An Integrated Framework to Optimise Consolidating the Last Leg of Deliveries in the Inner-City

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Dedicated to

My late father Abdulrahman who instilled a love of learning in me,

My mother Aisha who always had confidence in me,

My wife Zainab who has been a beacon of light through this journey.

Declaration of Authorship

This is to certify that:

- The thesis comprises only my original work towards the PhD,
- Due acknowledgement has been made in the text to all other material used,
- The thesis is less than 100,000 words in length, exclusive of figures, tables, bibliographies and appendices.

Signed: Khalid Aljohani

Date: 28th April 2020

Abstract

Efficient and reliable freight delivery and pickup services are important for the functioning of retailers and businesses in the inner-city area as well as the consumption of products for residents, visitors and workers. Furthermore, the limited availability of affordable industrial land for logistics facilities and inefficient loading infrastructure in the inner-city coupled with the increasing demand for express and fragmented deliveries make it operationally difficult and economically cost-prohibitive for freight carriers to maintain offering reliable and low-cost delivery services to inner-city receivers.

Policymakers and transport researchers have considered freight consolidation delivery solutions to address negative externalities caused by growth in last mile deliveries. However, there has been an imbalance of focus in previous initiatives towards freight carriers, with far less emphasis placed on goods receivers. This is a critical oversight given that the success of consolidation schemes is inextricably linked to the willingness of receivers to accept and respond positively to the consolidation scheme. Moreover, the lack of focus on financial viability of consolidation solutions early in the planning process often results in making these schemes highly dependent on government incentives. Site selection of consolidation facilities is mainly evaluated using decision support models that are performed by numerical computations or multi-criteria analysis without inputs from spatial analysis. These issues and shortcomings of previous consolidation policies have adversely impacted their efficacy and suitability. An effective and properly planned consolidation policy could offer an alternative solution for freight carriers to cope with increasing activities of express deliveries in the highly congested inner-city.

Accordingly, the objective of this research is to develop an integrated framework to optimise the design and set-up of a suitable, sustainable and financially viable freight consolidation facility in the inner-city based on operational, social, environmental and economic objectives of all stakeholders. The integrated framework developed in this research consists of five stages. In the 1st stage (Chapter 4), direct insights from freight carriers describe their delivery trips specifically inside the inner-city and subsequently the proposed design of the consolidation facility incorporates operational requirements, sustainable freight land-use polies and business value propositions. Analysis of operational parameters from freight carriers revealed that their delivery trips in the inner-city include higher use of delivery vans, higher number of delivery stops and lower vehicle fill-in rate compared to deliveries in other parts of the urban area. Then, the 2nd stage (Chapter 5) applies a multi-stakeholder decision-support approach to evaluate the suitability of four consolidated delivery fleet configurations in addressing the requirements of six stakeholder groups involved in last mile delivery. The multi-criteria analysis of the alternatives is performed using the PROMETHEE method based on the priority weights of 30 decision criteria. The multi-actor analysis reveals that the combined use of battery-electric delivery vans and electricity-assisted cargobikes addresses the concerns of societal stakeholders and operational requirements of business stakeholders in a balanced approach. The mono-actor analysis of the alternatives underlines the clashing views of each stakeholder group regarding the optimal delivery fleet.

Moreover, the 3rd stage (Chapter 6) of the integrated framework applies econometric models to examine the willingness of receivers to request their freight carriers to transfer the parcels to the proposed consolidation facility for subsequent consolidated delivery to

their businesses. Behavioural responses were collected using a stated-preference survey from 255 retailers and businesses representing 13 different sub-industries in Melbourne CBD. The study findings reveal a general potential willingness to participate in the proposed consolidated delivery. The ordered logit model estimations illustrate that the receivers' willingness to participate is significantly influenced by the intensity of their delivery activities. Furthermore, the mixed logit model estimations highlight that the consolidated delivery time-window and availability of relevant value-added services hold the greatest potential to sway receivers' support or opposition to delivery consolidation. Subsequently, the 4th stage (Chapter 7) presents a GIS-based Multi-Criteria Decision-Making (GIS-MCDM) approach to locate and rank optimal sites for the proposed consolidation facility in the inner-city. Real geographic datasets from Inner Melbourne, Australia, are applied to identify 20 candidate sites using geoprocessing tools in ArcGIS that are then evaluated and ranked using the TOPSIS method based on 11 weighted decision criteria. The spatial suitability analysis confirms that the most suitable candidate sites are in zones with affordable industrial land with excellent accessibility to major roads and receivers. A sensitivity analysis was performed to examine the influence of changing the criteria weight on the stability of candidate sites' rankings and test the robustness of the process and the confidence in the outcomes.

Finally, the 5th stage (Chapter 8) presents a two-phase ex-ante profitability assessment approach to analyse the business case of the proposed consolidation policy in the upper-phase and a mixed integer linear programming model is formulated in the lower-phase to optimise the facility profitability. The holistic cost model incorporates a stochastic approach in the profitability estimation by accounting for the uncertainty of the interest of freight carriers to transfer their inner-city parcels to the consolidation facility. The genetic algorithm solution of the MILP model estimates that personnel costs contribute to the largest share of total costs and that the profit margin could be very tight. Unlike other studies in the literature that question the viability of a consolidation facility to be self-sustaining, this study provides evidence that these facilities could be profitable without government subsidies. Based on the optimisation solution, it is recommended that a successful consolidation facility should focus on i) ensuring a minimum daily throughput; ii) employing a strategy to effectively manage critical staffing resources – primarily drivers; iii) ensuring vehicle fill-in rates are optimised.

The data-adjusted decision-support framework presented in this thesis incorporates the freight industry operational requirements as well as social and environmental concerns to optimally and sustainability establish a suitable consolidation facility in the inner-city. The modelling results of the integrated framework enable decision-makers and transport researchers to not only apply value-decisions at the onset of the process, but also allow for understanding and visualisation of the results and of the importance of chosen criteria in the decision-making process. The findings of the econometric models provide valuable insights into the type and size of receivers that might be useful in formulating an effective consolidated delivery policy that is tailored for most willing receivers. The acquired knowledge from freight carriers facilitate an enhanced understanding and depict an accurate picture of the current state of the last leg of delivery in the inner-city. Hence, appropriate and practical solutions could be proposed to enhance the efficiency of freight carriers and alleviate the negative impacts of their operations in the inner-city area.

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List of Publications

The thesis is based on research outcomes published in the following places. I am the first author of all these publications, as I was the main researcher responsible for all sections of the published works including concept formation, development of numerical models, data analysis of the acquired results, as well as the composition of the manuscripts. My co-author (primary research supervisor: A/Prof Russell G. Thompson) has provided valuable guidance and feedback throughout the manuscript preparation.

Peer-reviewed Journal Articles

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List of Acronyms

AHP	Analytic Hierarchical Process
ANZSIC	Australian and New Zealand Standard Industrial Classification
B2B	Business-to-Business
B2C	Business-to-Consumer
BAU	Business-as-Usual
BEV	Battery Electric LCV
BMC	Business Model Canvas
C2C	Consumer-to-Consumer
CA	Continuous Approximation
CBD	Central Business District
CCCF	Central City Consolidation Facility
CEP	Couriers, Express and Parcel
CLUE	Census of Land Use and Employment
CO_2	Carbon Dioxide
CSS	Context Sensitive Solutions
DCE	Discrete Choice Experiment
DSP	Delivery Service Plan
ELECTRE	ELimination and Choice Expressing REality
F-AHP	Fuzzy Analytic Hierarchical Process
FDM	Freight Demand Management
GA	Genetic Algorithm
GIS	Geographic Information System
HoReCa	Hotel, Restaurants and Catering
LCV	Light Commercial Vehicle

LPP	Logistics Property Provider
LSP	Logistics Service Provider
MAMCA	Multi-Actor Multi-Criteria Analysis
MCDM	Multi-Criteria Decision Making
MILP	Mixed Integer Linear Programming
NIS	Negative Ideal Solution
NO_x	Nitrogen Oxides
OHD	Off-peak Hours Delivery
OLZ	On-street Loading Zone
PIS	Positive Ideal Solution
PQ	Product Quality & Quantity Check Serve
PR	Product Return Service
PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations
RLC	Receiver-led Delivery Consolidation
RT	Receiver time-specific delivery Service
SP Survey	Stated-Preference Survey
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TS	Temporary Storage Service
UCC	Urban Consolidation Centre
UN	Unpacking & Waste Removal Service
WTP	Willingness to Pay

Chapter 1.

Introduction

1.1. Background

1.1.1. Trends and Issues Impacting Last Mile Delivery

Over the last few decades, the urban freight industry has experienced significant changes due to various operational and socio-economic factors and trends (Cherrett et al. 2012; Visser et al. 2014). Recent trends and requirements such as online shopping, the increasing desire for speed in delivery, crowd logistics, omni-channel fulfilment and just-in-time strategies for low-inventories have impacted last mile delivery activities to receivers in urban areas (Savelsbergh and Van Woensel 2016; Ruesch et al. 2016; Cardenas et al. 2017a). These trends are increasing the number of express deliveries as well as causing fragmentation of shipments, i.e. receiving smaller parcels daily rather than a weekly consolidated delivery (Dablanc and Rodrigue 2014; Cepolina and Farina 2015; Lagorio et al. 2016a). This situation has resulted in increasing the movements and frequency of freight vehicles in urban areas as well as the complexity and transportation cost of their delivery activities (Melo and Baptista 2017; Kin et al. 2017). Allen et al. (2017) and Bates et al. (2018a) caution that these trends and challenges are adversely impacting the ability of freight carriers to balance between managing a profitable business in the low-margin and highly competitive urban freight industry and consumers' desire for cheap and express delivery. This problem is further complicated by consumers refusing to pay for the extra cost for the express delivery (Savelsbergh and Van Woensel 2016). Consequently, the increasing number of freight vehicle movements contribute to adverse environmental conditions and negative social impacts on society and the urban environment including air pollution, noise, congestion and exacerbated road safety problems (Browne et al. 2012).

1.1.2. Operational Issues of Last Mile Delivery in the Inner-City Area

Freight deliveries and pickup activities within the inner-city area are very complex due to the varied nature of freight demand, the physical structure of the area as well as the sensitive surrounding uses and heavy pedestrian traffic (Thompson and Flores 2016; Eidhammer et al. 2016; Antún et al. 2018). Visser et al. (2017) underline the increasing use of light commercial vehicles (LCVs) in the congested inner-city area due to trucks bans and limited parking spaces as well as LCVs' improved operational efficiency and costs compared to trucks. Freight carriers are increasingly using LCVs to perform delivery activities to receivers in this area. Furthermore, the extremely diverse mix of commercial receivers and residents in the inner-city area require different and sometimes conflicting types, size and frequency of deliveries. Due to these complexities, freight vehicles are forced to perform a large number of stops to fulfil these delivery requirements. For example, Allen et al. (2018a) highlight that a parcel delivery van

usually performs on average 37 stops to deliver 118 items to 72 customers per delivery round in central London.

Freight carriers, receivers and citizens in the inner-city area suffer considerably from issues impacting last mile delivery. These problems are many and include (1) limited and inefficient on-street parking and loading infrastructure, (2) traffic movement which is congested with a high mix of passenger vehicles and cyclists, (3) poor accessibility of streets in the city centre with large concentrations of pedestrianised zones, and (4) lack of off-street loading facilities (Jaller et al. 2013; Verlinde et al. 2014; Marcucci et al. 2015). The results of these problems are also many and include (1) deteriorating travel time (2) increasingly complicated freight deliveries, (3) the inability of freight carriers to meet the time requirements of their deliveries, and (4) rising distribution costs (Muñuzuri et al. 2012; Anderluh et al. 2017). Furthermore, average traffic speed has been significantly reducing in the area, which adversely impacts travel time and reliability of deliveries. Allen et al. (2018a) reported that the vehicle delays have increased by almost 31% in central London while congestion is expected to increase 60% by 2030 (Bates et al. 2018a).

1.1.3. Solutions to Address the Increasing Movements of Freight Vehicles in the Inner-City

Enabling more optimised and efficient freight vehicles into the inner-city area requires more innovative and sustainable logistics facilities. Savelsbergh and Van Woensel (2016) suggest that for freight carriers to maintain the ability to maintain offering low-cost and competitive delivery services, they need improved coordination of the flows of goods, higher consolidation of freight movement and better multi-organisation cooperation. Taniguchi et al. (2016) and Heitz et al. (2019) further highlight the need to establish models to determine the optimal location and number of suitable logistics facilities in the inner-city areas. It can be argued that customers' demand for express deliveries coupled with their reluctance to cover the additional delivery cost may compel delivery companies to consider adding a new layer of transshipment and consolidation facilities that are geographically much closer to receivers inside inner urban areas.

Focusing only on freight measures such as promoting eco-friendly vehicles, congestion charging, and/or off-peak deliveries overlook the fact that freight land-use as well as shippers and receivers' delivery requirements highly dictate the operational practices of freight carriers to comply with the time-sensitive requirements of express deliveries. Furthermore, the limited availability of industrial land in the inner-city area to establish suitable logistics facilities and ineffective loading infrastructure for loading/unloading activities coupled with increasing demand for express deliveries contribute to more under-utilised freight vehicles in the inner-city. Accordingly, the freight consolidation policy offers an alternative and effective solution for freight carriers in the highly congested and dense inner-city area in order to cope with the increasing activities of fragmented and express deliveries as well as alleviate the negative impacts and deficiencies of last mile delivery in this area. This policy focuses on freight carriers and receivers to combine the parcels from various delivering routes and under-utilised freight vehicles at an intermediate consolidation facility into optimised loads and rationalised delivery routes addressed to neighbouring receivers in clearly defined destination zones (Holguín-Veras and Sánchez-Díaz 2016; Estrada and Roca-Riu 2017). This policy contributes to increasing the fill-in rates of delivery vehicles, minimising the total

travelled distance per parcel and offering value-added and retailing services to receivers (Allen et al. 2014). Consequently, the consolidation scheme would reduce delivery activities by under-utilised and unsustainable freight vehicles as well as increase the drop density of delivery operations (Suksri and Raicu 2012; Lin et al. 2016). It is important to highlight that the notion of the freight consolidation policy in this research is not to be equated or limited to the widely reported initiative of the freight carrier-focused urban consolidation centre (UCC) in the literature. The UCC solution suffers from several methodological and regulatory issues that impacted its operations and efficiency (Vahrenkamp and Berlin 2016; Lagorio et al. 2016b).

Moreover, previous freight consolidation facilities were established in suburban parts of the metropolitan area (Kin et al. 2016), which resulted in increasing the distance and cost of the consolidated deliveries in inner urban. Although many previous consolidation initiatives throughout Europe have failed due to various reasons, several consolidation facilities are still operational, especially in Japan and Europe. These facilities minimised the environmental emissions, reduced the number of freight vehicles in urban areas, improved the delivery reliability and enhanced efficiency of freight carriers (Quak and Tavasszy 2011). For example, Monaco UCC, which was established in 1989, contributed to various positive impacts on urban environment including minimising the vehicle noise pollution and CO_2 emissions by 30% and 25%, respectively as well as reducing traffic congestion by 38% (Patier 2006). Similarly, the Bristol UCC in Bristol, UK, which operates two large trucks to deliver goods to 300 retailers in Broadmead Shopping Centre, achieved a reduction of 75% in vehicle kilometres, 89 tonnes of CO_2 and 1,000 kg of NOx emissions (Allen et al. 2014). The Regent St UCC in London achieved a reduction of 180,000 vehicle-kms, 66 tonnes CO_2 and 2,300 kg NOx emissions (Van Duin et al. 2016).

1.2. Overview of the Research Problem

Today, the urban freight industry appears to have conflicting issues, as it is required to operate sustainably and at the same time adjust to the increasing freight movements inside the inner-city. This situation has forced logistics facilities to relocate to the periphery of metropolitan areas because of logistics sprawl (Dablanc and Rakotonarivo 2010; Labussière and Nappi-Choulet 2014). The significant vehicle-kms that freight vehicles must travel between these suburban logistics facilities to receivers inside the city centre plus the necessity to find parking results in additional transport costs, fuel consumption and traffic congestion (Quak 2007). The limited availability of affordable industrial land in the inner-city area make it very cost-prohibitive for freight carriers to establish suitable logistics facilities to cope with the increasing demand for express deliveries (Marcucci et al. 2015). The increasing movements of freight vehicles place additional pressure on infrastructure and freight carriers to comply with the time-sensitive requirements of receivers as well as increasing the delivery costs inside the inner-city area.

Various local authorities acknowledge the increasing presence and use of LCVs by freight carriers in the inner-city area. However, limited data is available on the characteristics, operational practices and utilisation of these LCVs in the inner-city compared with intra-metropolitan last mile delivery. For the last leg of last mile delivery in the inner-city area, the operational practices of freight carriers, challenges impacting the carriers, freight vehicles types and delivery requirements of receivers are significantly different from

freight deliveries to other receivers located in other parts of the metropolitan area. Thus, it may not be adequate to deal with the shortcomings and challenges of this last leg of the delivery using the same approaches and solutions that were proposed for suburban freight deliveries. It could be argued that many of the existing studies failed to take into consideration the recent trends and challenges adversely impacting last mile delivery in the congested inner-city especially logistics sprawl and express deliveries.

In order to facilitate the sustainable establishment of a suitable and profitable freight consolidation facility in the inner-city area, a holistic multi-stakeholder approach is required to incorporate the operational requirements and perspectives of all stakeholder groups as well as the facility's financial viability in the design, planning and location selection of the consolidation facility. More emphasis should be placed on the best operational requirements and practices for the potential operator of the facility to ensure the facility would be efficient and successful. Furthermore, the entire network from the suburban distribution centre to the receivers inside the city area need to be systematically evaluated in order to compensate for the additional transshipment and distribution costs that result from the new layer in the urban distribution network. Finally, freight behavioural research is required to engage and examine goods receivers' preferences and interest regarding consolidating their deliveries.

1.3. Research Questions

The following research questions are investigated in this thesis with respect to establishing a suitable and sustainable consolidation facility in the inner-city area to address the increasing activities of express and fragmented deliveries:

 Research Question#1: How do freight carriers currently perform delivery and pickup activities specifically inside the inner-city area?

> ***Background:*** While various studies have analysed and discussed the delivery activities of last mile delivery in urban areas, the last leg (hundreds of metres) of delivery in dense inner-city areas has not receive similar academic focus from transport researchers. It could be argued that most previous studies on last mile delivery and city logistics failed to capture the complexity of this delivery segment. Acquiring updated and detailed operational parameters directly from freight carriers performing delivery activities inside the inner-city enable the researcher to be better-informed about the operational practices, challenges and requirements of freight industry specifically inside dense inner-city areas.

 Research Question#2: How could a suitable and financially viable freight consolidation facility be sustainably reintegrated into the inner-city based on the operational and business requirements of freight carriers and receivers?

> ***Background:*** A main limitation with many previous consolidation solutions and schemes is the failure to incorporate the operational and business requirements of carriers and receivers in the formulation of the consolidation scheme. Several consolidation solutions were initiated by local authorities to replace trucks with cargobikes or set up a consolidation facility without enforcing sustainable freight land-use. However, these projects overlooked considering the various aspects that would make the proposed consolidation facility operationally and economically attractive for freight carriers to consolidate their deliveries. Thus,

it is important for the research to systematically and thoroughly delve deeper into the mechanisms and approaches that facilitate proposing a consolidation facility that would contribute actual value propositions and operational enhancement for carriers and receivers. Additionally, determining and ensuring the economic viability of the consolidation policy has to be the forefront to overcome reliance on government subsidies for long-term financial success.

 Research Question#3: What are the objectives of all stakeholders with respect to the consolidation delivery service in the inner-city? What is the relative importance of the objectives to stakeholders?

Background: Consolidation schemes impact business stakeholders such as freight carriers and receivers as well societal stakeholders such as citizens and local authorities both in direct and indirect outcomes. However, it is essential to include all the various stakeholder groups involved in last mile delivery in the planning and formulation of the proposed consolidation scheme rather than focusing on key actors as mainly performed in several consolidation studies. Hence, the various objectives of all stakeholder groups have to determined and included in the assessment of the alternative configuration of the proposed consolidated delivery service in a holistic approach that ensures considering the assigned importance by the stakeholders of these objectives.

 Research Question#4: Which categories of goods receivers might be willing to participate in consolidating their deliveries? Which policy variables influence their likely level of participation?

Background: Receivers have a considerable market power in last mile delivery. Overlooking this important group in the planning of consolidation schemes may lead to making the consolidation service difficult to implement by freight carriers. Additionally, it can be argued that some businesses might be unlikely to participate at all in the proposed consolidation policy. Hence, it is important to determine the business characteristics of receivers that would spur their willingness to participate. Knowing how sub-industries differ with respect to preferences towards various attributes of the consolidation scheme allows not only prioritisation of the sectors that receivers from which should be targeted first; but also the right attributes to be highlighted of the proposed consolidation policy depending on what receivers from each sub-industry value the most. This facilitates proposing suitable and optimal consolidation schemes tailored for the preferences of sub-industries most willing to participate.

 Research Question#5: What is the most optimal location to establish a suitable freight consolidation facility in the inner-city based on the operational requirements and societal concerns of stakeholders as well as the spatial factors of the study area?

Background: Identifying the optimal location for the proposed consolidation facility play an important role in the efficacy and potential acceptance of the consolidation policy. Freight carriers might not favourably perceive the proposed consolidation policy if the location of the facility fail to efficiency integrate with key freight corridors. Receivers may refuse to allow their parcels to pass through the proposed facility if its location lead to any disruption or changes in their current parcel receiving practices. Additionally, it is necessary to consider the spatial interrelationships between the various nodes and links in

the last mile delivery network as well as assessing the impacts of the facility on surrounding sensitive uses in the approach developed to assess and select the optimal location for the proposed consolidation facility.

1.4. Research Aim and Objective

The primary aim of this research is to develop an integrated framework for an optimised and sustainable Central City Consolidation Facility (CCCF) in the inner-city area that combines carriers-focused and receivers-engaged consolidation schemes based on the operational, social, environmental and economic perspectives and requirements of all stakeholders involved in last mile delivery.

The following objectives are proposed to achieve the overall research aim:

- ***1st Objective:*** Design a Central City Consolidation Facility that could be sustainably integrated in the inner-city area to facilitate: a) increasing the load utilisation of incoming freight vehicles, b) reducing the number of freight vehicles, c) perform delivery and pickup activities to receivers on eco-friendly freight vehicles and soft transportation modes, and d) enhancing the use of on-street loading zones.
- ***2nd Objective:*** Examine the goods receivers' willingness to participate in the proposed freight consolidation policy.
- ***3rd Objective:*** Optimise the selection of the operational configuration and location of the consolidation facility based on the various operational, social, spatial and financial perspectives, requirements and concerns of all stakeholders.
- ***4th Objective:*** Estimate the financial viability of the proposed consolidation facility while taking into consideration all the various operational costs associated with operating the facility and the potential revenue streams.

1.5. Research Design

The design of socio-technical systems such as last mile delivery networks involve a high-level of combined economic, operational, social and physical complexity, uncertainty and decision-making processes. The research design incorporated several cross-over modelling approaches to consider both the physical and social networks of the proposed consolidation policy in order to account for the physical infrastructure and complex behaviours of the various actors as asserted by Herder et al. (2008). To achieve the research objectives, the research framework fully integrated the objectives of all stakeholders in the development and selection of the most suitable operational configuration and location for the proposed CCCF. The freight consolidation policy presented in this framework focused on engaging and appraising the willingness of receivers to coordinate and work with shippers and freight carriers to deliver their parcels to the proposed consolidation facility. More emphasis was placed on freight land-use and spatial aspects of the consolidation facility in selection of the optimal location for the facility in the dense inner-city. Moreover, the freight consolidation policy was evaluated not only from operational and environmental perspectives, but also, from a business perspective in a systematic approach. This ensured evaluating and identifying the business aspects that could contribute to making the proposed facility profitable. Due to

the prohibitive cost of establishing and operating a consolidation facility in the inner-city, the various costs associated with operating the proposed facility were comprehensively incorporated to ensure that the facility would generate revenue for the potential operator. Furthermore, the integrated framework included various data collection techniques to acquire primary operational parameters and insights from all the stakeholders involved in last mile delivery. This is a very essential component in the design of complex projects to ensure the suitability of the proposed design of the consolidation facility and receiving critical knowledge and feedback from key actors as outlined by Dym et al. (2013). Fig. 1.1 displays the conceptual stages that were performed to develop the five stages of the research framework, which are described in more detail in chapter 3.

