty running vehicles of the retailer network. The results of testing this scenario with the random instance sets showed that the cost of carrying parcels from shopping centres to the 3PL's main DC was $38.00 per pallet on average. The cost of empty running vehicles was also included in this cost. It took around nine hours and 20 minutes to deliver parcels to the 3PL's main DC. Each vehicle travelled around 73 kilometres on average, with a 28% utilisation rate in the whole system.

We investigated how changes in the number of retailers, shopping centres and parcels affected the performance of the 3PL network and retailer network. The performance of Scenario I improved by changing these factors. These improvements were limited and were sometimes not under the control of the carrier. For example, the number of parcels depends on consumers' preferences and the carrier cannot change this easily.

In general, increasing the number of retailers had a positive effect on lead-time and cost indicators and did not affect utilisation rate in Scenario I. The system experienced lower cost and lower lead-time when the number of retailers increased from two to 10 in Scenario I. The cost to the whole system decreased by around seven cents per parcel ($7.00 per pallet) on average. Parcels reached the 3PL's main DC two hours and 21 minutes (141 minutes) sooner on average. Increasing the number of vehicles dispatching from each dispatch point can be a potential reason for lower lead-time rate. The numbers of vehicles dispatching from each dispatch point in the first echelon increased from 1.5 vehicles on average to four and seven vehicles when the number of retailers increased from two to five and 10, respectively. In the second echelon, it increased from one to 1.5 and three. Therefore, there were more chances for each parcel to be collected in both echelons, which decreased the lead-time rate.

The utilisation rate did not significantly change by increasing the number of retailers. For random instance sets, the utilisation rate stood between 14% and 16% when the number of retailers increased from two to 10. Utilisation rate depends on the number of allocated parcels and capacity of vehicles. It was assumed that the capacity of vehicles was fixed in this model; hence, the number of allocated parcels was essential for utilisation rate in our model. Changing the number of retailers did not change the number of allocated parcels in the first echelon because of the structure of the model. According to the model assumption, 3PL allocated a separate vehicle to each retailer. Thus, by adding a retailer, vehicles with similar utilisation rates were added to the system. However, in the second echelon, there was a potential opportunity to increase the utilisation rate. More parcels were carried to each 3PL's local DC when the number of retailers in each shopping centre increased. Therefore, the number of parcels dispatched from each 3PL's local DC increased, which was an opportunity to increase the utilisation rate. Considering the random instance sets, the utilisation rate in the second echelon increased from 25% to 42.4% when the number of retailers increased from two to five, while there were no changes when the number of retailers increased from five to 10. Despite the significant improvement in utilisation rate in the second echelon, the utilisation rate of the system did not improve significantly. This is because of number of vehicles in the first and second echelons. The number of vehicles in the first echelon was higher than the second echelon (71.77 and 10.38 on average, respectively), which moderated the improvement rate.

Moreover, when the number of retailers increased in Scenario I, more empty running vehicles were added to the system, which negatively affected the utilisation rate of the whole system. If we only focused on the 3PL network, the utilisation rates would be 31.1%, 36.8% and 37.8% with two, five and 10 retailers in the system, respectively, which indicated that the utilisation of 3PL by itself increased by around 6%.

Changes in the number of shopping centres did not affect the cost, lead-time or utilisation rates of the total system. It was supposed that each vehicle had direct delivery. This meant that the vehicles were not running between shopping centres and were just running between shopping centres and DCs and between DCs. Therefore, adding shopping centres did not provide consolidation opportunities at the shopping centre. Meanwhile, all parcels of each shopping centre were carried to a separate 3PL's local DC. Therefore, adding shopping centres did not provide consolidation opportunities at the 3PL's local DCs either. In other words, when a shopping centre was added to the system, new opportunities for consolidating parcels were not added to the system. Therefore, there were no significant changes in the utilisation and cost indicators. In addition, adding a shopping centre to the system would not increase the number of vehicles dispatching from other shopping centres. Therefore, the parcels had the same opportunity to be collected. Consequently, there were no significant changes in lead-time rate either.

Increasing the number of parcels had a positive effect on indicators in Scenario I. The system experienced a lower cost, lower lead-time and higher utilisation rate when the numbers of parcels of each retailer in each shopping centre increased from 500 parcels (five pallets) to 900 parcels (nine pallets) per retailer shopping centre. 3PL allocated more vehicles per day in the first and second echelon to collect parcels from the shopping centres and 3PL's local DCs. Therefore, each parcel had a greater chance of being collected at dispatching points (shopping centre in the first echelon and 3PL's local DCs in the second echelon). This reduced the delay time at shopping centres and the 3PL's local DCs. The number of vehicles dispatching from each dispatch point increased from three to 5.3 vehicles on average in the first echelon. In the second echelon, it increased from 1.3 to 2.3 vehicles on average. Using more vehicles normally increases cost; however, because of carrying a higher number of parcels, the utilisation rate increased and consequently the average cost per parcel decreased. Although the utilisation rate of the total system did not increase very much (6%), the utilisation rate of the 3PL network, especially in the first echelon, changed notably (20%).

### 6.3.2 Scenario II, with Coopetition Strategy

In Scenario II, retailers shared their vehicles running empty from the shopping centres to the retailer's DCs. The 3PL network used the empty running vehicles to collect parcels from shopping centres. Using the empty running vehicles eliminated all round trips between the shopping centres and the 3PL's local DCs in the first echelon and all round trips between the 3PL's local DCs and 3PL's main DC in the second echelon. However, to carry parcels from the retailer's DCs to the 3PL's main DC, new round trips between the retailer's DCs and 3PL's main DC were added to the second echelon of the system. Eliminating all round trips in the first echelon had a large effect on the cost to the whole system. Considering optimum solutions of the random instance sets, Scenario II decreased cost by 60% on average. Considering the real case study data, Scenario II decreased cost by 55% on average. This collaborative model cut the cost to the 3PL network in the first echelon. The system did not need to pay to carry parcels in the first echelon because parcels were carried by the retailer's empty running vehicles and the cost of these empty running vehicles had already been considered in the cost of the system.

In the second echelon, the round trips between the 3PL's local DCs and 3PL's main DC were replaced with the round trips between the retailer's DCs and 3PL's main DC, which decreased the cost; however, the reduction was not as large as in the first echelon. The cost reduction in the second echelon arose from two issues: (i) lower number of allocated vehicles and (ii) lower distance between dispatching and delivery points. On average, Scenario II used one vehicle less than Scenario I in the second echelon, considering random instance sets. Moreover, we assumed that the distance between the dispatching and delivery points of the second echelon in Scenario II was less than that in Scenario I. These distances were assumed to be between 20 and 70 kilometres in Scenario I and between five and 20 kilometres in Scenario II. The information from real cases confirmed these assumptions. For example, in Melbourne, most of the retailer's DCs were located in an industrial area in the west of city, while the 3PL's local DCs were spread around the city. In our case study, the distance between the retailer's DCs and the 3PL's main DC was five kilometres, while the distance between the 3PL's local DCs and the 3PL's main DC was more than 35 kilometres on average.

This collaborative model decreased the lead-time of delivering parcels from shopping centres to the 3PL's main DC by around 36% on average (around three hours and 20 minutes) in random instance sets, and by 40% in the real case study. Availability of vehicles was the main reason for the reduction of lead-time in Scenario II. Compared with Scenario I, there were more vehicles available to collect parcels from each shopping centre in the first echelon of Scenario II. On average, 4.2 vehicles collected parcels from each shopping centre in Scenario I, while 7.5 vehicles collected parcels from the shopping centres in Scenario II, based on random instance sets. This meant that each parcel in Scenario II had a greater chance of being collected from a shopping centre, which helped reduce the delay time at shopping centres. In the second echelon, there was no significant difference between Scenarios I and II in the number of vehicles dispatching from dispatching points (1.8 and 1.83 vehicles on average for random instance sets, respectively). In addition, the numbers of dispatching points in both scenarios were almost the same (5.6 and 5.7 on average for random instance sets in Scenarios I and II, respectively). The dispatching points in Scenario I were the 3PL's local DCs and in Scenario II were the retailer's DCs. Despite these similarities, the delay of parcels in Scenario II was lower than that in Scenario I. This was because of the model assumptions. In Scenario I, vehicles in the second echelon left the 3PL's local DCs at the end of the day with fixed scheduling, while, in Scenario II, the dispatching time was optimised with an optimisation program.

Scenario II reduced the total travelling distance by around 66% for random instance sets and by around 57% for the real case study. Lower numbers of running vehicles and shorter routes were the two main reasons for the reduction of travelling distance in Scenario II. The numbers of running vehicles in Scenario II were significantly less than that in Scenario I. On average, 82.16 vehicles were running in Scenario I, while there were 57.55 running vehicles in Scenario II for random instance sets. Moreover, vehicles travelled shorter distances to deliver parcels in Scenario II, compared with Scenario I. Each vehicle travelled around 73 kilometres on average in Scenario I, and travelled only

34 kilometres in Scenario II. These consisted of all trips in both the first echelon and the second echelon, including empty return trips.

The utilisation rate in Scenario II significantly improved compared with Scenario I. It improved to around 50% and changed from 28% to 42%. The utilisation rate significantly improved even further in the case study sets, to around 114%, and changed from 11% to 24%. The main improvement occurred in the first echelon. The utilisation rate improved from 23.6% to 47.29% in this echelon in random instance sets, mainly because of eliminating the round trips of the 3PL network. Note that, the utilisation rate of Scenario I was higher than Scenario II in the second echelon (41.5 and 38.22, respectively). However, despite this, because the number of vehicles in the first echelon was much higher than the number of running vehicles in the second echelon (48.16 and 9.3 on average, respectively), the utilisation rate of vehicles in the first echelon had a greater effect on the final utilisation rate.

### 6.3.3 Scenario III, with Coopetition Strategy—Mixed Model

As with Scenario II, retailers shared their vehicles running empty from the shopping centres to the retailer’s DCs in Scenario III. In Scenario III, parcels could be collected from shopping centres with both the retailer’s and 3PL’s vehicles. This meant that more vehicles were available at the shopping centre to collect parcels, which decreased the delay time at shopping centres. Hence, lead-time improved more in Scenario III than in Scenario II. The best lead-time solutions of Scenario III improved lead-time by 56% on average, while Scenario II improved by 36% in random instance sets. A similar pattern occurred in the case study sets. The best lead-time solutions of Scenario III improved lead-time by 46% on average, while Scenario II improved it by 40% in the case study sets. The numbers of vehicles leaving each shopping centre and numbers of dispatching points in the second echelon were the main reasons for this improvement. In the first echelon, 9.3 vehicles on average left each shopping centre in Scenario III, while 4.2 and 7.5 vehicles left for Scenarios I and II, respectively, based on the random instance sets. However, in the second echelon, the number of vehicles leaving each dispatching point was less in Scenario III than in Scenario II or I (1.3, 1.8 and 1.8, respectively). This issue should have increased the delay time in the second echelon of Scenario III; however, the number of dispatching points in this scenario was about twice that of the two other scenarios (10 in Scenario III and 5.6 and 5.7 in Scenarios I and II, respectively). This issue helped the optimisation program find a shorter route for each parcel in total. Therefore, the delay time in Scenario III was significantly less than the two other scenarios on average.

Despite lead-time, Scenario III could not improve the cost indicator more than Scenario II (60% and 57% for the best cost solutions in Scenarios II and III, respectively, for random instance sets). A similar pattern occurred in the case study set, with 55% and 26% for the best cost solutions in Scenario II and III, respectively. Along with retailer vehicles, the third scenario had the opportunity to use 3PL's vehicles. While this could further reduce the lead-time, it increased the cost of the total system. Using 3PL's vehicles in the first echelon meant the system did not use the retailer's empty running vehicles completely. Using the 3PL's vehicles added cost to the system. The numbers of vehicles in both echelons increased in comparison with Scenario II, which created extra cost for the whole system. Scenario III used around 12 of 3PL's vehicles on average, while the second scenario did not use 3PL's vehicles in the random instance sets. Scenario III used around three more vehicles on average in the second echelon, mainly because of the increase in the number of dispatching points. Involving 3PL's vehicles meant that the 3PL's local DCs should also be added to the system. Therefore, if lead-time is the main objective of the system, Scenario III is recommended; however, if the priority is cost, Scenario II is preferable. In other words, compared with Scenario II, Scenario III can only improve lead-time and cannot improve cost and lead-time simultaneously. In Scenario III, we sacrifice a small cost to attain better lead-time results.

Considering random instance sets, parcels travelled shorter distances to be delivered to the 3PL's main DC from shopping centres in Scenario II than in Scenario III. The travel distance per parcel was 0.09 kilometres in Scenario II, and 0.10 kilometres in Scenario II. This pattern differed in the case study sets. Travel distance per parcel was 0.11 kilometres in Scenario II, and 0.09 kilometres in Scenario II in the case study set. The results showed that the difference between the results of Scenario II and III was not great. However, the main reason for the difference between the total travelling distance of Scenario II and III derived from using 3PL's vehicles in the first echelon in Scenario III. Adding 3PL's vehicles in the first echelon meant more routes were added to the system to carry the same number of parcels, which increased total travelling distances; however, the different distances between shopping centres and DCs could affect the results.

From the resource allocation perspective, Scenario II had the least number of vehicles used in the system. Considering the best cost solutions, Scenario II decreased the number of vehicles by around 36% and Scenario III decreased it by around 30% in the random instance sets. In the case study set, both Scenario II and III decreased the number of vehicles by around 42%. The number of running vehicles affected the utilisation rate. The utilisation rate changed from 28% in Scenario I to 42% and 39% in Scenarios II and III, respectively, in the random instance sets. The utilisation rate changed from 11% in Scenario I to 24% in Scenarios II and III in the case study set.

### 6.3.4 Case Study Results

We considered a case study that included two 3PLs and one retailer working in Melbourne to test the proposed coopetition LMD model and analyse the results. One retailer with one DC operated in the system. There were six shopping centres in this case study, but the 3PL had four DCs to serve these shopping centres. Each DC served one shopping centre, except one DC, which served three shopping centres. The results of conducting the case study proved that the proposed LMD with coopetition strategy improved delivery performance in terms of cost, lead-time, travelling distance, utilisation rate and number of vehicles. The results of the case study sets confirmed the results of the random instance sets. Both sets indicated that the coopetition strategy improved the performance of LMD. However, there were some differences in the results obtained by these two datasets. The random instance sets provided higher improvement in cost, while it was the opposite in utilisation rate and number of vehicles. The results obtained by the case study datasets showed that Scenario III decreased cost by around 26%, while the random datasets provided a 57% cost reduction. There was not a large difference in cost reduction in Scenario II for either dataset (60% and 55% for random and case study sets, respectively).

The lead-time for delivering parcels from shopping centres to the 3PL's main DC decreased in Scenario II by around 36% on average in the random instance sets and 40% in the real case study. The lead-time improvements obtained by both random instance and case study sets were even greater in Scenario III. Unlike Scenario II, the lead-time improvement in random instance sets was higher than the case study sets in Scenario III (56% and 46% on average, respectively). Scenario II reduced the total travelling distance by around 66% for random instance sets and around 57% for the real case study. The improvement of travelling distance in both the random instance and case study sets was almost the same (around 64%) in Scenario III.

The improvement of utilisation rate in the case study sets was significantly high (114%) in both Scenario II and III. These rates were much higher than the improvement indicated in the random instance sets, at 50% and 39% in Scenarios II and III, respectively. The number of vehicles reduced further in the case study sets than in the random instance sets, in both Scenario II and III. The vehicle number reduction rate in the case study sets was 42% in both scenarios, while it was 36% and 30% for the random instance sets for Scenarios II and III, respectively.

### 6.3.5 Implementation of Proposed Last Mile Delivery Model with Coopetition Strategy

The proposed model with coopetition strategy is applicable in any urban area and context where the following conditions are established in the retailer network and 3PL network. These situations can be also extracted from the proposed LMD ontology:

- retailer network conditions:
    - vehicle utilisation: low (empty running vehicles)
    - delivery point: store
    - delivery time: working hours
    - time window: high (one day)
    - delivery frequency: high (at least once per day/week)

- number of deliveries per tour: the model presented is based on one delivery per tour, but the model can also be solved by more than one
- sensitivity of consignment: no sensitivity
- vehicle: medium or light goods vehicles
- vehicle accessory: general vehicle accessories

- 3PL network conditions
    - dispatching point: store
    - dispatching time: working hours
    - time window: high (one day)
    - delivery frequency: high (at least once per day/week)
    - sensitivity of consignment: no sensitivity
    - vehicle: medium or light goods vehicles
    - vehicle accessory: general vehicle accessories.

Sharing the benefits of coopetition is one of the main concerns of stakeholders involved in coopetition. In the proposed model with coopetition strategy, parcels were carried by the retailer network, which generated increased workload and cost for this network. However, the numbers of vehicles in the 3PL network decreased and the 3PL network gained the benefits of cost reduction. These benefits and costs must be shared fairly among all stakeholders involved in the coopetition practice. Sharing the benefits helps all stakeholders attain sufficient motivation to be involved in the coopetition practice. Moreover, other notable benefits should be recognised, such as lead-time and travelling distance reduction and greater flexibility because of using fewer vehicles.

In the proposed model, it was assumed that the retailer's DCs were close to the 3PL's main DC. The model with coopetition strategy experienced greater performance improvement when these DCs were much closer. Moreover, the model with coopetition strategy attained better results when the shopping centres were located far from the DCs. This issue can be considered when decision makers are making decisions regarding adding more retailers to the coopetition practice.

It was also assumed that the retailer concurrently added the number of empty running vehicles and parcels that needed to be collected from shopping centres to the model with coopetition strategy. Some retailers may offer to add their empty running vehicles to the system without adding parcels to the system. In this case, more empty vehicles will be available to collect the same number of parcels, which will provide more chances for parcels to be collected from the shopping centres. This will potentially reduce the lead-time indicator.

## 6.4 Summary

In this chapter, we have discussed the structure and meaning of the LMD phenomenon. We debated how different situations in a supply chain can affect the structure of LMD. Moreover, we discussed how coopetition can help companies improve their delivery performance and the benefits of applying coopetition strategy in the LMD context. We compared different scenarios with and without coopetition strategy. We discussed the positive and negative aspects of each scenario and debated the reasons behind the different results of the different scenarios. Finally, we discussed the important concerns in applying the proposed LMD model. Sharing the benefits, availability of LMD facilities and location of DCs are some of the main concerns in applying the proposed LMD model with coopetition strategy.

# Chapter 7: Implications, Conclusions, Limitations and Future Research Opportunities

The purpose of this chapter is to conclude the research and present the implications and limitations of this study, as well as recommendations for future research. Section 7.1 discusses the theoretical and practical implications of this study, while Section 7.2 presents the conclusion of the study. Finally, Section 7.3 presents the study limitations and areas of this research that can be expanded in future studies.

## 7.1 Implications of the Study

This study proposed conceptual and mathematical models of LMD with a coopetition strategy to improve the performance of the delivery process. The model examined the ways that sharing empty running vehicles among competitors can affect delivery cost, lead-time and travelling distance. The study also demystified the LMD phenomenon in terms of terminology, definition, scope, components, problems, solutions and structures. In so doing, this study contributes several practical and theoretical implications, which are expanded below.

### 7.1.1 Theoretical and Methodological Implications

This study provides a substantial contribution to the application of a coopetition strategy in the LMD context. This study investigated the effect on LMD performance of collaboration between competitors. This study contributes to calculating lead-time for estimating LMD performance, which has not previously been investigated in the LMD context. In the literature, it is common to use travelling time or travelling distance to examine the time of delivery. Through considering travelling time alongside waiting time at dispatch points and satellites, this study contributes to calculating and improving lead-time in the LMD context. Moreover, along with lead-time, this study calculated cost to estimate the performance of LMD. This study contributes to investigating the effect of coopetition on cost and lead-time indicators simultaneously, which has not previously been addressed in the literature.

This study has presented a two-echelon VRP model with simultaneous consideration of lead-time and cost, which has not previously been presented in the LMD context. The proposed two-echelon VRP model can be used in other contexts and disciplines.

Additionally, this study contributes to theory on the concept of LMD. LMD is not a well-defined phenomenon in the literature and there is an ambiguity in its scope and structure. This study contributes to redefining the LMD definition, demystifying LMD's scope and classifying LMD components in the form of ontology concepts. This study contributes 40 possible structures for LMD based on the possible locations of preparation points and delivery points, which has not previously been investigated properly in the literature.

This study proposed an LMD ontology, which has not previously been developed. The proposed LMD ontology provides a framework to explore the LMD phenomenon and its components, and extract possible problems and solutions. The proposed LMD ontology can formulate the problems and solutions of LMD, which will enrich the theory in this field.

### 7.1.2 Practical Implications

This research has demystified the LMD phenomenon and presented an LMD ontology, which helps create a common language and perception of LMD among people working or studying in this area. Common perceptions can decrease conflict between the parties involved in coopetition and facilitate coopetition schemes.

The LMD ontology framework presented in this study provides a valuable source of information. Different parties involved in LMD can use this framework to extract potential LMD problems, solutions and structures that suit their processes. This will help decision makers develop improvements and restructure their business processes. Decision makers may be from government authorities who make decisions about transportation rules and regulations in cities, or from companies who determine the structure of LMD and business strategies.

The coopetition model proposed in this study decreases cost and lead-time simultaneously, which supports retailers and logistics providers to providing faster services at lower cost. While lower cost and shorter lead-time are beneficial for retailers and logistics providers, consumers also enjoy the lower price and faster delivery.

Rapid urbanisation and the increasing popularity of online shopping have created a surge in goods movement in cities. Therefore, decision makers in government authorities who make decisions on transportation rules and regulations in cities are seeking solutions to manage the goods movement. This study's proposed coopetition model decreases the number of vehicles and increases the vehicle utilisation rate, which is a potential solution to increase the capacity of the system to handle goods movement. Moreover, implementation of the proposed model on a large scale would reduce congestion and improve the sustainability aspects of deliveries in cities. This can occur through the contribution of the proposed model to reducing the number of vehicles running in cities and the total travelling distance required to deliver goods. Government authorities have a critical role in implementing the proposed coopetition model on a large scale. Government authorities can encourage different companies to share empty running vehicles. Moreover, the authorities may have critical information about empty running vehicles in different networks and can work as a facilitator of coopetition between different networks.

Certain LMD stakeholders—such as residents, authorities and end consumers—may enjoy the benefits of the coopetition without being directly involved in the coopetition practice. A shorter time for receiving parcels and the lower price of service are potential benefits of end consumers, while lower traffic and less air pollution and other negative environmental effects are potential advantages for residents and government authorities. These benefits provide reasonable motivation for government authorities to support and facilitate coopetition practices.

## 7.2 Conclusions

This thesis has focused on LMD and coopetition among actors of LMD, especially in the retail sector. It has revealed that coopetition among logistics providers and retailers is a potential strategy to improve cost, lead-time and utilisation rate indicators. This study has focused on regular empty running vehicles in return trips, which are potential resources that can be shared among different companies to improve delivery performance.

The objective of this study was divided into two main subjects: clarifying the LMD phenomenon and developing LMD with a coopetition strategy to improve delivery performance. This study clarifies LMD from several aspects: (i) terminology, definition and scope; (ii) components; (iii) potential problems, solutions and structure; and (iv) the situation of current studies in LMD and potential areas for research. Chapter 4 emphasised LMD clarification, while Chapter 5 focused on LMD with a coopetition strategy. Chapter 6 presented some discussions on findings of both main subjects.

Reviewing the existing literature indicated that LMD remains an unclear phenomenon in terms of definition, scope and structure. In Chapter 4, we conducted a systematic literature review to investigate the existing terminologies addressing the LMD phenomenon. We revealed that 'last mile delivery' is the most commonly used phrase in the literature. In addition, to clarify the LMD definition, we collected and investigated all extant definitions of LMD. We suggested a new definition of LMD based on the results of a content analysis on the extant definitions. According to the proposed definition, the scope of LMD is limited to the last transportation in a supply chain, which begins from the last dispatch point and finishes at the delivery point where the goods are delivered.

Chapter 4 also presented an LMD ontology. The LMD ontology presents a systematic classification of all components of LMD, which clarify this phenomenon. Through considering LMD as a process, all components were classified based on the process approach. The proposed LMD ontology was used for further investigations to clarify different aspects of the LMD phenomenon. Adding some conjunctions, prepositions and verbs between different classes of the proposed LMD ontology provided a framework for extracting potential problems, solutions and structures of LMD in the form of sentences.

We divided the extant literature into several clusters based on their similarity in addressing similar components of LMD ontology. We revealed that there have been few studies addressing stakeholders and regulations, which are considered potential areas for future research in this field. Moreover, we indicated how each combination of classes has been addressed by the literature, and revealed that some subjects—including stakeholders and regulation—have not been thoroughly investigated in the literature. In fact, there is a gap in the literature in addressing the combination of stakeholders with other classes, as well as the combination of regulation with other classes.

Using the LMD ontology, this study presented a classification for LMD structure. Some combinations of classes describe the possible structure of LMD. Through considering the location of the main actions involved in LMD, 40 LMD structures were extracted from the proposed LMD ontology. Each structure (model) describes a specific combination of the potential locations for conducting preparation, last dispatching and delivering processes. In future research, other aspects of LMD can be also considered to present other classifications of the LMD structure.

The proposed LMD ontology and proposed LMD structures (models) were examined in five real cases in the retail sector in Melbourne, Australia. We revealed that the proposed LMD ontology and proposed LMD structures (models) were applicable in a real situation. The LMD structure of one retailer and four logistics service providers working in the retail sector in Melbourne were depicted with the proposed models and LMD ontology. Through focusing on a coopetition strategy in LMD, problems and possible solutions were discussed with relevant senior managers of one retailer, four 3PLs and one shopping centre. The interviewees suggested that sharing empty running vehicles among retailers and 3PLs was the main solution for improving LMD performance. The interviewees believed that coopetition among stakeholders via sharing empty running vehicles was an applicable scenario that would improve the utilisation rate and decrease cost and lead-time.

Based on all the findings from the interviews and the systematic literature review and from using the LMD ontology, this study suggested a model with coopetition strategy in which regular empty running vehicle in the retailer's LMD network were shared with 3PLs to conduct the first mile deliveries. This model was presented in Chapter 5. The model with coopetition strategy was extracted from the discussion during the interviews with logistics managers. This model was clearly described by the proposed LMD ontology. Sharing empty running vehicles eliminates the running of some vehicles in an urban context and increases the utilisation rates, which reduces the cost and improves the sustainability of the whole system. Along with cost reduction and sustainability improvement, the model with coopetition strategy also reduced the lead-time of delivering goods.

This study suggested and investigated three scenarios, as follows. Scenario I was the current situation, with no coopetition among retailers and 3PLs. Retailers carried their goods from their DC to their shops at shopping centres. 3PL collected consumers' parcels from the same shops to deliver to consumer location. Scenario II was a scenario with a coopetition strategy. Instead of 3PL vehicles, retailer vehicles that were empty on their return trips collected parcels from the shops and delivered them to the retailer's DCs. Then larger vehicles carried parcels from the retailer's DCs to the 3PL's main DC for distribution to consumers' locations. Several vehicles ran empty from each shop; therefore, the best vehicle to optimise the performance of the total system was selected to collect parcels from each shop. Scenario III was another scenario with a coopetition strategy. In this scenario, the vehicles of both the retailer network and 3PL network were potentially allowed to collect parcels from shops. The best vehicle from the retailer network or 3PL network that could optimise the performance of the total system was selected to collect parcels from each shop.

The results indicated that both scenarios with a coopetition strategy significantly improved the cost and lead-time indicators. In comparison with Scenario I, Scenario II reduced the cost and lead-time of each instance by around 60% and 36% on average, respectively, and Scenario III reduced the cost and lead-time in each instance by around 57% and 56% on average, respectively. This outcome revealed that Scenario II was more efficient than Scenario III, while Scenario III was faster than Scenario II. To find solutions with optimal cost and lead-time, multi-objective optimisation models were developed in Scenarios II and III. The optimisation models used a GA to find the best routes from shops to the 3PL's main DC and to optimise the cost and lead-time of the total system simultaneously.

Both scenarios with a coopetition strategy improved the environmental aspects of delivery. Scenario II was the best scenario from environmental (sustainability) perspectives. Considering the best solutions, Scenario II reduced the total number of running vehicles in the whole system by 36% on average, decreased the travelling distance in the whole system by 66% on average and increased the utilisation rate of the whole system by 50% on average. Considering the best solutions, Scenario III reduced the total number of running vehicles in the whole system by 30% on average, decreased the travelling distance in the whole system by 63% on average and increased the utilisation rate of the whole system by 39% on average.

A sensitivity analysis was conducted to analyse how changes in the number of retailers, shopping centres and parcels involved in the system could affect the performance of the system. The results of the sensitivity analysis indicated that the increase in the number of retailers involved in the system significantly decreased the lead-time in both Scenario I and II. Increasing the number of shopping centres did not strongly affect performance; it only slightly increased the lead-time of Scenario III and utilisation rate of Scenario II. Increasing the number of parcels significantly decreased the cost of Scenario I, the lead-time of Scenarios I and II and the utilisation rate of Scenario III. It also slightly increased the utilisation rate of Scenario I.

## 7.3 Limitations and Future Research Opportunities

The proposed model with coopetition strategy presented in this study was limited to one 3PL in the 3PL network. Thus, future research could examine this proposed model with the involvement of more than one 3PL in the 3PL network. Moreover, the proposed model with coopetition strategy was developed and examined based on the structure of LMD in the retail sector in Melbourne. A similar study could be conducted in other cities and other sectors. In addition, this study assumed that a vehicle could collect parcels from only one shopping centre, and that the vehicles in the retailer network undertook direct delivery from each retailer's DC to each shopping centre. The possibility of collecting parcels from more than one shopping centre by one vehicle may provide different results. This issue can be investigated in future research.

The proposed models with coopetition strategy in Scenarios II and III were solved by considering cost and lead-time objectives simultaneously. An extension of this research will be beneficial for government authorities by having the model to calculate and optimise other objectives, such as environmental impact, congestion and utilisation rate, along with cost and lead-time. These issues can be considered as potential areas for future research.

In this study, the models with coopetition strategy were executed using MATLAB software to attain the optimal solution. Other software, such as GAMS, could also be used to solve the problems. This study also used a GA to solve the multi-objective optimisation problems. Other algorithms, such as Strength Pareto Evolutionary Algorithm, could also be used to solve the problem and determine the results.

This study introduced 40 LMD structures (models) based on the locations of preparation, last dispatch point and delivery point. These models were extracted from the proposed LMD ontology. The proposed LMD ontology provides an outline for introducing different classifications for LMD structure. Through considering other aspects of LMD—such as reception modes, carrier and type of consignments—other classifications for LMD structure could be extracted from the proposed LMD ontology, which is a potential area for future research.

The proposed LMD model with coopetition strategy assumed that the size of each vehicle was the same in each echelon. In practice, vehicles with different sizes may be used for deliveries. Moreover, shopping centres may have limitations regarding the size of vehicles. These issues can be considered in future research.

LMD processes—including dispatching, transporting and delivery processes—require certain facilities, such as forklifts and pallets. The availability of these types of facilities is an important issue that needs to be considered during the coopetition practice. For example, a 3PL may use special pallets for carrying parcels, which must be returned to the shopping centres. Returning the empty pallets may generate an extra cost for the coopetition model, which needs to be calculated.

## 7.4 Summary

In this chapter, we first discussed the theoretical and practical implications of this study. The main theoretical and practical implications of this study were proving the positive effects of applying a coopetition strategy on LMD performance and creating a common language and perception of LMD among people working in the field. We then presented a conclusion to the study, which included a description of the thesis structure, research process, data collection, data analysis and results and findings. Clarification of the LMD phenomenon and recommendations for applying a coopetition strategy in LMD were the main findings of this study. Finally, we discussed the limitations of this study and presented future research opportunities that can be derived from this study. The indicators, context and number of case studies were some limitations of this study that can be expanded in future research.

## References


Agatz, N, Campbell, A, Fleischmann, M and Savelsbergh, M 2010, 'Time slot management in attended home delivery', Transportation Science, vol. 45, no. 3, pp. 435-49.

Aized, T and Srai, JS 2013, 'Hierarchical modelling of last mile logistic distribution system (report)', The International Journal of Advanced Manufacturing Technology, vol. 70, no. 5-8, pp. 1053-61.

Al-nawayseh, MK, Alnabhan, MM, Al-Debei, MM and Balachandran, W 2013, 'An adaptive decision support system for last mile logistics in e-commerce: a study on online grocery shopping', International Journal of Decision Support System Technology (IJDSST), vol. 5, no. 1, pp. 40-65.

Alho, AR and de Abreu e Silva, J 2015, 'Utilizing urban form characteristics in urban logistics analysis: a case study in Lisbon, Portugal', Journal of Transport Geography, vol. 42, pp. 57-71.

Allegre, T and Paché, G 2014, 'No more trouble: driving a sustainable city logistics', Advances in Management and Applied Economics, vol. 4, no. 5, pp. 1-11.

Allen, J, Thorne, G and Browne, M 2007, 'Best Urban Freight Solutions (BESTUFS) good practice guide on urban freight transport', ESTUFS administration centre, Rijswijk, The Netherlands.

Anand, N, Yang, M, van Duin, JHR and Tavasszy, L 2012, 'GenCLOn: an ontology for city logistics', Expert Systems with Applications, vol. 39, no. 15, pp. 11944-60.

Australian Government 2005, 'Vehicle standard (Australian design rule — definitions and vehicle categories)', viewed 01/07/2017, <https://www.legislation.gov.au/Series/F2005L03850>.

Ballantyne, E and Lindholm, M 2012, 'How local authorities can include freight in their transport planning process', in Proceedings of the Annual Logistics Research Network (LRN) Conference, Cranfield, UK.

Barratt, M 2004, 'Understanding the meaning of collaboration in the supply chain', Supply Chain Management: An International Journal, vol. 9, no. 1, pp. 30-42.

Battaia, G, Faure, L, Marquès, G and Montoya-Torres, JR 2014, 'A methodology to anticipate the activity level of a collaborative network: an urban consolidation center', Supply Chain Forum: An International Journal. vol. 15, no. 4, pp. 70-81.

Bengtsson, M and Kock, S 1999, 'Cooperation and competition in relationships between competitors in business networks', Journal of Business and Industrial Marketing, vol. 14, no. 3, pp. 178-94.

Benjelloun, A, Crainic, TG and Bigras, Y 2010, 'Towards a taxonomy of city logistics projects', Procedia—Social and Behavioral Sciences, vol. 2, no. 3, pp. 6217-28.

Boyer, KK, Frohlich, MT and Hult, GT 2004, Extending the Supply Chain: How Cutting-edge Companies Bridge the Critical Last Mile into Customers’ Homes, 1st edn, American Management Association, New York, USA.

Boyer, KK, Prud’homme, AM and Chung, W 2009, ‘The last mile challenge: evaluating the effects of customer density and delivery window patterns’, Journal of Business Logistics, vol. 30, no. 1, pp. 185-201.

Brown, JR and Guiffrida, AL 2014, ‘Carbon emissions comparison of last mile delivery versus customer pickup’, International Journal of Logistics: Research and Applications, vol. 17, no. 6, pp. 503-21.

Browne, M, Allen, J and Attlassy, M 2007, ‘Comparing freight transport strategies and measures in London and Paris’, International Journal of Logistics: Research and Applications, vol. 10, no. 3, pp. 205-19.

Browne, M and Gomez, M 2011, ‘The impact on urban distribution operations of upstream supply chain constraints’, International Journal of Physical Distribution and Logistics Management, vol. 41, no. 9, pp. 896-912.

Buhrkal, K, Larsen, A and Ropke, S 2012, ‘The waste collection vehicle routing problem with time windows in a city logistics context’, Procedia-Social and Behavioral Sciences, vol. 39, pp. 241-54.

Cambridge Dictionariy 2019, English to English Dictionary, Cambridge University Press, Viewed 22/06/2019, < https://dictionary.cambridge.org/>

Campbell, AM and Savelsbergh, M 2006, ‘Incentive schemes for attended home delivery services’, Transportation Science, vol. 40, no. 3, pp. 327-41.

Casey, N, Rao, D, Mantilla, J, Pelosi, S and Thompson, RG 2014, ‘Understanding last kilometre freight delivery in Melbourne’s central business district’, Procedia—Social and Behavioral Sciences, vol. 125, 20 March 2014, pp. 326-33.

Chen, Q 2014, Sustainable Last-mile Solutions: Urban Freight Consolidation and Eco-routing Strategies, doctoral dissertation, University of Illinois, Chicago, USA.

Cherrett, T, Allen, J, McLeod, F, Maynard, S, Hickford, A and Browne, M 2012, ‘Understanding urban freight activity—key issues for freight planning’, Journal of Transport Geography, vol. 24, September 2012, pp. 22-32.

Chinh, NQ, Kim, HC, Siwei, J and NengSheng, Z 2016, ‘Collaborative vehicle routing problem for urban last-mile logistics’, in 2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC), (pp. 001531-6), Budapest, Hungary.