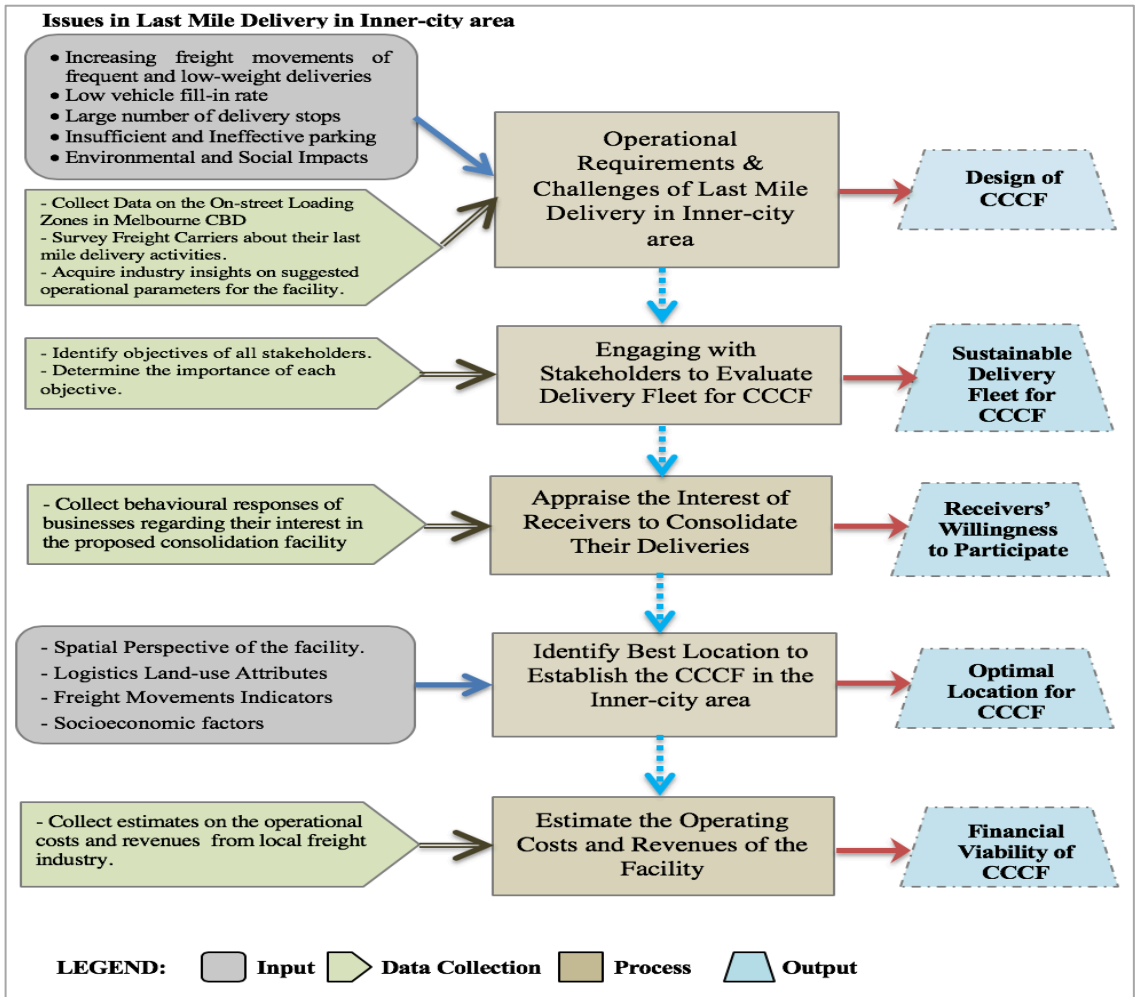


Figure 1.1. Conceptual Design of Research Framework

1.6. Research Contribution

The data-adjusted integrated framework sequentially and collectively involves stakeholder engagement, sustainable freight land-use policies, freight behavioural research, business modelling and location selection to optimise the establishment of a consolidation facility in the inner-city from the operational, sustainability, financial viability and spatial perspectives. The optimisation framework combines multi-criteria decision-making (MCDM) models and spatial analysis to further extend existing

knowledge with respect to siting of logistics facilities. Moreover, incorporating the objectives of the different stakeholders in all stages of the holistic and multi-stakeholder decision-support approach makes policy makers and transport researchers better-informed on which criteria are more influential in establishing the consolidation facility. Furthermore, the econometric models applied in this research characterised receivers' willingness to participate in and pay for receiver-led delivery consolidation service (RLC) without government financial incentives as well as exploring the appropriate RLC policy levers that can be used to foster receivers' participation. Finally, the focus on business aspects of the proposed consolidation initiative early in the planning and decision-making process ensures optimising the profitability of the proposed initiative to facilitate setting up a financially viable consolidation facility, a net profit-generating and self-sustaining facility without government financial incentives, for the potential operator and an operationally and economically-attractive consolidated delivery scheme for the participating freight carriers and receivers.

1.7. Research Significance

City centres often serve as the most important financial, trade, tourism and service hub in large metropolitan areas, especially in Europe, Asia and Australasia with hundreds of thousands of workers, visitors and residents commuting and visiting these city centres every working day. Many metropolitan areas have embarked on residential gentrification initiatives and commercial projects to revitalise and economically regenerate the inner-city, which attracted more people to live and work there (Lehrer et al. 2010; Williams 2013; Searle 2018). Moreover, there are many high-rise towers in the city centre with each one generating and attracting a significantly large volume of freight vehicle movements that sometimes exceeds a whole city block or precinct (Thompson and Flores 2016). Furthermore, many local authorities are implementing more pedestrianisation policies to improve the amenity of the city centre and promote active transport (walking and cycling). For instance, local authorities in some European cities such as Vienna, Munich, and Zurich have changed the city centre to be almost a car-free zone (Buehler et al. 2017). It could be argued that while these policies enhance the walkability and attractiveness of the city centre, they adversely affect the accessibility and efficiency of the freight vehicles to the large number of retailers inside the pedestrian zones (Verlinde et al. 2016).

The inner-city area experiences a large presence of freight vehicle movements. For instance, more than 10,000 and 12,000 freight vehicles perform deliveries in Melbourne CBD and London CBD, respectively (Casey et al. 2014; Litman 2012). More than 35,000 commercial vehicle trips are required for deliveries and services in Sydney CBD each weekday (Stokoe 2016) while 100,000 trips are performed daily by freight vehicles for deliveries in Manhattan, New York (Zou et al. 2015). However, the limited availability and ineffective parking and loading infrastructure for freight vehicles further complicates deliveries and adversely impacts the cost and efficiency of the freight carriers. Although freight deliveries to commercial receivers have increased over the last three decades, the supply and regulation of loading spaces and bays have not kept up with demand (Morris 2004; Jaller et al. 2013). The increasing movements of freight vehicles due to express and fragmented deliveries, the illegal use of on-street loading spaces and the pressure on roads and infrastructure will continue to exacerbate these problems.

Many local transport agencies in different cities have implemented freight strategies plans for the wider metropolitan area, but very few cities have taken actions to create effective last-mile freight plans for the inner-city area. The last leg (hundreds of metres) of delivery in the inner-city area represent a major choke point and severe operational challenge for freight carriers due to the difficulty of finding parking and necessity to navigate through multiple buildings to perform high number of stops (Allen et al. 2017). Some of freight solutions for this area were proposed based on erroneous assumptions that might have contributed to the failure of these solutions as they were irrelevant to actual practices and requirements of freight carriers in the inner-city.

The marginal profit of the parcel delivery industry is significantly very small compared to other sectors in the freight industry due to the increasing costs and customers' current delivery requirements (Bates et al. 2018b). Furthermore, consumers are increasingly demanding same- or next-day delivery as well as flexible and customer-tailored delivery channels. While many customers demand express deliveries, a large share of the customer base is reluctant to bear the additional delivery costs. For example, a study performed in the US on the willingness of online consumers to pay for express delivery cost revealed that 88% preferred free delivery while only 12% were willing to pay for the quick delivery (Keyes 2018). A UK study reported that 73% of the customers considered "free delivery" a major deciding factor when making an online purchase (Zenezini et al. 2018). It could be argued that it is becoming more challenging for freight carriers to satisfy these time-sensitive requirements with longer transport distances and under-utilised freight vehicles.

Hence, last-mile delivery is considered the least efficient, most polluting and most expensive link within freight transport network as its share of the total freight transport cost is 53% (Gevaers et al. 2014; Wang et al. 2016). Although freight deliveries account only for less than 20% of all vehicles-km in urban areas (Stathopoulos et al. 2011), they cause almost 16%-50% of the transport-related emissions (Arvidsson and Pazirandeh 2017) generating on average 21.7 kg of CO_2 for an 80 km daily delivery trip (Edwards et al. 2010). These operational costs and emissions could be significantly exacerbated for freight deliveries in the inner-city.

1.8. Delimitation of the Research (Scope)

The geographical scope of this study focuses on the inner-city area, which includes the central business district (CBD) and surroundings suburbs within a 5 km radius. For instance, the geographical area covering the City of Melbourne or City of London local councils. However, the integrated framework does not focus only on the CBD because other inner-city suburbs also include large freight generators such as employment, retail and education, precincts. Furthermore, the freight vehicle movements under consideration in this study are exclusively performed within the inner-city area whether for delivery or pick up services. Other intra-metropolitan freight movements, which occur outside the inner-city area, and inter-metropolitan freight movements are excluded from the focus of this research due to their different type of freight vehicles and operational requirements as well as the end-destination being outside of the scope of the policy.

1.9. Thesis Outline

The thesis is comprised of nine chapters, which are briefly outlined below:

Chapter	Title	Description	Approach
Ch. 2	Literature Review	Critical review and synthesis of following topics: logistics facilities in urban areas, freight consolidation policies, modelling and evaluation methods of freight consolidation policies, issues of last mile delivery in inner-city area, and addressing increasing express deliveries and limitations of industrial land in inner-city area.	
Ch. 3	Research Design & Methodology	Describes the development of the 5 stages of the integrated framework to achieve the research objectives including data collection techniques.	
Ch. 4	1st Stage of Integrated Framework	- Presents and discusses the results and policy implications of the two data collection techniques used to acquire characteristics of delivery trips in the inner-city area. - Describes the proposed design of the freight consolidation policy (structural and operational design of the facility and supporting government regulations).	System Approach *Data Collection:* - Observational study: use of on-street loading zones in city centre by freight vehicles - Semi-structured interviews & survey of freight carriers
Ch. 5	2nd Stage of Integrated Framework	Applies a multi-stakeholder decision-support approach for evaluation and selection of the most suitable delivery fleet for the consolidated deliveries based on 30 weighted decision criteria of six stakeholder groups. The multi-stakeholder analysis and mon-actor analysis highlight the various and conflicting views of the stakeholders groups with respect to optimal delivery fleet.	Multi-Actor Multi-Criteria: Fuzzy AHP – PROMETHEE *Data Collection:* - Pairwise Comparison for Stakeholders' Perspectives.
Ch. 6	3rd Stage of Integrated Framework	Estimates the receivers' willingness to participate in the consolidation service. The behavioural responses were analysed using two models: - Estimates the receivers' willingness based on their delivery characteristics using an ordered logit model. - Estimates the receivers' willingness based on the attributes of the consolidated delivery service using a mixed logit model and measure their willingness to pay for the service.	- Freight Behavioural Research. - Logit models. *Data Collection:* - Stated-Preference Survey
Ch. 7	4th Stage of Integrated Framework	Models and optimises the assessment and selection of most suitable location for the proposed consolidation facility in the inner-city area based on weighted priorities of 11 decision criteria. The developed approach incorporated stakeholders' engagement, MCDM models and spatial models in the location assessment of 20 identified candidate sites in the inner-city.	Fuzzy AHP-GIS-TOPSIS methods *Data Collection:* - Pairwise comparison for stakeholders' views. - Spatial datasets on the 11 decision criteria

Ch. 8	5th Stage of Integrated Framework	- Examines the business aspects of the proposed consolidation policy. - Formulates a mixed integer linear programming model to optimise the operational costs and the expected revenues of the consolidation facility to derive a financially viable consolidation facility without government incentives. The MILP model was solved using a genetic algorithm.	- Business Model Canvas - MILP Cost Model *Data Collection:* Operational and financial datasets from local freight carriers.
Ch. 9	Conclusion	Presents concluding remarks on the thesis's major findings, applications of the integrated framework, and future research directions.	

Chapter 2.

Literature Review

In this chapter, a literature review on studies related to this thesis is provided. Fig. 2.1 displays the different sections in this review, which is divided in three main parts:

- Part A (Sections 2.1 and 2.2) describes the various aspects and problems associated with last mile delivery and logistics facilities in urban areas.
- Part B starts with section 2.3 analysing the literature on freight consolidation policies while section 2.4 critically evaluates the primary modelling and evaluation approaches used in the decision-making and assessment of freight consolidation facilities. This part attempts to identify key shortcomings and limitations of exiting models and approaches.
- Part C summarises the issues adversely impacting last mile deliveries specifically in the inner-city area (section 2.5) and analyses the limited consolidation initiatives and sustainable freight land-use policies specifically in the inner-city (section 2.6).
- Finally, section 2.7 highlights the main gaps and limitations identified by the literature review.

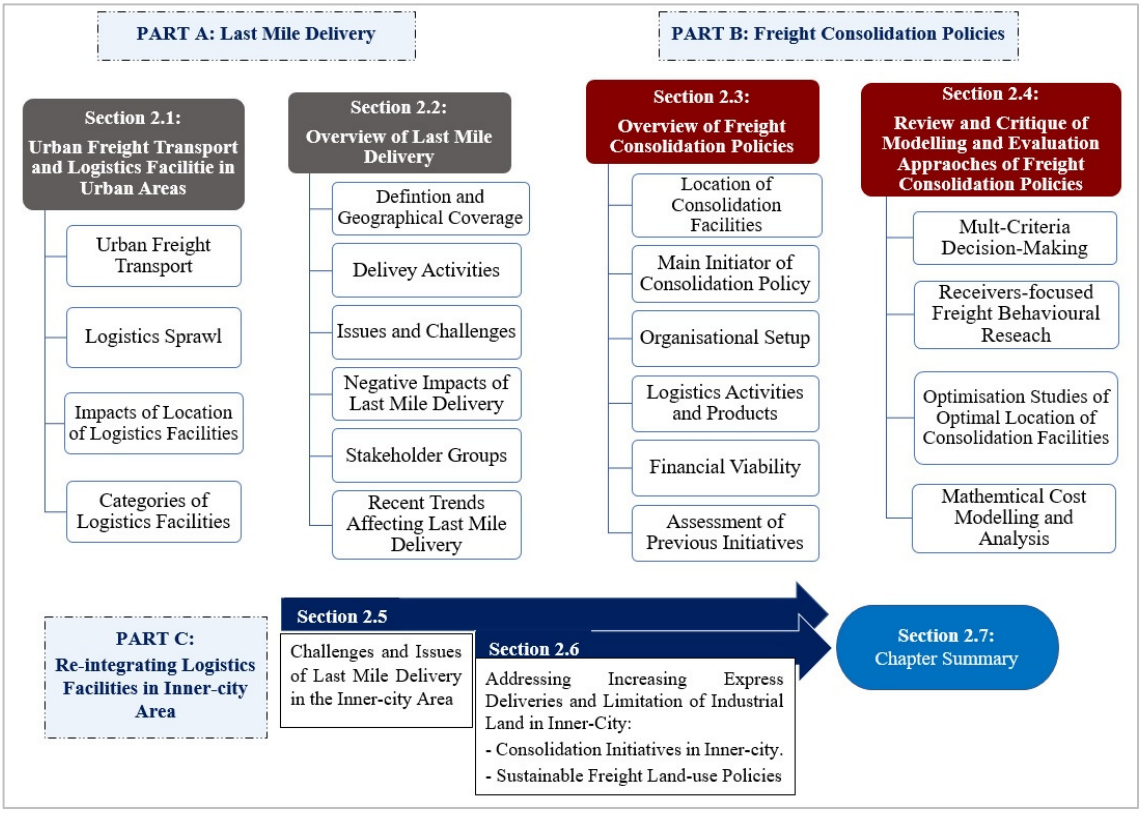


Figure 2.1. Summary Diagram of the Literature Review Chapter

2.1. Urban Freight Transport and Logistics Facilities

2.1.1. Overview of Urban Freight Transport

Urban freight transport establishes the link between global and regional transport flows and the last mile of distribution of goods in urban areas (Rodrigue 2013). Urban freight transport includes intra-city freight journeys, i.e. freight movements that entirely originate and end within the same metropolitan area, as well as the freight movements of inter-city freight journeys once the vehicle enters or before leaving the boundary of the urban area for line-haul transport origin or destination in other cities. Intra-city freight journeys represent a considerable share of the total transported freight occurring inside urban areas. For instance, intra-metropolitan freight represented about 42% of all transported freight in Greater London (Allen and Browne 2010) while their share is almost 47% of total freight transported on more than 80,000 trucks in Greater Paris (Hall and Hesse 2013; Dablanc 2013). Several urban form factors such as city layout, population density, road infrastructure and availability of logistics facilities result in different operational structures and distribution networks of urban freight journeys. These different types of urban freight journeys involve different sizes, frequencies and numbers of freight vehicles to and from logistics facilities. The facilities act as origins and destinations of freight journeys and linking points that connect the transport nodes and logistics operations in the urban freight transport network (Hesse 2004).

2.1.2. Overview of Logistics Sprawl

2.1.2.1. Factors and Policies that Contributed to Relocation of Logistics Facilities

Historically, storage of goods was decentralised with multiple warehouses positioned across the supply chain at the manufacturing site and at receiver's site with intermediate warehouses between these two locations (Allen et al. 2012a). Many of these warehouses were smaller and located in inner urban areas in the proximity of rail yards and docklands (Cidell 2010). However, majority of logistics facilities are currently located in primarily logistics clusters in the outer edges of metropolitan areas close to highway networks, major airports and seaports (Cidell 2011; Leigh and Hoelzel 2012). This trend of relocation of logistics facilities away from inner urban areas to suburban and exurban areas has been termed as Logistics Sprawl by Dablanc and Rakotonarivo (2010).

The geography of logistics facilities has significantly changed over the last three decades (Cidell 2011). Government pressure through land use control and exclusion of freight in urban planning have been influential in the relocation of logistics facilities to suburban areas (Leigh and Hoelzel 2012; Sakai et al. 2016). To maximise property tax revenues, local authorities have modified land-use zoning in inner-city areas that were formerly industrial land to non-industrial classifications (mixed-use, commercial and residential development). Consequently, land prices in urban cores have become significantly unaffordable for logistics facilities, which have forced logistics companies to relocate to the highly affordable suburban areas (Hesse 2008). Another land-use issue that contributed to relocation of logistics facilities is the conflict between incompatible freight related activities and other sensitive land use when they operate and function in the same vicinity. Furthermore, several researchers have argued that regional and operational shifts in manufacturing industry, expansion of global trade and new practices such as Just-in-

Time and containerisation have played a prominent role in the restructuring and transformation of the functionality of logistics facilities (Hesse and Rodrigue 2004; McKinnon 2009; Benjelloun and Crainic 2009). These shifts have contributed to new requirements of large-scale regional distribution centres serving major local and regional markets (O'Connor and Parsons 2011; Hall and Hesse 2013). Therefore, suburban areas offer more affordable and robust locations for logistics facilities that provide more efficient operation and access to regional markets (Andreoli et al. 2010).

2.1.2.2. Impacts of Logistics Sprawl on Logistics Industry and Urban Environment

Logistics sprawl has contributed to changes in geography of urban freight, increasing trucks' travelled distance and negative environmental emissions. Bowen's (2008) study of the changes in number of warehouses in 50 metropolitan areas in the US during 1998-2005 demonstrated that warehouses experienced faster growth in percentage terms in suburban counties than central counties. Heitz and Dablanc (2015) highlighted that logistics facilities in Paris moved to exurban areas far away from residential areas, which contributed to the expansion of the urban fabric further outward. Philippe Gallois co-founder of SAGL, the Paris-based designer of logistics real estate, described that the move and building of large logistics facilities in suburban areas have paid attention only to efficiency and practicality while neglecting any aesthetic considerations. Consequently, this trend contributed to uncoordinated growth in logistics buildings that were poorly integrated into the urban environment, which consequently harmed the image of logistics facilities (Labussière and Nappi-Choulet 2014).

Logistics sprawl has resulted in increasing the distances travelled by freight trucks to deliver products in urban areas as logistics facilities are becoming much larger and serve more businesses and households than they used to do. Several researchers applied spatial centrographic analysis to measure the additional distance between logistics terminals and their geographical centre in the urban area resulting from logistics sprawl in several metropolitan areas including Paris (Dablanc and Rakotonarivo 2010), Atlanta, USA (Dablanc and Ross 2012), Los Angeles and Seattle, USA (Dablanc et al. 2014), Toronto, Canada (Woudsma et al. 2016) and Tokyo, Japan (Sakai et al. 2015). It can be summarised that Paris, Atlanta, Los Angeles, Tokyo and Toronto all experienced significant logistics sprawl while Seattle did not display similar results. Fig. 2.2 displays the additional distance - on average- that freight carriers travel to deliver goods due to logistics sprawl.

The additional distances travelled by freight trucks contribute to negative environmental impacts. Dablanc and Rakotonarivo (2010) estimated that relocation of logistics facilities in Paris has created an annual net addition of 15,000 tonnes of CO_2 emissions. While this number might be only a marginal figure compared to the overall emissions of CO_2 produced by freight transport in Paris, it still represents a harmful impact on the urban environment that needs to be carefully evaluated and mitigated. Dablanc and Ross (2012) and Wygonik et al. (2015) have argued that logistics sprawl contributed to the unsustainable nature of urban freight transport. However, Sakai et al. (2015) challenged this assumption, arguing whether relocating a logistics facility to suburban areas is actually socially detrimental as several factors relevant to the individual facility need to be taken into consideration, e.g. vehicle types used or time of operation.

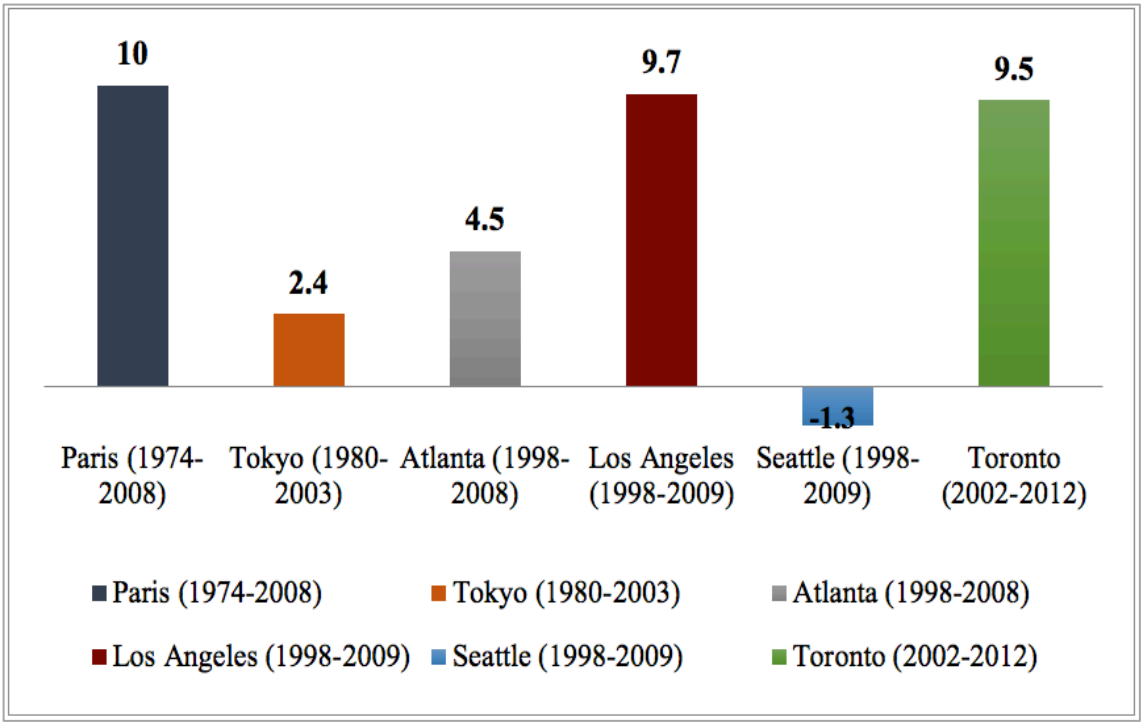


Figure 2.2. Change in average distance of logistics facilities from their barycentre in selected metropolitan areas (Data sourced from Dablanc and Rakotonarivo 2010; Dablanc and Ross 2012; Dablanc et al. 2014; Woudsma et al. 2016 and Sakai et al. 2015)

2.1.3. Overviews of Logistics Facilities in Urban Areas

There are different categories of logistics facilities with each type having their own operational requirements and functionalities including a warehouse, distribution centre (DC), truck terminal, express parcel depot or intermodal facility (McKinnon 2009). They provide break-bulk, transshipment, transfer, distribution of materials and goods between freight transport nodes as well as long-term and intermediate storage for shippers and logistics service providers (LSPs) (Allen and Browne 2010). Moreover, Wagner (2008) classified the logistics facilities according to the industry that they serve: 1) trade-related logistics facilities such as DCs of retailers and wholesalers; 2) industry-related logistics facilities such as warehouses supplying materials and distributing products of a particular factory; 3) depots of express couriers which include national hubs, regional transfer depot and local distribution depot for distribution of packaged goods and parcels; 4) inter-modal facilities which include both national and regional containerised transport terminals; 5) shared truck terminals which provide multi-user warehouses for subcontractor or trucking companies that offer transport services.

Logistics facilities are also multi-scalar and could be classified according to the spatial level depending on their location and intensity of their activities where a maritime shipping facility has a major influence on the macro-level of the national freight transport flows. Alternatively, a regional distribution facility influences freight journeys at the meso-level in urban areas compared to an express parcel depot that influences parcel deliveries at the micro-level in inner-urban areas (Hall and Hesse 2013). Due to the centralisation of supply chain and freight transport network, the sizes of logistics facilities

have considerably increased over the last few decades as some national and regional DCs could occupy up to 75,000-100,000 m^2 facility with high use of automation and advanced information communication technologies (Hesse 2004). The locations of logistics facilities affect not only logistics companies, but also the urban environment. Lindsey et al. (2014) indicated that for public stakeholders, the location of logistics facilities affects truck traffic patterns and influence the well-being of citizens by contributing to several negative impacts. For logistics companies, the location of logistics facilities has considerable influence on total transport costs and the efficiency of their operations (Dablanc et al. 2014).

2.2. Overview of Last Mile Delivery

2.2.1. Last Mile Delivery Activities in Urban Areas

Cardenas et al. (2017a) makes the distinction between the two key logistics domains within the urban logistics network based on their geographical scope, which are urban freight transport and last mile delivery. Last mile delivery, which covers the micro-level in the freight transport network, encompasses all transport activities related to delivery and pickup of products and materials from logistics facilities primarily in suburban parts to the end-receiver whether a retailer, business or consumer (Gevaers et al. 2014). Last mile delivery activities occur entirely inside the urban area and are not part of line-haul freight transport (Schliwa et al. 2015). In large cities, the last mile link extends geographically over a large distance of tens of miles or kilometres.