Chopra, S 2003, ‘Designing the distribution network in a supply chain’, Transportation Research Part E: Logistics and Transportation Review, vol. 39, no. 2, pp. 123-40.

Corrie, C., 2004. ‘ISO 9000 Introduction and Support Package: Guidance on the Concept and Use of the Process Approach for management systems’, Secretariat of ISO/TC, 176.

Cruijssen, F, Dullaert, W and Fleuren, H 2007, ‘Horizontal cooperation in transport and logistics: a literature review’, Transportation Journal, vol. 46, no. 3, pp. 22-39.

Cuda, R, Guastaroba, G and Speranza, MG 2015, ‘A survey on two-echelon routing problems’, Computers and Operations Research, vol. 55, March 2015, pp. 185-99.

Daniel, BK and Harland, T 2017, ‘Higher Education Research Methodology: A Step-by-Step Guide to the Research Process’, Routledge, Abingdon, England.

de Grancy, GS 2015, ‘An adaptive metaheuristic for vehicle routing problems with time windows and multiple service workers’, Journal of Universal Computer Science, vol. 21, no. 9, pp.1143-67.

Denyer, D and Tranfield, D 2009, ‘Producing a systematic review’, in The Sage Handbook of Organizational Research Methods, in D Buchanan and A Bryman (eds), (pp. 671-89), Sage Publications Ltd, London, UK.

Deutsch, M, Coleman, PT and Marcus, EC 2011, ‘The Handbook of Conflict Resolution: Theory and Practice’, John Wiley and Sons, San Francisco, USA.

Domino’s 2017, Domino’s robotic unit, viewed 24/07/2017, <https://www.dominos.com.au/inside-dominos/technology/dru>.

Durand, B and Gonzalez-Feliu, J 2012, ‘Urban logistics and e-grocery: have proximity delivery services a positive impact on shopping trips?’, Procedia—Social and Behavioral Sciences, vol. 39, 2012, pp. 510-20.

Edwards, JB, McKinnon, AC and Cullinane, SL 2010, ‘Comparative analysis of the carbon footprints of conventional and online retailing: a “last mile” perspective’, International Journal of Physical Distribution and Logistics Management, vol. 40, no. 1/2, pp. 103-23.

Ehmke, JF and Campbell, AM 2014, ‘Customer acceptance mechanisms for home deliveries in metropolitan areas’, European Journal of Operational Research, vol. 233, no. 1, pp. 193-207.

Ehmke, JF and Mattfeld, DC 2012, ‘Vehicle routing for attended home delivery in city logistics’, Procedia—Social and Behavioral Sciences, vol. 39, 2012, pp. 622-32.

Ferrucci, F 2013, ‘Introduction to tour planning: vehicle routing and related problems’, in Pro-active Dynamic Vehicle Routing: Contributions to Management Science, (pp. 15-79), Physica, Berlin, Heidelberg, Germany.

Figliozzi, M 2006, ‘Modeling impact of technological changes on urban commercial trips by commercial activity routing type’, Transportation Research Record, vol. 1964, no. 1, pp. 118-26.

Figliozzi, MA 2007, ‘Analysis of the efficiency of urban commercial vehicle tours: data collection, methodology, and policy implications’, Transportation Research Part B, vol. 41, no. 9, pp. 1014-32.

Flick, U (ed) 2017, The SAGE Handbook of Qualitative Data Collection, SAGE Publications, London, England.

Florida Department of Transportation, 2018, Truck Empty Backhaul, Transportation Data and Analytics Office, viewed 03/07/2019 <https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/statistics/docs/truck-empty-back-haul-final-report-2018.pdf?sfvrsn=8efaa9c_0>.

Foltyński, M 2014, ‘Electric fleets in urban logistics’, Procedia—Social and Behavioral Sciences, vol. 151, pp. 48-59.

Fraenkel, JR, Wallen, NE and Hyun, HH 1993, How to Design and Evaluate Research in Education (Vol. 7), McGraw-Hill, New York, USA.

Fremantle Ports 2014, Truck Productivity Study, viewed 29/12/2016, <http://www.fremantleports.com.au/Operations/Landside/Pages/Container-Movement-Study.aspx>.

Gevaers, R 2013, Evaluation of Innovations in B2C Last Mile, B2C Reverse and Waste Logistics, Doctoral dissertation, University of Antwerp, Belgium.

Gevaers, R, Van de Voorde, E and Vanelslander, T 2011, ‘Characteristics and typology of last-mile logistics from an innovation perspective in an urban context’, in C Macharis and S Melo (eds), in City Distribution and Urban Freight Transport: Multiple Perspectives (pp. 56-71), Edward Elgar Publishing, Cheltenham, UK.

Goethals, F, Leclercq-Vandelannoitte, A and Tütüncü, Y 2012, ‘French consumers’ perceptions of the unattended delivery model for e-grocery retailing’, Journal of Retailing and Consumer Services, vol. 19, no. 1, pp. 133-9.

Gonzalez-Feliu, J, Perboli, G, Tadei, R and Vigo, D 2008, The two-echelon capacitated vehicle routing problem, Viewed 03/07/2019, <https://halshs.archives-ouvertes.fr/halshs-00879447/>

Gonzalez-Feliu, J and Salanova, J-M 2012, ‘Defining and evaluating collaborative urban freight transportation systems’, Procedia—Social and Behavioral Sciences, vol. 39, 2012, pp. 172-83.

Handoko, SD, Lau, HC and Cheng, SF 2016, ‘Achieving economic and environmental sustainabilities in urban consolidation center with bicriteria auction’, IEEE Transactions on Automation Science and Engineering, vol. 13, no. 4, pp. 1471-9.

Harbison, JR and Pekar Jr, P 1998, ‘Smart Alliances: A Practical Guide to Repeatable Success’, (Vol. 2), Jossey-Bass, San Francisco, USA.

Herrel, K 2014, ‘A visual interactive simulation application for minimizing risk and improving outbound logistical efficiency in time-sensitive attended home deliveries and services’, Simulation, vol. 90, no. 4, pp. 377-404.

Hoff, A, Gribkovskaia, I, Laporte, G and Løkketangen, A 2009, ‘Lasso solution strategies for the vehicle routing problem with pickups and deliveries’, European Journal of Operational Research, vol. 192, no. 3, pp. 755-66.

Holguin-Veras, J, Amaya-Leal, J, Wojtowicz, J, Jaller, M, González-Calderón, C, Sánchez-Díaz, I, Wang, X, Haake, DG, Rhodes, SS, Hodge, SD and Frazier, RJ 2015, ‘Improving freight system performance in metropolitan areas: a planning guide’ , (No. Project NCFRP-38), Transportation Research Board, Washington, USA.

Hong, J, Chin, AT and Liu, B 2007, ‘Logistics service providers in China: current status and future prospects’, Asia Pacific Journal of Marketing and Logistics, vol. 19, no. 2, pp. 168-81.

Isaac, S and Michael, WB 1995, ‘Handbook in Research and Evaluation: A Collection of Principles, Methods, and Strategies Useful in the Planning, Design, and Evaluation of Studies in Education and the Behavioral Sciences’, Edits Publishers, San Diego, USA.

Jin, X and Srai, JS 2015, ‘A typology on last mile distribution systems’, in KS Pawar, H Rogers and F Ferrari (eds), The Proceedings of 20th International Symposium on Logistics, 6-8 July 201, Bologna, Italy.

Kämäräinen, V and Punakivi, M 2002, ‘Developing cost-effective operations for the e-grocery supply chain’, A Leading Journal of Supply Chain Management, vol. 5, no. 3, pp. 285-98.

Kämäräinen, V, Saranen, J and Holmström, J 2001, ‘The reception box impact on home delivery efficiency in the e-grocery business’, International Journal of Physical Distribution and Logistics Management, vol. 31, no. 6, pp. 414-26.

Konak, A, Coit, DW and Smith, AE 2006, ‘Multi-objective optimization using genetic algorithms: a tutorial’, Reliability Engineering & System Safety, vol. 91, no. 9, pp. 992-1007.

Krajewska, MA, Kopfer, H, Laporte, G, Ropke, S and Zaccour, G 2008, ‘Horizontal cooperation among freight carriers: request allocation and profit sharing’, Journal of the Operational Research Society, vol. 59, no. 11, pp. 1483-91.

Kull, TJ, Boyer, K and Calantone, R 2007, ‘Last-mile supply chain efficiency: an analysis of learning curves in online ordering’, International Journal of Operations and Production Management, vol. 27, no. 4, pp. 409-34.

Langevin, A and Riopel, D (eds) 2005, Logistics Systems: Design and Optimization, Springer Science & Business Media, New York, USA.

Larson, PD and Gammelgaard, B 2001, ‘Logistics in Denmark: a survey of the industry’, International Journal of Logistics, vol. 4, no. 2, pp. 191-206.

Leavy, P 2017, ‘Research Design: Quantitative, Qualitative, Mixed Methods, Arts-based, and Community-based Participatory Research Approaches’, Guilford Publications, New York, USA.

Lenstra, JK and Rinnooy Kan, AHG 1981, ‘Complexity of vehicle routing and scheduling problems’, Networks, vol. 11, no. 2, pp. 221-7.

Leukel, J and Kirn, S 2008, ‘A supply chain management approach to logistics ontologies in information systems’, in International Conference on Business Information Systems (pp. 95-105), Springer, Berlin, Heidelberg, Germany.

Lewandowski, K 2014, ‘5 Cases in the last 100 meters of delivery of goods’, Procedia—Social and Behavioral Sciences, vol. 151, 30 October 2014, pp. 183-95.

Li, Y, Lin, Q and Ye, F 2014, ‘Pricing and promised delivery lead time decisions with a risk-averse agent’, International Journal of Production Research, vol. 52, no. 12, pp. 3518-37.

Lian, P, Park, DW and Kwon, HC 2007, ‘Design of logistics ontology for semantic representing of situation in logistics’, in Second Workshop on Digital Media and its Application in Museum and Heritages (pp. 432-7), IEEE, Chongqing, China.

Lim, SFW, Zhang, AN, Goh, M, Ong, YS and Tan, PS 2016, ‘Three-dimensional vehicle routing problem for urban last mile logistics: problem formulation and computational analysis’, in 2016 UKSim-AMSS 18th International Conference on Computer Modelling and Simulation (UKSim) (pp. 252-7), IEEE, Cambridge, England.

Lindawati, van Schagen, J, Goh, M and de Souza, R 2014, ‘Collaboration in urban logistics: motivations and barriers’, International Journal of Urban Sciences, vol. 18, no. 2, pp. 278-90.

Lindholm, M 2014, ‘Successes and failings of an urban freight quality partnership—the story of the Gothenburg local freight network’, Procedia—Social and Behavioral Sciences, vol. 125, pp. 125-35.

Ljungberg, D and Gebresenbet, G 2004, ‘Mapping out the potential for coordinated goods distribution in city centres: the case of Uppsala’, International Journal of Transport Management, vol. 2, no. 3/4, pp. 161-72.

Luo, Y 2007, ‘A coopetition perspective of global competition’, Journal of World Business, vol. 42, no. 2, pp. 129-44.

Macário, R 2013, ‘Modeling for public policies inducement of urban freight business development’, in M Ben-Akiva , H Meersman , E Van de Voorde (eds), Freight Transport Modelling (pp. 405-32), Emerald Group Publishing Limited, Bradford, UK.

Macário, R, Galelo, A and Martins, PM 2008, 'Business models in urban logistics', Ingeniería y desarrollo, vol. 24, pp. 77-96.

Maden, W, Eglese, R and Black, D 2010, 'Vehicle routing and scheduling with time-varying data: a case study', Journal of the Operational Research Society, vol. 61, no. 3, pp. 515-22.

Malnight, TW 2001, 'Emerging structural patterns within multinational corporations: toward process-based structures', Academy of Management Journal, vol. 44, no. 6, pp. 1187-210.

McKinnon, AC and Tallam, D 2003, 'Unattended delivery to the home: an assessment of the security implications', International Journal of Retail and Distribution Management, vol. 31, no. 1, pp. 30-41.

Miles, J and Gilbert, P 2005, 'A Handbook of Research Methods for Clinical and Health Psychology', Oxford University Press on Demand, New York, USA.

Minguela-Rata, B and De Leeuw, S 2013, 'Managing the last mile of the supply chain for spare parts*/Gestión de la última milla de la cadena de suministro para piezas de repuesto', Universia Business Review, no. 39, pp. 104-17.

Morganti, E, Dablanc, L and Fortin, F 2014a, 'Final deliveries for online shopping: the deployment of pickup point networks in urban and suburban areas', Research in Transportation Business and Management, vol. 11, July 2014, pp. 23-31.

Morganti, E, Seidel, S, Blanquart, C, Dablanc, L and Lenz, B 2014b, 'The impact of e-commerce on final deliveries: alternative parcel delivery services in France and Germany', Transportation Research Procedia, vol. 4, 2014, pp. 178-90.

Morganti, ME 2011, 'Urban food planning, city logistics and sustainability: the role of the wholesale produce market—the cases of Parma and Bologna food hubs', Doctoral dissertation, University of Bologna, Bologna, Italy.

Muñoz-Villamizar, A, Montoya-Torres, JR and Vega-Mejía, CA 2015, 'Non-collaborative versus collaborative last-mile delivery in urban systems with stochastic demands', Procedia CIRP, vol. 30, 2015, pp. 263-8.

Noy, NF and McGuinness, DL 2001, 'Ontology development 101: A guide to creating your first ontology', Stanford knowledge systems laboratory technical report KSL-01-05 and Stanford medical informatics technical report SMI-2001-0880.

Nuzzolo, A and Comi, A 2014a, 'Urban freight demand forecasting: a mixed quantity/delivery/vehicle-based model', Transportation Research Part E: Logistics and Transportation Review, vol. 65, pp. 84-98.

Nuzzolo, A and Comi, A 2014b, 'A system of models to forecast the effects of demographic changes on urban shop restocking', Research in Transportation Business & Management, vol. 11, pp. 142-51.

Nuzzolo, A and Comi, A 2014c, ‘City logistics planning: demand modelling requirements for direct effect forecasting’, Procedia—Social and Behavioral Sciences, vol. 125, pp. 239-50.

O’Dwyer, LM and Bernauer, JA 2013, ‘Quantitative Research for the Qualitative Researcher’, Sage Publications, USA.

Ogden, KW 1992, Urban Goods Movement: A Guide to Policy and Planning, Ashgate, Aldershot, UK.

Oxford Dictionaries 2019, English to English Dictionary, Oxford University Press, Viewed 22/06/2019, <https://www.lexico.com/en/>

Paez, T.L., 2008. ‘Introduction to Model Validation’, (No. SAND2008-7314C). Sandia National Lab.(SNL-NM), Albuquerque, USA.

Pathumnakul, S 1996, ‘Solving multi depot vehicle routing problem for Iowa recycled paper by Tabu Search heuristic’ Retrospective Theses and Dissertations, 16982, Iowa State University, USA.

Patier, D and Browne, M 2010, ‘A methodology for the evaluation of urban logistics innovations’, Procedia—Social and Behavioral Sciences, vol. 2, no. 3, pp. 6229-41.

Punakivi, M and Tanskanen, K 2002, ‘Increasing the cost efficiency of e-fulfilment using shared reception boxes’, International Journal of Retail and Distribution Management, vol. 30, no. 10, pp. 498-507.

Punakivi, M, Yrjölä, H and Holmström, J 2001, ‘Solving the last mile issue: reception box or delivery box?’, International Journal of Physical Distribution and Logistics Management, vol. 31, no. 6, pp. 427-39.

Quak, HH 2008, ‘Sustainability of urban freight transport: retail distribution and local regulations in cities’, (No. EPS-2008-124-LIS), Erasmus University, Rotterdam, The Netherland,

Rahman, S 2011, ‘An exploratory study of outsourcing 3PL services: an Australian perspective’, Benchmarking: An International Journal, vol. 18, no. 3, pp. 342-58.

Ramaprasad, A and Papagari, SS 2009, ‘Ontological design’, in Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology, p. 5, ACM, Philadelphia, USA.

Saltelli, A, Ratto, M, Andres, T, Campolongo, F, Cariboni, J, Gatelli, D, Saisana, M and Tarantola, S 2008, ‘Global Sensitivity Analysis: The Primer’, John Wiley and Sons, Chichester, UK.

Schliwa, G, Armitage, R, Aziz, S, Evans, J and Rhoades, J 2015, ‘Sustainable city logistics—making cargo cycles viable for urban freight transport’, Research in Transportation Business and Management, vol. 15, June 2015, pp. 50-7.

Schoemaker, J 2002, 'Stadsdistributiecentrum leiden', in D Egger and M Ruesch (eds), BESTUFS—Best practice handbook 2002, BESTUFS, Rijswijk, The Netherlands.

Scott, M, Anderka, S and O'Donnell, E 2009, Improving Freight Movement in Delaware Central Business Districts, Institute for Public Administration, Newark, USA.

Scott Wilson Ltd 2010, Freight Consolidation Study—Final Report, viewed 03/07/2019, <http://www.dryport.org/files/doc/SEStran_Freight%20Consolidation%20Centre%20Study%20-%20Final%20Report.pdf>.

Souza, Rd, Goh, M, Lau, H-C, Ng, W-S and Tan, P-S 2014, 'Collaborative urban logistics—synchronizing the last mile: a Singapore research perspective', Procedia—Social and Behavioral Sciences, vol. 125, 20 March 2014, pp. 422-31.

Stathopoulos, A., Valeri, E. and Marcucci, E., 2012. Stakeholder reactions to urban freight policy innovation. Journal of Transport Geography, 22, pp.34-45.

Statista 2019, Number of Digital Buyers Worldwide, viewed 3/03/2019, <https://www.statista.com/statistics/251666/number-of-digital-buyers-worldwide/>.

Suksri, J, Raicu, R and Yue, WL 2012, Towards Sustainable Urban Freight Distribution—A Proposed Evaluation Framework, ATRF-Australasian Transport Research Forum, Perth, Australia.

Taniguchi, E, Thompson, RG and Yamada, T 2003, 'Predicting the effects of city logistics schemes', Transport Reviews, vol. 23, no. 4, pp. 489-515.

Taniguchi, E, Thompson, RG and Yamada, T 2012, 'Emerging techniques for enhancing the practical application of city logistics models', Procedia—Social and Behavioral Sciences, vol. 39, pp. 3-18.

Thacker, BH, Doebling, SW, Hemez, FM, Anderson, MC, Pepin, JE and Rodriguez, EA 2004, Concepts of Model Verification and Validation (No. LA-14167), Los Alamos National Laboratory, Los Alamos, USA.

The City of Melbourne 2013, Melbourne Retail and Hospitality Strategy, viewed 20/12/2015, <http://www.melbourne.vic.gov.au/business/doing-business/sectors/retail-hospitality/Pages/retail-and-hospitality-strategy-report-2013-14.aspx>.

The City of Melbourne 2015, Last Kilometre Freight—Case Study Report, viewed 20/12/2015, <http://participate.melbourne.vic.gov.au/innovate-freight>.

The City of Melbourne 2019, Shopping Centres and Markets, viewed 21/05/2019, <https://whatson.melbourne.vic.gov.au/Shopping/RetailCentres/Pages/RetailCentres.aspx>.

Thirumalai, S and Sinha, KK 2005, ‘Customer satisfaction with order fulfillment in retail supply chains: implications of product type in electronic B2C transactions’, Journal of Operations Management, vol. 23, no. 3-4, pp. 291-303.

Thomas, KW 1992, ‘Conflict and negotiation processes in organizations’, in M Dunnette and L Hough (eds), Handbook of Industrial and Organizational Psychology (vol. 3), Consulting Psychologists Press, Palo Alto, USA.

Thompson, R and Hassall, K 2012, ‘A collaborative urban distribution network’, Procedia—Social and Behavioral Sciences, vol. 39, pp. 230-40.

Thompson, R, Taniguchi, E and Yamada, T 2011, ‘Estimating the benefits of considering travel time variability in urban distribution’, Transportation Research Record: Journal of the Transportation Research Board, vol. 2238, pp. 86-96.

Tidström, A 2006, ‘Conflicts When Competitors Cooperate: Exploring Elements of Conflicts from a Business Network Perspective’, Svenska handelshögskolan, Helsinki, Finland.

Tipagornwong, C and Figliozzi, M 2014, ‘Analysis of competitiveness of freight tricycle delivery services in urban areas’, Transportation Research Record: Journal of the Transportation Research Board, vol. 2410, pp. 76-84.

Toth, P. and Vigo, D. eds., 2002. ‘The vehicle routing problem’, Society for Industrial and Applied Mathematics, Philadelphia, USA.

Tozzi, M, Corazza, MV and Musso, A 2013, ‘Recurring patterns of commercial vehicles movements in urban areas: the Parma case study’, Procedia—Social and Behavioral Sciences, vol. 87, pp. 306-20.

Tran, B 2016, ‘The nature of research methodologies: terms and usage within quantitative, qualitative, and mixed methods’, in Mixed Methods Research for Improved Scientific Study, in R Baran, E Diehnelt, E Dimmitt, and G Harpen (eds), (pp. 1-27), IGI Global, Philadelphia, USA.

Tranfield, D, Denyer, D and Smart, P 2003, ‘Towards a methodology for developing evidence-informed management knowledge by means of systematic review’, British Journal of Management, vol. 14, no. 3, pp. 207-22.

United Nations 2014, World Urbanization Prospects, viewed 20/12/2015, <http://www.un.org/en/development/desa/population/theme/urbanization/index.shtml>.

van Rooijen, T and Quak, H 2010, ‘Local impacts of a new urban consolidation centre—the case of Binnenstadservice.nl’, Procedia—Social and Behavioral Sciences, vol. 2, no. 3, pp. 5967-79.

Victoria, SGo 2013, Victorian Freight and Logistics Plan, viewed 20/12/2015, <http://www.railfreightalliance.com/>.

Visser, J, Nemoto, T and Browne, M 2014, ‘Home delivery and the impacts on urban freight transport: a review’, Procedia—Social and Behavioral Sciences, vol. 125, 20 March 2014, pp. 15-27.

WA, WNI, Shaiful, M, Shamsunarnie, MZ, Zainuddin, ZM and Fuad, M 2012, ‘Genetic algorithm for vehicle routing problem with backhauls’, Journal of Science and Technology, vol. 4, no. 1, pp. 9-15.

Woodard, JB 2013, ‘’Last-Mile’ Deliveries in High-Density Urban Residential Areas of Manhattan’, Columbia University, New York, USA.

Wu, H, Shao, D and Ng, W 2015, ‘Locating self-collection points for last-mile logistics using public transport data’, in T Cao, E-P Lim, Z-H Zhou, T-B Ho, D Cheung and H Motoda (eds), Advances in Knowledge Discovery and Data Mining (vol. 9077, pp. 498-510), Springer International Publishing, Cham, Switzerland.

Xu, JJ and Hong, L 2013, ‘Impact factors of choosing willingness for picking up service’, Research Journal of Applied Sciences, Engineering and Technology, vol. 6, no. 14, pp. 2509-13.

Xu, M, Ferrand, B and Roberts, M 2008, ‘The last mile of e-commerce—unattended delivery from the consumers and eTailers’ perspectives’, International Journal of Electronic Marketing and Retailing, vol. 2, no. 1, pp. 20-38.

Yang, F, Yang, M, Xia, Q and Liang, L 2015, ‘Collaborative distribution between two logistics service providers’, International Transactions in Operational Research, vol. 6, no. 23, pp.1025-50.

Yin, R 2009, ‘Case Study Research: Design and Methods’, 4th edn, SAGE, Los Angeles, USA.

Zambuzi, NC, Cunha, CB, Blanco, E, Yoshizaki, H and Carvalho, CD 2016, ‘An evaluation of environmental impacts of different truck sizes in last mile distribution in the city of São Paulo, Brazil’, 6th International Conference on Information Systems, Logistics and Supply Chain ILS Conference 2016, Bordeaux, France.

## Appendix A: Interview Questionnaire

**Interview Questionnaire**

| | |
|---|---|
| **Project Title** | Last Mile Delivery in the retail sector within an urban context |
| **Senior Supervisor** | |
| **Associate Supervisor** | |
| **Principal Research Student** | |
| **Interview time** | 75 minutes |

### Section 1: Organisation Profile

The following information requires details of the organisation.

1. Number of employees in your organisation in Australia:
   1-19 ☐ 20-199 ☐ 200-500 ☐ 500-1000 ☐ more than 1000 ☐

2. Number of years that your organisation has been operating:
   Less than 3 years ☐ 3-5 years ☐ 6-10 years ☐ 11-15 years ☐ 16-20 years ☐
   21-30 years ☐ more than 30years ☐

3. Type of organisation (based on the geographic coverage of operation):
   Global ☐ Australasia ☐ National ☐ State (Victoria) ☐ Intrastate (Melbourne) ☐

4. What category of services does your organisation provide? (tick all relevant boxes)
   Logistics information systems ☐ Order processing ☐ Product returns ☐ Relabelling and repacking ☐ Shipment ☐ Consolidation ☐ Warehousing ☐ Spare parts ☐ Inventory management ☐ Order fulfilment ☐ Product assembly ☐ Carrier selection ☐ Product testing ☐ Fleet management /operations ☐ Others ………

5. Which Industry sectors does your organisation provide services for? (tick all relevant boxes)

Agriculture, forestry and fishing ☐ Mining ☐ Manufacturing ☐ Construction ☐
Electricity, gas, water and waste ☐ Services ☐ Wholesale trade ☐ Retail trade ☐ Accommodation and food services ☐ Transport, postal and warehousing ☐
Information media and telecommunications ☐ Administrative and support services ☐ Rental, hiring and real estate services ☐ Professional, scientific and technical services ☐
Financial and insurance services ☐ Public administration and safety ☐Education and training ☐
Health care and social assistance ☐ Arts and recreation services ☐ Other…………..

6. If your business is the retail sector, in which category of retail does your organisation work? (tick all relevant boxes)
   Motor vehicle ☐ Motor vehicle parts and tyre ☐ Fuel ☐ Supermarket and grocery stores ☐ Specialised food ☐ Furniture, floor coverings, housewares and textile goods ☐
   Electrical and electronic goods ☐ Hardware, building and garden supplies ☐ Recreational goods ☐ Clothing, footwear and personal accessory ☐ Department stores ☐ Non-store retailing ☐ Pharmaceutical and other store-based retailing ☐ Retail commission-based buying and/or selling ☐ Other …………..

7. Which kind of guidance or management system standards are your organisation following or certified for? (tick all relevant boxes)
   ISO 9001 ☐ ISO 14001 ☐ OHSAS 18001 ☐ ISO 26000 ☐ Other …………..

8. Number of your business customers in the retail sector in Melbourne's CBD: ……

**Section 2: Respondent Profile**

The following information requires details of interviewee.

1. Your position in the organisation:
   Director/ group director ☐ General manager ☐ Business development manager ☐ Distribution manager ☐ HS&E manager ☐ Others …………………….

2. Department that you are associated to:
   Scheduling/ Planning ☐ Operations ☐ Sales ☐ Strategy and development ☐ Others ……………….

3. Your level of education:
   Post-Secondary/Secondary ☐ Diploma ☐ Graduate/Bachelors ☐ Post-graduate/Masters ☐
   PhD ☐

4. Years of managerial experience:

1year or less ☐ 02- 05 years ☐ 06-10 years ☐ 11-15 years ☐ 16- 20years ☐
Above 20 years ☐

5. Years of managerial experience with 3PL firms:
1year or less ☐ 02- 05 years ☐ 06-10 years ☐ 11-15 years ☐ 16- 20years ☐
Above 20 years ☐

## Section 3: LMD related questions

The following questions are related to various aspects of LMD.

**LMD structure**

1. Could you tell us about the structure of LMD in your organisation? Where and how do LMD processes start and finish? Do you follow the same processes for all customers and consignments?
2. What are your key indicators for measuring LMD performance? Please note that these indicators can be related to cost, services such as lead-time and timeliness, operations such as load factors (weight or volume) and empty running, environment such as pollution, social issues such as land use.
3. How do you calculate the price of each delivery?

**Consignment (Freight)**

4. Could you tell us about the characteristics of your freights in terms of type, size, weight, price, and sensitivity (environment, quality, time)?

**Dispatch point**

5. Could you tell us from where you dispatch the freights which directly go to your customers in Melbourne's CBD? These places can be anywhere including your own warehouse, customer's warehouse, port, and factory.
6. Could you also indicate where these are located and why?

**Vehicle (fleet)**

7. Could you explain how you manage your fleet in terms of
   - Location of vehicle hub
   - Number and capacity of vehicles
   - Fuel type of vehicles
   - Vehicle special facilities (such as cooler and freezer)
   - Outsourcing vehicle

**Delivery point**

8. Could you tell us where you usually deliver the customers' freight in Melbourne's CBD? These places can be anywhere such as customers' own bay, freight docks in shopping centres and collection centres.
9. How much is the demand of each delivery points?

**Dispatching and delivery facilities**

10. Please explain the type of equipment and machinery used in loading and unloading processes.

**Scheduling**

11. Could you tell us about your scheduling procedure? How do you manage to reduce the number of running vehicles? Do you have any procedure for improving the rate of performance such as load factor and empty running?
12. Could you tell us about your consolidation process if there is any? How do you manage it?
13. Could you tell us about the rates of vehicles and deliveries that are going to Melbourne's CBD?
14. Could you tell us about the delivery time and time window? Do you have any procedure for them?
15. What is your business day in terms of dispatching and delivering consignments?

## Section 4: Collaboration

The following questions are related to the concept of collaboration.

1. Could you tell us about your experience in collaboration especially with competitors if there is any? Which resources did you share? What were the advantages and disadvantages?
2. Is there any capacity or opportunity for sharing your resources such as dispatch points, delivery points and vehicles with others?
3. Do you think there is any tendency to collaborate with other 3PL service providers in your organisation? If yes, in which areas and resources? If no, could you tell us about the main reasons?
4. What are the main motivational factors for your organisation to collaborate with other 3PL firms or retailers?
5. Have you encountered any challenges during collaboration? If so, what are those challenges and how do you overcome?

______________________________ END ______________________________

**Appendix B: Participant Information Sheet**

RMIT UNIVERSITY

# Participant Information Sheet/Consent Form

# (For Interview)

| | |
|---|---|
| **Title** | last mile delivery in the retail sector in an urban context |
| **Senior Supervisor** | |
| **Associate Supervisor** | |
| **Principal Research Student** | |

---

## What does my participation involve?

### 1. Introduction

You are invited to take part in this research project, which is called collaborative Last Mile Delivery (LMD) in the retail sector within an urban context. You have been invited because your company is one of the largest third-party logistics (3PL) service providers in Australia. The contact details of your company were obtained from the web site of your company. Contacting your company, your contact details were then obtained.

This Participant Information Sheet/Consent Form tells you about the research project. It explains the processes involved with taking part. Knowing what is involved will help you decide if you want to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative or friend.

Participation in this research is voluntary. If you don't wish to take part, you don't have to.

If you decide you want to take part in the research project, you will be asked to sign the consent section. By signing it you are telling us that you:

• Understand what you have read

• Consent to take part in the research project

You will be given a copy of this Participant Information and Consent Form to keep.

**2. What is the purpose of this research?**

The objective of this study is to develop a comprehensive model for 3PL service providers involved in LMD in the retail sector in Melbourne's CBD and investigate the impact of the proposed model on the delivery performance measured in terms of cost, service, social, and environmental impacts. In this study collaboration amongst 3PL firms under co-opetition relationships is considered to optimise the proposed LMD system which hasn't been research before and is considered a critical gap in LMD literature.

The results of this research will be used by the researcher Joerin Motavallian to obtain a PhD (supply chain and logistics) degree.

**3. What does participation in this research involve?**

If you agree to participate, you will be asked to participate in an interview. First, you will be asked to read the Participant Information Sheet and Consent Form and sign if you agree to participate. In the interview you will be asked questions relating to various aspects of LMD which are as follows:

- Distribution structure
- Vehicle
- Dispatch and delivery points
- Freight
- Loading and unloading facilities
- Scheduling
- Collaboration experience and opportunities

The questionnaire will have no sensitive or personal questions which may disclose the participants' identity. The interview will take approximately 75 minutes which will be audio recorded. The interview will take place at a mutually convenient location. You can ask to cease recording at any time of the interview.

There are no costs associated with participating in this research project, nor will you be paid.

**4. Do I have to take part in this research project?**

Participation in any research project is voluntary. If you do not wish to take part, you do not have to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage.

If you do decide to take part, you will be given this Participant Information and Consent Form to sign and you will be given a copy to keep.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect your relationship with the researchers or with RMIT University.

You may stop the interview at any time. Unless you say that you want us to keep them, any recordings will be erased and information you have provided will not be included in the study results. You may also refuse to answer any questions that you do not wish to answer during the interview.

### 5. What are the possible benefits of taking part?

We cannot guarantee or promise that you will receive any benefits from this research; however, you may appreciate contributing to knowledge. In addition, you may explore the implications of the study on receiving the report at the end of the project.

### 6. What are the risks and disadvantages of taking part?

There is no risk associated with participating in this interview.

### 7. What if I withdraw from this research project?

If you do consent to participate, you may withdraw at any time. If you decide to withdraw from the project, please notify a member of the research team.

You have the right to have any unprocessed data withdrawn and destroyed, providing it can be reliably identified.

### 8. What happens when the research project ends?

You will receive a final report containing a summary of the project by mid-2018.

## How is the research project being conducted?

### 9. What will happen to information about me?

By signing the consent form you consent to the research team collecting and using information from you for the research project. Any information obtained in connection with this research project that can identify you will remain confidential. Data will be stored in RMIT server for a period of five (5) years using security passwords before destroyed. To ensure that data collected is protected, only the researcher/s will have access to the data.

It is anticipated that the results of this research project will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be provided in such a way that you cannot be identified. Interview notes and audio recording will be kept in a secured locker. To ensure confidentiality, only the researchers will have access to the origin data.

In accordance with relevant Australian and/or Victorian privacy and other relevant laws, you have the right to request access to the information about you that is collected and stored by the research team. You also have the right to request that any information with which you disagree be corrected. Please inform the research team member named at the end of this document if you would like to access your information.

Any information that you provide can be disclosed only if (1) it is protect you or others from harm, (2) if specifically allowed by law, (3) you provide the researchers with written permission. Any information obtained for the purpose of this research project that can identify you will be treated as confidential and securely stored.

**10. Who is organising and funding the research?**

This research project is being conducted by ×××.

**11. Who has reviewed the research project?**

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). This research project has been approved by the RMIT University HREC.

This project will be carried out according to the *National Statement on Ethical Conduct in Human Research* (2007). This statement has been developed to protect the interests of people who agree to participate in human research studies.

**12. Further information and who to contact**

If you want any further information concerning this project, you can contact the researcher on

××× or any of the following people:

**Research contact person**

| | |
|---|---|
| Name | |
| Position | |
| Telephone | |
| Email | |

**13. Complaints**

Should you have any concerns or questions about this research project, which you do not wish to discuss with the researchers listed in this document, then you may contact:

| | |
|---|---|
| Reviewing HREC name | RMIT University |
| HREC Secretary | |
| Telephone | |
| Email | |
| Mailing address | |

## Appendix C: Participant Consent Form

RMIT UNIVERSITY

# Consent Form

| | |
|---|---|
| **Title** | Last Mile Delivery in the Retail Sector in an Urban Context |
| **Senior Supervisor** | |
| **Associate Supervisor** | |
| **Principal Research Student** | |

**<u>Acknowledgement by Participant</u>**

I have read and understood the Participant Information Sheet.

I understand the purposes, procedures and risks of the research described in the project.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time during the project without affecting my relationship with RMIT.

I understand that I will be given a signed copy of this document to keep.

Name of Participant (please print) ______________________________

Signature ______________________ Date ______________________

**Declaration by Researcher†**

I have given a verbal explanation of the research project, its procedures and risks and I believe that the participant has understood that explanation.

| | | | |
|---|---|---|---|
| Name of Researcher† (please print) | ______________________ | | |
| Signature | ______________________ | Date | ______________________ |

† An appropriately qualified member of the research team must provide the explanation of, and information concerning, the research project.

Note: All parties signing the consent section must date their own signature.

# Appendix D: Ethics Approval Letter

RMIT UNIVERSITY

**Deputy Pro Vice-Chancellor**
**(Research & Innovation)**
**College of Business**

GPO Box 2476
Melbourne VIC 3001
Australia

Tel: +61 3 9925 5432
Fax: +61 3 9925 5624

**Notice of Approval**

| | |
|---|---|
| Date: | 13 October 2017 |
| Project number: | 21129 |
| Project title: | *Collaborative last mile delivery in the retail sector within an urban context* |
| Risk classification: | Low Risk |
| Chief Investigator: | Prof Shams Rahman |
| Student Investigator: | Mr Joerin Motavallian |
| Other Investigators: | Prof Caroline Chan |
| **Project Approved:** | **From: 11 October 2017** **To: 2 March 2019** |

**Terms of approval:**

*Responsibilities of the principal investigator*

It is the responsibility of the principal investigator to ensure that all other investigators and staff on a project are aware of the terms of approval and to ensure that the project is conducted as approved by BCHEAN. Approval is only valid while the investigator holds a position at RMIT University.