2.2.1.1. Main Categories of Freight Vehicles Used in Last Mile delivery

Freight vehicles involved in last mile deliveries are typically much smaller and older than freight vehicles used in line-haul transport (Hall and Hesse 2013). Many local governments applied various restrictions policies limiting large freight vehicles from entering the city centre based on weight, class or time (Dablanc et al. 2013). Allen et al. (2017) and Visser et al. (2018) underline that freight carriers are increasingly utilising light commercial vehicles (LCVs) in urban areas as a result of limited parking spaces and truck bans as well as LCVs' improved operational efficiency and costs compared to trucks. Moreover, Holguín-Veras et al. (2017a) estimated that LCVs generate about 66% of freight trips in New York Metropolitan Area compared to trucks accounting for 34% while Allen et al. (2017) reported that LCVs represent about 80% of total freight movements in London. Fig. 2.3 displays the main classes of freight vehicles typically used in urban areas. While LCV freight movements represent a large share of the total intra-metropolitan freight movements; however, their share of the total freight task might be less than total freight moved by heavy trucks. For example, LCVs deliver only 10% of the total freight task in Greater Melbourne compared to rigid and articulated trucks, which deliver 41% and 40% of total metropolitan freight task, respectively (Australian Bureau of Statistics [ABS] 2015a). The majority of freight vehicles are diesel-fuelled.

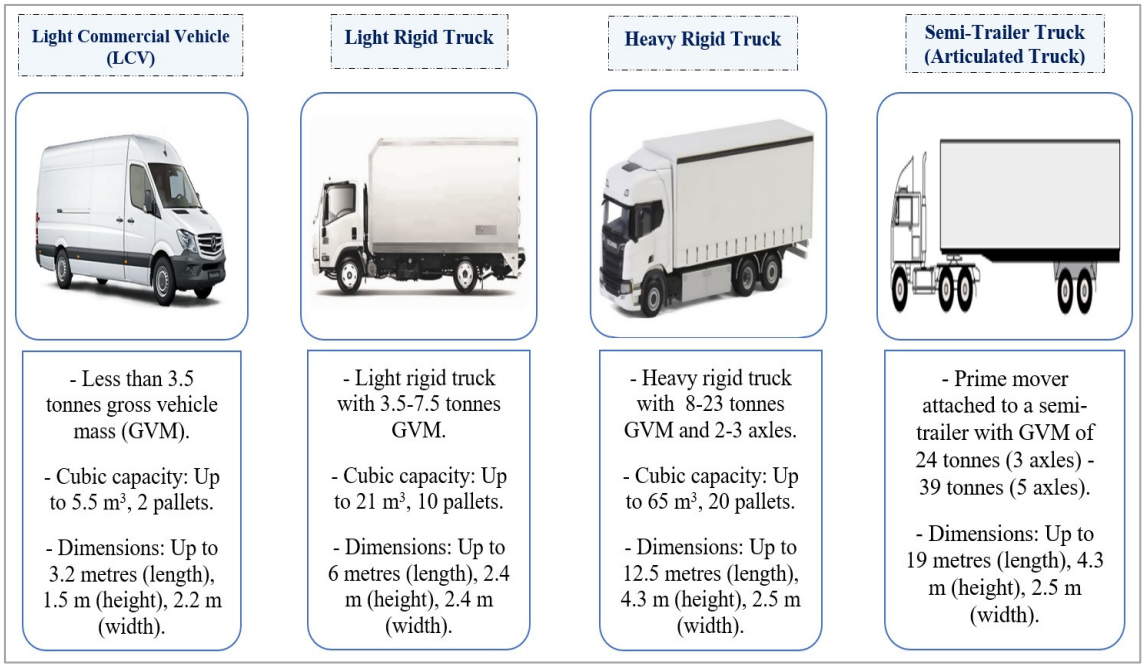


Figure 2.3. Overview of the Main Classes of Vehicles Used in Last Mile Delivery (Data acquired from freight industry via Own research; VicRoads 2016)

2.2.1.2. Type of Products and Distribution Channels

A large share of goods in last mile delivery could be classified as light freight. Light freight distribution encompasses delivery and pick-up trips of primarily smaller parcels for diverse industries including retail, mail and packages, office supplies, hotel, restaurants and catering (HoReCa), household waste removal, service and maintenance industries (Tsolakis and Naude, 2008). Moreover, light freight is associated with high use of LCVs, time-sensitivity requirement of deliveries and low-weight parcels (ibid.). Each type of these products is transported in a different distribution channel and might require different freight vehicle category and operational practices, which contribute to making last mile delivery a very complex and challenging arena (Dablanc and Rodrigue 2014).

- ***Retail***: Deliveries to retailers represent a considerable component of last mile delivery and could be classified based on their organisational structure: chain retailing and independent retailing (Behrends 2016). The re-stocking and logistical decision-making of large chain stores are usually controlled and coordinated by centralised distribution channels within the corporation to supply all franchise stores using large freight carriers and optimised delivery trips (ibid.). Conversely, the re-stocking decision-making of small and independent retailers is usually organised by store owners or staff through direct relationship with shippers and small freight carriers (Danielis et al. 2010). These stores still represent a noticeable proportion of the total retailers especially in the inner-city area even though their stores might be decreasing in many cities (Dablanc and Rodrigue 2014). Due to the decentralised and inefficient re-stocking strategies of these independent stores, they typically receive about 3-10 deliveries per week, which is three times the number of deliveries to large chain stores (Cherrett et al. 2012). Deliveries to most retailers

are performed using LCVs and light trucks in the early morning hours in which the driver carries multiple shipments into each store (Suksri and Raicu 2012).

- ***Couriers, Express and Parcel (CEP):*** The CEP network is composed of three different distribution channels (Ducret 2014). *Courier* and *express services* perform the door-to-door and fast transport of mail, home deliveries and light parcel shipments with value-added services while *parcel services* focus on heavier and standardised shipments up to 30 kg (Behrends 2016). Furthermore, the delivery lead time and time-windows of the CEP channels are significantly different as courier services are typically the shortest with direct delivery from the sender to the receiver usually within the same day; express services are time-sensitive with guaranteed delivery-window (typically next- two-day) while parcel services usually have no fixed delivery time-windows over multi-stop multi-journey delivery trips (Winkelmann et al. 2009). CEP service providers serve three different customer or market sub-segments: business-to-business (B2B), business-to-consumer (B2C) and consumer-to-consumer (C2C). In 2012, B2C deliveries accounted for almost 56% of total parcel market in the UK while B2B accounted for 38% and C2C accounted for 6% (Allen et al. 2018b). Home deliveries cause major operational challenges for CEP service providers due to the high delivery failures, low load utilisation and low drop density compared to B2B deliveries (Behrends 2016).

- ***Hotel, Restaurants and Catering (HoReCa):*** The HoReCa distribution channel covers food deliveries and supplies to restaurants, cafes, hotels, bars, canteens and catering (Danielis et al. 2010). Due to the perishable nature of these deliveries, they usually involve specialised, refrigerated, time-sensitive, unpredictable and very early morning delivery activities (Ponce-Cueto and Carrasco-Gallego 2009). A considerable share of these deliveries are performed by wholesalers and own-account transport in highly unoptimised and frequent delivery trips, which contribute to the large number of HoReCa delivery trips in urban areas. For example, deliveries to HoReCa establishments in Paris represent about 5% of total daily freight trips to all businesses with a typical HoReCa establishment receiving daily 5 times the number of deliveries to a large supermarket (Dablanc and Rodrigue 2014). Moreover, Eidhammer et al. (2016) reported that retailers and HoReCa establishments in Oslo's city centre attract a total of between 4.7 shipments (1,777 kg) and 5.3 shipments (2,650 kg) per week.

- ***Other types of freight (non-light freight):*** Delivery of construction materials and equipment to major constructions sites represent a noticeable share of freight trips performed in urban areas. They require intensive utilisation of heavy and specialised freight vehicles (Rodrigue 2013). It was estimated that construction sites generated about 30% of total tonnage in French cities (Dablanc 2011). Furthermore, collection and transport of household and commercial waste to disposal sites and recycling facilities generate a significant amount of freight trips that also require specialised trucks and dedicated pick-up routes (Behrends 2016).

2.2.2. Issues and Negative Impacts of Last Mile Delivery Activities

Restrictions enforced on freight vehicles in urban areas such as time-windows, low emission zones, vehicle weight and size allow local authorities to set required regulations

to reduce negative impacts of freight vehicles (Anderson et al. 2005). However, these restrictions result in severe problems for the operational activities of freight carriers. de Oliveira et al. (2014) argue that the inefficiencies of freight carriers could be attributed to low load utilisation of vehicle capacity, poor traffic accessibility in main roads and high failure rate of deliveries. For instance, it was estimated that the average load factor of vans in urban areas in Europe is less than 30% (Dablanc 2007) while another study reported that more than 20% of freight vehicles drive empty in urban areas in Europe (Kin et al. 2016). Furthermore, freight carriers incur financial losses in terms of waste of resources and unreliable delivery time to due to deteriorated traffic conditions and increasing operational costs to maintain the delivery requirements of receivers (Behrends 2016). Thus, last mile delivery is considered as the most expensive link in the urban freight transport network as its share of the total freight transport cost is 53% whereas it may reach up to 75% in case of online deliveries (Gevaers et al. 2014; Wang et al. 2016).

Increasing movements of freight vehicles negatively affect the liveability and amenity of urban areas as they contribute to negative externalities and issues including traffic accidents, congestion, air pollutions, greenhouse gas (GHG) emissions, noise and visual pollution (Browne et al. 2012; Lindsey et al. 2014; Melo and Baptista 2017). Last mile delivery vehicles are more polluting than line-haul freight vehicles for the same number of tonne-kilometre due to older vehicle age, lower vehicle loads and lower operating speeds and idling (Rodrigue 2013). Furthermore, the significant vehicle-kms that freight vehicles travel between distribution centres in suburban areas to receivers in inner-urban areas in addition to the often necessity to circulate around to find parking result in an additional fuel consumption and traffic congestion (Quak 2007). These freight movements consume almost 30% of the total urban transport energy consumption even though they represent only about 15-20% of vehicle-kilometres (Schoemaker et al. 2006; Duriez 2015). Furthermore, freight vehicles have considerable fuel consumption in highly congested areas when performing multiple stops (Mårtensson 2005).

Different figures were reported in the literature on the negative externalities of last mile delivery. A European study estimated that last mile delivery activities contribute almost 16-50% of the transport-related emissions (Arvidsson and Pazirandeh 2017). Similarly, another European study reported that freight transport contributed about 30% of transport-related nitrogen oxides (NO_x) and 50% of transport-related particulate matter emissions in large European cities (Rodrigue 2013). A Paris-based study indicated that the circulation of freight vehicles contributes an additional 5-10 decibels to the noise level emitted from passenger vehicles. Zanni and Bristow (2010) suggested that LCVs generate 13.3 million tonnes of CO_2 equivalent emissions in London. Additionally, it was estimated that a delivery van generates on average about 21.7 kg of CO_2 for an 80 km delivery trip in large European cities (Edwards et al. 2010). Jaller et al. (2016) reported that while heavy freight vehicles accounted for only 1% of total freight vehicles in Mexico City; however, they contributed about 40% and 45% of PM_{10} and $PM_{2.5}$ emissions, respectively. Russo and Comi (2012) reported that the costs of negative externalities of urban freight transport in Italian cities were more than twice the externalities costs of passenger transport with this figure being six times higher for pollutant externalities.

2.2.3. Stakeholders in Last Mile Delivery

2.2.3.1. Overview of Different Stakeholders Groups

Bjerkan et al. (2014) emphasise that the success of freight improvement solutions is highly influenced by acceptability and responses of all stakeholders involved in last mile delivery. Ballantyne et al. (2013) makes the distinction between actors who directly influence issues and decision-making of last mile delivery and stakeholders who have an interest in freight deliveries and are directly or indirectly affected by their activities. Hensher and Puckett (2004) warn that failure to consider the interactions between the various stakeholders and their preferences in the decision-making of proposed freight transport projects would contribute to erroneous decisions and assessment of their likely success. Hence, Stathopoulos et al. (2011) highlight that it is important for policy makers and transport researchers to appropriately and systematically identify the stakeholders and understand their various viewpoints. The literature on stakeholders in last mile delivery revealed more or less similar categories of stakeholders depending on the local context and background of the freight transport project (Macharis et al. 2014). Quak and Tavasszy (2011) focused on residents, freight carriers, local authorities and receivers whereas Bjerken et al. (2014) identified shippers, freight carriers, local authorities and end-receivers as the main stakeholder groups. However, most recent studies identified five main groups of stakeholders: shippers, receivers, logistics service providers (LSP), local authorities and citizens (Macharis et al. 2014; Behrends 2016; Kin et al. 2016). An emerging sixth stakeholder group, which includes logistics property developers and providers (LPP), has received increasing attention from scholars recently due to their impact on the availability of logistics facilities in urban areas (Rodrigue 2013).

Before attempting to understand the objectives of each stakeholder group, it is necessary to identify the roles of each stakeholder group. Shippers usually coordinate and contract the transport service with freight carriers to deliver their products to the end-receivers (Macharis et al. 2014). The shippers group includes manufacturers, wholesalers and some retailers that send out products. In most cases, shippers not receivers are the agent that is mostly in contact with freight carriers with respect to transport decision-making of the delivery (Dablanc 2011). The end-receivers group is highly diverse and complex due to the different types of commercial, industrial and residential entities involved in last mile delivery. This group includes industrial receivers such factories, commercial receivers such corporations and retailers, public establishments such as government buildings and service receivers such as health, education and hospitality establishments as well home deliveries (Stathopoulos et al. 2011). Shippers and receivers both have direct influence on the size of the shipment and delivery frequency (Behrends 2016).

Alternatively, the logistics service providers (LSPs) group are primarily responsible for coordinating and performing the point-to-point transport of materials and products between the shippers and receivers. This group includes freight carriers and express couriers that carry out the transport activity as well as freight forwarders who organise and contract the delivery service on behalf of shippers (Macharis et al. 2014). LSPs decide the delivery time-window that maximises their efficiency and minimises their transport cost as well as satisfying their customers (the shippers and receivers) (De Jong et al. 2016). Local authorities plan, finance, regulate and monitor the utilisation and traffic management of road infrastructure and on-street loading facilities as well as setting and carrying out land-use planning and allocation of industrial land in urban areas (Quak and Tavasszy 2011). The citizens group represents society in general including residents, workers, shoppers, and visitors (Taniguchi et al. 2003). Logistics property developers and providers have not been discussed as much as the other five stakeholder groups. They

own, develop and lease commercial properties to LSPs to perform their logistics activities (Hesse 2004).

2.2.3.2. Objectives and Conflicts of Stakeholder Groups

Each stakeholder group has its own objectives, which might conflict with some objectives of other stakeholders (Rodrigue 2013). Although some of the stakeholder groups share common interest and concerns, they are more likely to act and operate based on the notion of maximising their benefits independently of other stakeholder groups (Anand et al. 2012). Shippers aim to maintain offering a high service level to their customers – the receivers – through on-time delivery, minimum transport cost, safe delivery of product (Macharis et al. 2014). Moreover, end-receivers look for an attractive urban shopping environment with minimum freight truck nuisances as well as efficient, frequent and convenient deliveries that do not disrupt their operations (Quak and Tavasszy 2011). LSPs aim to minimise the total duration and cost of the delivery to maximise their profits (Taniguchi et al. 2003). Local authorities and citizens aim to enhance the liveability of the urban areas and minimise nuisances (pollution, health and safety hazards and unnecessary traffic flow) (Anand et al. 2012). Furthermore, local authorities focus on providing an attractive business environment to encourage commercial developments and investments (Macharis et al. 2014). Citizens prefer to limit the presence of freight trucks due to their negative impacts on their wellbeing the liveability of urban areas (Taylor 2005). Commercial property developers aim to increase their profit and return on investment as well as minimising damage to property.

Land-use planning and allocation is the arena in which local authorities exert their control and power through regulation and zoning of road infrastructure and industrial land (Behrends 2016). It could be argued that freight land-use has not received as much attention transport research as much as mobility of people (Hall and Hesse 2013). Many authorities instead of attempting to comprehend and determine the operational requirements and challenges of the urban freight industry to supply required industrial land for logistics facilities, they apply the notion of prevent and control when it comes to freight land-use allocation. The efficiencies and operational practices of LSPs' delivery activities are highly influenced by regulations enforced by local authorities. Hence, freight carriers prefer to be more involved in the planning of these policies. When new freight transport projects are proposed, the relationships between the different stakeholder groups typically change to conflict in case of different viewpoints or encountering problems while they change to collaboration in case of reaching agreements and realising that the benefits could be achieved only through cooperation (Rodrigue 2013).

2.2.4. Recent Trends and Challenges Affecting Last Mile Delivery

Recent trends such as the increasing desire for speed in delivery lead time, crowd logistics, environmental measures implemented by local authorities and omni-channel retail have considerably influenced delivery activities and operational practices of freight carriers (Savelsbergh and Van Woensel 2016; Melo and Baptista 2017; Cardenas et al. 2017b). These trends are increasing the frequency and number of express deliveries and fragmentation of shipments, i.e. receiving smaller parcels rather than a large weekly delivery (Cepolina and Farina 2015). More freight vehicles are required to perform these express and frequent low-weight deliveries, which result in more freight movements on

local roads (Kin et al. 2018). Allen et al. (2018a) underline that growth of B2C and C2C deliveries contribute to higher operational costs and lower profits for freight carriers compared to B2B as B2C and C2C deliveries are associated with higher failure rates and small packages to individual consumers.

Many large retailers also apply omni-channel fulfilment strategies to provide integrated availability and visibility across all retail channels as customers are increasingly making shopping and product pickup decisions simultaneously inside the store and online (Piotrowicz and Cuthbertson 2014). These strategies allow quick click and collect options as well as same- or next-day delivery options, which push retailers and freight carriers to ensure efficient and quick delivery turnaround between stores and distribution centres. Due to the increasing demand for speed in deliveries, freight carriers started offering different time-windows for express and guaranteed delivery to customers especially for B2C and C2C deliveries. For instance, a UK-based report highlighted that more than 10% of retailers offer six different delivery time-window options for online shoppers with more than 36% of deliveries sent for next-day delivery time-window (IMRG and Metapack 2016). Furthermore, the 'free' delivery offered by many retailers places more pressure on freight carriers to offer cheaper and cost-competitive delivery services. Moreover, many retailers offer their customers free product return for online purchases as almost 50-75% of product returns in the UK were paid by online retailers (Allen et al. 2018a).

In Crowd logistics, which builds on crowdsourcing and the sharing economy, an online platform acts as a mediator that coordinates demand and supply for transport services and matches shippers and receivers with qualified individuals and businesses to conduct the transport service (Mehmann et al. 2015). They significantly expedite the speed of delivery compared to traditional couriers. Moreover, failed deliveries adversely impact the efficiency and transport costs of couriers as drivers return multiple times to successfully complete the delivery (Kim et al. 2018). The rate of successful deliveries on first attempt for B2B deliveries is higher compared to B2C as home deliveries often require multiple attempts due to unavailability of consumers at home (Allen et al. 2018b). A London-based revealed that 13-14% of all online purchase deliveries in the UK arrived either late or when the resident was not at home, which resulted in £771 million additional costs for retailers and carriers (IMRG 2014). The rate of failure for parcel deliveries in Netherlands and Belgium is 25% and 14% respectively (Buldeo Rai et al. 2018).

Bates et al. (2018b) caution that these trends and challenges are adversely impacting the efficacy of freight carriers to balance between managing a profitable business in the low-margin and highly competitive urban freight industry and consumers' desire for cheap and express delivery. Saskia et al. (2016) warn that express delivery services make coordination and consolidation of delivery loads more challenging for freight carriers as the location of storage facility becomes a very critical in their success to offer cost-competitive and efficient delivery services. Thus, these new operational requirements and competition might compel traditional logistics companies to consider adding a newer layer of small-scale logistics facilities that are geographically much closer to the consumers inside inner urban areas to minimise the delivery lead time.

2.3. Freight Consolidation Initiatives and Schemes

2.3.1. Overview of Measures and Policies to Enhance Last Mile Delivery

Various solutions and policies have been trialled and implemented by local authorities and transport researchers to alleviate the negative impacts of last mile delivery activities in urban areas with various degrees of success and failure. Many of the implemented measures and solutions are influenced by the city logistics domain. City logistics attempts to totally optimise the logistics and transport activities of freight carriers and minimise the nuisances associated with freight transport while supporting the economic and social development of cities through the focus on mobility, sustainability and liveability in urban areas (Taniguchi et al. 1999).

Most measures and policies have been trialled and implemented in various urban areas throughout Europe and Japan with some cases in North America. Several authors have classified these measures according to various aspects. Holguín-Veras et al. (2016a) classified freight solutions and measures into seven main categories: *infrastructure management* initiatives which focus on improving freight infrastructure such as road and facilities; *parking/loading area management* measures which aim to improve use of urban spaces for delivery such as booking schemes; *vehicle-related strategies* which attempt to set regulations to utilise eco-friendly vehicles and minimise externalities created by freight trucks*; traffic management initiatives* which focus on setting policies that improve the mobility and traffic conditions such as access restrictions; *pricing schemes* which attempt to foster better use of road infrastructure and generate revenue such as congestion pricing, *logistics management* which aims to enhance the efficiency of logistics activities such as an urban consolidation centre (UCC) or intelligent transport systems (ITS); and *freight demand management policies* which seek to modify the freight demand at receivers by changing their destination, frequency and time.

In recent years, there have been an increasing number of trials and experiments especially in Europe to utilise eco-friendly freight vehicles primarily LCVs and cargobikes for last mile delivery (Quak et al. 2016). There are several vehicle technologies for eco-friendly LCVs including battery electric, hybrid electric and natural gas-powered delivery vans (Pelletier et al. 2016). The near zero or zero-emission vehicle technologies and alternative fuels of these sustainable delivery fleet options enable negative issues and externalities of last mile delivery including emissions, noise, fuel and energy consumption and infrastructure degradation to be addressed (Quak et al. 2016; Juan et al. 2016). These benefits facilitate improved energy efficiency, improved mobility, enhanced quality of life, minimised environmental impacts; minimised running and maintenance costs and lowered total costs of ownership (Cagliano et al. 2017; Wątróbski et al. 2017; Melo and Baptista 2017). However, the main concerns of battery electric LCVs (BEV) are the high purchase cost, limited driving range due to restricted capacity of the on-board electric battery, inconvenience of the charging time, and limited payload (Juan et al. 2016). Alternatively, Tipagornwong and Figliozzi (2014) proposed that electrically-assisted cargobikes could also be effective in congested and dense inner urban areas due to their eco-friendliness, smaller size, easy access and manoeuvrability.

Various research studies have assessed the potential and merits of using electric delivery vans and cargobikes to address negative impacts of last mile delivery. Giordano et al. (2018) developed an economic and environmental model that compared BEV and diesel delivery vans in several European cities. They indicated that BEVs could be more cost-

effective than diesel vans especially in cities with high government subsidies for BEV and estimated that replacing new diesel vans with BEVs could achieve a 12–13% reduction in CO_2 emissions. Similarly, the two-echelon city distribution scheme developed by Anderluh et al. (2017) illustrated that the combined use of delivery vans and cargobikes to perform deliveries in central Vienna, Austria could achieve reductions in costs and emissions in some settings compared with vans alone. Alternatively, the traffic simulation model developed by Melo and Baptista (2017) estimated that up to 10% of delivery vans could be replaced by cargobikes to conduct last mile delivery with a maximum linear distance of 2 km.

Furthermore, one commonly discussed and implemented solution in the context of city logistics is the freight consolidation initiative through an urban consolidation centre (UCC) (Janjevic and Ndiaye 2017). This solution attempts to provide freight carriers with a consolidation facility usually located in suburban parts of the city to consolidate deliveries to their receivers (Browne et al. 2005). The goods are bundled at the facility, and consolidated shipments are carried out using neutral trucks in subsequent deliveries to receivers. The UCC concept attempts to increase the load utilisation of delivery vehicles, minimise the total travelled distance per parcel and offer value-added and retailing services to receivers (Allen et al. 2014). These benefits contribute to reducing the number of freight vehicles, improving the delivery reliability and enhancing the efficiency of freight carriers (Quak and Tavasszy 2011). Lowering the number of freight vehicles and reducing the total transport distance per parcel contribute to reductions in negative environmental emissions especially with the use of eco-friendly freight vehicles (Browne et al. 2011). Several terms are used in the literature to label the freight consolidation facilities besides the UCC term including urban distribution centre (UDC), freight consolidation centre and public logistics terminal (Teo et al. 2015). The UCC concept has been trialled and established in several European and Japanese cities due to their highly dense and congested inner urban areas (Lin et al. 2016).

Most city logistics measures and solutions have targeted improvements in the freight carrier's operations and practices. However, Holguín-Veras et al. (2016a) suggested a different approach to look at the freight demand of receivers. They underline the notion that freight demand is different from freight traffic and this necessitates a completely different approach to address its issues. While freight traffic constitutes the transportation and flow of freight vehicles to transport the goods, freight demand represents the freight generation and attraction of goods by commercial establishments and individuals. Altering freight traffic through measures such as introducing tolls on roads might not induce behavioural change in the freight demand of receivers to change the timing or destination of deliveries. Freight demand management (FDM) policies build on this notion and the market powers of receivers over freight carriers and shippers to foster behavioural changes that can modify freight demand at receivers to address negative impacts of last mile delivery. Holguín-Veras et al. (2015) and Holguín-Veras and Sánchez-Díaz (2016) recommended that instead of focusing only on freight carriers to enhance last mile delivery, FDM initiatives should be considered due to the power that receivers exert on delivery requirements.