1. *Amendments*
   Approval must be sought from BCHEAN to amend any aspect of a project including approved documents. To apply for an amendment submit a request for amendment form to the BCHEAN secretary. This form is available on the Human Research Ethics Committee (HREC) website. Amendments must not be implemented without first gaining approval from BCHEAN.
2. *Adverse events*
   You should notify BCHEAN immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
3. *Participant Information and Consent Form (PICF)*
   The PICF must be distributed to all research participants, where relevant, and the consent form is to be retained and stored by the investigator. The PICF must contain the RMIT University logo and a complaints clause including the above project number.
4. *Annual reports*
   Continued approval of this project is dependent on the submission of an annual report.
5. *Final report*
   A final report must be provided at the conclusion of the project. BCHEAN must be notified if the project is discontinued before the expected date of completion.
6. *Monitoring*
   Projects may be subject to an audit or any other form of monitoring by BCHEAN at any time.
7. *Retention and storage of data*
   The investigator is responsible for the storage and retention of original data pertaining to a project for a minimum period of five years.

Regards,

Associate Professor Penny Weller
Chairperson
RMIT BCHEAN

## Appendix E: LMD Ontology Hierarchy

**1. Process**
**(Function)**

**1.1. Scheduling**

(How)

- **Constraint**
  - Time constraint
  - Location constraint
  - Consignment constraint
  - Distance constraint
  - Facilities constraint

**1.2. Dispatching**

(Where)

- **Dispatch Area**
  - Urban Area
  - Suburb Area
  - Rural Area
- **Dispatch Point**
  - Factory
  - Warehouse
  - Consolidation Centre
  - Store
  - Collection Centre

- **Dispatch Time**
  - Limited dispatch time
  - Unlimited dispatch time
- **Loading Duration**
  - High loading duration
  - Low loading duration

- **Vehicle Utilisation**
  - High vehicle utilisation
  - Low vehicle utilisation

**1.3. Transporting**

(Where)

| **Transportation Area** |
|---|
| Urban Area |
| Suburb Area |
| Rural Area |

| **Transportation Time** |
|---|
| Peak Time |
| Off-Peak Time |
| **Tour Duration** |
| High tour duration |
| Low tour duration |

| **Tour Length** |
|---|
| Long tour length |
| Short tour length |

**1.4. Delivering**

- 1.4.1. Delivery (Handing over)
  - 1.4.1.1. Attended delivery
  - 1.4.1.2. Unattended delivery
    - 1.4.1.2.1. Secure unattended delivery
      - 1.4.1.2.1.1. Fixed box delivery
      - 1.4.1.2.1.2. Portable box delivery
    - 1.4.1.2.2. Unsecure unattended delivery
- 1.4.2. Picking up
  - 1.4.2.1. Manned picking up
  - 1.4.2.2. Unmanned picking up

(Where)

| **Delivery Area** |
|---|
| Urban Area |
| Suburb Area |
| Rural Area |
| **Delivery Point** |
| Factory |
| Warehouse |
| Consolidation Centre |
| Store |
| Collection Centre |
| Consignee place |

| **Delivery Time** |
|---|
| During working hours |
| Out of working hours |
| **Delivery duration** |
| High delivery duration |
| Low delivery duration |
| **Time window** |
| High time window |
| Low time window |
| **Delivery frequency** |
| High delivery frequency |
| Low delivery frequency |

| **Number of delivery point per tour** |
|---|
| Single delivery point per tour |
| Multiple delivery points per tour |

**1.5. Developing**

| 2. Input/ output | |
|---|---|
| (What) | |
| **2.1. Consignment** | |
| 2.1.1. Convenience goods | **Size** |
| 2.1.1.1. Food | large size |
| 2.1.2. Non-food | Medium size |
| 2.1.2. Shopping goods | Small size |
| 2.1.3. Specialty goods | **Sensitivity** |
| | **Time sensitivy** |
| | **Tempreture sensitivity** |
| | Freezing temprature condition |
| | Fresh temperature condition |
| | Room temperature condition |
| | Warm temprature condition |
| | **Quality sensitivity** |
| | **No sensitivity** |
| | **Weight** |
| | Heavy weight consignment |
| | Medium weight consignment |
| | Light weight consignment |
| | **Price** |
| | High price consignment |
| | low price consignment |
| | **Quantity** |
| | **Number of goods in package** |
| | Single goods consignment |
| | Multiple goods consignment |
| | **Number of package** |
| | single package consignment |
| | Multiple package consignment |
| **2.2. Incoming information of delivery** | |
| **2.3. Stakeholders' attitude and Behavior** | |

| 3. Stakeholder (Who/Whom) | 4. Procedure and Regulation |
|---|---|
| **3.1. Sender** | **4.1. Internal procedure** |
| 3.1.1. Business | **4.2. External regulation** |
| 3.1.1.1. Manufacturer | 4.2.1. Access time regulation |
| 3.1.1.2. Distributor | 4.2.2. Access area and space use regulation |
| 3.1.1.3. Retailer | 4.2.3. Environment regulation |
| 3.1.1.4. E-tailer | 4.2.4. Load regulation |
| 3.1.2. Third Party (Outsourced) | 4.2.5. Health and safety regulation |
| 3.1.3. Supplier (Outsourced) | |
| **3.2. Carrier** | |
| 3.2.1. Business(Insourced) | |
| 3.2.1.1. Manufacturer | |
| 3.2.1.2. Distributor | |
| 3.2.1.3. Retailer | |
| 3.2.1.4. E-tailer | |
| 3.2.2. Third Party (Outsourced) | |
| 3.2.3. Supplier(Outsourced) | |
| **3.3. Receiver (consignee)** | |
| 3.3.1. Business | |
| 3.3.1.1. Manufacturer | |
| 3.3.1.2. Distributor | |
| 3.3.1.3. Retailer | |
| 3.3.1.4. E-tailer | |
| 3.3.2. Consumer | |
| 3.3.2.1. Consumer by itself | |
| 3.3.2.2. Consumer's representativ | |
| **3.4. Planner** | |
| **3.5. Resident/Visitor** | |
| **3.6. Government Authority** | |

| 5. Resource | | 6. Indicator |
|---|---|---|
| **5.1. Personnel** | | **6.1. Economic** |
| **5.2. Technology** | | 6.1.1.Cost |
| 5.2.1. Information & communication technology | | 6.1.2. Investment |
| 5.2.2. Decision-making technology | | **6.2. Operation** |
| **5.3. Dispatching Facility** | | 6.2.1. Time |
| 5.3.1. Loading Equipment | | 6.2.2. Service quality |
| 5.3.2. Loading Zone | | 6.2.3. Security |
| **5.4. Transportation Facility** | | 6.2.4. Failure |
| 5.4.1. Vehicle | **Vehicle Capacity** | 6.2.5. Utilisation |
| 5.4.1.1. Rail Vehicle | **Fuel** | **6.3. Environment** |
| 5.4.1.1.1. Tram | High Emission fuel | 6.3.1. Noise |
| 5.4.1.1.2. Trian | Low Emission fuel | 6.3.2. Pollution |
| 5.4.1.2. Road Vehicle | Zero Emission fuel | **6.4. Social Life** |
| 5.4.1.2.1. Goods vehicle | | 6.4.1. Safety/ Health |
| 5.4.1.2.1.1. Heavy goods vehicle | | 6.4.2. Congestion |
| 5.4.1.2.1.2. Medium goods vehicle | | 6.4.3. Land Use |
| 5.4.1.2.1.3. Light goods vehicle | | **6.5. Stakeholders' Satisfaction** |
| 5.4.1.2.2. Passenger vehicle | | 6.5.1. Sender satisfaction |
| 5.4.1.2.3. Motor Cycle | | 6.5.2. Carrier satisfaction |
| 5.4.1.2.4. Pedal Cycle | | 6.5.3. Receiver satisfaction |
| 5.4.1.2.5. Robot | | 6.5.4. Planner satisfaction |
| 5.4.1.2.6. On foot | | 6.5.5. Resident/Visitor satisfaction |
| 5.4.1.3. Water Vehicle | | 6.5.6. Government authority satisfaction |
| 5.4.1.4. Space Vehicle | | |
| 5.4.1.5. Pipeline | | |
| 5.4.2. Vehicle Accessory | | |
| 5.4.2.1. Consignment protector | | |
| 5.4.2.1.1. Cooler | | |
| 5.4.2.1.2. Freezer | | |
| 5.4.2.1.3. Warmer | | |
| 5.4.2.1.4. General | | |
| 5.4.2.2. Communication device | | |
| 5.4.3. Route Facility | | |
| **5.5. Delivery Facility** | | |
| 5.5.1. Unloading Equipment | | |
| 5.5.2. Unloading Zone | | |
| 5.5.3.1. On-street Parking | | |
| 5.5.3.2. Off-street Parking | | |
| 5.5.3. Pick-up Facilities | | |
| 5.5.4. Pick-up Space | | |
| 5.5.5. Delivery Equipment | | |

# Appendix F: Ontological Framework on LMD

**1. Process**
**(Function)**

**1.1. Scheduling**

(How)

[with]

- **Constraint**
  - Time constraint
  - Location constraint
  - Consignment constraint
  - Distance constraint
  - Facilities constraint

**1.2. Dispatching**

(Where)

[From][At]

- **Dispatch Area**
  - Urban Area
  - Suburb Area
  - Rural Area
- **Dispatch Point**
  - Factory
  - Warehouse
  - Consolidation Centre
  - Store
  - Collection Centre

(When)

[In] [With]

- **Dispatch Time**
  - Limited dispatch time
  - Unlimited dispatch time
- **Loading Duration**
  - High loading duration
  - Low loading duration

(How)

[With]

- **Vehicle Utilisation**
  - High vehicle utilisation
  - Low vehicle utilisation

[×][for][in]

**1.3. Transporting**

(Where)

[Within]
- **Transportation Area**
  - Urban Area
  - Suburb Area
  - Rural Area

(When)

[During]
- **Transportation Time**
  - Peak Time
  - Off-Peak Time
- **Tour Duration**
  - High tour duration
  - Low tour duration

(How)

[With]
- **Tour Length**
  - Long tour length
  - Short tour length

**1.4. Delivering**

- 1.4.1. Delivery (Handing over)
  - 1.4.1.1. Attended delivery
  - 1.4.1.2. Unattended delivery
    - 1.4.1.2.1. Secure unattended delivery
      - 1.4.1.2.1.1. Fixed box delivery
      - 1.4.1.2.1.2. Portable box delivery
    - 1.4.1.2.2. Unsecure unattended delivery
- 1.4.2. Picking up
  - 1.4.2.1. Manned picking up
  - 1.4.2.2. Unmanned picking up

(Where)

[To][At][In]
- **Delivery Area**
  - Urban Area
  - Suburb Area
  - Rural Area
- **Delivery Point**
  - Factory
  - Warehouse
  - Consolidation Centre
  - Store
  - Collection Centre
  - Consignee place

(When)

[×][During][with]
- **Delivery Time**
  - During working hours
  - Out of working hours
- **Delivery duration**
  - High delivery duration
  - Low delivery duration
- **Time window**
  - High time window
  - Low time window
- **Delivery frequency**
  - High delivery frequency
  - Low delivery frequency

(How)

[With][In]
- **Number of delivery point per tour**
  - Single delivery point per tour
  - Multiple delivery points per tour

**1.5. Developing**

| | | | |
|---|---|---|---|
| | **2. Input/ output** | | |
| | **(What)** | | |
| [×] [by using][for] | **2.1. Consignment** | [with] | |
| | 2.1.1. Convenience goods | | **Size** |
| | 2.1.1.1. Food | | large size |
| | 2.1.2. Non-food | | Medium size |
| | 2.1.2. Shopping goods | | Small size |
| | 2.1.3. Specialty goods | | **Sensitivity** |
| | | | **Time sensitivy** |
| | | | **Tempreture sensitivity** |
| | | | Freezing temprature condition |
| | | | Fresh temperature condition |
| | | | Room temperature condition |
| | | | Warm temprature condition |
| | | | **Quality sensitivity** |
| | | | **No sensitivity** |
| | | | **Weight** |
| | | | Heavy weight consignment |
| | | | Medium weight consignment |
| | | | Light weight consignment |
| | | | **Price** |
| | | | High price consignment |
| | | | low price consignment |
| | | | **Quantity** |
| | | | **Number of goods in package** |
| | | | Single goods consignment |
| | | | Multiple goods consignment |
| | | | **Number of package** |
| | | | single package consignment |
| | | | Multiple package consignment |
| | **2.2. Incoming information of delivery** | | |
| | **2.3. Stakeholders' attitude and Behavior** | | |

| [×][By][To][For][With][Within] | 3. Stakeholder (Who/Whom) |
| --- | --- |
| | **3.1. Sender** |
| | 3.1.1. Business |
| | 3.1.1.1. Manufacturer |
| | 3.1.1.2. Distributor |
| | 3.1.1.3. Retailer |
| | 3.1.1.4. E-tailer |
| | 3.1.2. Third Party (Outsourced) |
| | 3.1.3. Supplier (Outsourced) |
| | **3.2. Carrier** |
| | 3.2.1. Business(Insourced) |
| | 3.2.1.1. Manufacturer |
| | 3.2.1.2. Distributor |
| | 3.2.1.3. Retailer |
| | 3.2.1.4. E-tailer |
| | 3.2.2. Third Party (Outsourced) |
| | 3.2.3. Supplier(Outsourced) |
| | **3.3. Receiver (consignee)** |
| | 3.3.1. Business |
| | 3.3.1.1. Manufacturer |
| | 3.3.1.2. Distributor |
| | 3.3.1.3. Retailer |
| | 3.3.1.4. E-tailer |
| | 3.3.2. Consumer |
| | 3.3.2.1. Consumer by itself |
| | 3.3.2.2. Consumer's representative |
| | **3.4. Planner** |
| | **3.5. Resident/Visitor** |
| | **3.6. Government Authority** |

| [×][Following] | 4. Procedure and Regulation |
| --- | --- |
| | **4.1. Internal procedure** |
| | **4.2. External regulation** |
| | 4.2.1. Access time regulation |
| | 4.2.2. Access area and space use regulation |
| | 4.2.3. Environment regulation |
| | 4.2.4. Load regulation |
| | 4.2.5. Health and safety regulation |

| | 5. Resource | | | | 6.Indicator |
|---|---|---|---|---|---|
| [Using][By using][For using][For][With][Sharing] | **5.1. Personnel** | | | [To][affect][increase][decrease] | **6.1. Economic** |
| | **5.2. Technology** | | | | 6.1.1.Cost |
| | 5.2.1. Information & communication technology | | | | 6.1.2. Investment |
| | 5.2.2. Decision-making technology | | | | **6.2. Operation** |
| | **5.3. Dispatching Facility** | | | | 6.2.1. Time |
| | 5.3.1. Loading Equipment | | | | 6.2.2. Service quality |
| | 5.3.2. Loading Zone | | | | 6.2.3. Security |
| | **5.4. Transportation Facility** | | | | 6.2.4. Failure |
| | 5.4.1. Vehicle | [with] | **Vehicle Capacity** | | 6.2.5. Utilisation |
| | 5.4.1.1. Rail Vehicle | | **Fuel** | | **6.3. Environment** |
| | 5.4.1.1.1. Tram | | High Emission fuel | | 6.3.1. Noise |
| | 5.4.1.1.2. Trian | | Low Emission fuel | | 6.3.2. Pollution |
| | 5.4.1.2. Road Vehicle | | Zero Emission fuel | | **6.4. Social Life** |
| | 5.4.1.2.1. Goods vehicle | | | | 6.4.1. Safety/ Health |
| | 5.4.1.2.1.1. Heavy goods vehicle | | | | 6.4.2. Congestion |
| | 5.4.1.2.1.2. Medium goods vehicle | | | | 6.4.3. Land Use |
| | 5.4.1.2.1.3. Light goods vehicle | | | | **6.5. Stakeholders' Satisfaction** |
| | 5.4.1.2.2. Passenger vehicle | | | | 6.5.1. Sender satisfaction |
| | 5.4.1.2.3. Motor Cycle | | | | 6.5.2. Carrier satisfaction |
| | 5.4.1.2.4. Pedal Cycle | | | | 6.5.3. Receiver satisfaction |
| | 5.4.1.2.5. Robot | | | | 6.5.4. Planner satisfaction |
| | 5.4.1.2.6. On foot | | | | 6.5.5. Resident/Visitor satisfaction |
| | 5.4.1.3. Water Vehicle | | | | 6.5.6. Government authority satisfaction |
| | 5.4.1.4. Space Vehicle | | | | |
| | 5.4.1.5. Pipeline | | | | |
| | 5.4.2. Vehicle Accessory | | | | |
| | 5.4.2.1. Consignment protector | | | | |
| | 5.4.2.1.1. Cooler | | | | |
| | 5.4.2.1.2. Freezer | | | | |
| | 5.4.2.1.3. Warmer | | | | |
| | 5.4.2.1.4. General | | | | |
| | 5.4.2.2. Communication device | | | | |
| | 5.4.3. Route Facility | | | | |
| | **5.5. Delivery Facility** | | | | |
| | 5.5.1. Unloading Equipment | | | | |
| | 5.5.2. Unloading Zone | | | | |
| | 5.5.3.1. On-street Parking | | | | |
| | 5.5.3.2. Off-street Parking | | | | |
| | 5.5.3. Pick-up Facilities | | | | |
| | 5.5.4. Pick-up Space | | | | |
| | 5.5.5. Delivery Equipment | | | | |

# Appendix G: Matrix X for the First Level of LMD Ontology

| Articles (i↓and j→) | Indicator | Input | Procedure | Process | Resource | Stakeholder |
|---|---|---|---|---|---|---|
| A01 | 1 | 1 | 0 | 1 | 0 | 1 |
| A02 | 1 | 0 | 0 | 1 | 1 | 0 |
| A03 | 0 | 0 | 0 | 1 | 0 | 0 |
| A04 | 1 | 0 | 0 | 1 | 0 | 1 |
| A05 | 1 | 1 | 1 | 1 | 0 | 0 |
| A06 | 1 | 0 | 0 | 1 | 0 | 0 |
| A07 | 1 | 1 | 0 | 1 | 0 | 0 |
| A08 | 1 | 0 | 0 | 1 | 0 | 0 |
| A09 | 0 | 1 | 0 | 1 | 0 | 0 |
| A10 | 1 | 0 | 0 | 1 | 1 | 0 |
| A11 | 1 | 1 | 0 | 1 | 1 | 1 |
| A12 | 1 | 1 | 0 | 1 | 0 | 0 |
| A13 | 1 | 0 | 0 | 1 | 0 | 0 |
| A14 | 1 | 1 | 0 | 1 | 1 | 0 |
| A15 | 0 | 1 | 0 | 1 | 1 | 0 |
| A16 | 1 | 1 | 0 | 1 | 0 | 1 |
| A17 | 0 | 1 | 0 | 1 | 0 | 1 |
| A18 | 1 | 0 | 0 | 1 | 0 | 0 |
| A19 | 1 | 0 | 1 | 1 | 1 | 1 |
| A20 | 1 | 0 | 0 | 1 | 1 | 0 |
| A21 | 1 | 1 | 0 | 1 | 0 | 1 |
| A22 | 1 | 0 | 0 | 1 | 1 | 0 |
| A23 | 1 | 1 | 0 | 1 | 1 | 0 |
| A24 | 1 | 1 | 0 | 1 | 1 | 1 |
| A25 | 1 | 0 | 0 | 1 | 0 | 0 |
| A26 | 0 | 0 | 0 | 1 | 0 | 0 |
| A27 | 1 | 1 | 0 | 1 | 0 | 1 |
| A28 | 1 | 0 | 1 | 1 | 1 | 0 |
| A29 | 1 | 1 | 0 | 1 | 1 | 0 |
| A30 | 1 | 0 | 0 | 1 | 0 | 0 |
| A31 | 1 | 0 | 0 | 1 | 0 | 0 |
| A32 | 1 | 1 | 0 | 1 | 1 | 0 |
| A33 | 1 | 1 | 0 | 1 | 1 | 1 |
| A34 | 0 | 1 | 0 | 1 | 0 | 1 |
| A35 | 1 | 1 | 0 | 1 | 1 | 1 |
| A36 | 0 | 0 | 0 | 1 | 0 | 0 |
| A37 | 1 | 1 | 0 | 1 | 1 | 0 |
| A38 | 1 | 0 | 0 | 1 | 1 | 0 |
| A39 | 1 | 0 | 0 | 1 | 0 | 1 |
| A40 | 1 | 1 | 0 | 1 | 0 | 0 |
| A41 | 1 | 0 | 0 | 1 | 0 | 0 |
| A42 | 1 | 1 | 0 | 1 | 0 | 1 |
| A43 | 1 | 1 | 0 | 1 | 1 | 1 |
| A44 | 1 | 1 | 0 | 1 | 0 | 1 |
| A45 | 1 | 1 | 0 | 1 | 1 | 0 |
| A46 | 1 | 0 | 0 | 1 | 1 | 0 |
| A47 | 1 | 0 | 0 | 1 | 1 | 0 |
| A48 | 1 | 1 | 0 | 1 | 1 | 0 |
| A49 | 1 | 0 | 0 | 1 | 1 | 1 |

| Articles (i↓and j→) | Indicator | Input | Procedure | Process | Resource | Stakeholder |
|---|---|---|---|---|---|---|
| A50 | 0 | 1 | 0 | 1 | 0 | 0 |
| A51 | 1 | 1 | 0 | 1 | 0 | 0 |
| A52 | 1 | 0 | 1 | 1 | 1 | 0 |
| A53 | 0 | 1 | 0 | 1 | 1 | 0 |
| A54 | 1 | 0 | 0 | 1 | 0 | 0 |
| A55 | 1 | 1 | 0 | 1 | 1 | 1 |
| A56 | 1 | 1 | 0 | 1 | 0 | 0 |
| A57 | 0 | 0 | 0 | 1 | 1 | 1 |
| A58 | 1 | 1 | 0 | 1 | 0 | 1 |
| A59 | 1 | 1 | 0 | 1 | 0 | 0 |
| A60 | 1 | 0 | 0 | 1 | 0 | 1 |
| A61 | 1 | 1 | 0 | 1 | 1 | 1 |
| A62 | 1 | 1 | 0 | 1 | 1 | 0 |
| A63 | 1 | 0 | 0 | 1 | 1 | 0 |
| A64 | 1 | 1 | 0 | 1 | 0 | 0 |
| A65 | 1 | 1 | 0 | 1 | 1 | 0 |
| A66 | 1 | 1 | 0 | 1 | 1 | 1 |
| A67 | 1 | 0 | 0 | 1 | 0 | 0 |
| A68 | 1 | 0 | 0 | 1 | 1 | 0 |
| A69 | 1 | 1 | 0 | 1 | 1 | 0 |
| A70 | 1 | 1 | 0 | 1 | 1 | 1 |
| A71 | 1 | 0 | 0 | 1 | 1 | 0 |
| A72 | 0 | 1 | 0 | 1 | 1 | 1 |
| A73 | 1 | 1 | 0 | 1 | 0 | 1 |
| A74 | 1 | 0 | 0 | 1 | 1 | 1 |
| A75 | 1 | 1 | 0 | 1 | 0 | 0 |
| A76 | 1 | 1 | 0 | 1 | 1 | 1 |
| A77 | 1 | 1 | 0 | 1 | 1 | 0 |
| A78 | 1 | 1 | 0 | 1 | 0 | 1 |
| A79 | 1 | 0 | 0 | 1 | 1 | 1 |
| A80 | 1 | 1 | 0 | 1 | 1 | 1 |
| A81 | 1 | 0 | 1 | 1 | 1 | 1 |
| A82 | 1 | 1 | 0 | 1 | 1 | 0 |
| A83 | 1 | 0 | 0 | 1 | 1 | 0 |
| A84 | 1 | 0 | 0 | 1 | 1 | 0 |
| A85 | 1 | 1 | 0 | 1 | 1 | 1 |
| A86 | 0 | 0 | 0 | 1 | 1 | 0 |
| A87 | 1 | 1 | 0 | 1 | 0 | 1 |
| A88 | 1 | 1 | 0 | 1 | 0 | 1 |
| A89 | 1 | 0 | 0 | 1 | 0 | 1 |
| A90 | 1 | 0 | 0 | 1 | 0 | 1 |
| A91 | 1 | 0 | 0 | 1 | 1 | 1 |
| A92 | 1 | 1 | 0 | 1 | 0 | 1 |
| A93 | 1 | 0 | 0 | 1 | 1 | 0 |

## Appendix H: A Sample Part of Matrix X for all Levels of LMD Ontology

| Articles (i↓and j→) | Indicator | Efficiency | Cost | Investment | Environment | Noise | Pollution | Operation | Failure |
|---|---|---|---|---|---|---|---|---|---|
| A01 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A02 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A04 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A05 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A06 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A07 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A08 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A09 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A10 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| A11 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A12 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| A13 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A14 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A16 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A18 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 |
| A19 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A20 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A21 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A22 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| A23 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| A24 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| A25 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A27 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A28 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A29 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A30 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A31 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A32 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A33 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A35 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| A36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A37 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A38 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 |
| A39 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A40 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A41 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| A42 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A43 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A44 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| A45 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A46 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A47 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A48 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A49 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |

| Articles (i↓and j→) | Indicator | Efficiency | Cost | Investment | Environment | Noise | Pollution | Operation | Failure |
|---|---|---|---|---|---|---|---|---|---|
| A50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A51 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A52 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 |
| A53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A54 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A55 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| A56 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A58 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A59 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A60 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 |
| A61 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A62 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A63 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A64 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A65 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| A66 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| A67 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| A68 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| A69 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| A70 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| A71 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| A72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A73 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| A74 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| A75 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A76 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A77 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 |
| A78 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| A79 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| A80 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| A81 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 |
| A82 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| A83 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| A84 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| A85 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A86 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A87 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A88 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| A89 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A90 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| A91 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| A92 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| A93 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |

## Appendix I: Matrix S for the First Level of LMD Ontology

| Articles | Total |
|---|---|
| A01 | 4 |
| A02 | 3 |
| A03 | 1 |
| A04 | 3 |
| A05 | 4 |
| A06 | 2 |
| A07 | 3 |
| A08 | 2 |
| A09 | 2 |
| A10 | 3 |
| A11 | 5 |
| A12 | 3 |
| A13 | 2 |
| A14 | 4 |
| A15 | 3 |
| A16 | 4 |
| A17 | 3 |
| A18 | 2 |
| A19 | 5 |
| A20 | 3 |
| A21 | 4 |
| A22 | 3 |
| A23 | 4 |
| A24 | 5 |
| A25 | 2 |
| A26 | 1 |
| A27 | 4 |
| A28 | 4 |
| A29 | 4 |
| A30 | 2 |
| A31 | 2 |
| A32 | 4 |
| A33 | 5 |
| A34 | 3 |
| A35 | 5 |
| A36 | 1 |
| A37 | 4 |
| A38 | 3 |
| A39 | 3 |
| A40 | 3 |
| A41 | 2 |
| A42 | 4 |
| A43 | 5 |
| A44 | 4 |
| A45 | 4 |
| A46 | 3 |

| Articles | Total |
|---|---|
| A47 | 3 |
| A48 | 4 |
| A49 | 4 |
| A50 | 2 |
| A51 | 3 |
| A52 | 4 |
| A53 | 3 |
| A54 | 2 |
| A55 | 5 |
| A56 | 3 |
| A57 | 3 |
| A58 | 4 |
| A59 | 3 |
| A60 | 3 |
| A61 | 5 |
| A62 | 4 |
| A63 | 3 |
| A64 | 3 |
| A65 | 4 |
| A66 | 5 |
| A67 | 2 |
| A68 | 3 |
| A69 | 4 |
| A70 | 5 |
| A71 | 3 |
| A72 | 4 |
| A73 | 4 |
| A74 | 4 |
| A75 | 3 |
| A76 | 5 |
| A77 | 4 |
| A78 | 4 |
| A79 | 4 |
| A80 | 5 |
| A81 | 5 |
| A82 | 4 |
| A83 | 3 |
| A84 | 3 |
| A85 | 5 |
| A86 | 2 |
| A87 | 4 |
| A88 | 4 |
| A89 | 3 |
| A90 | 3 |
| A91 | 4 |
| A92 | 4 |
| A93 | 3 |

## Appendix J: Matrix S for the Second Level of LMD Ontology

| Articles | Total |
|---|---|
| A01 | 5 |
| A02 | 6 |
| A03 | 1 |
| A04 | 6 |
| A05 | 5 |
| A06 | 5 |
| A07 | 5 |
| A08 | 4 |
| A09 | 5 |
| A10 | 4 |
| A11 | 10 |
| A12 | 5 |
| A13 | 3 |
| A14 | 6 |
| A15 | 5 |
| A16 | 6 |
| A17 | 3 |
| A18 | 5 |
| A19 | 6 |
| A20 | 5 |
| A21 | 6 |
| A22 | 5 |
| A23 | 7 |
| A24 | 8 |
| A25 | 4 |
| A26 | 3 |
| A27 | 9 |
| A28 | 8 |
| A29 | 8 |
| A30 | 5 |
| A31 | 3 |
| A32 | 8 |
| A33 | 8 |
| A34 | 5 |
| A35 | 8 |
| A36 | 1 |
| A37 | 7 |
| A38 | 7 |
| A39 | 6 |
| A40 | 7 |
| A41 | 3 |
| A42 | 7 |
| A43 | 8 |
| A44 | 7 |
| A45 | 7 |
| A46 | 3 |

| Articles | Total |
|---|---|
| A47 | 4 |
| A48 | 7 |
| A49 | 6 |
| A50 | 4 |
| A51 | 6 |
| A52 | 7 |
| A53 | 6 |
| A54 | 4 |
| A55 | 8 |
| A56 | 5 |
| A57 | 5 |
| A58 | 7 |
| A59 | 5 |
| A60 | 8 |
| A61 | 6 |
| A62 | 7 |
| A63 | 6 |
| A64 | 6 |
| A65 | 7 |
| A66 | 6 |
| A67 | 6 |
| A68 | 5 |
| A69 | 6 |
| A70 | 8 |
| A71 | 6 |
| A72 | 9 |
| A73 | 5 |
| A74 | 11 |
| A75 | 4 |
| A76 | 6 |
| A77 | 7 |
| A78 | 8 |
| A79 | 8 |
| A80 | 8 |
| A81 | 15 |
| A82 | 7 |
| A83 | 7 |
| A84 | 8 |
| A85 | 6 |
| A86 | 3 |
| A87 | 5 |
| A88 | 7 |
| A89 | 4 |
| A90 | 5 |
| A91 | 6 |
| A92 | 7 |
| A93 | 7 |

## Appendix K: Results Table Scenario I

| Instance No. | Set No. | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|
| 1 | 1 | 972.4 | 48.6 | 589 | 703 |
| 2 | 1 | 1159.6 | 58.0 | 583 | 867 |
| 3 | 2 | 2025.2 | 40.5 | 865 | 1547 |
| 4 | 2 | 1873.2 | 37.5 | 581 | 1415 |
| 5 | 3 | 4296.4 | 43.0 | 575 | 3303 |
| 6 | 3 | 3306.0 | 33.1 | 434 | 2471 |
| 7 | 4 | 1216.0 | 33.8 | 522 | 884 |
| 8 | 4 | 1077.6 | 29.9 | 595 | 778 |
| 9 | 5 | 2627.2 | 29.2 | 609 | 1882 |
| 10 | 5 | 2552.8 | 28.4 | 429 | 1872 |
| 11 | 6 | 5564.8 | 30.9 | 425 | 4148 |
| 12 | 6 | 6105.6 | 33.9 | 424 | 4604 |
| 13 | 7 | 2242.4 | 44.8 | 671 | 1614 |
| 14 | 7 | 2403.6 | 48.1 | 728 | 1753 |
| 15 | 8 | 4948.4 | 39.6 | 548 | 3772 |
| 16 | 8 | 4980.0 | 39.8 | 672 | 3769 |
| 17 | 9 | 9117.2 | 36.5 | 594 | 6969 |
| 18 | 9 | 9645.6 | 38.6 | 501 | 7264 |
| 19 | 10 | 2924.0 | 32.5 | 534 | 2124 |
| 20 | 10 | 3113.6 | 34.6 | 660 | 2290 |
| 21 | 11 | 7628.4 | 33.9 | 478 | 5606 |
| 22 | 11 | 6178.8 | 27.5 | 502 | 4454 |
| 23 | 12 | 13008.8 | 28.9 | 423 | 9640 |
| 24 | 12 | 13334.4 | 29.6 | 460 | 9850 |
| 25 | 13 | 4875.6 | 48.8 | 604 | 3619 |
| 26 | 13 | 4623.2 | 46.2 | 658 | 3432 |
| 27 | 14 | 8627.2 | 34.5 | 607 | 6472 |
| 28 | 14 | 8861.2 | 35.4 | 600 | 6717 |
| 29 | 15 | 22072.0 | 44.1 | 500 | 16860 |
| 30 | 15 | 19880.0 | 39.8 | 497 | 15068 |
| 31 | 16 | 6109.6 | 33.9 | 611 | 4490 |
| 32 | 16 | 5672.8 | 31.5 | 722 | 4130 |
| 33 | 17 | 13668.0 | 30.4 | 514 | 10052 |
| 34 | 17 | 13917.6 | 30.9 | 477 | 10324 |
| 35 | 18 | 27556.0 | 30.6 | 465 | 20298 |
| 36 | 18 | 28364.8 | 31.5 | 483 | 20924 |