FDM initiatives attempt to encourage changes in freight demand at receivers by modifying the destination, timing and frequency of deliveries (Holguín-Veras and Sánchez-Díaz 2016). Some of the FDM initiatives include re-timing deliveries to off-peak

hours (OHD), spreading deliveries throughout the day and Receiver-Led Delivery Consolidation (RLC) schemes to encourage receivers to consolidate deliveries from different suppliers (Holguín Veras et al. 2016b). In their assessment of 48 freight measures, Holguín-Veras et al. (2018) reported that FDM measures facilitate considerable reduction in congestion and delivery costs as well as emissions reduction compared with other financial and logistical management solutions. OHD policies aim to shift deliveries from regular business hours to only off-peak hours with or without the presence of staff at the receiving establishment (Holguín-Veras and Aros-Vera 2015). For instance, the pilot test of a OHD initiative in São Paulo, Brazil and Bogotá, Columbia illustrated that a full switch to OHD (7 PM-6AM) would contribute to 45-67% emission reductions while partial OHD (6PM-10PM) would lead to 13% emission reductions compared with deliveries during normal business hours (Holguín-Veras et al. 2016b).

2.3.2. Locations and Main Initiators of Freight Consolidation Facilities

Table 2.1 displays the main categories of consolidation facilities based on their location and geographical focus in the urban area. Allen et al. (2012b) suggested that site-specific and construction UCCs might be less challenging to establish and operate as the decision-making and coordination of deliveries to these sites could be organised by a single entity rather than city-based UCCs where the decision-making of deliveries undergo through various freight carriers. Triantafyllou et al. (2014) highlighted that the location of a UCC and the transport distance to receivers play an important role in the type of the freight vehicles used by the UCC. Lewis et al. (2007) reported that older UCCs depended on trucks and vans as 25-40% of the final leg of the delivery was performed by rigid trucks while vans and articulated trucks were each used in the range of 17-25%. It is worth nothing that many of the heavy trucks were utilised in UCCs serving large commercial sites away from the city centre. On the other hand, recent UCCs have been utilising eco-friendly delivery vans (Browne et al. 2011).

Table 2.1. Main Locations and Catchment Areas of UCCs (Browne et al. 2005; Gonzalez-Feliu et al. 2014a)

Category	Scope and Coverage	Examples	Remarks
City-based UCC	- Serve all or parts of urban area. - Aim to reduce trucks from entering city centre.	- Elcidis UCC, La Rochelle, France. - Monaco UCC. - Cityporto UCC, Padua, Italy	- Many cases either served small cities or were established in suburban parts of the city. - Some cases involved truck ban that made the UCC initiative more favourable. - 24 cases (Out of 34) of UCCs in France and Italy (Gonzalez-Feliu et al. 2014a). - 85% of UCCs in Europe (total of 114

			cases) (Allen et al. 2012b).
Site-Specific UCC	- Serve a large commercial site that is controlled by single entity or landlord such a shopping centre or an airport.	- Bristol UCC, Bristol, UK. - Meadowhall Shopping Centre UCC, Sheffield, UK. Heathrow Airport UCC, London.	- Many cases all deliveries were performed by the UCC operator. - Few cases of voluntary participation.
Construction UCC	Coordinate and Manage deliveries of construction materials to large construction projects.	- London Construction UCC - Hammerby Construction UCC, Stockholm, Sweden	- Closed down after completion of the projects.

There are primarily two steering structures and financing schemes with respect to the main initiator of freight consolidation facilities (Allen et al. 2014). The first type is based on direct steering structure by local authorities in order to address the negative impacts of last mile delivery (Van Duin 2009). Local authorities worked with freight carriers and shippers in many of these public-initiated consolidation facilities. The majority of the public-initiated facilities belong to the city-based UCC category such as Monaco UCC and Padua UCC. The second type is the private-initiated consolidation facilities where a private entity establishes a facility to consolidate deliveries to a large commercial site or the last leg of the express parcel deliveries (Dablanc et al. 2011). Most of the private-initiated consolidation facilities are site-specific UCCs such as the Meadowhall UCC although there are some few cases of city-based UCC such as Aachen UCC, Germany or Chronopost Urban Logistics Space (ULS) in Paris (Panero et al. 2011). Gonzalez-Feliu et al. (2014a) highlighted that most UCCs in France and Italy were established by local authorities (24 UCCs) while 10 UCCs were established by private operators, which were mainly express parcel facilities. However, Lagorio et al. (2016b) reported that only 8% of the evaluated UCCs in Europe (total of 83 cases) were privately initiated facilities.

With respect to the type of government support, Lebeau et al. (2017) highlighted that there were two primary categories of government support provided to 61 cases of consolidation initiatives in Europe and Japan: financial and regulatory support measures. The financial support category included start-up subsidies to finance the initiation of the facility whether fully or partially until it reached self-sustaining status and structural support measures such as favourable public loans, provision of public infrastructure and public subsidies to cover the facility operational costs. In contrast, the regulatory support category included direct regulatory measures such as favourable measures to the facility operator including extended time-window or access to priority lanes. It also included measures such as developing a license system to enforce other freight carriers to comply with sustainable practices or transfer their deliveries in the city to the consolidation facility. Alternatively, indirect regulatory measures that were enforced by local authorities to regulate the access of freight vehicles in the city such as access time-window contributed indirectly to the success of many consolidation facilities as they supported their access to the city compared to other freight carriers.

2.3.3. Types of Freight Consolidation Policies

2.3.3.1. Main Organisational Setup of Freight Consolidation Policies

There are two organisational setups or primary stakeholder leaders for consolidation initiatives, which are carrier-focused or receiver-led consolidation strategies (Holguín-Veras and Sánchez-Díaz 2016). In carrier-led consolidation initiatives, there are various operational structures and users for the consolidation facility whether a single-carrier or multiple-carriers that utilise the facility to sort and distribute their parcels to receivers (Leonardi 2017). Multi-carrier operated consolidation facilities are somewhat problematic as the consolidation initiative requires collaboration among freight carriers, which is very difficult due to market competition between freight carriers (Estrada and Roca-Riu 2017). Janjevic et al. (2016) and Lagorio et al. (2016b) emphasised that most previous freight consolidation policies have focused primarily on freight carriers in the planning and decision-making to initiate and coordinate the effort to consolidate deliveries to goods receivers. Furthermore, many previous carriers-focused UCCs have focused on a single area or site in the urban areas or involved a large freight carrier.

Paddeu (2018) warn that freight policies that focus only on freight carriers might not be very effective as they assume that carriers have the power to dictate delivery practices and overlook the delivery requirements imposed by shippers and receivers. Accordingly, the receiver-led delivery consolidation (RLC) strategy attempts to lower the number of deliveries by motivating the receivers to consolidate their deliveries from multiple freight carriers (Holguín-Veras and Sánchez-Díaz 2016). Receivers could capitalise on shippers' priority, i.e. satisfying and offering high service level to the receivers, to exercise market power and influence changes to delivery practices for their shipments. Freight consolidation initiatives involve changing the delivery destination, albeit temporary. Thus, it is important to involve receivers to foster their willingness to change the delivery destination of their parcels through the consolidation facility.

2.3.3.2. Receiver-Led Delivery Consolidation (RLC) Policy

The RLC policy primarily promotes two initiatives to reduce the number of deliveries to receivers. The first initiative attempts to induce receivers to request their freight carriers to transfer their parcels to an alternative location such as a UCC where their orders are bundled and delivered in consolidated loads to their businesses (Holguín-Veras and Sánchez-Díaz 2016). This initiative requires setting up a physical facility to receive, sort and perform the consolidated deliveries and builds on the receivers' market power. This initiative could be seen as a receiver-engaged initiative and a management policy of an UCC. Alternatively, the second initiative focuses on large commercial establishments and buildings to understand their freight needs and formulates a delivery service plan (DSP) to efficiently coordinate and manage deliveries to the receivers inside the establishment or building (Transport for London 2013; Jaller et al. 2015). This initiative does not require substantial infrastructural changes to the delivery destinations of the receives. Jaller et al. (2015) argue that establishing a centralised staging area in large commercial establishments facilitate receiving deliveries without time constraints and enable consolidating the deliveries to various receivers in the building. Holguín-Veras and Sánchez-Díaz (2016) suggest that RLC initiatives might offer the highest benefits compared with other FDM initiatives. Johansson and Björklund (2017) argue that

receivers might benefit the most from freight consolidation policies compared to other stakeholder groups. Moreover, Holguín-Veras et al. (2016a) emphasise that RLC initiatives could facilitate minimising disruption to businesses due to frequent and conflicting deliveries made by multiple freight carriers, reduce number of freight vehicle movements and enhance the amenity of shopping environment for citizens and businesses. For instance, Holguín-Veras and Sánchez-Díaz (2016) estimated that establishing a RLC scheme in Manhattan, New York would potentially contribute to a reduction of 6.4-14.0% in truck traffic, 33,445-104,255 miles in vehicle-miles travelled and $USD 57-100 million per year in economic benefits.

There have been very few implemented receiver-focused freight consolidation initiatives in Japan and Europe. For example, the Motomachi joint delivery system using a consolidation facility has been successful since starting in 2004 in a busy shopping street in Motomachi, Yokohama City. A neutral freight carrier has been delivering about 1,000-1,200 parcels using CNG trucks to 500 retail shops and 850 homes instead of 20 different freight carriers (Taniguchi 2014). Another successful solution is the Binnenstadservice (BSS), which focused on independent retailers in Nijmegen, Netherlands, to offer consolidated delivery services for their orders through a privately-operated consolidation facility as well as additional value-added services such as storage, home deliveries and product returns (Van Rooijen and Quak 2010). The retailers pay a membership fee and a delivery fee for the BSS to deliver their orders from the consolidation centre to their stores using compressed natural gas trucks and electric cargobikes (Van Duin et al. 2016). The BSS service facilitated efficient and reliable deliveries to the retailer as well as a reduction in the number of vehicle-kms and emissions. The consolidated delivery service was extended to 15 other cities in the Netherlands (Björklund et al. 2017). Alternatively, the DSP concept was tested at the Palestra Building in London to consolidate cargo to receivers in the building. It achieved a 20% reduction in total number of deliveries to businesses in the building (Transport for London 2013). Overall, engaging receivers in consolidation initiatives and projects have not been commonly applied or discussed by local authorities and transport researchers as much as the heavily engaged freight carriers.

2.3.4. Logistics Activities and Products Targeted by Freight Consolidation Facilities

Besides the consolidated delivery service, consolidation facilities could offer various logistics services to freight carriers and receivers. They offer *cross-docking services* for participating freight carriers to bring in their goods into the facility during the night or *stockholding services* for short-time transfer of inventory for future deliveries (Triantafyllou et al. 2014). Furthermore, some consolidation facilities offer *pre-retailing* and *in-store services* to receivers such as product quality check, unpacking of product, product preparation for display, waste collection, inventory management and temporary storage (Benjelloun et al. 2010; Allen et al. 2014). Lebeau et al. (2017) suggest that consolidation facilities could be utilised as a platform to promote other city logistics concepts that might be risky due to inefficient infrastructure such as off-peak deliveries to retailers, reverse logistics services and deliveries using soft-transport modes.

Van Duin (2009) underlines that consolidation schemes may not be suitable for all types of goods. The consolidation facility operator may have operational difficulties bundling different products due to conflicting handling and storage practices as well as the

receivers' delivery requirements (Browne et al. 2005). Thus, many operational consolidation facilities have focused on parcel deliveries in their early stages to reduce transshipment costs and the necessity for specialised handling (Panero et al. 2011). Janjevic et al. (2016) highlighted that the literature on the most suitable types of products for consolidated deliveries is not quite developed and is mostly scattered. Based on the retailers using the Bristol UCC, Hapgood (2005) reported that the most suitable products for the UCC were non-perishable, medium size and low to average value. Alternatively, Marcucci and Danielis (2008) expressed that clothing and other specialised goods were more suitable for the UCC, whereas food deliveries were least suitable based on retailers in Fano, Italy. Similarly, Danielis et al. (2010) highlighted that clothing and footwear deliveries could be suitable while pharmaceutical products and fresh food deliveries would not be suitable for consolidated deliveries. However, Holguín-Veras et al. (2008) suggested that food carriers, chemical carriers and household good carriers might find consolidation facilities suitable for their products in Manhattan and Brooklyn, New York.

2.3.5. Financial Viability of Freight Consolidation Facilities

According to Björklund et al. (2017), most emphasis in previous studies of freight consolidation policies has been on the operational, social and environmental suitability of the consolidation facility rather than on the business and financial aspects. Janjevic and Ndiaye (2017a) warn that while many previous studies evaluated the consolidation initiative concept from different aspects; however, transport researchers have not paid similar attention to quantifying the costs of consolidated deliveries and potential gains by the consolidation facility users. Björklund and Johansson (2018) point out that while a large number of studies underline the importance of reaching economies of scale for the facility to be financially viable; nevertheless, previous studies discussed this notion mostly using qualitative analysis and only few studies have attempted to determine threshold values of the freight demand to achieve financial viability, i.e. self-sustaining status. Triantafyllou et al. (2014) indicate that reaching financial viability of site-specific UCCs might be more achievable than a city-based UCC as the single management could finance the UCC and get back some of their investment from other users compared to a city-based UCC where it might be more difficult to distribute the costs across different types of agents.

Several studies in the literature have performed an evaluation of existing UCCs especially in Europe to explore their economic effectiveness. In their evaluation of five cases of freight consolidation solutions in Europe, Björklund et al. (2017) reported that consolidating the deliveries of municipality procurements in Eskilstuna and Osterlen in Sweden as well as the Binnenstadservice service in the Netherlands were financially viable. Van Duin et al. (2016) presented an analytical framework to describe how three operational UCCs in Europe were able to be viable and how they created value to their users, which were the BSS service, the Bristol-Bath UCC and the London Regent Street UCC. However, many studies in the literature have not incorporated detailed cost estimates of the operations of the consolidation facility in their assessment of the financial viability of the facility. As many of the evaluated UCCs in these studies received government subsidies especially during the start-up phase, there might be doubts on the suggested financial viability of these facilities especially with there being no reporting of the full cost breakdown of the consolidated deliveries and the total revenue received from users.

2.3.6. Assessment of Existing Freight Consolidation Facilities

2.3.6.1. Success Factors of Operational Freight Consolidation Facilities

While many trialled or implemented consolidation facilities have failed due to various reasons as highlighted by Vahrenkamp and Berlin (2016); however, there are many operational and successful facilities especially in Europe and Japan. Gonzalez-Feliu et al. (2014a) indicated that out of the 34 UCCs in France and Italy, about 23 UCCs are still active. Similarly, Lagorio et al. (2016b) reported that out of the 83 evaluated UCCs in Europe, about 26% of them are still in operation. Conversely, Allen et al. (2012b) highlighted that only 12 UCCs were still active out of more than 100 UCCs in Europe. Van Duin et al. (2012) and Gonzalez-Feliu et al. (2014b) argue that consolidation facilities could still be successful with more emphasis on the factors that impact their suitability and an improved understanding of interactions between the various stakeholders involved in last mile delivery.

Various studies evaluated the aspects and factors that played important roles in the success of operational consolidation facilities. Panero et al. (2011) and Taniguchi (2014) underlined the influence of organisational aspects such as leadership, government support and stakeholder involvement as well as operational factors such as facility location on the efficiency of UCCs. Browne et al. (2005) highlighted that operational aspects such high congestion problems and delivery issues in the area of the UCC as well as a single operator of the facility could highly contribute to a successful UCC. Teo et al. (2015) indicated that public support and good organisational leadership contributed to successful implementations of Cityport in Padua and Motomachi joint delivery scheme in Yokohama. Taniguchi (2014) and Van Duin et al. (2016) highlighted that involvement of retailers in the Motomachi and Binnenstadservice consolidation initiatives played a significant role in their success as retailers were instrumental in covering major costs through delivery service fees and strong participation. Van Duin et al. (2012) emphasised the importance of public subsidies on the UCC profitability and its likely success. Allen et al. (2012b) pointed out that the UCC scheme must deliver cost gains and operational benefits for freight carriers to foster their participation. Nordtømme et al. (2015) argued that financial concerns and stakeholder acceptability have a high influence on participation of freight carriers in consolidation policies. Based on their evaluations of several UCCs in Europe, Björklund et al. (2017) highlighted the following as critical factors for viable consolidation facilities: ability to scale up to reach economies of scale, adaptability to changing operational and customer environment, ability to offer new services and logistics competence to access potential value streams.

The literature included different figures on the delivered benefits of successful consolidation facilities. Bristol UCC, which operates two large trucks to deliver goods to 300 retailers in Broadmead Shopping Centre, achieved a reduction of 75% in vehicle kilometres, 89 tonnes of CO_2 and 1,000 kg of NOx emissions (Allen et al. 2014). Similarly, a UCC project in Antwerp, Belgium achieved a 22% reduction in total travelled distance and 36% reduction in fuel consumption using a fleet of 8-tonne rigid trucks (Kin et al. 2016). However, the UCC was not financially viable due to the lower number of orders and high start-up costs. The Medowhall UCC, which performs consolidated deliveries to 180 retailers in Meadowhall Shopping Centre in Sheffield, achieved a 65% reduction in number of deliveries using two 7.5 tonne trucks (Allen et al. 2014). It is

worth noting that the majority of these UCCs were established in suburban parts of the metropolitan area. Conversely, the Shinjuku Matenro Staff UCC was established in 1992 in a major commercial and administrative centre in Tokyo (Taniguchi and Qureshi 2018). Four CNG trucks perform daily consolidated deliveries to loading bays of more than 20 high-rise buildings with an annual volume of 500,000 packages. It was estimated that the Shinjuku Matenro Staff UCC reduced daily freight trips from 60-70 trips to only 16 trips (TURBLOG 2011).

2.3.6.2. Reasons Contributing to the Failure of Freight Consolidation Facilities

Allen et al. (2012b) reported that majority of the UCC projects in Europe had a short life and success. Table 2.2 provides a synthesis of the main factors and aspects that contributed to the failure of various consolidation initiatives. Vahrenkamp and Berlin (2016) argued that key determinants for the failure of various UCCs in Europe resulted from the problem that the acquired benefits from participation for users were much less than the costs of the consolidated deliveries as well as the limited scale of deliveries into the city that UCCs could target due to their operational constraints. Verlinde et al. (2012) suggested that many previous UCCs were more aimed to optimise the load of delivery vans than focusing on the economic and operational competitiveness of freight carriers. Van Amstel (2015) indicated that many city logistics projects and UCCs in particular have failed in Europe due to the extra cost the new concept have added to freight carriers. Quak and Tavasszy (2011) and Quak et al. (2014) warned that many initiatives did not assess the financial viability of the consolidation facility in the early stages of planning.

Moreover, Suksri and Raicu (2012) argued that several consolidation initiatives failed to become successful in real-life context because these initiatives did not focus on the objectives of all the stakeholders early in the planning and decision-making process. It could be argued that some previous freight policies were proposed based on erroneous assumptions on the preferences of the stakeholders as well as their current practices and operational challenges. This contributed to the failure of some proposed solutions as they were irrelevant and impractical to the actual practices and requirements of freight carriers. Bjerkan et al. (2014) stressed that stakeholders would accept and cooperate with implemented measures and policies if they don't impose negative outcomes on their objectives and operations.

Table 2.2. Main Factors that Contributed to the Failure of Previous Consolidation Initiatives

Factor	**Studies**	**Remarks**
Lack of Consideration for Objectives of All Stakeholders	Suksri and Raicu 2012; Macharis and Verlinde (2012); Bjerkan et al. 2014; Lagorio et al. 2016b.	- Various consolidation initiatives favoured objectives of dominant stakeholders or even ignored incorporating the objectives of all stakeholders.
Lack of Focus on Operational Requirements	- Verlinde et al. 2012; Vahrenkamp and Berlin 2016; Lagorio et al. 2016b; Simoni et al.	- Limited attention to the facility operator and the logistics management and efficiency of their consolidated deliveries.

	2018; Björklund and Johansson 2018.	- Inappropriate selection and configuration of delivery fleet and operational practices.
Failure to Assess Long-Term Financial Viability of Concept	Van Duin et al. 2010; Quak and Tavasszy 2011; Van Duin et al. 2012; Quak et al. 2014; Zenezini et al. (2015; Vahrenkamp and Berlin 2016; Lagorio et al. 2016b.	- Failure to approach the freight consolidation initiative from a business-oriented perspective. - Limited attention to cost analysis and attractiveness of the initiative - High dependence on government subsidies.
High set-up and operational costs	Allen et al. 2014; Van Amstel 2015; Lagorio et al. 2016b; Estrada and Roca-Riu 2017; Janjevic and Ndiaye 2017a.	- Bundling the parcels through the consolidation facility contribute to additional transshipment and distribution costs.
Low demand of consolidated deliveries	Triantafyllou et al. 2014; Allen et al. 2014; Vahrenkamp and Berlin 2016; Lagorio et al. 2016b.	- Difficulty to attract wide participation by freight carriers.

2.4. Modelling and Evaluation Approaches of Freight Consolidation Facilities

2.4.1. Multi-criteria Evaluation Methods of Freight Transport Policies

In order to support policy makers in decision-making of new freight transport solutions, it is essential to perform a systematic and comprehensive assessment of all aspects associated with the solution. This evaluation could be performed during different stages of the life cycle of the project. Transport researchers have utilised various evaluation methods for planning, decision-making and assessment of freight projects including cost-effectiveness analysis (CEA), cost-benefit analysis (CBA), economic-effect analysis (EEA), economic impact analysis (EIA), social cost-benefit analysis (SCBA) and multi-criteria decision-making (MCDM) (Macharis et al. 2009). Macharis et al. (2012) argue that while the CEA, CBA, EEA, EIA approaches might have some merits; however, they fail to consider the different viewpoints of the stakeholders and limit the evaluation to mostly monetary values, which could be problematic for unmeasurable objectives in transport projects. In contrast, the MCDM method assists decision makers in evaluating and selecting the best option among several, often competing, alternatives of the transport solution based on different decision criteria (Aruldoss et al. 2013).

MCDM methods provide a structured decision support framework for considering the different opinions among multiple decision makers regarding the specific criteria or alternatives that should be evaluated (Banville et al. 1998). In MCDM methods, the following steps are conducted to evaluate the transport project: problem definition, developing the alternatives, identifying the criteria and determining their priority weights, performing the evaluation of the alternatives and finally the implementation of the best alternative (Macharis 2007). In their evaluation of MCDM in transport fields, Macharis

and Bernardini (2015) highlighted that the most prevalent approaches were the Analytic Hierarchical Process (AHP), Analytic Network Process (ANP), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), ELimination and Choice Expressing Reality (ELECTRE) and Multi-Actor Multi-Criteria Analysis (MAMCA).

The AHP method, which was introduced by Saaty (1980), structures the decision problem into a hierarchy and applies a system of pairwise comparison of the decision criteria to determine their weights. This method applies the mathematical techniques of eigenvectors and eigenvalues to determine the weight of each criterion (Macharis et al. 2014). Alternatively, the TOPSIS method, which was developed by Hwang and Yoon (1981), is based on the concept that the optimal alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). The PIS is the solution that maximises benefit decision criteria of the transport policy and minimises the cost criteria while the NIS is the solution that maximises the cost criteria and minimises the benefit criteria. This approach has been successfully applied in many transport studies due to its ease of use and simple computations especially with large number of alternatives and decision criteria as well as providing robust ranking of the alternatives (Özcan et al. 2011; Liao and Kao 2011). The PROMETHEE method, which was developed by Brans and Vincke (1985) and later improved by Macharis et al. (1998), is an outranking method that provides a ranking of alternatives based on a set of criteria. It is based on the calculation of a preference degree, which indicates how an alternative is preferred over another alternative from the decision-maker's point of view. The results are expressed by the preference functions, which calculate the difference between the assessment of each two alternatives and provide the preference degree from zero to one (Hadavi et al. 2016). Zero indicates that there is no difference between the pair of the alternatives while 1 indicates a big difference.

The MAMCA approach, which is an extension of the traditional MCDM, has been used extensively in the evaluation of freight transport projects in many European cities with valuable insights. One of the strengths of the MAMCA approach is that it permits every stakeholder group to have their own unique objectives in the analysis whereas the objectives are the same for all stakeholder groups in other MCDM techniques (Roukouni et al. 2018). Unlike other evaluation methods, the MAMCA approach incorporates the objectives and views of all stakeholders not only in the early stages of planning; but also, throughout the whole evaluation process (Macharis et al. 2014). The MAMCA approach organises the engagement and consultation of stakeholders in a structured and integrated approach to produce suitable and practical outcomes (Macharis and Bernardini 2015). It enables conducting the evaluation of alternatives of the freight transport solutions per each stakeholder group in addition to the aggregated evaluation for the multi-actor views. This produces evaluation results for each stakeholder group, which could be used to identify the alternative that might be supported the most by all groups.

There are various approaches to determine the decision criteria weights in multi-criteria analysis including 100-point allocation, equal weights or pairwise comparison techniques (AHP or ANP) (Macharis et al. 2009). Involving key stakeholders to obtain the priority weights for the decision criteria provides valuable insights and relevant views about the perspectives of these stakeholders. The Fuzzy AHP method, which was developed by Van Laarhoven and Pedrycz (1983), complements the conventional AHP method by

incorporating fuzzy sets in the pairwise comparison to address the uncertainty associated with conventional AHP (Beskese et al. 2015). This method enables acquiring viewpoints of stakeholders on the decision criteria. Using the Fuzzy AHP method, each set of two criteria are paired and evaluated one-on-one using a linguistic verbal scale. This process is repeated to pair each criterion with all other criteria to create an evaluation matrix. There are several existing techniques of the F-AHP method for the prioritisation of the criteria weights including Chang Extent Analysis (1992) and Buckley (1985) approaches.

2.4.2. Freight Behavioural Modelling

2.4.2.1. Overview of Freight Behavioural Research

Marcucci and Gatta (2017) emphasise that in order for freight policies to be successful and foster the required behavioural changes, the preferences of the main stakeholders should be taken into consideration. dell'Olio et al. (2017) urge that more freight behavioural research is required to appraise the responses of receivers as many previous freight policies were implemented without solid understanding of the interactions and power levels within the local freight industry. Lack of understanding of the interactions and market powers between the various stakeholders as well as failing to appraise the likely responses to proposed policies could lead to ineffective and rejected policies (Holguín-Veras et al. 2014). Hence, Marcucci and Gatta (2017) suggest this oversight by local authorities to consider the asymmetric power relations among stakeholders made their efforts to alleviate last mile delivery problems unsuitable and counterproductive. This has been demonstrated by the failure of various public interventions arising from freight policies to regulate and force freight carriers to change their operational practices.

Gatta and Marcucci (2014) advocate that freight behavioural research facilitates overcoming these issues by collecting stated preferences and utilising behavioural models to elucidate stakeholders' behavioural responses to policies and appraise their likely adoption. Stated preference (SP) data is considered ex-ante information that indicates how an entity may respond to choices in hypothetical transport decisions. SP data facilitates evaluating the impact of new transport policy or alternatives before they are implemented by asking individuals or organisations to indicate their attitudes and preferences regarding a finite set of alternatives in a discrete choice experiment (DCE) (Ben-Akiva et al. 1994). Based on the concept of random utility theory (RUT), DCEs enable researchers to predict behaviour of individuals based on individual choice behaviour theory over sets of hypothetical choices of transport solutions and assess the significance of attributes based on the individual's preferences (Ben-Akiva and Lerman 1985). RUT assumes when an individual selects a choice within a choice set, they select the choice that maximises their latent utility (benefit). The utility of the alternative depends on utilities associated with its composing attributes and attribute levels (Louviere et al. 2000).

The design of the SP survey using a discrete choice experiment involves setting out the relevant attributes of the alternatives that would be compared in the choice scenarios and identifying the number of levels (range of values) for each attribute (Louviere et al. 2008). Each alternative is characterised by several attributes that describe the transport solution under investigation. The DCE determines how to best allocate the attribute levels in the decision matrix that present the choice scenarios in the stated-preference survey (Hensher et al. 2005). Consequently, different combinations of the attributes' values are selected

for each alternative that are mixed in choice scenarios and presented to the respondent for evaluation and selection (Bliemer and Rose 2009).

2.4.2.2. Overview of Receiver-focused Freight Behavioural Research

Several studies have collected behavioural responses towards freight policies using stated preference surveys to evaluate the stakeholders' preferences, mainly freight carriers such as Holguín-Veras et al. (2008); Marcucci et al. (2012); Stathopoulos et al. (2012) or Marcucci et al. (2015) as well as receivers such as Holguín-Veras et al. (2007); Holguín-Veras and Sánchez-Díaz (2016); dell'Olio et al. (2017) or Marcucci and Gatta (2017). Holguín-Veras et al. (2015) indicate that freight policies that induce behavioural changes in receivers would contribute to fostering behavioural changes on freight carriers as they usually strive to conform to the freight demand generated by the receivers. Gatta et al. (2017) argue that while there might be a large number of recent freight behavioural studies, the field could be still understudied especially for receivers compared with other empirical and modelling studies. Paddeu (2018) suggests that the somewhat limited knowledge of the factors impacting receivers' choice of delivery makes it difficult for policymakers to design and implement suitable freight policies that effectively influence receivers' behaviours. Table 2.3 presents a summary of the relevant freight behavioural studies that collected stated preferences from receivers to evaluate their behavioural preferences towards different FDM policies. The synthesis of the main findings provides valuable insights into the main variables that influence the interest and preferences of receivers towards the proposed freight policies investigated in the cited studies.

Table 2.3. Summary of Freight Behavioural Studies on Receivers-focused Freight Demand Management Initiatives

Study	No. of Receivers	Location	Logit Model	Main Findings
Targeted Policy: Off-Hour Delivery (OHD)				
Holguín-Veras et al. (2007)	180	New York, USA	Binary and Mixed logit	• Receivers from food, retail and accommodation sectors are willing to accept OHD with financial incentives.
Jaller and Holguín-Veras (2013)	380	Manhattan & Brooklyn, New York	Binary logit	• Willingness to accept OHD is influenced by: - Policy incentives (tax deductions and shipping cost discounts) - Company characteristics - Logistic issues
De Jong et al. (2016)	158	Flanders, Belgium	Multinomial and Mixed logit	• OHD acceptance is influenced by rise in transport prices for peak-hour deliveries.
Holguín-Veras et al. (2017)	263	Manhattan, New York	Ordered logit	• Unassisted-OHD acceptance is influenced by: - Number of deliveries - Industry sector - Policy levers
Marcucci and Gatta (2017)	198	Rome, Italy	Binary logit	• OHD acceptance is influenced by: - Tax reduction - Subsidies for safety - Instrument acquisitions - "Green seller" public recognition.

				• High interest for OHD from food, house accessories and stationary sectors.
Targeted Policy: OHD vs UCC				
dell'Olio et al. (2017)	200, 200	Barcelona & Santander, Spain	Mixed logit	• Receivers are not so inclined to participate if the new policy results in increased costs • Offering financial & non-financial incentives to receivers would encourage acceptance of both policies
Targeted Policy: Receiver-focused UCC				
Marcucci and Danielis (2008)	86	Fano, Italy	Multinomial logit	• Participation in consolidated deliveries is influenced by: - Access permit cost - Consolidation centre' Service cost - Delay in delivery time - Distance to the shop
de Oliveira et al. (2012)	52	Belo Horizonte & Fortaleza, Brazil	Conditional logit	• Participation in consolidated deliveries is influenced by: - Delivery cost - Improving the delivery reliability - In-store space for product display
Holguín-Veras and Sánchez-Díaz 2016	248	Manhattan, New York	Binary logit	• Receivers from wholesale electronics, retail and accommodation sectors are willing to participate • Participation is influenced by the establishment size except for food and beverage stores

Holguín Veras and Sánchez-Díaz (2016) emphasised that much uncertainty still exists about the behavioural preferences of receivers towards the receivers-led delivery consolidation (RLC) policy as it has received very limited academic attention. One criticism of much of the literature on freight demand is that most studies have focused on OHD polices than other FDM initiatives. Björklund and Johansson (2018) underlined the existing gap in knowledge with respect to the consolidation facility users' willingness to pay for consolidated services. One of the early studies about receiver-focused consolidation initiatives was the SP survey carried out by Marcucci and Danielis (2008) to examine the potential demand for UCC by retailers in Fano, Italy. They reported that certain types of stores such as food and grocery businesses and shops with limited storage space were more interested in consolidation services than bars, restaurants and hotels as well as large specialised stores. de Oliveira et al. (2012) collected behavioural responses to investigate the likely adoption of UCC by retailers in Belo Horizonte and Fortaleza, Brazil. It was revealed that the adoption of retailers in Belo Horizonte depend on additional costs of the consolidated delivery, improving the service reliability of carriers and increasing the space for the display of products in their stores. However, the adoption of retailers in Fortaleza might be influenced by improvements in reliability and delivery service. The findings of the two studies should be interpreted with caution as no emphasis was placed on appraising the retailers' willingness to exercise their market power on the shippers and carriers; but, rather offering the options of UCC vs current situation.

In contrast, Holguín-Veras and Sánchez-Díaz (2016) acquired behavioural responses from receivers in New York to estimate their willingness to coordinate with their supplies to consolidate deliveries. Businesses from accommodation, retail, wholesale electronic sectors were reported as likely to participate. However, the study would have been more useful if a more in-depth breakdown of the industry sectors had been explored due to the heterogeneity of receivers within each industry sector. The retail sector includes stores with a very diverse and wide range of goods that require completely different delivery needs. The estimation of the behaviour responses of receivers in Santander and Barcelona, Spain as reported by dell'Olio et al. (2017) indicated that the receivers were not so inclined to adopt OHDs or UCC policies if the new policy contributed to additional costs (either in terms of time or money). They suggested that the UCC policy was more accepted than the OHDs policy and the importance of offering financial and non-financial incentives to motivate receivers to accept both policies. One key problem with their results is that the higher inclination towards UCC by some respondents could be due to their rejection of OHD than actually accepting UCC due to its benefits.

2.4.3. Optimisation Approaches for Solutions of Freight Transport Problems

2.4.3.1. Overview of Optimisation Techniques

Optimisation is systematic and scientific procedure for decision-making and finding solutions of theoretical and real-life problems. Once the optimisation problem is properly formulated, optimisation techniques could be applied using suitable search methods to find a suitable solution based on sets of decision variables, objective function, and constraints (Sörensen et al. 2018). The nature of optimisation models varies depending on the problem context, which could be a deterministic or stochastic. Deterministic models treat static data in their constant nature parameters whereas the change or randomness in parametric values such as demand over time is modelled using stochastic models. Optimisation methods are classified into two categories mainly exact and heuristics (Sun et al. 2015). Mathematical and linear programming (LP) models and techniques such as branch and bound, interior-point, and dynamic programming are exact methods. Exact methods follow the symmetric and systematic gradient search in the feasible region to find out a global optimum (Marin and Salmeron 1996). These methods are best for small scale linear and combinatorial optimisation problems, which could be solved using commercial solvers such as IBM ILOG CPLEX. However, solution quality in large scale optimisation problems becomes poor because of the higher constraint tolerances in large size problems resulting into the violation of some constraints (Bensana et al. 1996). Additionally, the size of real-life optimisation problems is very large, and the non-polynomial (NP)-hard nature of the problem makes it difficult to obtain a solution using exact methods due to the exponential computational time (Mancini 2013).

Alternatively, heuristic search algorithms efficiently explore the search space in systematic way to find a near optimal solution using rules to avoid getting trapped in confined areas of the search space (Yang 2010). The advantage of heuristics over exact methods includes their efficacy to reach a good solution for large scale optimisation problems in reasonable computational time with a reasonable use of memory and no requirements of complex derivatives (Fernandes et al. 2014). However, they do not guarantee obtaining the global optimum because of random search pattern (Yamada et al. 2009). Various heuristics algorithms have been extensively applied to solve complex

transportation optimisation problems. Specifically, nature inspired algorithms including population-based techniques such as genetic algorithms (GA), the particle swarm algorithm (PSO) and ant colony optimisation (ACO) or single-solution techniques such as simulated annealing (SA) and Tabu search are the most commonly used heuristic methods (Yang 2010; Fathollahi-Fard et al. 2018). Genetic algorithms, developed by Holland (1975), is inspired by Darwin's theory of evolution that emphasises survival of fittest. The particle swarm algorithm (PSO), which was developed by Kennedy and Eberhart (1995), is inspired by movement patterns of fish, flocks of birds because fish and birds can relocate themselves to position of available food. Simulated annealing, which was developed by Kirkpatrick et al. (1983), is inspired by the annealing process of metals, in which the metal is heated and cooled slowly to increase the strength of material.

2.4.3.2. Overview of Metaheuristics

Heuristic algorithms are very specific and problem-dependent whereas metaheuristics provide a high-level problem-independent framework that provides a set of guidelines to develop a heuristic algorithm to reach a sufficiently good solution even with incomplete information of the optimisation problem (Sörensen et al. 2018). Metaheuristics algorithms are equally good and flexible for large scale and small-scale optimisation problems because of the provision of initial feasible set of solutions that improves search speed (Yamada et al. 2009). Most metaheuristics are population-based algorithm techniques due to the higher probability of reaching a good solution when a population is used to search the solution space compared to single-solution algorithm techniques (Fathollahi-Fard et al. 2018). Among the various metaheuristic algorithms, genetic algorithms (Yamada et al. 2009; Fernandes et al. 2014; Thompson and Zhang 2018; Simoni et al. 2018) and the particle swarm optimisation algorithm (Ai and Kachitvichyanukul 2009; Tan et al. 2013; Hua et al. 2016) have been commonly used in complex freight optimisation problems. In fact, Muñuzuri et al. (2012) and Sun et al. (2015) indicated that the highly extensive applications of genetic algorithms in location and routing studies in freight transport research corroborate the suitability of this technique in solving complex freight transport optimisation problems.

Genetic algorithms (GA) are an adaptive search method, which simulate the process of natural selection to mimic the reproduction behaviour of biological populations (Sörensen et al. 2018). A population consists of set of individual/chromosomes which are evaluated to get the value of fitness function. The natural selection process involves the selection of fittest to select and produce individuals that are adapted to their environment in next generations. The individual/chromosomes with best fitness values, i.e. better objective function value and meeting the constraint requirement, are called elite chromosomes and have a higher probability of survival during the selection process. Changes in genes in a chromosome bring changes in upcoming generations and desired traits will evolve over weaker undesirable attributes. The process starts with random initial solutions and reaches to the optimum solution by using genetic operators such as crossover, mutation, and natural selection process over the generations.

There are various advantages and merits of using GA compared to other metaheuristics specifically its adaptability to deal with different types of optimisation problems as well as the ability of multiple offspring in a population to simultaneously explore the search space in different directions (Yang 2010). As GA uses parallel computations in a

generation, its computational effort could be less than the required effort for PSO (Jones 2005). As far as limitation of GA is concerned, its solution might be affected because of the variation in parameters values. GA does not guarantee a global optimum, but its solution is robust enough and closer to the global optimum. The performance of GA depends on parameter values. Therefore, tuning of these parameters improves its performance (Liu et al. 2013).

2.4.4. Selection of the Optimal Location of Freight consolidation Facilities

2.4.4.1. Overview of Location Studies of Freight Consolidation Facilities

Proper location selection of freight consolidation facilities represents an integral aspect in lowering the distribution cost, reducing freight traffic movements and minimising the impact on urban environment and residents (Muñoz-Villamizar et at. 2014). Location selection analysis is very complex and involves evaluating a set of alternative locations based on a set of independent decision criteria from the perspectives of different stakeholders as well existing constraints (Awasthi et al. 2011). There are several academic studies that have attempted to optimise the location of freight consolidation facilities in urban areas. The majority of these works approached the topic primarily using MCDM methods (Farahani et al. 2010; Agrebi et al. 2015). Alternatively, other studies performed locational selection analysis using optimisation techniques to solve the facility location problem for optimal delivery routes or placement of the facility (Melo et al. 2009).

Muñoz-Villamizar et at. (2014) developed a mixed integer linear programming (MILP) model to optimise the location and routes of a consolidation facility based on the objective of minimising the total cost/distance of the delivery routes. Similarly, Simoni et al. (2018) formulated a MILP approach to optimise the location and vehicle routing of UCC. They solved their model using a metaheuristic technique based on genetic algorithm to evaluate several scenarios of locations and delivery configurations for the optimal policy to establish a UCC that minimise costs or emission. One drawback of these two studies is that while some operational parameters are included in the MILP model; however, the decision-making of the optimal location for the facility was primarily based on achieving the objective of minimising the transportation cost and budget constraints. Conversely, Amchang and Song (2018) applied the AHP method to evaluate three districts in Bangkok, Thailand to establish a UCC for parcel deliveries. The pairwise comparison of the decision criteria revealed that the delivery service factor including proximity to customers and upside delivery flexibility as the most important factors to determine the location of a UCC in urban areas and enhance customers' satisfaction.

Moreover, many studies have treated the logistics facility location problem as a two-level hierarchical or multi-objective optimisation problem (Crainic et al. 2009; Mancini 2013; Żak and Węgliński 2014). In the upper level, macro-analysis of the urban area is thoroughly performed to select the area that is most suited and feasible to establish the facility based on identified decision criteria or objective functions. In the lower level, micro-analysis of alternative locations in the suitable area is performed to select the optimal location and optimise vehicle routes. For instance, Crainic et al. (2010) developed a computational approach to address the two-echelon location problem of the consolidation facility and solved the problem using a clustering-based heuristics algorithm for the total distribution cost of the overall distribution network. Szczepański

et al. (2014) developed a genetic algorithm to optimise the location of the two-tier distribution system of consolidation facility and transshipment hub based on a cost index.

Cardenas et al. (2017a) argued that previous location studies of consolidation facilities focused more in their approaches to optimise the location on accessibility, costs, fleet composition, optimal routes and environmental emissions. It can be argued that many of these studies did not sufficiently consider the locational analysis aspect in their approach. For instance, Olsson and Woxenius (2014) proposed a network accessibility analysis framework that estimated travel times to proposed UCCs in Gothenburg, Sweden in order to determine the most suitable area to establish the facility. Janjevic et al. (2016) performed a location scenario analysis of various locations of UCC to assess their impact on transport costs, environmental emissions and congestion across Brussels, Belgium. Gonzalez-Feliu et al. (2014b) developed a valuable locational accessibility framework to identify and assess the suitability of alternative locations for a UCC. The three-step framework included generating an estimate of the goods transport demand, a heuristic vehicle routing method for determining routes for consolidated deliveries and performing an accessibility calculation on the location of the UCC based on transport cost.

2.4.4.2. Spatial Modelling of the Optimal Location for Freight Consolidation Facilities

Fraile et al. (2016) urge that locational studies of logistics and transport facilities must also consider the geographical aspects and incorporate spatial analysis in the selection of the optimal location of the facility. Sopha et al. (2016) highlight that failing to include comprehensive spatial datasets would adversely impact the success of the decision-maker in selecting the most appropriate location for the logistics facility. Specifically, Özceylan et al. (2016) and Önden et al. (2018) suggest integrating geographic information system (GIS) models and MCDM methods in the location studies of logistics facilities. GIS facilitates identifying and evaluating the spatial relationship between mapped places of interest and performing geographical analysis (Malczewski 2006). GIS models provide geoprocessing tools that combine different geographic datasets in the process of complex spatial analysis (Malpica et al. 2007). The integration of spatial models and multi-criteria analysis assists transport researchers in evaluating and selecting the best transport alternative by incorporating the spatially-referenced data, evaluation criteria and viewpoints in a structured decision support framework (Erbaş et al. 2018).

Recently, there have been few studies that have applied GIS-based evaluation models in the location selection of logistics facilities, albeit very scarce compared to other transport site selection studies. For example, Özceylan et al. (2016) combined GIS-based spatial models and TOPSIS method to evaluate and rank the potential locations for a freight village in Ankara, Turkey. The application of their framework produced a significantly higher ranking of the proposed locations for the facility compared to the existing freight village in Ankara especially for the proximity to railroad, distance to population density, distance to natural resources and cost of land decision criteria. Similarly, Önden et al. (2018) applied GIS-spatial models and Fuzzy AHP method to evaluate the suitability of the proposed locations of 19 on-going logistics centres in different regions across Turkey. The application of their model indicated that the most suitable areas are located closest to key transport infrastructure, highly populated areas and trade zones. Sopha et al. (2016) developed a two-tier ranking and optimisation approach for the optimal location of a UCC

in Yogyakarta, Indonesia. In the upper-level, the approach applied spatial analysis and AHP method to rank the potential areas for the UCC while in the lower-level a multi-objective MILP technique selected the optimal location.

2.4.4.3. Decision Criteria for the Selection of the Optimal Location of Freight Consolidation Facilities

Table 2.4 presents a summary of the number of decision criteria and main analysis approaches for the relevant location studies of logistics facilities in urban areas. This summary includes studies that focused specifically on consolidation facilities as well as studies that evaluated other type of facilities such as freight villages, logistics centres and distribution centres. It was necessary to include other type of facilities due to the limited number of studies that focused on consolidation facilities. The number of criteria varied from the highest number being 23 criteria (Dobrota et al. 2015) to the lowest number being 5 criteria (Chen et al. 2014; Elevli 2014) with an average of 11 criteria per study. With respect to the most commonly used MCDM method for evaluation, the TOPSIS method was applied in 9 studies followed by the AHP and ELECTRE methods, which were both applied in 6 and 4 studies, respectively.

Table 2.4. Number of Decision Criteria Considered in MCDM Studies of Logistics Facilities

Study	Region	Number of Criteria	Analysis Approach
Facility: Urban Consolidation Centre			
Rao et al. (2015)	-	13	Fuzzy TOPSIS
Sopha et al. (2016)	Yogyakarta, Indonesia	6	GIS-Optimisation
Amchang and Song (2018)	Bangkok, Thailand	11	AHP
Facility: Distribution Centre			
Awasthi et al., (2011)	-	11	Fuzzy TOPSIS
Zhang et al. (2011)	Chongqing, China	13	Fuzzy AHP
Ashrafzadeh et al. (2012)	Iran	15	TOPSIS
Bouhana et al. (2013)	-	10	Fuzzy AHP
Dobrota et al. (2015)	Serbia	23	Fuzzy AHP
Agrebi et al. (2017)	-	7	ELECTRE I
Facility: Logistics Centre			
Li et al. (2011)	-	13	TOPSIS
Regmi and Hanaoka (2013)	Laos	13	AHP-Optimisation
Tomić et al. (2014)	Balkan Peninsula	9	Optimisation-AHP
Chen et al. (2014)	Shanghai, China	5	TOPSIS
Żak and Węgliński (2014)	Poland	9	ELECTRE III/IV
Elevli 2014	Samsun, Turkey	5	Fuzzy PROMETHEE
Făgărăşan and Cristea (2015)	Romania	12	ELECTRE III
Dey et al. (2016)	India	16	Fuzzy TOPSIS
Pham et al. (2017)	Vietnam	14	Fuzzy TOPSIS

He et al. (2017)	Chongqing, China	13	Fuzzy TOPSIS
Önden et al. (2018)	Turkey	7	GIS-Fuzzy AHP
Facility: Freight Village			
Yıldırım and Önder (2014)	Istanbul, Turkey	7	PROMETHEE
Uysal and Yavuz (2014)	Black Sea Region, Turkey	11	ELECTRE I
Özceylan et al. (2016)	Ankara, Turkey	13	GIS-TOPSIS

Furthermore, Fig. 2.4 displays the frequency of the most commonly used decision criteria in the location studies of logistics facility in the existing literature. According to this analysis, the top criteria are proximity to customers/market, proximity to highway, land price, proximity to multi-modal transport hubs (seaport, railway and airport) and transportation cost. On the other hand, the least used criteria are land slope, security and safety, distance to bike lanes and service level. Furthermore, these criteria could be grouped under four main categories: ***operational*** (proximity to suppliers, proximity to customers/market, proximity to multi-modal transport hubs, proximity to highway, distance to bike lanes, land slope); ***economic*** (service level, expansion availability, land price, transportation cost, access to labour); ***environmental*** (impact on environment, access restrictions, distance to natural resources, proximity to industrial lands/zones); ***social*** (security and safety, distance to population density, congestion/road density).

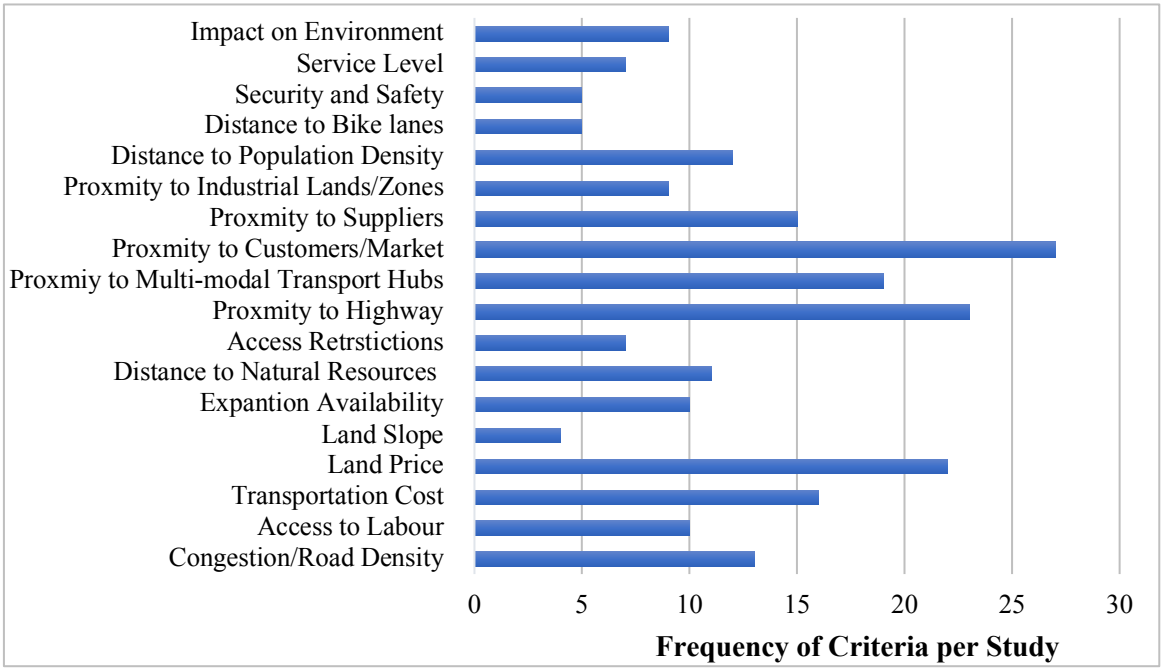


Figure 2.4. Frequency Analysis of the Most Commonly Considered Decision Criteria (Own Research)

2.4.5. Mathematical Cost Modelling of Freight Consolidation Facilities

2.4.5.1. Overview of Mathematical Cost Models of Freight Consolidation Facilities

There has been somewhat an increasing number of studies that presented mathematical models for assessment of the economic aspects of consolidation facilities. However, Estrada and Roca-Riu (2017) highlighted that there are a limited number of cost models that have performed a comprehensive quantitative assessment of the financial viability of freight consolidation facilities. It can be argued that existing studies hitherto overlooked quantifying the profitability of the consolidation facility when highlighting the operational conditions under which these facilities could be profitable.

Two mathematical approaches were applied in the majority of studies to formulate the cost model for the economic evaluation of consolidation facilities. The first one is to formulate a discrete mathematical model and then solve the problem optimally. This approach involves a massive amount of discrete input data at each customer endpoint and solving these complex problems require huge computational effort (Chen et al. 2012; Lin et al. 2016). Alternatively, the second approach is to solve the problem "approximately" using continuous approximation (CA) techniques, indicating that the solution would not be optimal but an approximation to the optimal solution. The CA approach produces assumptions about temporal and spatial density and average distribution of destination points (Langevin et al. 1996). Consequently, data points could be approximated by a continuous function with a closed form solution with no requirement for the exact customer information at every exact location. This approach requires less computational effort and less accurate input data compared to the discrete models (Ansari et al. 2018).