## Appendix L: Results Table Scenario II

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 334.0 | 16.7 | 573 | 150 |
| 1 | 1 | 2 | 286.0 | 14.3 | 747 | 105 |
| 2 | 1 | 1 | 297.2 | 14.9 | 601 | 178 |
| 3 | 2 | 1 | 681.2 | 13.6 | 337 | 348 |
| 3 | 2 | 2 | 722.8 | 14.5 | 283 | 375 |
| 4 | 2 | 1 | 834.0 | 16.7 | 422 | 460 |
| 4 | 2 | 2 | 789.2 | 15.8 | 464 | 371 |
| 5 | 3 | 1 | 1410.0 | 14.1 | 266 | 700 |
| 5 | 3 | 2 | 1486.8 | 14.9 | 262 | 810 |
| 6 | 3 | 1 | 1368.4 | 13.7 | 251 | 786 |
| 6 | 3 | 2 | 1429.2 | 14.3 | 244 | 858 |
| 7 | 4 | 1 | 502.4 | 14.0 | 314 | 249 |
| 8 | 4 | 1 | 567.2 | 15.8 | 274 | 289 |
| 9 | 5 | 1 | 1361.6 | 15.1 | 323 | 730 |
| 9 | 5 | 2 | 1300.8 | 14.5 | 325 | 692 |
| 10 | 5 | 1 | 1450.4 | 16.1 | 393 | 839 |
| 10 | 5 | 2 | 1469.6 | 16.3 | 392 | 829 |
| 11 | 6 | 1 | 2883.2 | 16.0 | 254 | 1765 |
| 11 | 6 | 2 | 2969.6 | 16.5 | 248 | 1802 |
| 11 | 6 | 3 | 2944.0 | 16.4 | 249 | 1835 |
| 11 | 6 | 4 | 2931.2 | 16.3 | 252 | 1787 |
| 11 | 6 | 5 | 2908.8 | 16.2 | 253 | 1854 |
| 12 | 6 | 1 | 2995.2 | 16.6 | 253 | 1687 |
| 12 | 6 | 2 | 3020.8 | 16.8 | 251 | 1622 |
| 13 | 7 | 1 | 554.4 | 11.1 | 578 | 366 |
| 14 | 7 | 1 | 688.4 | 13.8 | 790 | 409 |
| 15 | 8 | 1 | 1756.4 | 14.1 | 513 | 1212 |
| 15 | 8 | 2 | 1782.0 | 14.3 | 420 | 1162 |
| 16 | 8 | 1 | 1580.0 | 12.6 | 397 | 1015 |
| 16 | 8 | 2 | 1637.6 | 13.1 | 364 | 950 |
| 16 | 8 | 3 | 1605.6 | 12.8 | 368 | 930 |
| 16 | 8 | 4 | 1596.0 | 12.8 | 396 | 1025 |
| 17 | 9 | 1 | 3142.8 | 12.6 | 300 | 2125 |
| 18 | 9 | 1 | 1429.2 | 14.3 | 244 | 842 |
| 18 | 9 | 2 | 1368.4 | 13.7 | 249 | 814 |
| 19 | 10 | 1 | 1357.6 | 15.1 | 338 | 915 |
| 19 | 10 | 2 | 1367.2 | 15.2 | 331 | 756 |
| 20 | 10 | 1 | 1422.4 | 15.8 | 459 | 1004 |
| 20 | 10 | 2 | 1371.2 | 15.2 | 460 | 830 |
| 21 | 11 | 1 | 3046.0 | 13.5 | 289 | 1921 |
| 21 | 11 | 2 | 3071.6 | 13.7 | 276 | 1990 |
| 22 | 11 | 1 | 3320.4 | 14.8 | 376 | 2170 |
| 22 | 11 | 2 | 3374.8 | 15.0 | 362 | 2204 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 22 | 11 | 3 | 3342.8 | 14.9 | 368 | 2187 |
| 23 | 12 | 1 | 6896.8 | 15.3 | 277 | 4656 |
| 23 | 12 | 2 | 6992.8 | 15.5 | 250 | 4643 |
| 23 | 12 | 3 | 6912.8 | 15.4 | 263 | 4505 |
| 23 | 12 | 4 | 6951.2 | 15.4 | 252 | 4617 |
| 24 | 12 | 1 | 6894.4 | 15.3 | 240 | 4424 |
| 24 | 12 | 2 | 6801.6 | 15.1 | 309 | 4616 |
| 24 | 12 | 3 | 6884.8 | 15.3 | 297 | 4710 |
| 24 | 12 | 4 | 6849.6 | 15.2 | 299 | 4552 |
| 25 | 13 | 1 | 1392.4 | 13.9 | 554 | 957 |
| 25 | 13 | 2 | 1357.2 | 13.6 | 556 | 888 |
| 26 | 13 | 1 | 1316.0 | 13.2 | 460 | 894 |
| 27 | 14 | 1 | 3488.0 | 14.0 | 370 | 2383 |
| 27 | 14 | 2 | 3510.4 | 14.0 | 366 | 2397 |
| 28 | 14 | 1 | 3389.2 | 13.6 | 438 | 2262 |
| 28 | 14 | 2 | 3491.6 | 14.0 | 360 | 2285 |
| 28 | 14 | 3 | 3488.4 | 14.0 | 418 | 2334 |
| 28 | 14 | 4 | 3440.4 | 13.8 | 423 | 2264 |
| 28 | 14 | 5 | 3418.0 | 13.7 | 434 | 2328 |
| 28 | 14 | 6 | 3427.6 | 13.7 | 430 | 2168 |
| 28 | 14 | 7 | 3437.2 | 13.7 | 425 | 2290 |
| 29 | 15 | 1 | 7126.4 | 14.3 | 300 | 4829 |
| 29 | 15 | 2 | 7110.4 | 14.2 | 358 | 4851 |
| 30 | 15 | 1 | 6913.6 | 13.8 | 333 | 4597 |
| 31 | 16 | 1 | 2474.4 | 13.7 | 315 | 1707 |
| 32 | 16 | 1 | 2796.0 | 15.5 | 360 | 1882 |
| 33 | 17 | 1 | 6474.4 | 14.4 | 256 | 4218 |
| 33 | 17 | 2 | 6493.6 | 14.4 | 255 | 4230 |
| 34 | 17 | 1 | 7252.8 | 16.1 | 180 | 5109 |
| 34 | 17 | 2 | 7233.6 | 16.1 | 231 | 5097 |
| 35 | 18 | 1 | 13562.4 | 15.1 | 180 | 8925 |
| 35 | 18 | 2 | 13447.2 | 14.9 | 287 | 9053 |
| 35 | 18 | 3 | 13524.0 | 15.0 | 234 | 8879 |
| 35 | 18 | 4 | 13482.4 | 15.0 | 277 | 9144 |
| 35 | 18 | 5 | 13485.6 | 15.0 | 250 | 8644 |
| 35 | 18 | 6 | 13520.8 | 15.0 | 249 | 8964 |
| 36 | 18 | 1 | 13000.0 | 14.4 | 279 | 8462 |
| 36 | 18 | 2 | 13038.4 | 14.5 | 249 | 8637 |
| 36 | 18 | 3 | 13019.2 | 14.5 | 278 | 8527 |
| 36 | 18 | 4 | 13022.4 | 14.5 | 250 | 8659 |