2.4.5.2. Assessment of Cost Models on the Financial Viability and Cost Analysis of Freight Consolidation Facilities

Handoko et al. (2016) constructed a profit-maximising auction mechanism for consolidated deliveries via a UCC based on MILP approach. The solution of the MILP model using a greedy approximation algorithm illustrated that the proposed auction mechanism could make the UCC profitable for its users. Li et al. (2018) developed a MILP model to optimise the location of an urban distribution centre based on minimising the total costs. The CPLEX solution of their model illustrated that the transportation cost represented 53% of total costs while the facility fixed costs accounted for 26%. Faure et al. (2016) presented an integrated approach that solved the vehicle routing problem to determine the delivery routes of UCC and estimated the logistics costs of the facility to evaluate the influence of the shape of the city on. The results of their approach suggest that urban morphology impact the travelled distance for the consolidated deliveries, which in return increases fixed cost of the vehicles and affect the viability of the facility. However, a major drawback of the above studies is that they fail to account for the myriad of costs that are not necessarily contingent upon location. Another limitation of these studies is that other important cost components were not incorporated into the models, which might produce different results for the facility's cost-attractiveness if considered.

Alternatively, various studies in the literature extended the CA-based logistics cost model introduced by Daganzo (2005) to develop various cost models for the cost estimation of consolidation facilities. Kawamura and Lu (2007) presented a model based on the CA technique to estimate the logistics cost per item with consolidation via UCC and without consolidation for shoe deliveries. The application of their model indicated that the current situation was more cost-effective than the UCC scenario. Estrada and Roca-Riu (2017) presented a cost model based on the CA technique to estimate transportation and capital

costs for carrier-led consolidation strategies and assessed whether the potential cost savings for the carriers exceeded the cost of participation in consolidation services. In Kin et al (2018), a model was developed to determine the cost-effectiveness of alternative distribution set-up including UCC based on the CA technique for small and fragmented volumes. The results of their model suggest that direct deliveries might be most cost-competitive under current conditions due to the additional cost (rent and handling) of the depot. While the logistics cost models using the CA technique are useful, cost components in these estimations were represented as major cost blocks, without specifying the secondary cost variables that collectively make up the main cost function. Although these logistics cost models included critical distance- and time-related operational parameters, there was a paucity of personnel and administrative expenses in the cost analysis of the consolidation facility. Another issue with these studies is that they overlooked estimating the net profit of the facility to determine its likely financial viability.

Janjevic & Ndiaye (2017a) developed an analytical formulation for estimating the time and distance-related costs of deliveries with and without UCC and determining the economic attractiveness of the UCC. The application of their framework to a specific case in Brussels revealed that the UCC economic attractiveness is highly influenced by the properties of the delivery trip, features of the UCC such as its location and the attributes of the service area such as the size of the city. However, findings of the study would have been more useful if the facility-related costs such as infrastructure cost (e.g. rent) and operational parameters (e.g. handling equipment) were incorporated in the generalised cost assessment. In contrast, the theoretical framework by Janjevic & Ndiaye (2017b) is of great significance as it represented the first attempt to comprehensively include the various costs and revenue associated with consolidation facilities in appraising the financial viability of the facility. The application of their model for a UCC in Brussels highlighted that the UCC profitability is highly thin and challenging due to the volatile revenues that could be significantly diminished if resources are not efficiently utilised. Unlike previous UCC literature that focused on the infrastructure and vehicles, this study illustrated that the biggest category of costs is related to human resources. However, this study would have been more relevant if a wider range of freight vehicles including cargobikes had been explored in the economic assessment.

2.5. Last Mile Delivery in Inner-City Area

2.5.1. Availability of Industrial Land for Logistics Facilities in Inner-City

It is important to pay attention to the negative impacts of logistics sprawl and the consequences of not incorporating freight transport in urban planning and land-use policies especially in congested inner-city areas. Policy makers need to plan and execute policies to ensure the supply and availability of industrial land, both in quantity and location, for logistics facilities as stressed by Sakai et al. (2015). Giuliano et al. (2013) warn that local governments and urban planners need to be careful when putting into place strategies and policies to balance lowering the number of freight trucks and reducing conflicts with other modes of transport while ensuring efficient freight flows that are required to sustain urban life. Guyona et al. (2012) suggested that local authorities should re-consider current policies of limiting the presence of logistics facilities in the city centre.

For large cities especially in Europe, Asia and Australasia, the city centre represents a major destination for last mile delivery and pick-up activities with very limited supply of available and affordable industrial land to establish and operate logistics facilities (Marcucci et al. 2015). Broaddus et al. (2015) reported that warehousing floor space decreased by almost 82% in the congestion charge zone inside City of London while the warehousing floor space increased by more than 20% in outer suburbs of London between the 1998 and 2008. Moreover, out of the 25,712 hectares of industrially zoned lands across Greater Melbourne, only 976 hectares of industrial land is located in Inner Melbourne with only 36 hectares being vacant (Urban Development Program 2015). This figure represents only 4% of all industrial land across Greater Melbourne even though about 23% of total daily intra-metropolitan truck movements in Greater Melbourne occur within the inner-city area of Melbourne (ABS 2015b). According to Melbourne's Census of Land Use & Employment (CLUE), transport and storage premises represents only 1% of all built space in Melbourne CBD (Last Kilometre Freight Plan 2016).

Furthermore, the city centre includes many high-rise towers with several commercial, retail and residential receivers that generate and attract significantly large number of freight movements. For example, Jaller et al. (2015) estimated that about 4% of the total truck traffic in Manhattan, New York was generated by only 56 large buildings in the area. Browne et al. (2016) described that more than 40% of all freight vehicles delivering to a major office block in central London were associated with parcel and mail flows. According to Thompson and Flores (2016), a 57-storey mixed-use tower in Melbourne CBD typically receives more than 130 freight vehicles per day to perform delivery services to more than 52 businesses and 10 retail stores. Furthermore, Bates et al. (2018a) warned that difficulty to locate entry points and delivery destinations in high-rise towers further complicate the delivery operations and efficiencies of freight carriers. Kawamura (2014) and Thompson and Flores (2016) called for further research to collect additional data on use of on-street loading spaces especially near residential and commercial towers to develop effective guidelines that maximise the use of on-street loading spaces.

2.5.2. Existing Knowledge on Last Mile Delivery inside the Inner-City

There is a limited number of studies in the literature clarifying the current state of last mile delivery specifically in the inner-city area. The literature on the utility of locating businesses in the city centre is well established from the perspectives of commercial attractiveness and accessibility to consumers (Hounwanou et al. 2018). However, the literature on last mile freight does not differentiate between the operational activities and challenges of freight carriers across the whole metropolitan area and inside the inner-city area. For this last leg of delivery, the operational practices of freight carriers, challenges and issues impacting the carriers, type of freight vehicles and receivers' requirement might be significantly different from freight deliveries to other receivers in other parts of the metropolitan area. Hence, it may not be suitable to deal with the inefficiencies and problems of this last leg of the delivery using the same approaches and solutions that were proposed for freight deliveries in other parts. Butrina et al. (2017) argue that there is a lack of understanding with respect to freight movements in the last hundreds of metres of the delivery inside the congested and dense inner-city area. Buldeo Rai et al. (2018) underline that there is a limited knowledge about the vehicle fill-in rate (load utilisation). Some polies assumed that delivery vans typically enter the city centre almost fully loaded or couriers could park their vehicles immediately outside receiving establishment. It can

be argued that these erroneous assumptions contributed to failure of some proposed solutions as they were irrelevant and impractical to the actual practices and requirements of freight carriers in the inner-city.

Another observation of the literature is that several studies and policies focused on large freight carriers with delivery fleet of hundreds of vehicles that might be more efficient and well-utilised than small and medium operators with inefficient and unsustainable delivery fleet and practices. While these small and medium operators might individually operate small number of vehicles in the inner-city. However, they collectively represent a larger proportion of the overall number of freight vehicles than leading freight carriers. Additionally, there is very limited knowledge on the utilisation of LCVs in dense inner-city areas as well as detailed characterisation of the operational practices and challenges for couriers to perform the last leg of delivery to the various and conflicting receivers within the area. Furthermore, Combes (2016) called for further research to examine the competition and spatial structure between the various freight carriers to understand whether they focus on same zones in the inner-city area or specialise in distinct territories.

2.5.3. Challenges and Issues in The Inner-City Area

Several operational factors and issues such as different delivery requirements of receivers, physical structure of the area and sensitive land uses complicate freight deliveries and pickups inside the inner-city (Antún et al. 2018). The last leg of delivery in the inner-city represent a major choke point and severe operational challenge for freight carriers. Traffic movement is noticeably congested with a high mixture of passenger vehicles, cyclists and pedestrians, which result in deteriorating travel time (Muñuzuri et al. 2012). Jaller et al. (2013) underline the poor accessibility of streets in the city centre. Average traffic speed has been significantly reducing. Allen et al. (2018b) reported that the vehicle delays have increased by almost 31% in central London while congestion is expected to increase 60% by 2030 (Bates et al. 2018b). These issues complicate the reliability and efficiency of freight carriers to comply with time-sensitive delivery requirement of receivers.

The congested inner-city area especially the city centre often does not provide on-street infrastructure to conduct parking and loading activities for freight vehicles. Every day, thousands of freight vehicles compete for very limited number of on-street loading zones (OLZs), which might force some vehicles to double park or circulate around to find alternative space and consequently result in additional traffic and congestion (Kawamura 2014; Holguín-Veras et al. 2015). Couriers experience significant difficulties using off-street loading docks and are forced to depend on the kerbside especially near high-rise towers. A study performed in Seattle revealed that couriers had to use the kerbside to deliver to 87% of all buildings in downtown Seattle (UW Supply Chain Transportation & Logistics Center 2018). Similarly, another study demonstrated that almost 95% of the deliveries were performed using kerbside in central London (Allen et al. 2018b). Illegal parking in on-street loading zones (OLZs) by non-freight vehicles further complicate making deliveries inside the city centre (Aiura and Taniguchi 2006). According to two surveys of loading bays in Paris and Bologna, it was reported that these loading spaces were illegally used by private cars on 47% and 57% of the time respectively (Browne et al. 2007; Dezi et al. 2010). Moreover, freight vehicles are often issued parking fines for illegal parking. For instance, Holguín-Veras et al. (2008) reported that monthly parking fines cost freight carriers in New York City between $500-1,000 per truck.

Jaller et al. (2013) and Holguín-Veras et al. (2015) argued that guidelines for the use of OLZs do not differentiate between freight vehicles and service vehicles even though they have different parking requirements. This fails to assign priority of use for freight vehicles as they need to park much closer to receivers. Alho and e Silva (2014) warned that when freight vehicles are forced to park far away from receivers, the size and volume of parcels that couriers could carry are significantly constrained. A survey conducted with freight carriers in central London illustrated that couriers spent about 62% of their delivery round time parked at an OLZ (Allen et al. 2018a). The study also estimated that the average walking distance to deliver the goods to receivers was 105 metres per customer. This long walking distance is significant especially in case of multiple deliveries. Aiura and Taniguchi (2006) and Dezi et al. (2010) suggested that up to 50 metres between the on-street loading space and receivers would be an acceptable distance according to responses collected from drivers in Kyoto, Japan and Bologna, Italy. Thus, couriers might be forced to overstay the allowable parking time at OLZs to perform the multiple deliveries.

Anderluh et al. (2017) warn that these issues and challenges adversely affect the efficiency and convenience of the delivery experience of receivers in the inner-city area compared to receivers in other parts of the metropolitan area. Savelsbergh and Van Woensel (2016) and Kin et al. (2018) suggest that for freight carriers to overcome these challenges and maintain the ability to offer low-cost and competitive delivery services, they need improved coordination of the flows of goods, higher consolidation of freight movement and better multi-organisation cooperation.

2.6. Addressing the Increasing Express Deliveries and Limitation of Industrial Land in Inner-City

2.6.1. Freight Consolidation Initiatives Specifically in the Inner-City Area

Recently, there have been some initiatives to trial or establish micro-consolidation facilities closer to receivers in inner urban areas in Europe with different levels of success and failure (Janjevic and Ndiaye 2014). A majority of these facilities were trialled in London and Paris, which ranged in size between 500-3000 m^2 (Boudouin 2012). For example, a trial of Micro-UCC for office supplies in central London achieved a reduction of 20% in total vehicle kilometre travelled (VKT) and 54% in CO_2 equivalent emissions using electrically assisted cargobikes and vans (Browne et al. 2011). Similarly, the 1,000 m^2 Concorde Urban Logistics Space, which is operated by Chronopost to deliver daily about 2,800 parcels to customers in Central Paris, achieved a saving of 75% of travel distance and 33 tonnes of CO_2 emissions per year using a fleet of electric delivery vans (TURBLOG 2011; Heitz, 2015). Moreover, Gnewt Cargo, which delivers about 9,500 parcels/day from two MUCC in central London, achieved a reduction of 20% in VKT and 61% in emissions per parcel using of a fleet of electric vans and electric tricycles (BESTFACT 2013; Schliwa et al. 2015). Another successful case in establishing a micro-UCC has been La Petite Reine, which operates two urban logistics spaces in central Paris. La Petite Reine utilises more than 100 electrically-assisted cargobikes to make more than 3,500 deliveries from the stores of major retailers to homes of consumers (TURBLOG, 2011). It is worth noting that the previously mentioned cases were all privately-operated micro-consolidation facilities.

Gonzalez-Feliu et. al. (2014a) indicated that MUCCs in Europe were significantly less trialled than traditional UCCs that were established in suburban parts of the city. Moreover, most micro-consolidation initiatives did not involve setting up a logistics facility to consolidate the deliveries as several measures focused on other platforms including a vehicle or goods reception point to set up a space for carriers for better management of unloading activities and delivery to receivers in the same zone (Janjevic and Ndiaye 2014). Janjevic et al. (2013) reported in their evaluation of micro-consolidation initiatives in Europe that only French-based MUCCs such as Chronopost ULSs and London-based Gnewt Cargo operated logistics facilities such as a warehouse or parking infrastructure that were in fact established inside the city's centre. It is worth noting that while many of the privately-operated MUCCs are successfully and efficiently managed; however, they required government subsidies in the initial stage and did not involve comprehensive stakeholder engagement and holistic assessment of their aspects in the early planning and decision-making process. Hence, it could be argued that their success and efficiency might be somewhat attributed to the relative convenience of planning and performing consolidated deliveries through an internal or individual distribution channel compared to public-initiated or multi-carrier UCCs. Most MUCCs were established in European cities with the benefits of various governmental subsidies and supporting regulations. However, other metropolitan areas in different parts of the world may not benefit from same governmental support measures.

Moreover, Treasure (2014), the Operations Director at UK-based retail consultant Javelin Group, reported that recent growth of online grocery orders encouraged various grocery retailers in Europe to establish e-grocery fulfilment centres in inner urban areas. These distribution centres, which are called 'dark stores', enable large supermarket chains to offer express deliveries of e-grocery orders to shoppers in inner urban area using delivery vans. For instance, Waitrose, a leader in the UK grocery industry, established a dark store in West London that deliver about 2,000 orders/week (Butler 2014). Similarly, Amazon established a 50,000 ft^2 warehouse in 5^{th} floor of a Mid-Manhattan office tower in New York to offer one-hour and two-hour delivery of online orders (Bensinger and Morris 2014). Moreover, CEP service providers and online retailers have been implementing alternative delivery services for consumers to collect their parcels in inner city areas such as a) click&collect from physical retail stores, b) collection points in convenience stores and c) parcel lockers near public transport hubs and shopping centres to minimise failed deliveries and difficulty to find parking spaces (Ducret 2014; Lachapelle et al. 2018).

2.6.2. Freight Land-use Policies to Facilitate Re-integrating Suitable Logistics Facilities in the Inner-City

There is an urgent need to develop policy solutions to address the negative externalities caused by last mile deliveries especially in the congested inner-city. Reintegrating logistics facilities in this area presents an effective solution for freight carriers to deal with recent trends especially express and fragmented shipments as suggested by Wygonik et al. (2015). Broaddus et al. (2015) recommend that local governments consider enabling logistics facilities geographically closer to receivers inside the inner-city, which could shorten the delivery trips and might be more effective than pricing schemes in reducing number of LCVs. Enabling larger and optimised freight vehicles into the congested inner-city require more innovative and sustainable logistics buildings. More emphasis is required to incorporate sustainable logistics landuse policies in suitable and effective

freight consolidation facilities to address negative impacts of freight movements in inner-city. Sakai et al. (2016) suggest that sustainable logistics land-use policies might be a viable solution to address the negative impacts of logistics sprawl. However, they claim that there is limited knowledge on how to effectively implement these policies.

Preserving industrial land in the inner-city might enable future freight use and re-integration of logistics facilities. Christensen Associates et al. (2012) assert that comprehensive and sustainable freight land use planning serve as the most successful freight corridors protection strategy. They warn against the loss of freight facilities in inner urban areas and suggested that local policymakers need to be proactive in their approach to achieve freight-compatible development in urban areas. Redevelopment of brownfields sites, which are old, neglected or underutilised industrial properties, may present an opportunity to provide necessary industrial land for growing demand for logistics facilities in inner urban areas (US Federal Highway Administration [FHWA] 2012). However, local authorities may encounter high pressure to capitalise on these valuable properties and convert them into commercial and residential use to generate high property taxes. Taniguchi et al. (2016) advocate that local authorities and transport researchers should study the merits of preserving freight intensive areas in inner-urban areas to enable reducing the distance travelled by freight vehicles.

Furthermore, the report published by FHWA (2012) highlighted several sustainable freight land-use policies that could reduce the impact of logistics facilities and freight vehicles on sensitive uses such as utilising zoning powers or applying the context sensitive solutions (CSS) approach when planning for new logistics facilities close to residential and commercial uses. The CSS collaborative approach attempts to take into consideration the community's sustainability and surrounding sensitive uses as well as objectives of all stakeholders in planning and development of a new transportation facility. Applying zoning tools such as zoning overlay, preferential zoning or creating buffer zones could reduce the interference between freight activities and surrounding uses and establish operational requirements on how to operate the logistics facility. For instance, Christensen Associates et al. (2012) reported that City of Baltimore, USA was able to preserve valuable waterfront land for future freight use and minimise land use conflicts through setting of an overlay zone (MIZOD) at the Port of Baltimore. It banned development of non-industrial use within the overlay zone and facilitated robust operational environment for freight companies to operate with minimum encroachment with non-industrial uses. Moreover, local authorities could utilise form-based zoning to set the physical and aesthetic relationship of the logistics facility and its surroundings to conform to community standards through setting regulations for sound walls, open space or restriction of loading activities around the property (Guiliano et al. 2013). This results in reducing the aesthetic, noise and pollution impacts on nearby residents and users.

2.7. Chapter Summary

In this chapter, an extensive review and analysis of literature on last-mile delivery in the inner-city as well as modelling and evaluation approaches of freight consolidation facilities. This review revealed three gaps in knowledge with respect to providing a detailed description of the delivery trips in the last hundreds of meters in the inner-city:

- The literature on last mile delivery does not differentiate between the operational

practices of freight carriers across the whole metropolitan area versus the inner-city area as highlighted in Section 2.5.2. Many of the previous studies included both types of freight activities as one category in their analysis of the last mile delivery. There might be a lack of understanding with respect to freight movements and delivery practices in the last leg of the delivery within the congested and dense inner-city area as indicated by Combes (2016), Butrina et al. (2017) and Bates et al. (2018a).

- Various local authorities acknowledge the increasing presence and use of LCVs by freight carriers in the inner-city. Yet, there is somewhat limited data on their characteristics and activities compared with metropolitan-wide freight journeys as indicated in Section 2.5.2.
- Most city logistics studies and freight consolidation policies paid more attention to retail and HoReCa deliveries to businesses in shopping and commercial precincts in the inner-city area. However, express and light parcel deliveries to the various mix of businesses in high-rise commercial towers in city centres did not garner the same attention from transport researchers as pointed out in Section 2.5.1.

Furthermore, this review revealed several limitations and shortcomings with respect to the aspects and approaches applied in freight consolidation policies as follows:

- Focusing on sustainable freight land-use policies to reduce negative impacts of freight movements in the inner-city area has not received similar academic research as other freight improvement policies, which was underline in Section 2.6.1, as highlighted by Huber et al. (2014); Broaddus et al. (2015); Taniguchi et al. (2016).
- Engaging the receivers in the freight consolidation policy to induce behavioural changes has received very limited attention as corroborated by Holguín-Veras and Sánchez-Díaz (2016), which was highlighted in Section 2.3.3.2. Even the limited number of RLC studies failed to incorporate key operational parameters in their formulation of the RLC policy levers as they focused more on including financial and non-financial incentives. It can be argued that little is known about the factors that influence receivers' willingness to adopt RLC initiatives to exercise their market powers on the freight carriers and shippers to consolidate their shipments as emphasised in Section 2.4.2. There is still uncertainty whether businesses are interested in paying for the benefits and value-added services of the RLC delivery as previous studies did not attempt to estimate their willingness to pay (WTP).
- Most location studies of consolidation facilities have mainly focused on achieving certain objectives such as minimising transport cost and distance or maximising service level using optimisation techniques or multi-criteria analysis. However, most of these studies overlooked the significance of including real geographic data and spatial analysis to consider all the spatial interrelationships between all the components, stakeholders and activities in the urban freight network in the location selection of the consolidation facility, which was underlined in Section 2.4.4. Furthermore, many of these studies have not dealt with the complexity of the congested, dense and expensive inner-city area.
- Most previous mathematical cost models on the financial viability of consolidation policies did not incorporate the unknown and stochastic nature of parcel demand

and delivery activities of freight consolidation in their assessment of cost assessment, which was emphasised in Section 2.4.5. Moreover, most studies overlooked generating key profitability indicators such as the net profit margin and revenue streams to facilitate quantifying the net profit of the facility as indicated in Section 2.3.5. Furthermore, appraising the financial viability of consolidation facilities inside the inner-city area, which typically has significantly expensive real-estate prices, has not been investigated in previous academic studies.

Hence, the focus of this research is to address these gaps by incorporating and combining carriers-focused and receivers-engaged consolidation schemes to optimise the establishment of suitable, sustainable, optimally located and financially viable consolidation facility in the inner-city area to address the increasing amount of express and fragmented deliveries.

Chapter 3.

Research Design and Methodology for Designing an Integrated Framework for Optimised Freight Consolidation Policy in the Inner-City

This chapter presents and describes the five stages of the integrated framework to facilitate an optimised and sustainable freight consolidation facility in the inner-city area.

- Section 3.1 introduces the integrated framework.
- Section 3.2 describes the 1st stage of integrated framework, which collected operational parameters from freight carriers about their delivery trips specifically in the inner-city and consequently presented the proposed design of the Central City Consolidation Facility (CCCF).
- Section 3.3 describes the multi-stakeholder approach for the selection of the most suitable delivery fleet for consolidated deliveries based on the objectives of all stakeholders, which represents the 2nd stage of the integrated framework.
- Section 3.4 describes the 3rd stage of the integrated framework, which estimated the interest of receivers to participate in the proposed consolidation service.
- Section 3.5 presents the spatial multi-criteria approach to optimise the selection of the most suitable location for the proposed CCCF in the inner-city area.
- Section 3.6 describes the business-oriented approach and mathematical cost model to examine the financial viability of the proposed consolidation policy.
- Section 3.7 provides a concluding summary for this chapter.

3.1. Description of the Integrated Framework

The developed research framework utilised and built on approaches and models from the city logistics system approach, freight industry's best practices, multi-criteria decision-making and land-use suitability assessment. The developed framework enables establishing in a sustainable and optimal way the freight consolidation facility in the congested inner-city area while taking into consideration the various operational, social and environmental aspects and objectives of all the stakeholders in the decision-making process. The integrated framework to facilitate establishing the proposed CCCF, which is presented in Fig. 3.1, is composed of five stages

The ***1st stage*** acquired relevant and detailed data from freight carriers on last mile delivery activities in the inner-city and proposed the design of CCCF based on current practices and operational requirements of freight carriers in the inner-city. The ***2nd stage*** utilised the Multi-Actor Multi-Criteria Analysis (MAMCA) method to evaluate alternative delivery fleet configurations for the consolidated deliveries based on the objectives of all stakeholder groups involved in last mile delivery. The ***3rd stage*** collected and estimated

behavioural responses of receivers in the inner-city to appraise their willingness to participate in the consolidated delivery scheme. The ***4th stage*** presented a novel approach that combined fuzzy multi-criteria decision-making (MCDM) methods and spatial analysis to model and optimise the selection of the most suitable location for the freight consolidation facility in the inner-city area based on spatial and operational factors. The ***5th stage*** developed a two-phase ex-ante profitability assessment approach to determine the financial viability of the proposed consolidation facility: the upper-phase applied the principles of the Business Model Canvas (BMC) to analyse the business case of the consolidation initiative whereas a mixed integer linear programming (MILP) cost model was formulated in the lower-phase to optimise the profitability of the facility. The following sections in this chapter describe the five stages of the integrated framework and how they were performed to achieve the objectives of this research.

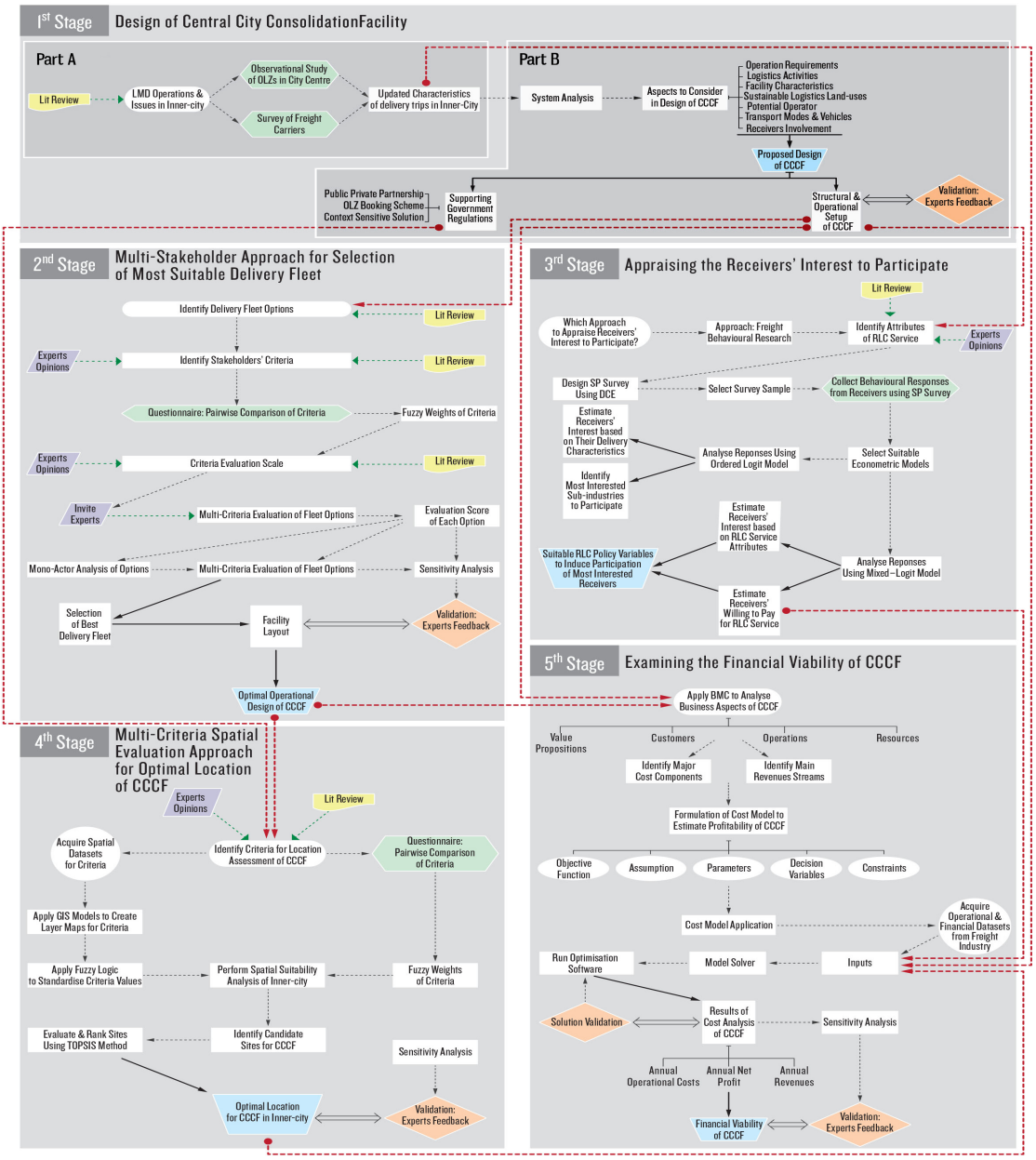


Figure 3.1. Integrated Framework to Establish Central City Consolidation Facility

3.2. 1st Stage: Design of Central City Consolidation Facility

This stage focused on acquiring direct insights from freight carriers (Part A) about their operational practices and challenges to perform the last leg of delivery in order to propose a relevant and suitable design for the consolidation facility (Part B). Fig. 3.2 displays the various steps that were applied to achieve the research objective for the 1st stage of the integrated framework.

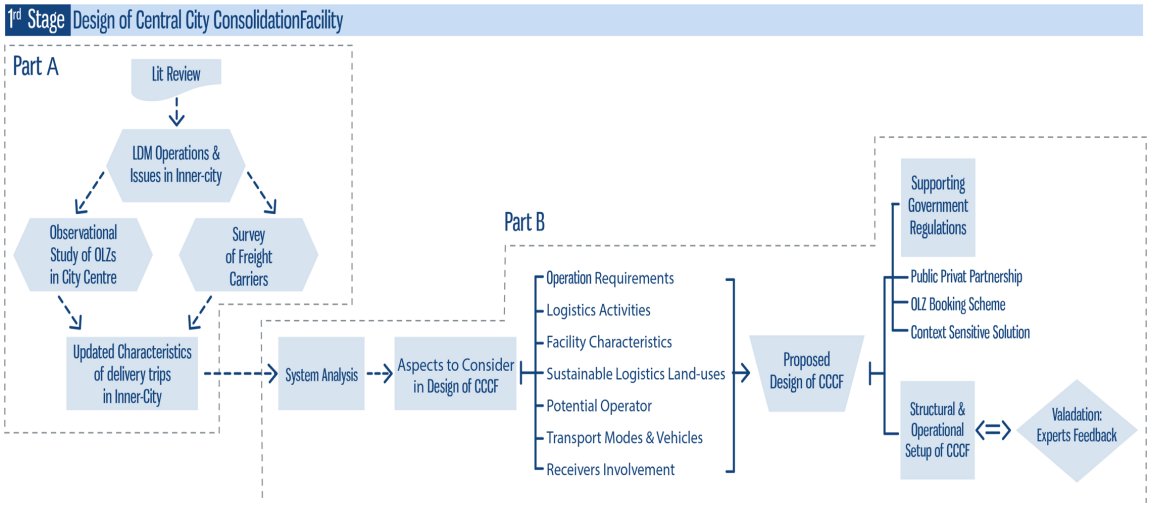


Figure 3.2. Overview of the 1st Stage of the Integrated Framework

3.2.1. Part A: Acquiring Insights on the Delivery Practices and Operational Activities of Freight Carriers in the Inner-City

Due to the limited knowledge on the last leg of delivery and pickup activities inside the congested inner-city area, it was necessary to collect primary data through surveys with freight carriers to develop a detailed description of their delivery fleet, characteristics of their delivery trips, loading and parking practices and assessment of the influence of critical operational challenges and issues on the efficiency of their activities. The acquired insights would facilitate proposing suitable and effective design for the Central City Consolidation Facility based on actual delivery practices and challenges that couriers experience on a daily basis inside the congested inner-city.

Acquiring reliable operational data and insights from freight carriers, receivers and local authorities required using a systematic approach that involves critical quality checks and due diligence to optimise the data collection process. Hence, the transportation survey process, which was developed by Richardson et al. (1995) and is depicted in Fig. 3.3, was slightly modified and applied in planning and carrying out of all various surveys and interviews undertaken in this research project. This holistic approach ensures the robustness and integrity of the data collection techniques in acquiring reliable and valid primary data from the respondents in the data collection process.

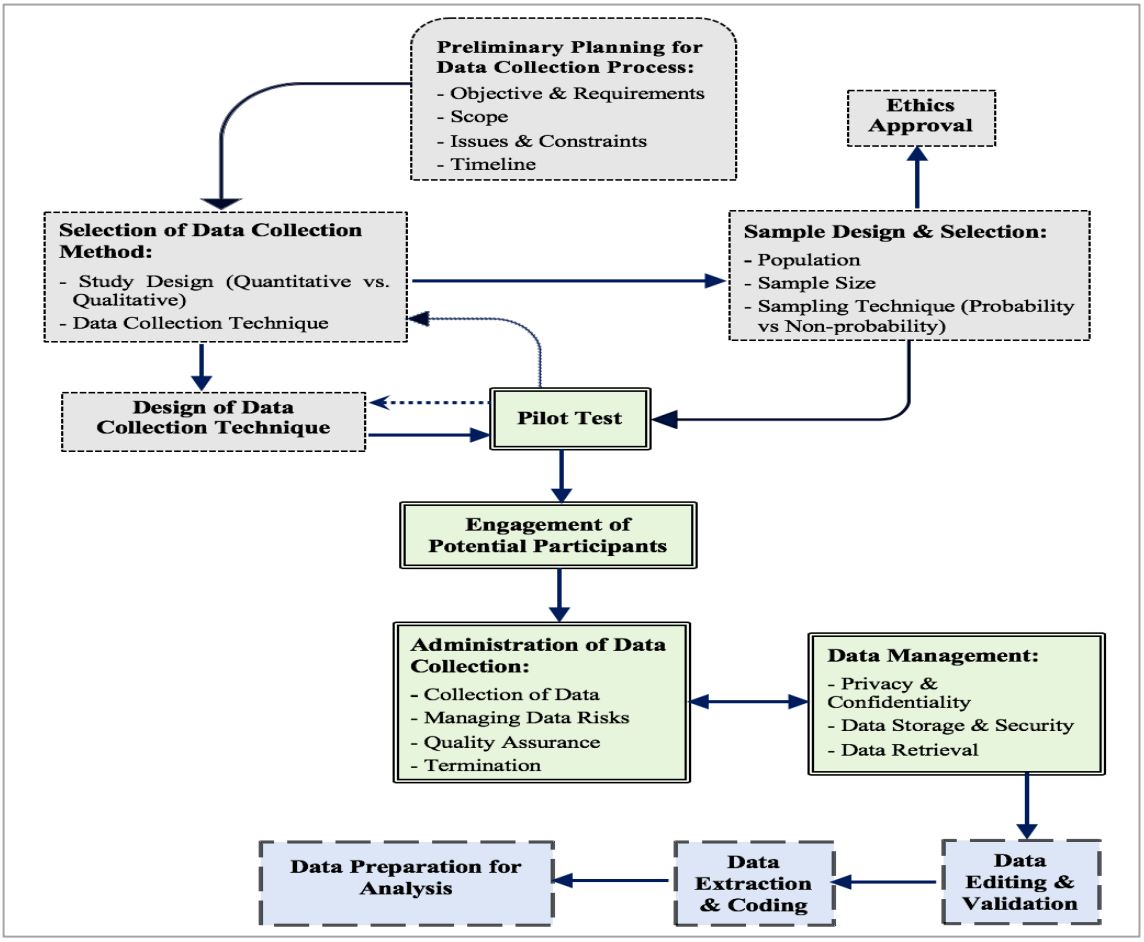


Figure 3.3. Planning Process for Primary Data Collection Techniques

3.2.1.1. Use of On-Street Loading Zones (OLZs) by Freight Vehicles in Inner-City

An observational study (parking survey) of the use of selected OLZs by freight vehicles in Melbourne CBD was conducted to develop a better understanding of the utilisation and efficiency OLZs in the city centre. The study attempted to shed more light on the increasing use of LCVs in the inner-city area. *The observational study focused on Research Question #1*. Nine OLZs in the busiest streets in Melbourne CBD were observed in person on different weekdays between 07:30-10:30 AM and 2:30-4:30 PM to record activities and utilisation of loading spaces by freight vehicles. This time was selected based on findings reported by Casey et al. (2014) that indicated up to 39% of deliveries in Melbourne CBD were between 9-11 AM. The data collected included: vacancy of loading spaces, parking duration, vehicle type, delivery address (on-street or off-street), distance from loading space to delivery address and product type. The selected OLZs serve various receivers such as office buildings (Collins St and Queen St), retail (Elizabeth St, Bourke St and Little Collins St) and the hospitality industry (Flinders Lane, Little Lonsdale St and Little Bourke St). The time window of OLZs varied from a location to another with the majority allowing vehicles to park for either 15 or 30 minutes during 07:30AM – 07:30PM. However, there were other time windows such as 09:30AM – 6:30PM or 07:30AM – 4:30PM.

3.2.1.2. Current Operational Activities of Freight Carriers inside the Inner-city

This section attempted to investigate and describe the attributes of the delivery trips that occur entirely within the inner-city area. Two data collection techniques were utilised to provide an up-to-date synopsis of the operational practices of freight carriers in the last leg of the last mile delivery and highlight in great detail the difficulties encountered when performing delivery and pickup services to receivers in the inner-city. The responses were collected using semi-structured interviews with leading couriers, express & parcel (CEP) service providers and an online survey with freight carriers in Melbourne, Australia. The research motivation originates from the limited existing knowledge about characteristics of delivery trips that are designated for receivers inside the congested city centre.

3.2.1.2.1. Semi-structured Interviews with Couriers, Express and Postal (CEP) Services Providers

The interviews were carried out with transport managers of ten large CEP service providers to acquire an updated description of their logistical activities at the depot and their delivery activities. The respondents were asked to describe when and how parcels were received on freight trucks and sorted from inter-state and intra-state into their facilities. More insights were obtained on the structure and network of their deliveries to the inner-city area. *This part of the interview focused on Research Question #1*. The perspectives of the transport managers on the suggested operational parameters of the consolidation facility were acquired during the interviews. Suggestions for the following parameters were included in the discussion with the transport managers (size of the CCCF, expected daily number of parcels, number of delivery vans and cargobikes required, operational capacity of the vehicles and cargobikes, facility manpower, suggested fee charge (AU$/parcel) by the CCCF operator and type of equipment required for the facility). This part acquired the financial and operational parameters and estimates that would be used to investigate the financial viability of the proposed CCCF and how it would generate revenue for the CCCF operator in the 5th stage of the integrated framework (section 8.4). *This part of the interview focused on Research Question #2.*

3.2.1.2.2. Online Survey with Freight Carriers

3.2.1.2.2.1. Description of the Survey

An online survey was undertaken with depot managers of various freight carriers in Melbourne. The survey collected operational data about delivery activities and operational challenges only within the inner-city. The following characteristics of the delivery trip were collected: class and number of freight vehicles, average vehicle fill-in rate, decision-maker of the order of the stops, number of daily delivery rounds, number of stops per vehicle, average number of parcels delivered per stop and the rate of successful delivery on 1st attempt. Furthermore, the depot managers were also asked to rank (100-point allocation) the impact of selected issues on the efficiency and operations of their delivery trips in the inner-city area. The following issues were included: finding parking, traffic congestion, regulations of on-street loading zones, receiver's availability, access to high-rise building, finding the correct entry point to the receiver and the street design. *This survey focused on Research Question #1*. Leedy and Ormrod (2005) underline the importance of checking for content validity. Hence, the researcher carried

out a pilot test of the survey with three freight carriers to check the logical progression and order of the questions and eliminate any words or phrases that might create confusion or misunderstanding of the questions. Accordingly, some questions were refined and simplified to eliminate any misunderstanding by the respondents.

3.2.1.2.2.2. Sampling Strategy

Systematic desktop research using several online directories and databases for businesses and local councils was conducted to create a comprehensive list of all the available freight carriers operating in Greater Melbourne. According to the Australian and New Zealand Standard Industrial Classification (ANZSIC), all these businesses operate under the classification of Transport, Postal and Warehousing (TPW) and belong to four sub-classifications (4610 Road Freight Transport, 5101 Postal Services, 5102 Courier Pick-up and Delivery Services, 5309 Other Warehousing and Storage Services). The desktop research generated a total of 285 companies representing these four sub-classifications. The warehouses and depots of these companies are located and disbursed across clearly defined geographical sub-regions (clusters) in Greater Melbourne: Inner Melbourne (Port Melbourne, West Melbourne and North Melbourne), East (Knoxfield, Rowville), Southeast (Moorabbin and Dandenong South), North (Tullamarine and Campbellfield) and West (Altona/Laverton and Truganina). Accordingly, a multi-stage cluster sampling technique was applied to select potential freight carriers to participate in the online survey. This sampling strategy enabled achieving a more representative sample of the population than a single sampling technique as well as reaching a larger sample size (Saunders et al. 2009). The multiple stage cluster sampling was performed as follows:

- 1st Stage: out of the possible 5 clusters in Greater Melbourne, all 5 clusters were selected. Number of selected clusters: 5
- 2nd Stage: out of the possible 4 TPW sub-industries in each cluster, all 4 TPW sub-industries will be selected. Number of sub-clusters: 20
- 3rd Stage: 12 TPW businesses from 4 TPW sub-industries were selected by simple random sampling in each cluster. Total sample: 240 delivery companies.

Allen et al. (2012c) reported that the average response rate for carrier-based survey is around 40% with an average sample size of 250 freight carriers. The researcher invited 240 freight carriers to participate in the survey. Potential participants were contacted via phone to inform them about the study and acquire contact details of transport managers. Transport Managers from selected freight carriers were formally invited via email and/or phone to participate in the online survey.

3.2.1.2.2.3. Response Rate of the Survey

In total, the researcher collected responses from 55 participants (depot managers of freight carriers), which represented a 23% active response rate. The responses were collected from freight carriers serving receivers in the CBD, Docklands and Southbank. Fig. 3.4 displays the final count of the participants and their respective geographical clusters within Greater Melbourne. The 55 freight carriers represent 20% of all freight carriers in the original dataset in Greater Melbourne.

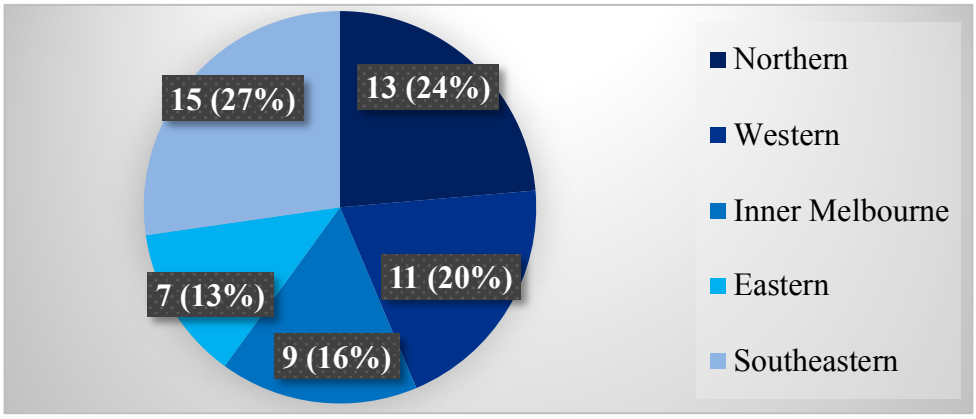


Figure 3.4. Number of Participants from Each Cluster in Greater Melbourne

3.2.2. Part B: Design of the Central City Consolidation Facility

This stage applied a systems approach to propose the setup and configuration of the CCCF, which combined carriers-led and receivers-engaged initiatives to bring light parcel consolidation inside the inner-city area. The systems approach incorporated several aspects in the proposed design of CCCF, which are displayed in Fig. 3.5, to ensure its suitability for consolidated deliveries in the inner-city. These aspects were included in the proposed design of CCCF based on the extensive review of previous consolidation facilities and schemes to build on the key success factors that contributed to the success of previous consolidation initiatives as highlighted in section 2.3.6.1 as well as overcome the issues and limitations of pervious solutions that were discussed in section 2.3.6.2. Moreover, the acquired insights obtained from the freight carriers were incorporated in the proposed design of the CCCF to ensure the consolidation facility reflected the current practices and requirements of freight carriers and facility operator. Careful consideration was given to facilitating operational benefits and efficiency gains for participating freight carriers to make the proposed consolidation initiative cost-attractive and operationally appealing. Strenuous efforts and continuous improvements were applied to ensure the proposed design addressed the limitations and shortcomings that adversely impacted previous consolidation facilities. The proposed design was continually improved and modified based on feedback and suggestions from local freight carriers and consultation with expert transport researchers and local government personnel involved in last mile delivery.

As the various types of parcels for receivers in the inner-city area have different operational requirements, it was necessary to focus on the parcel types that could be consolidated at the facility without major structural changes in the design of the facility. For instance, food and perishable deliveries require additional cold storage and special handling and sorting equipment, which would increase the infrastructural costs of the facility to provide the additional equipment. Thus, it was decided to focus on non-perishable light freight parcel deliveries that facilitate standard handling, sorting and distribution practices for the consolidated deliveries. Furthermore, this stage included the supporting regulations that local authorities should provide to enable the effective operations of the facility. The proposed design of the CCCF and the supporting regulations are presented and discussed in great detail in Chapter 4.

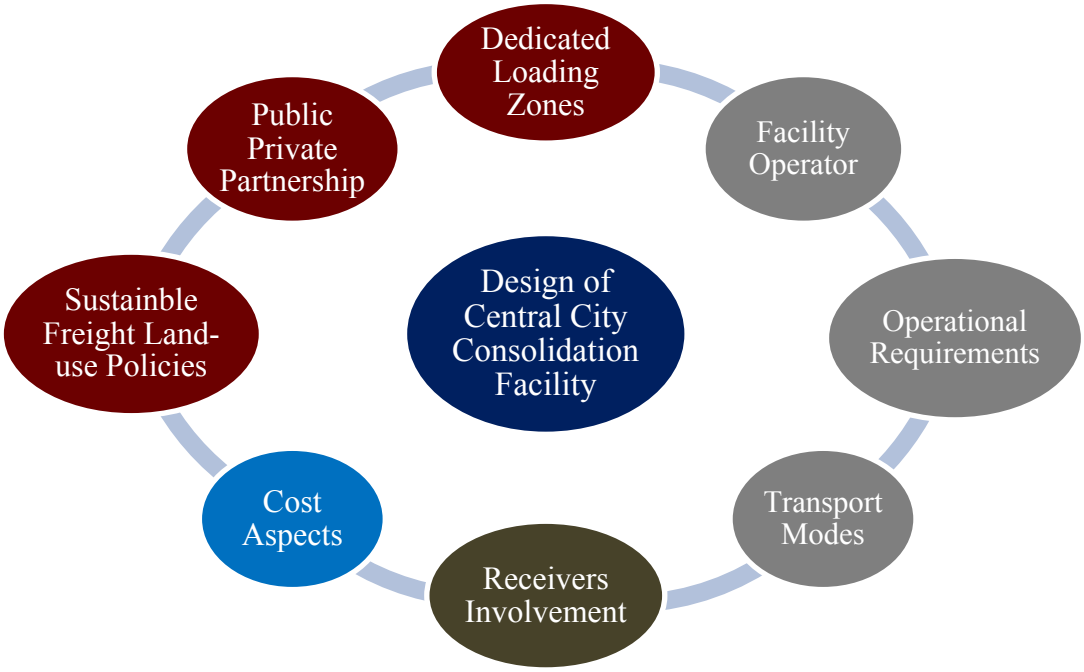


Figure 3.5. Overview of Main Aspects Considered in the Design of the CCCF

3.3. 2nd Stage: Multi-stakeholder Evaluation Approach for the Most Suitable Delivery Fleet for the Consolidated Deliveries

There are different types and classes of transport modes and vehicles that could be used to perform the consolidated deliveries in the inner-city. The type of freight vehicle is very critical in reducing the negative impacts of last mile delivery as well as garnering acceptance from various stakeholders. Many previous consolidation policies overlooked incorporating a more comprehensive list of the objectives of all stakeholders in their decision-making. It could be argued that many previous local governments and transport researchers paid more attention to promoting cargobikes to replace or complement conventional delivery vans. However, they did not pay similar attention to other key operational aspects that might critically affect the operational efficiency of freight carriers and receivers such as ability to efficiently integrate with existing delivery operations or ensuring the security of the parcels. This might not be an appropriate approach and contribute to failure or rejection of the proposed policy.

In order to overcome these issues, this stage applied a multi-stakeholder participatory decision-support approach to evaluate the suitability of different types of freight vehicles based on the objectives and perspectives of all the stakeholders involved in last mile delivery. The key objectives of all the stakeholders were identified with respect to the freight consolidation policy as well as determining the relative importance of the objectives for each stakeholder group. This was achieved by utilising the Multi-Actor Multi-Criteria Analysis (MAMCA) approach to assess and rank various delivery configurations involving a combination of eco-friendly delivery vehicles, trucks and cargobikes based on the objectives of the stakeholders. The MAMCA approach enabled taking into consideration the various objectives and requirements of all the stakeholders of the different alternative configurations of the consolidated delivery fleet under investigation throughout the entire evaluation process. The MAMCA approach consists

of two main phases. The first phase, which includes four steps, focuses on acquiring required information about the stakeholders and their objectives. The second phase, which includes three steps, performs the multi-actor analysis of the alternatives based on objectives of the stakeholders and proposes suitable implementation plans. The following steps were applied to evaluate and rank the most suitable consolidated delivery configurations for the consolidated delivery in the inner-city area (Macharis 2007):

- **1st Step:** Problem Definition and Identifying the Alternatives for Evaluation.

The sustainability and operational concerns were taken into consideration in proposing the alternatives of the consolidated delivery fleet. As the proposed consolidation policy attempts to minimise negative impacts of last mile delivery on the amenity of the inner-city, it was important to include eco-friendly freight vehicles and cargobikes in the proposed alternatives. Starting from the assumption of freight carriers' propensity for using delivery vans, various consolidated delivery fleet configurations using cargobikes, eco-friendly LCV and/or freight trucks could be proposed. Accordingly, three proposed operational scenarios were evaluated and compared with the business-as-usual (BAU) scenario using MAMCA framework to rank the most suitable and optimal configuration based on the stakeholders' objectives. These alternative configurations were proposed based on extensive evaluation of available literature on last mile delivery as follows:

  - ***Scenario #1 "Cargobike":*** The consolidated delivery trips are conducted using only cargobikes with parcel carry component.
  - ***Scenario #2 "Eco-friendly LCV + Truck (Only Off-Peak Hours)":*** The consolidated delivery trips are conducted using eco-friendly LCVs in all times and trucks only during off-peak hours.
  - ***Scenario #3 "Eco-friendly LCV + Cargobike":*** The consolidated delivery trips are conducted using eco-friendly LCVs and cargobikes with dedicated on-street loading zones in the inner-city area.
  - ***Scenario #4 "BAU":*** Business-as-usual (BAU) where carriers deliver directly to receivers using LCVs and trucks with no consolidation or coordination.

- **2nd Step:** Identify all stakeholders involved and determine their objectives.

The logistics services providers (LSP), receivers, shippers, local authorities, citizens, and logistics property providers (LPP) stakeholder groups were included in the evaluation of the alternatives using the MAMCA approach. The LPP stakeholder group has not been frequently included in similar studies. However, it was necessary to involve the LPP group in the MAMCA analysis to acquire their perspective on the proposed consolidation policy. Receivers in the inner-city are primarily retailers, wholesalers, offices, education and government establishments as well as residents and workers. Their delivery requirements are quite different from large commercial and industrial receivers that are usually located out of the inner-city area. A large volume of the inner-city receivers' daily delivery requirements would be frequent, fragmented and express light parcel shipments. These receivers might be the stakeholder group along with the LSP stakeholder group to be mostly and directly affected by the proposed consolidation scheme.