## Appendix M: Results Table Scenario III

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 874.0 | 43.7 | 225 | 507 |
| 1 | 1 | 2 | 334.0 | 16.7 | 624 | 192 |
| 1 | 1 | 3 | 579.6 | 29.0 | 258 | 362 |
| 2 | 1 | 1 | 909.2 | 45.5 | 252 | 622 |
| 2 | 1 | 2 | 297.2 | 14.9 | 601 | 178 |
| 2 | 1 | 3 | 554.0 | 27.7 | 366 | 368 |
| 3 | 2 | 1 | 722.8 | 14.5 | 286 | 339 |
| 3 | 2 | 2 | 973.2 | 19.5 | 164 | 511 |
| 3 | 2 | 3 | 957.2 | 19.1 | 215 | 535 |
| 4 | 2 | 1 | 1078.8 | 21.6 | 212 | 538 |
| 4 | 2 | 2 | 834.0 | 16.7 | 458 | 498 |
| 5 | 3 | 1 | 1486.8 | 14.9 | 290 | 919 |
| 5 | 3 | 2 | 1907.6 | 19.1 | 167 | 1158 |
| 5 | 3 | 3 | 1785.2 | 17.9 | 189 | 1056 |
| 5 | 3 | 4 | 1872.4 | 18.7 | 174 | 1121 |
| 6 | 3 | 1 | 1829.2 | 18.3 | 157 | 1212 |
| 6 | 3 | 2 | 1410.0 | 14.1 | 292 | 783 |
| 6 | 3 | 3 | 1429.2 | 14.3 | 273 | 925 |
| 6 | 3 | 4 | 1675.6 | 16.8 | 196 | 958 |
| 6 | 3 | 5 | 1694.8 | 16.9 | 180 | 1100 |
| 6 | 3 | 6 | 1810.0 | 18.1 | 172 | 1070 |
| 7 | 4 | 1 | 502.4 | 14.0 | 424 | 284 |
| 7 | 4 | 2 | 1065.6 | 29.6 | 246 | 613 |
| 7 | 4 | 3 | 745.6 | 20.7 | 278 | 458 |
| 8 | 4 | 1 | 567.2 | 15.8 | 295 | 308 |
| 8 | 4 | 2 | 1006.4 | 28.0 | 224 | 574 |
| 8 | 4 | 3 | 694.4 | 19.3 | 293 | 356 |
| 8 | 4 | 4 | 879.2 | 24.4 | 225 | 526 |
| 9 | 5 | 1 | 1614.4 | 17.9 | 215 | 940 |
| 9 | 5 | 2 | 1300.8 | 14.5 | 368 | 845 |
| 9 | 5 | 3 | 1505.6 | 16.7 | 247 | 893 |
| 9 | 5 | 4 | 1361.6 | 15.1 | 360 | 789 |
| 9 | 5 | 5 | 1553.6 | 17.3 | 218 | 902 |
| 10 | 5 | 1 | 1669.6 | 18.6 | 239 | 943 |
| 10 | 5 | 2 | 1450.4 | 16.1 | 384 | 870 |
| 10 | 5 | 3 | 1548.8 | 17.2 | 271 | 924 |
| 10 | 5 | 4 | 1600.0 | 17.8 | 255 | 885 |
| 10 | 5 | 5 | 1568.0 | 17.4 | 270 | 936 |
| 11 | 6 | 1 | 2883.2 | 16.0 | 283 | 1970 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 11 | 6 | 2 | 3169.6 | 17.6 | 267 | 2124 |
| 11 | 6 | 3 | 3084.0 | 17.1 | 276 | 2058 |
| 11 | 6 | 4 | 2908.8 | 16.2 | 282 | 1936 |
| 11 | 6 | 5 | 3109.6 | 17.3 | 274 | 2033 |
| 11 | 6 | 6 | 3144.0 | 17.5 | 268 | 2108 |
| 12 | 6 | 1 | 2995.2 | 16.6 | 271 | 1968 |
| 13 | 7 | 1 | 554.4 | 11.1 | 578 | 366 |
| 13 | 7 | 2 | 1601.6 | 32.0 | 310 | 1037 |
| 13 | 7 | 3 | 1287.2 | 25.7 | 361 | 815 |
| 13 | 7 | 4 | 768.0 | 15.4 | 523 | 508 |
| 13 | 7 | 5 | 1032.0 | 20.6 | 415 | 623 |
| 13 | 7 | 6 | 818.4 | 16.4 | 470 | 521 |
| 13 | 7 | 7 | 1023.2 | 20.5 | 469 | 700 |
| 14 | 7 | 1 | 688.4 | 13.8 | 792 | 479 |
| 14 | 7 | 2 | 1809.2 | 36.2 | 287 | 1012 |
| 14 | 7 | 3 | 851.6 | 17.0 | 566 | 601 |
| 14 | 7 | 4 | 1218.0 | 24.4 | 372 | 740 |
| 14 | 7 | 5 | 1411.6 | 28.2 | 341 | 798 |
| 14 | 7 | 6 | 1510.0 | 30.2 | 314 | 798 |
| 14 | 7 | 7 | 1119.6 | 22.4 | 400 | 779 |
| 14 | 7 | 8 | 1094.0 | 21.9 | 486 | 601 |
| 14 | 7 | 9 | 1710.8 | 34.2 | 288 | 1012 |
| 14 | 7 | 10 | 950.0 | 19.0 | 538 | 601 |
| 14 | 7 | 11 | 995.6 | 19.9 | 514 | 601 |
| 15 | 8 | 1 | 2966.8 | 23.7 | 240 | 1977 |
| 15 | 8 | 2 | 1756.4 | 14.1 | 513 | 1212 |
| 15 | 8 | 3 | 2941.2 | 23.5 | 297 | 1993 |
| 15 | 8 | 4 | 2458.0 | 19.7 | 349 | 1637 |
| 15 | 8 | 5 | 2483.6 | 19.9 | 300 | 1653 |
| 15 | 8 | 6 | 2174.8 | 17.4 | 399 | 1433 |
| 15 | 8 | 7 | 1941.2 | 15.5 | 453 | 1257 |
| 15 | 8 | 8 | 2149.2 | 17.2 | 402 | 1417 |
| 15 | 8 | 9 | 1782.0 | 14.3 | 507 | 1205 |
| 15 | 8 | 10 | 1915.6 | 15.3 | 457 | 1307 |
| 16 | 8 | 1 | 1580.0 | 12.6 | 432 | 1079 |
| 16 | 8 | 2 | 2892.8 | 23.1 | 180 | 1932 |
| 16 | 8 | 3 | 2560.8 | 20.5 | 232 | 1684 |
| 16 | 8 | 4 | 1605.6 | 12.8 | 424 | 1095 |
| 16 | 8 | 5 | 1820.8 | 14.6 | 391 | 1237 |
| 16 | 8 | 6 | 2410.4 | 19.3 | 279 | 1599 |
| 16 | 8 | 7 | 2436.0 | 19.5 | 240 | 1615 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 16 | 8 | 8 | 1912.0 | 15.3 | 364 | 1220 |
| 16 | 8 | 9 | 1975.2 | 15.8 | 331 | 1313 |
| 16 | 8 | 10 | 2152.8 | 17.2 | 325 | 1362 |
| 16 | 8 | 11 | 2000.8 | 16.0 | 328 | 1294 |
| 16 | 8 | 12 | 2188.8 | 17.5 | 316 | 1392 |
| 16 | 8 | 13 | 2216.0 | 17.7 | 290 | 1420 |
| 16 | 8 | 14 | 2277.6 | 18.2 | 280 | 1482 |
| 16 | 8 | 15 | 2535.2 | 20.3 | 233 | 1668 |
| 16 | 8 | 16 | 1846.4 | 14.8 | 383 | 1253 |
| 16 | 8 | 17 | 2163.2 | 17.3 | 317 | 1376 |
| 16 | 8 | 18 | 2252.0 | 18.0 | 281 | 1450 |
| 16 | 8 | 19 | 1856.8 | 14.9 | 380 | 1267 |
| 16 | 8 | 20 | 2241.6 | 17.9 | 289 | 1452 |
| 16 | 8 | 21 | 1886.4 | 15.1 | 370 | 1239 |
| 16 | 8 | 22 | 1882.4 | 15.1 | 374 | 1283 |
| 17 | 9 | 1 | 4242.8 | 17.0 | 240 | 2846 |
| 17 | 9 | 2 | 3142.8 | 12.6 | 392 | 2059 |
| 17 | 9 | 3 | 3504.4 | 14.0 | 300 | 2335 |
| 17 | 9 | 4 | 3491.6 | 14.0 | 348 | 2327 |
| 17 | 9 | 5 | 3289.2 | 13.2 | 378 | 2105 |
| 17 | 9 | 6 | 3459.6 | 13.8 | 349 | 2307 |
| 17 | 9 | 7 | 3371.6 | 13.5 | 369 | 2227 |
| 17 | 9 | 8 | 3174.8 | 12.7 | 391 | 2079 |
| 17 | 9 | 9 | 3339.6 | 13.4 | 370 | 2207 |
| 18 | 9 | 1 | 3306.4 | 13.2 | 399 | 2151 |
| 18 | 9 | 2 | 4338.4 | 17.4 | 240 | 2801 |
| 18 | 9 | 3 | 3582.4 | 14.3 | 377 | 2327 |
| 18 | 9 | 4 | 4233.6 | 16.9 | 299 | 2727 |
| 18 | 9 | 5 | 3731.2 | 14.9 | 346 | 2451 |
| 18 | 9 | 6 | 4005.6 | 16.0 | 320 | 2561 |
| 18 | 9 | 7 | 3656.8 | 14.6 | 351 | 2341 |
| 18 | 9 | 8 | 4080.0 | 16.3 | 315 | 2671 |
| 18 | 9 | 9 | 4159.2 | 16.6 | 304 | 2713 |
| 19 | 10 | 1 | 1357.6 | 15.1 | 338 | 915 |
| 19 | 10 | 2 | 1636.8 | 18.2 | 252 | 1044 |
| 20 | 10 | 1 | 1406.4 | 15.6 | 502 | 976 |
| 20 | 10 | 2 | 2647.2 | 29.4 | 226 | 1706 |
| 20 | 10 | 3 | 2286.4 | 25.4 | 251 | 1446 |
| 20 | 10 | 4 | 2045.6 | 22.7 | 302 | 1342 |
| 20 | 10 | 5 | 1422.4 | 15.8 | 476 | 986 |
| 20 | 10 | 6 | 1836.8 | 20.4 | 357 | 1182 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 20 | 10 | 7 | 1951.2 | 21.7 | 311 | 1212 |
| 20 | 10 | 8 | 1552.8 | 17.3 | 420 | 980 |
| 20 | 10 | 9 | 1710.4 | 19.0 | 369 | 1126 |
| 20 | 10 | 10 | 1517.6 | 16.9 | 421 | 958 |
| 20 | 10 | 11 | 1726.4 | 19.2 | 365 | 1118 |
| 21 | 11 | 1 | 3046.0 | 13.5 | 358 | 2057 |
| 21 | 11 | 2 | 5442.8 | 24.2 | 240 | 3738 |
| 21 | 11 | 3 | 4886.0 | 21.7 | 262 | 3274 |
| 21 | 11 | 4 | 3106.8 | 13.8 | 356 | 2095 |
| 21 | 11 | 5 | 3314.0 | 14.7 | 339 | 2209 |
| 21 | 11 | 6 | 4589.2 | 20.4 | 274 | 3112 |
| 21 | 11 | 7 | 4763.6 | 21.2 | 268 | 3172 |
| 21 | 11 | 8 | 4241.2 | 18.8 | 291 | 2831 |
| 21 | 11 | 9 | 4466.8 | 19.9 | 280 | 3010 |
| 21 | 11 | 10 | 4128.4 | 18.3 | 297 | 2763 |
| 21 | 11 | 11 | 4039.6 | 18.0 | 303 | 2711 |
| 21 | 11 | 12 | 3881.2 | 17.2 | 308 | 2585 |
| 21 | 11 | 13 | 3609.2 | 16.0 | 328 | 2384 |
| 21 | 11 | 14 | 3463.6 | 15.4 | 332 | 2238 |
| 21 | 11 | 15 | 3698.0 | 16.4 | 321 | 2410 |
| 21 | 11 | 16 | 4354.0 | 19.4 | 286 | 2916 |
| 21 | 11 | 17 | 3731.6 | 16.6 | 315 | 2495 |
| 21 | 11 | 18 | 4363.6 | 19.4 | 285 | 2959 |
| 21 | 11 | 19 | 3670.0 | 16.3 | 326 | 2457 |
| 21 | 11 | 20 | 3820.4 | 17.0 | 309 | 2486 |
| 21 | 11 | 21 | 3374.8 | 15.0 | 338 | 2212 |
| 21 | 11 | 22 | 3402.8 | 15.1 | 333 | 2235 |
| 21 | 11 | 23 | 3792.4 | 16.9 | 314 | 2524 |
| 21 | 11 | 24 | 4100.4 | 18.2 | 302 | 2775 |
| 22 | 11 | 1 | 4910.0 | 21.8 | 257 | 3241 |
| 22 | 11 | 2 | 3374.8 | 15.0 | 453 | 2193 |
| 22 | 11 | 3 | 3930.0 | 17.5 | 300 | 2589 |
| 22 | 11 | 4 | 3907.6 | 17.4 | 346 | 2575 |
| 22 | 11 | 5 | 3564.4 | 15.8 | 419 | 2323 |
| 22 | 11 | 6 | 4394.8 | 19.5 | 299 | 2860 |
| 22 | 11 | 7 | 3674.8 | 16.3 | 373 | 2415 |
| 22 | 11 | 8 | 3874.8 | 17.2 | 367 | 2543 |
| 22 | 11 | 9 | 3619.6 | 16.1 | 395 | 2369 |
| 22 | 11 | 10 | 4814.0 | 21.4 | 263 | 3161 |
| 22 | 11 | 11 | 3606.0 | 16.0 | 417 | 2349 |
| 22 | 11 | 12 | 4706.0 | 20.9 | 275 | 3071 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 22 | 11 | 13 | 4580.4 | 20.4 | 280 | 2995 |
| 22 | 11 | 14 | 4758.8 | 21.2 | 269 | 3130 |
| 22 | 11 | 15 | 4417.2 | 19.6 | 297 | 2874 |
| 22 | 11 | 16 | 4450.0 | 19.8 | 293 | 2891 |
| 22 | 11 | 17 | 4525.2 | 20.1 | 286 | 2964 |
| 22 | 11 | 18 | 4558.0 | 20.3 | 281 | 2981 |
| 22 | 11 | 19 | 4472.4 | 19.9 | 291 | 2905 |
| 22 | 11 | 20 | 4728.4 | 21.0 | 274 | 3085 |
| 22 | 11 | 21 | 4502.8 | 20.0 | 287 | 2950 |
| 23 | 12 | 1 | 7376.0 | 16.4 | 314 | 4821 |
| 23 | 12 | 2 | 7529.6 | 16.7 | 240 | 4949 |
| 23 | 12 | 3 | 7492.8 | 16.7 | 301 | 4915 |
| 23 | 12 | 4 | 7426.4 | 16.5 | 305 | 4863 |
| 23 | 12 | 5 | 7392.0 | 16.4 | 313 | 4831 |
| 23 | 12 | 6 | 7476.8 | 16.6 | 302 | 4905 |
| 23 | 12 | 7 | 7442.4 | 16.5 | 304 | 4873 |
| 24 | 12 | 1 | 10855.2 | 24.1 | 299 | 7375 |
| 24 | 12 | 2 | 8505.6 | 18.9 | 368 | 5578 |
| 24 | 12 | 3 | 8721.6 | 19.4 | 300 | 5675 |
| 24 | 12 | 4 | 8705.6 | 19.3 | 348 | 5665 |
| 24 | 12 | 5 | 8668.8 | 19.3 | 354 | 5679 |
| 24 | 12 | 6 | 8552.0 | 19.0 | 365 | 5537 |
| 24 | 12 | 7 | 8568.0 | 19.0 | 359 | 5630 |
| 24 | 12 | 8 | 8604.8 | 19.1 | 356 | 5592 |
| 25 | 13 | 1 | 3078.8 | 30.8 | 273 | 2167 |
| 25 | 13 | 2 | 1357.2 | 13.6 | 556 | 888 |
| 25 | 13 | 3 | 1965.2 | 19.7 | 380 | 1286 |
| 25 | 13 | 4 | 1748.4 | 17.5 | 421 | 1134 |
| 25 | 13 | 5 | 2199.6 | 22.0 | 340 | 1413 |
| 25 | 13 | 6 | 2846.8 | 28.5 | 287 | 1920 |
| 25 | 13 | 7 | 2749.2 | 27.5 | 300 | 1868 |
| 25 | 13 | 8 | 2431.6 | 24.3 | 326 | 1707 |
| 25 | 13 | 9 | 2197.2 | 22.0 | 370 | 1533 |
| 25 | 13 | 10 | 2517.2 | 25.2 | 313 | 1690 |
| 25 | 13 | 11 | 1392.4 | 13.9 | 554 | 910 |
| 25 | 13 | 12 | 1506.0 | 15.1 | 503 | 990 |
| 25 | 13 | 13 | 1722.8 | 17.2 | 475 | 1142 |
| 25 | 13 | 14 | 1541.2 | 15.4 | 502 | 1012 |
| 25 | 13 | 15 | 1740.4 | 17.4 | 462 | 1164 |
| 26 | 13 | 1 | 1316.0 | 13.2 | 462 | 894 |
| 26 | 13 | 2 | 2621.6 | 26.2 | 279 | 1846 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 26 | 13 | 3 | 2276.8 | 22.8 | 304 | 1602 |
| 26 | 13 | 4 | 1787.2 | 17.9 | 357 | 1238 |
| 26 | 13 | 5 | 1634.4 | 16.3 | 383 | 1130 |
| 26 | 13 | 6 | 2012.0 | 20.1 | 331 | 1404 |
| 26 | 13 | 7 | 2052.0 | 20.5 | 330 | 1436 |
| 26 | 13 | 8 | 1428.8 | 14.3 | 438 | 972 |
| 26 | 13 | 9 | 1581.6 | 15.8 | 409 | 1080 |
| 26 | 13 | 10 | 1521.6 | 15.2 | 412 | 1052 |
| 26 | 13 | 11 | 1468.8 | 14.7 | 434 | 1002 |
| 27 | 14 | 1 | 4698.4 | 18.8 | 240 | 3207 |
| 27 | 14 | 2 | 3488.0 | 14.0 | 404 | 2300 |
| 27 | 14 | 3 | 3657.6 | 14.6 | 300 | 2443 |
| 27 | 14 | 4 | 4588.0 | 18.4 | 297 | 3176 |
| 27 | 14 | 5 | 3654.4 | 14.6 | 375 | 2433 |
| 27 | 14 | 6 | 4652.8 | 18.6 | 291 | 3230 |
| 27 | 14 | 7 | 3523.2 | 14.1 | 403 | 2322 |
| 27 | 14 | 8 | 3619.2 | 14.5 | 376 | 2411 |
| 28 | 14 | 1 | 6414.0 | 25.7 | 300 | 4342 |
| 28 | 14 | 2 | 4377.2 | 17.5 | 548 | 2461 |
| 28 | 14 | 3 | 4687.6 | 18.8 | 543 | 2685 |
| 28 | 14 | 4 | 4809.2 | 19.2 | 335 | 3173 |
| 28 | 14 | 5 | 5313.2 | 21.3 | 302 | 3527 |
| 28 | 14 | 6 | 4907.6 | 19.6 | 324 | 3255 |
| 28 | 14 | 7 | 5169.2 | 20.7 | 307 | 3470 |
| 28 | 14 | 8 | 5070.8 | 20.3 | 318 | 3388 |
| 28 | 14 | 9 | 5051.6 | 20.2 | 319 | 3246 |
| 29 | 15 | 1 | 9440.0 | 18.9 | 500 | 5624 |
| 29 | 15 | 2 | 13630.4 | 27.3 | 321 | 9400 |
| 29 | 15 | 3 | 11412.8 | 22.8 | 420 | 6984 |
| 29 | 15 | 4 | 13387.2 | 26.8 | 337 | 9389 |
| 29 | 15 | 5 | 11118.4 | 22.2 | 434 | 6955 |
| 29 | 15 | 6 | 9871.2 | 19.7 | 466 | 6072 |
| 29 | 15 | 7 | 9804.0 | 19.6 | 488 | 5878 |
| 29 | 15 | 8 | 10149.6 | 20.3 | 455 | 6229 |
| 29 | 15 | 9 | 13540.8 | 27.1 | 328 | 9554 |
| 29 | 15 | 10 | 9718.4 | 19.4 | 497 | 5820 |
| 29 | 15 | 11 | 10601.6 | 21.2 | 439 | 6589 |
| 29 | 15 | 12 | 10255.2 | 20.5 | 445 | 6317 |
| 29 | 15 | 13 | 10008.0 | 20.0 | 461 | 6186 |
| 29 | 15 | 14 | 10392.0 | 20.8 | 442 | 6431 |
| 29 | 15 | 15 | 10865.6 | 21.7 | 436 | 6787 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 29 | 15 | 16 | 10854.4 | 21.7 | 437 | 6757 |
| 29 | 15 | 17 | 9775.2 | 19.6 | 489 | 5860 |
| 30 | 15 | 1 | 11641.6 | 23.3 | 283 | 8105 |
| 30 | 15 | 2 | 8016.0 | 16.0 | 483 | 5301 |
| 30 | 15 | 3 | 8952.8 | 17.9 | 379 | 6282 |
| 30 | 15 | 4 | 9024.8 | 18.0 | 365 | 6322 |
| 30 | 15 | 5 | 8776.0 | 17.6 | 406 | 6142 |
| 30 | 15 | 6 | 8656.0 | 17.3 | 419 | 6052 |
| 30 | 15 | 7 | 9336.8 | 18.7 | 357 | 6536 |
| 30 | 15 | 8 | 9375.2 | 18.8 | 347 | 6568 |
| 30 | 15 | 9 | 8344.0 | 16.7 | 460 | 5577 |
| 30 | 15 | 10 | 8592.8 | 17.2 | 441 | 6009 |
| 30 | 15 | 11 | 11321.6 | 22.6 | 285 | 7883 |
| 30 | 15 | 12 | 10584.8 | 21.2 | 309 | 7490 |
| 30 | 15 | 13 | 10236.8 | 20.5 | 325 | 7200 |
| 30 | 15 | 14 | 11024.0 | 22.0 | 293 | 7635 |
| 30 | 15 | 15 | 10448.0 | 20.9 | 316 | 7376 |
| 30 | 15 | 16 | 9937.6 | 19.9 | 330 | 6996 |
| 30 | 15 | 17 | 9712.0 | 19.4 | 346 | 6808 |
| 30 | 15 | 18 | 10882.4 | 21.8 | 300 | 7587 |
| 30 | 15 | 19 | 10740.8 | 21.5 | 303 | 7532 |
| 30 | 15 | 20 | 11180.0 | 22.4 | 288 | 7765 |
| 30 | 15 | 21 | 8456.8 | 16.9 | 454 | 5901 |
| 30 | 15 | 22 | 8238.4 | 16.5 | 473 | 5489 |
| 30 | 15 | 23 | 8190.4 | 16.4 | 475 | 5459 |
| 30 | 15 | 24 | 10311.2 | 20.6 | 322 | 7262 |
| 30 | 15 | 25 | 8728.0 | 17.5 | 408 | 6112 |
| 30 | 15 | 26 | 9750.4 | 19.5 | 341 | 6840 |
| 30 | 15 | 27 | 9824.8 | 19.6 | 335 | 6902 |
| 30 | 15 | 28 | 8528.8 | 17.1 | 446 | 5961 |
| 30 | 15 | 29 | 9863.2 | 19.7 | 332 | 6934 |
| 30 | 15 | 30 | 8567.2 | 17.1 | 445 | 5993 |
| 31 | 16 | 1 | 4224.8 | 23.5 | 229 | 2944 |
| 31 | 16 | 2 | 2474.4 | 13.7 | 333 | 1667 |
| 31 | 16 | 3 | 3878.4 | 21.5 | 231 | 2752 |
| 31 | 16 | 4 | 3760.8 | 20.9 | 239 | 2654 |
| 31 | 16 | 5 | 3536.8 | 19.6 | 246 | 2458 |
| 31 | 16 | 6 | 3419.2 | 19.0 | 253 | 2412 |
| 31 | 16 | 7 | 3224.0 | 17.9 | 260 | 2282 |
| 31 | 16 | 8 | 2654.4 | 14.7 | 318 | 1789 |
| 31 | 16 | 9 | 3044.0 | 16.9 | 275 | 2103 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 31 | 16 | 10 | 3106.4 | 17.3 | 267 | 2087 |
| 31 | 16 | 11 | 2738.4 | 15.2 | 304 | 1920 |
| 31 | 16 | 12 | 2842.4 | 15.8 | 298 | 1879 |
| 31 | 16 | 13 | 2926.4 | 16.3 | 283 | 2005 |
| 31 | 16 | 14 | 2918.4 | 16.2 | 290 | 1990 |
| 31 | 16 | 15 | 2662.4 | 14.8 | 313 | 1809 |
| 32 | 16 | 1 | 4452.8 | 24.7 | 240 | 2988 |
| 32 | 16 | 2 | 2796.0 | 15.5 | 459 | 1858 |
| 32 | 16 | 3 | 3464.0 | 19.2 | 300 | 2305 |
| 32 | 16 | 4 | 3019.2 | 16.8 | 432 | 2030 |
| 32 | 16 | 5 | 3975.2 | 22.1 | 297 | 2699 |
| 32 | 16 | 6 | 3109.6 | 17.3 | 384 | 2080 |
| 32 | 16 | 7 | 4371.2 | 24.3 | 273 | 2959 |
| 32 | 16 | 8 | 2860.0 | 15.9 | 447 | 1926 |
| 32 | 16 | 9 | 4223.2 | 23.5 | 281 | 2916 |
| 32 | 16 | 10 | 3457.6 | 19.2 | 337 | 2340 |
| 32 | 16 | 11 | 4098.4 | 22.8 | 289 | 2771 |
| 32 | 16 | 12 | 3332.8 | 18.5 | 353 | 2252 |
| 32 | 16 | 13 | 3400.0 | 18.9 | 342 | 2291 |
| 32 | 16 | 14 | 3176.8 | 17.6 | 373 | 2093 |
| 32 | 16 | 15 | 3275.2 | 18.2 | 359 | 2203 |
| 32 | 16 | 16 | 3234.4 | 18.0 | 368 | 2168 |
| 33 | 17 | 1 | 9489.6 | 21.1 | 281 | 6401 |
| 33 | 17 | 2 | 11081.6 | 24.6 | 240 | 7635 |
| 33 | 17 | 3 | 10324.8 | 22.9 | 263 | 7058 |
| 33 | 17 | 4 | 10178.4 | 22.6 | 266 | 6936 |
| 33 | 17 | 5 | 9571.2 | 21.3 | 278 | 6469 |
| 33 | 17 | 6 | 9895.2 | 22.0 | 271 | 6739 |
| 33 | 17 | 7 | 10032.0 | 22.3 | 269 | 6814 |
| 33 | 17 | 8 | 10041.6 | 22.3 | 268 | 6861 |
| 33 | 17 | 9 | 9758.4 | 21.7 | 274 | 6625 |
| 33 | 17 | 10 | 9652.8 | 21.5 | 277 | 6537 |
| 33 | 17 | 11 | 9854.4 | 21.9 | 272 | 6705 |
| 33 | 17 | 12 | 9708.0 | 21.6 | 275 | 6583 |
| 34 | 17 | 1 | 9878.4 | 22.0 | 515 | 5694 |
| 34 | 17 | 2 | 11717.6 | 26.0 | 240 | 8116 |
| 34 | 17 | 3 | 11345.6 | 25.2 | 286 | 7806 |
| 34 | 17 | 4 | 10716.0 | 23.8 | 456 | 6320 |
| 34 | 17 | 5 | 9919.2 | 22.0 | 480 | 5612 |
| 34 | 17 | 6 | 10176.0 | 22.6 | 475 | 5912 |
| 34 | 17 | 7 | 10264.8 | 22.8 | 466 | 5986 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 34 | 17 | 8 | 10429.6 | 23.2 | 465 | 6106 |
| 34 | 17 | 9 | 10448.8 | 23.2 | 462 | 6118 |
| 34 | 17 | 10 | 10584.8 | 23.5 | 460 | 6220 |
| 34 | 17 | 11 | 10591.2 | 23.5 | 459 | 6216 |
| 34 | 17 | 12 | 10221.6 | 22.7 | 468 | 5950 |
| 35 | 18 | 1 | 17616.0 | 19.6 | 289 | 11912 |
| 35 | 18 | 2 | 20116.8 | 22.4 | 240 | 14153 |
| 35 | 18 | 3 | 19075.2 | 21.2 | 268 | 13068 |
| 35 | 18 | 4 | 18794.4 | 20.9 | 269 | 12834 |
| 35 | 18 | 5 | 18480.0 | 20.5 | 272 | 12572 |
| 35 | 18 | 6 | 18588.0 | 20.7 | 271 | 12662 |
| 35 | 18 | 7 | 18686.4 | 20.8 | 270 | 12744 |
| 35 | 18 | 8 | 18295.2 | 20.3 | 274 | 12418 |
| 35 | 18 | 9 | 18372.0 | 20.4 | 273 | 12482 |
| 35 | 18 | 10 | 17692.8 | 19.7 | 286 | 11976 |
| 35 | 18 | 11 | 18187.2 | 20.2 | 275 | 12328 |
| 35 | 18 | 12 | 17654.4 | 19.6 | 288 | 11944 |
| 35 | 18 | 13 | 18110.4 | 20.1 | 277 | 12246 |
| 35 | 18 | 14 | 18033.6 | 20.0 | 278 | 12200 |
| 35 | 18 | 15 | 17817.6 | 19.8 | 283 | 12080 |
| 35 | 18 | 16 | 17956.8 | 20.0 | 280 | 12178 |
| 35 | 18 | 17 | 17894.4 | 19.9 | 281 | 12144 |
| 35 | 18 | 18 | 17870.4 | 19.9 | 282 | 12124 |
| 35 | 18 | 19 | 18148.8 | 20.2 | 276 | 12356 |
| 35 | 18 | 20 | 17995.2 | 20.0 | 279 | 12228 |
| 35 | 18 | 21 | 17755.2 | 19.7 | 285 | 12028 |
| 35 | 18 | 22 | 17769.6 | 19.7 | 284 | 12040 |
| 36 | 18 | 1 | 22318.4 | 24.8 | 240 | 15932 |
| 36 | 18 | 2 | 17492.8 | 19.4 | 504 | 11904 |
| 36 | 18 | 3 | 21360.8 | 23.7 | 284 | 15167 |
| 36 | 18 | 4 | 17498.4 | 19.4 | 442 | 12180 |
| 36 | 18 | 5 | 20594.4 | 22.9 | 286 | 14600 |
| 36 | 18 | 6 | 18013.6 | 20.0 | 374 | 12485 |
| 36 | 18 | 7 | 19610.4 | 21.8 | 291 | 13711 |
| 36 | 18 | 8 | 18033.6 | 20.0 | 353 | 12605 |
| 36 | 18 | 9 | 18124.8 | 20.1 | 340 | 12731 |
| 36 | 18 | 10 | 20193.6 | 22.4 | 287 | 14266 |
| 36 | 18 | 11 | 18314.4 | 20.3 | 331 | 12778 |
| 36 | 18 | 12 | 19965.6 | 22.2 | 288 | 14112 |
| 36 | 18 | 13 | 17800.0 | 19.8 | 422 | 12453 |
| 36 | 18 | 14 | 17972.8 | 20.0 | 398 | 12511 |

| Instance No. | Set No. | Solution No. (Pareto Front) | Total Cost ($) | Mean Cost per Pallet ($) | Mean Lead-time (Min) | Total Travel Distance (Km) |
|---|---|---|---|---|---|---|
| 36 | 18 | 15 | 17898.4 | 19.9 | 402 | 12489 |
| 36 | 18 | 16 | 19192.8 | 21.3 | 293 | 13412 |
| 36 | 18 | 17 | 17651.2 | 19.6 | 434 | 12289 |
| 36 | 18 | 18 | 18472.8 | 20.5 | 323 | 12880 |
| 36 | 18 | 19 | 17671.2 | 19.6 | 425 | 12293 |
| 36 | 18 | 20 | 18782.4 | 20.9 | 302 | 13106 |
| 36 | 18 | 21 | 19010.4 | 21.1 | 296 | 13260 |
| 36 | 18 | 22 | 18710.4 | 20.8 | 308 | 13061 |
| 36 | 18 | 23 | 19101.6 | 21.2 | 295 | 13287 |
| 36 | 18 | 24 | 18662.4 | 20.7 | 314 | 13038 |
| 36 | 18 | 25 | 18571.2 | 20.6 | 317 | 12945 |
| 36 | 18 | 26 | 18880.8 | 21.0 | 298 | 13152 |
| 36 | 18 | 27 | 18520.8 | 20.6 | 319 | 12903 |
| 36 | 18 | 28 | 18873.6 | 21.0 | 301 | 13182 |