It was important for the respective objectives for each stakeholder group to be relevant,

practical and encompassing of their operations and requirements. Several studies that utilised MAMCA focused more on environmental and social objectives and overlooked the operational objectives. Accordingly, an initial list of the objectives for each stakeholder group was developed. The list was discussed during meetings with key actors from the six stakeholder groups in Melbourne. Consequently, the stakeholders' objectives were updated based on discussion and feedback from key actors.

- **3rd Step:** Convert the stakeholders' objectives to criteria and assign a weight that indicates the criteria's importance based on the objective of the stakeholder.

The objectives of the six stakeholder groups that were determined in 2nd step would be used as evaluation criteria for the four scenarios in the following steps of the MAMCA approach. This study applied the Chang Extent Analysis Method (EAM) Fuzzy AHP approach to calculate fuzzy weights of the decision criteria based on direct responses from key stakeholders. This approach started with the use of triangular fuzzy numbers (TFN) for pairwise comparison by means of F-AHP scale. Then, the EAM method was applied to determine the criteria weights using synthetic extent values. A membership function was constructed for each linguistic term of the comparison scale for each criterion. A fuzzy evaluation matrix of the criteria could thus be theoretically constructed through pairwise comparison of linguistic variables and respective triangular fuzzy numbers as shown in Table 3.1 (Bozbura et al. 2007; Kabir and Hasin 2011). After obtaining the weights for each criterion, they were normalised using the centre of area (COA) approach.

Table 3.1. Linguistic Variables Used to Describe Criteria Weights and Rating Values

Linguistic scale for importance	Fuzzy numbers	Membership function	Domain	Triangular fuzzy scale (*l,m,u*)
Just Equal Equally important	$\breve{1}$	$\mu_{\mathrm{M}}(x) = (3-x)/(3-1)$	$1 \le x \le 3$	(1,1,1) (1,1,3)
Moderately important	$\breve{3}$	$\mu_{\mathrm{M}}(x) = (x-1)/(3-1)$ $\mu_{\mathrm{M}}(x) = (5-x)/(5-3)$	$1 \le x \le 3$ $3 \le x \le 5$	(1,3,5)
Strongly important	$\breve{5}$	$\mu_{\mathrm{M}}(x) = (x-3)/(5-3)$ $\mu_{\mathrm{M}}(x) = (7-x)/(7-5)$	$3 \le x \le 5$ $5 \le x \le 7$	(3,5,7)
Very strongly important	$\breve{7}$	$\mu_{\mathrm{M}}(x) = (x-5)/(7-5)$ $\mu_{\mathrm{M}}(x) = (9-x)/(9-7)$	$5 \le x \le 7$ $7 \le x \le 9$	(5,7,9)
Extremely important	$\breve{9}$	$\mu_{\mathrm{M}}(x) = (x-7)/(9-7)$	$7 \le x \le 9$	(7,9,9)
If factor *i* has one of the above numbers assigned to it when compared to factor *j*, then j has the reciprocal value when compared to *i*			Reciprocals of above $\breve{M}_1^{-1} = (1/u_1, 1/m_1, 1/l_1)$	

Accordingly, various representatives from all six stakeholder groups participated in a questionnaire to select the related linguistic variable to determine the importance levels of the criteria. *This questionnaire focused on Research Question#3.* Table 3.2 displays the criteria for each stakeholder group that were used in the pairwise comparison. The participants from each stakeholder group were presented with a matrix displaying their

respective objectives (criteria) for the one-on-one pairwise comparison of the objectives. Each set of two criteria were paired and the participants were asked to indicate "which criterion was more significant for the optimal delivery configuration of the consolidated delivery in the inner-city area?" based on the linguistic scale of importance. This process was repeated to pair each criterion with all other criteria to create an evaluation matrix.

The potential participants from the six stakeholder groups were determined using the purposive sampling technique, which is a non-probability sampling approach. The significant time-consuming process of the pairwise comparison approach made this sampling more appropriate for this questionnaire. A total of 70 respondents participated in the questionnaire (8 personnel from local authorities, 10 residents, 20 retailers, 17 freight carriers, 10 warehouse managers of shippers and 5 managers from the logistics property providers). This represented a reasonable response level as the objective was to acquire direct response from relevant organisations and individuals that are impacted by delivery activities in the inner-city. It is important to note that each stakeholder group included different participants with different viewpoints for the respective criteria. Hence, after collecting the responses of the pairwise comparison from all the participants in each group, the individual evaluation matrices (rankings) resulting from each participant were aggregated for each stakeholder group to calculate the geometric mean for each criterion's evaluation matrix per group. Accordingly, the final pairwise matrix for that group was constructed to calculate the criteria weights for each group.

- **4th Step:** Links each criterion to a measurable or qualitative indicator to determine a score and measurement scale.

Many of the criteria displayed in Table 3.2 such as harmonious integration, convenient delivery and network utilisation could not be expressed in numbers. Furthermore, there was a lack of quantitative data from the local freight industry for some of these criteria. This issue was overcome due to the strengths of MAMCA framework not requiring quantitative criterion to conduct the multi-criteria analysis of the alternatives as asserted by Roukouni et al. (2018). Accordingly, the quantitative and qualitative indicators and units of measurement for all the decision criteria were acquired through a comprehensive literature review and several consultation sessions with experts in the freight industry in Melbourne, which are displayed in Table 3.2. These criteria were operationalised to enable measuring and comparing the performance of each scenario with respect to the criterion under evaluation.

Table 3.2. Decision Criteria and Measurement Indicators for Each Stakeholder Group

Stakeholder	Criteria	Indicator	Unit of Measurement
LSP	Service Level	Customers Satisfaction Level (Ordinal Scale)	Very Satisfied, Satisfied, Neutral, Dissatisfied, Very Dissatisfied
	Delivery Lead Time	Time from drop off at CCCF until delivery to receiver	4,5,6,7,8,12, 24, 30, 36 or 48 Hours
	Multi-modality	Use of other Freight Transport modes	Very Likely, Likely, Neutral, Unlikely, Very Unlikely
	Transport Cost	Consolidated Delivery Charge	AUD$ 2.5, 3.0, 3.5, 4.0, 4.5, or 5.0
	Vehicle Fill-Rate	Vehicle Capacity Utilisation (%)	90%, 80%, 65%, 55% and 45%
	System Integration	Promptness of Delivery Updates and documents	Always, Frequently, Occasionally, Rarely, Never
	Delivery Security	Frequency of Damaged &Stolen Deliveries	Very Probable, Probable, Neutral, Somewhat Improbable, Not Probable
Receivers	Delivery Punctuality	On-time deliveries (%)	100%, 90%, 80%, 70%, 60%%
	Parcel Receiving Cost	Monetary Value	AUD$ 7.5, 8.0, 8.5, 9.0, 9.5, 10.0, 11.0 12.0 or 15.0
	Delivery Status Updates	Promptness of Delivery Updates	Always, Frequently, Occasionally, Rarely, Never
	Convenient Deliveries	Frequency of Delivery during off-peak hours	Very Probable, Probable, Neutral, Somewhat Improbable, Not Probable
	Business Environment Attractiveness	Presence of Freight Vehicles	Very High, High, Medium, Low, Very Low
	Delivery Security	Frequency of Damaged &Stolen Deliveries	Very Probable, Probable, Neutral, Somewhat Improbable, Not Probable
Shippers	Delivery Cost	Cost of Picking & Delivery of Parcel	AUD$ 5.0, 5.5, 6.0,6.5, 7.0, 7.5, 8.0 9.0 or 10.0
	Quick Delivery	Time from pickup to delivery	0.5, 1, 2, 3, 4 Days
	Delivery Document	Submission of Delivery Documents	Always, Frequently, Occasionally, Rarely, Never
	Receiver Satisfaction	Receivers' Rating of Delivery Service	Very Satisfied, Satisfied, Neutral, Dissatisfied, Very Dissatisfied
	Carrier's Availability	Time from Contact to Pickup	Excellent, Very Good, Good, Poor, Very Poor
Local Authorities	Liveable City	Level of nuisance and pollutions (environmental, visual and sound)	Very Acceptable, Acceptable, Neutral, Unacceptable, Very Unacceptable
	Low-Cost Measures	Cost of Proposed Solution	Very High, High, Moderate, Low, Very Low
	Network Utilisation	Use of Roads by Facility's Vehicles	Excellent, Very Good, Good, Poor, Very Poor
	Urban Accessibility	Congestion Level due to freight vehicles	Very High, High, Moderate, Low, Very Low
	Impact on Surroundings	Functional and operational integration of facility's vehicle with surrounding uses	Excellent, Very Good, Good, Poor, Very Poor
Citizens	Traffic Safety	Number of Accidents due to Freight Vehicles	Very High, High, Moderate, Low, Very Low
	Quality of Life	Nuisance and pollutions level (environmental, sound & congestion)	Very Acceptable, Acceptable, Neutral, Unacceptable, Very Unacceptable
	Product Availability	Frequency of Product Unavailability Due to Freight Vehicles	Very Probable, Probable, Neutral, Somewhat Improbable, Not Probable
Logistics Property Providers	Profitability	Return on Investment	Net Profit (30, 25, 20, 15, 10, 5 %)
	R&M Cost	Cost of R&M of Facility	AUD$ 4,000, 5,000, 6,000, 8,000, 10,000 or 15,000
	Harmonious Integration	Functional integration of facility's vehicle with surrounding uses	Excellent, Very Good, Good, Poor, Very Poor
	Location Accessibility	Distance to Major Freight Roads & Bike Lanes	Very Far, Far, Moderate, Close, Very Close

- **5th Step:** Perform the multi-criteria analysis to evaluate the alternatives with respect to the decision criteria. This evaluation attempted to measure what impact the implementation of the alternative will have on the criterion.

This step applied the PROMETHEE method to carry out the multi-criteria analysis of the four scenarios. The MAMCA™ software, which is an online platform for MAMCA application provided by the research group MOBI at Vrije Universiteit Brussel, was utilised to perform the multi-criteria analysis and determine the overall evaluation scores of all the alternatives based on the PROMETHEE method. The following steps of the PROMETHEE method were incorporated in the MAMCA software (Brans and De Smet 2016; Behzadian et al. 2010):

I. Finding the derivations based on pairwise comparisons as follows

$$d_j(a,b) = \mathrm{g}_j(a) - \mathrm{g}_j(b) \quad \text{(eq. 3.1)}$$

where $d_j(a,b)$ denotes the difference between the evaluations of *a* and *b* on each criterion.

II. Application of the preference function:

$$P_j(a,b) = \mathrm{F}_j\left[d_j(a,b)\right] \qquad j = 1, \ldots, k \quad \text{(eq. 3.2)}$$

where $P_j(a,b)$ denotes the preference of alternative *a* with regard to alternative *b* on each criterion, as a function of $d_j(a,b)$.

III. Calculation of an overall or global preference index

$$\forall a, b \epsilon A, \qquad \pi(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j \quad \text{(eq. 3.3)}$$

where $\pi(a,b)$ of *a* over *b* (from 0 to 1) is defined as the weighted sum *p* (a, b) for each criterion, and w_j is the weight associated with *j*th criterion.

IV. Calculation of outranking flows/The PROMETHEE I partial ranking

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x) \quad \text{(eq. 3.4)}$$

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x) \quad \text{(eq. 3.5)}$$

where $\phi^+(a)$ and $\phi^-(a)$ denote the positive outranking flow and negative outranking flow for each alternative, respectively.

V. Calculation of the net ranking flow/The PROMETHEE II complete ranking

$$\phi(a) = \phi^+(a) - \phi^-(a) \quad \text{(eq. 3.6)}$$

where $\phi(a)$ denotes the net ranking flow for each alternative.

- Accordingly, experts from the local freight and retail industries, local authorities and the researcher participated in an interactive workshop (focus group) sessions to perform the multi-criteria analysis of the four scenarios using the MAMCA™ software. Four experts from local authorities were selected to represent the societal concerns and objective whereas eight experts from local freight industry were selected to represent transport stakeholders including shippers, freight carriers and logistics property developers. Five experts from retail industry were selected to represent the various businesses that require freight deliveries. The selection of the participants for each stakeholder group was based on an expert sampling technique. This non-probability sampling technique facilitated rapid and inexpensive access to knowledgeable professionals and government employees who are highly involved in

last mile delivery. The evaluation scale used in the PROMETHEE method to perform the multi-criteria analysis of the four scenarios was qualitative (very negative, negative, slightly negative, neutral, slightly positive, positive, very positive). Experts from each stakeholder group evaluated each pair of scenarios based on their respective criteria to determine the evaluation score for the scenarios for each stakeholder group. During the group discussion for each stakeholder group evaluation session, various viewpoints of the different participants in each group were compared and analysed during the group session to come to a consensus for the group's viewpoint on each evaluated scenario. This ensured reaching an agreement during the group session for the experts' viewpoints on the performance of the four scenarios. **6th Step:** The multi-criteria analysis provided a ranking of the various alternatives as well as highlighting the strengths and weaknesses of the alternatives with respect to their performance on the stakeholders' criteria. A sensitivity analysis was performed to examine the significance of weight modifications on the final ranking and validate the robustness of the results.

- **7th Step:** Clearly defined policy recommendations and implementation plans for optimal delivery fleet were provided.

The full results and rankings of the four scenarios and the recommended implementation plan are described in section 5.2.2.

3.4. 3rd Stage: Appraisal of Receivers' Interest in Participating in the Proposed Consolidation Service

3.4.1. Examining the Interest of the Receivers to Participate in the Freight Consolidation Service

The 1st and 2nd stage of the integrated framework focused more on the perspectives and requirements of freight carriers, CCCF operator and local authorities. The re-stocking decision-making and operational requirements of receiving the parcels by businesses could play an important role in the success of freight consolidation initiatives. Although the market powers of receivers and their influence on freight carriers are highly dependent on the economic relations and dynamic interactions along the supply chain network, receivers might be reluctant to induce changes in the destination of their parcels without their involvement. However, if receivers find the proposed consolidation policy beneficial and attractive to their businesses, they might be interested in the consolidation service. Hence, the preferences and delivery requirements of receivers should be taken into consideration in the planning of the proposed consolidation policy to ensure designing a suitable freight consolidation scheme that effectively addresses the receivers' requirements. Fig. 3.6 displays the various data collection approaches and modelling methods that were applied in the 3rd stage of the integrated framework to examine the interest of receivers to consolidate their deliveries.

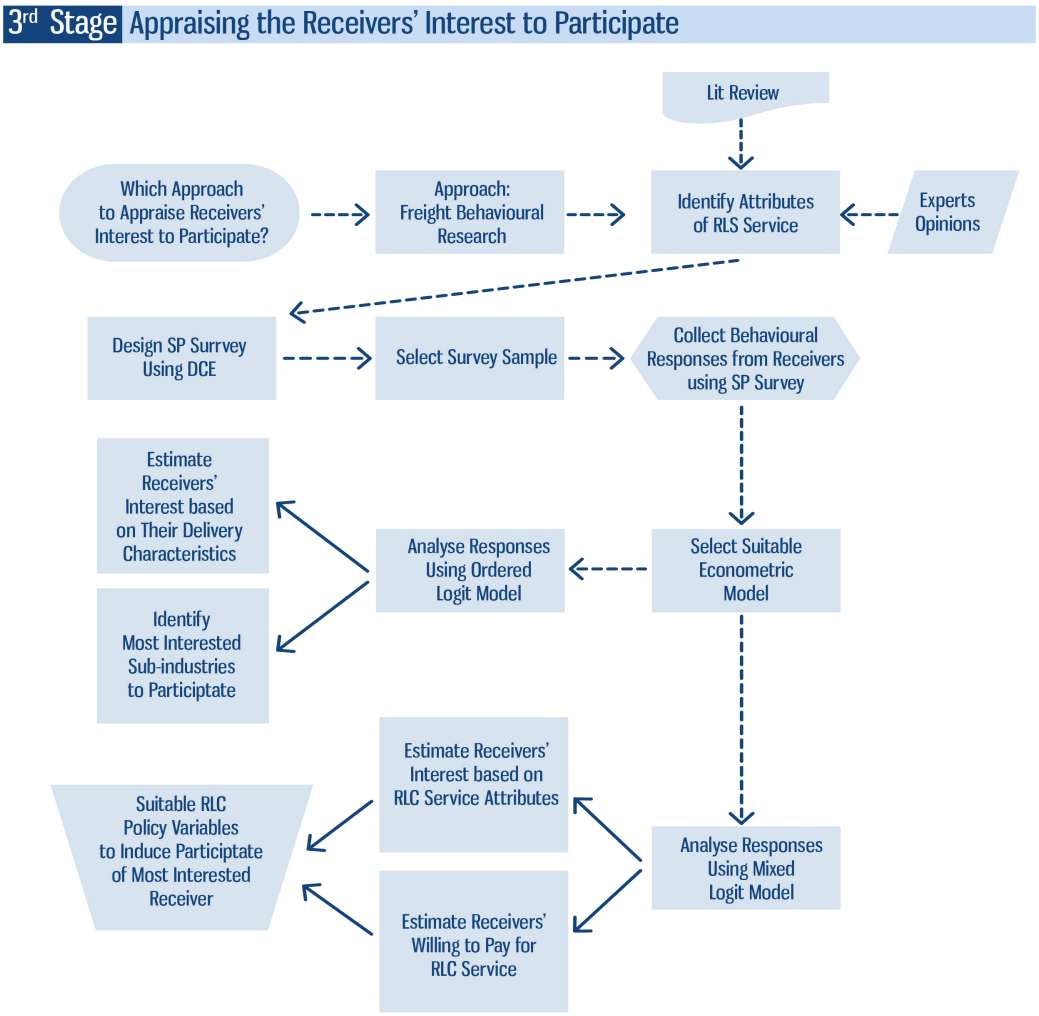


Figure 3.6. Flowchart of the Freight Behavioural Models Applied in the 3rd Stage

It was decided to build on the notion of the Receiver-led delivery consolidation (RLC) schemes to induce behavioural changes in the freight demand of receivers and consolidate their deliveries. The receivers could request their suppliers to deliver the orders to the proposed CCCF where different parcels would be combined in optimised loads to each individual receiver by the CCCF operator. As the RLC service introduced in the study is of a hypothetical nature, this limited knowledge called for freight behavioural research to evaluate the RLC initiative and estimate the receivers' interest in participating in the RLC service. Accordingly, this stage aimed to investigate the receivers' willingness to participate in the RLC service by appraising the perceptions and stated responses of retailers and businesses in the inner-city using a stated-preference (SP) survey. It attempted to elucidate the mechanism and factors that could influence and promote receivers to request their suppliers and freight carriers to transfer their shipments to the proposed consolidation facility without involving financial incentives. This was enabled by carrying out freight behavioural research using a discrete choice experiment (DCE) that facilitated collecting stated-preference data and utilising behavioural models to shed more light on the receivers' behavioural responses to the RLC service. The DCE allowed construction of hypothetical scenarios of the RLC service to estimate their behavioural preferences and likely adoption.

The stated-preference survey included two parts. The proposed CCCF was introduced and explained to the survey respondents using visual illustrations on how the consolidation delivery service might be performed. The 1st part collected current delivery requirements (type of business, number of daily deliveries and pickups services, number of delivery companies dealing with, most frequent time receiving deliveries, time spent on processing deliveries and a direct question on their willingness to participate in the proposed RLC delivery). The "willingness to participate" direct question appraised the receivers' willingness to ask their suppliers and freight carriers to deliver their orders to the proposed CCCF instead of directly to their businesses. The focus in the survey was on the deliveries that were regularly received by the receivers for their core business operations. Receivers typically are more involved and aware of their regular suppliers and freight carriers. However, other type of irregular deliveries including service and ad-hoc deliveries would add more uncertainty and complexity to the proposed consolidation scheme. Moreover, the 2nd part of the survey presented various hypothetical scenarios that displayed different alternative configurations of the proposed consolidated delivery service. *This survey focused on Research Question #4.*

The behavioural responses collected from the receivers in the SP survey were estimated using logit models in two consecutive phases to predict the receivers' willingness to participate in the RLC service. In the 1st phase, the responses were estimated using an ordered logit model to identify the characteristics of the receivers that could drive willingness to participate and determine the specific industries that contain businesses that were most and least inclined to consolidate their deliveries. In the 2nd phase, the behavioural responses were estimated using a mixed logit model to determine which RLC policy variables significantly influence and foster the receivers' preferences and participation as well as quantify the receivers' willingness to pay (WTP) for the consolidated delivery service. It is worth noting that this study is one of the first to estimate the receivers' willingness of to pay for the RLC service.

3.4.2. Design of the Stated-Preference Survey with Businesses in Melbourne's CBD

The design of the stated-preference survey using a discrete choice experiment (DCE) involved setting out the relevant attributes of the alternative configurations of the RLC service that would be compared in the choice scenarios. It was important to focus on the factors and policy variables that might promote and influence participation of receivers in consolidating their deliveries.

The attributes of the stated-preference survey were identified and selected using two consecutive steps. Firstly, a preliminary list of the attributes was developed based on a comprehensive evaluation of the literature on delivery consolidation policies and freight behavioural studies. While several studies focused on time- and distance-related attributes such as distance to the proposed consolidation facility or delay in delivery time, it was also necessary to include relevant attributes that would characterise the alternative configurations of the consolidated delivery service with respect to the potential offers and benefits of the proposed service. Furthermore, it was important to incorporate operational attributes that are in fact relevant and practical to the delivery requirements of receivers in order to make the survey appealing and increase the policy's credibility with the receivers. Secondly, the preliminary list of attributes and their levels was reviewed and

discussed during consultations with local experts from freight and retail businesses to ensure that the most relevant attributes were included. The experts recommended that the attribute levels should be pivoted around practical values that reflect issues impacting the freight carriers and the current delivery requirements of receivers. Accordingly, the following four attributes were included in the stated-preference survey based on the preliminary list developed from the literature review that were assessed and improved by the feedback and suggestions received during the meetings with the experts:

1. Time-Windows of the Consolidated Delivery: In order to accommodate the different delivery requirements of the various receivers in the inner-city area, different time-windows of the consolidated delivery service should be offered by the operator of the consolidation facility. Receivers could request the delivery of their shipments to their premise during one of the possible time-windows.

2. Reduction in Number of Daily Deliveries: The RLC service combines deliveries addressed to participating businesses from other carriers into consolidated deliveries to reduce the number of deliveries to each receiver. The number of current deliveries to the receiver varies significantly depending on industry sector, size of receiver as well as the size and volume of items delivered in each shipment. Although the number of parcels and frequency of the consolidated delivery service to the receiver is highly variable and difficult to determine in the planning stage, this attribute attempted to measure the perceived value of potential reduction in the number of current deliveries from the receiver's perspectives. Thus, it was recommended to offer a standard comparison scale and simpler terms of reduction, e.g. one third or half of existing deliveries would be consolidated. Proper illustrations were provided to the respondents to compare the relevant number of existing vs consolidated deliveries.

3. Value Added Services Offered by the Carrier of the Consolidated Delivery: The operator of the consolidation facility could offer ancillary services to the receivers to enhance their experience of receiving the parcels and the efficiency of their in-store operations for the staff. These pre-retailing and recycling services could generate additional revenues to the facility operator.

4. Delivery Information Updates: The facility operator should capitalise on advanced information communication technologies (ICT) and internet of things (IoT) to offer different options for the exchange of delivery documents and status updates to participating receivers.

Furthermore, Table 3.3 summarises the numbers and values of the main attribute levels proposed for the hypothetical choices of the consolidated delivery service in the survey.

Table 3.3. Number and Values of Attribute Levels for the Main Attributes Selected in the Design of the Stated-Preference Survey

Attribute	Number of Attribute Levels	Values of Attribute Levels
Time-Window of Consolidated Delivery	5	• 05:00 – 08:59 • 09:00 – 15:59 • 16:00 – 18:59 • 19:00 – 21:59**

		• 22:00 – 04:59**
Reduction in existing number of deliveries	5	• 25% • 33% • 50% • 67% • 75%
Value-added Services	5	• Receiver time-specific delivery • Unpacking & waste removal • Temporary storage • Product quality & quantity check • Product returns.
Delivery Status Updates	3	• Real-time updates • Fixed updates, e.g. once a day. • No updates

It is worth noting that this study did not attempt to include a cost attribute to characterise the RLC service cost in the SP survey for several reasons. Firstly, as the RLC policy might be a new and somewhat vague policy to the potential participants in the survey, including a cost attribute might lead to erroneous assumptions about the hypothetical scenarios presented in the survey. The respondents might have some confusion about interpreting the delivery charge shown for the cost attribute in the choice scenario and determining what is included or excluded in the cost structure. Secondly, the consolidation delivery service includes multiple freight carriers, shippers and the receiver. Attempting to address the various delivery cost structures of these multiple stakeholders would increase the complexity and uncertainty of the potential delivery charges for the cost attribute. Hence, these issues could have introduced respondent bias into the research design.

The orthogonal design with blocking method was applied to construct the choice scenarios in the survey. This approach facilitated limiting the correlation between attribute levels in the choice tasks within each block, which indicate that the attributes were statistically independent of each other (Louviere et al. 2000). The blocking technique divides the final choices into balanced blocks with different choice tasks that are displayed to different sub-sets of respondents. This approach was deemed more appropriate than the efficient design approach, which has been used in some recent freight behavioural studies. The efficient design approach required prior knowledge of parameter estimates for each attribute from existing or pilot studies (Bliemer et al. 2009), which was not available for the Australian perspective. It would have been costly and time-consuming to conduct a pilot study to obtain the prior estimates for this study. It was important to maintain the balance (occurrence) of the attribute levels in the choice tasks as much as possible. However, maintaining these two principles (orthogonality and balance) means that no single attribute level would appear twice in the same choice task. Thus, it was necessary to relax this rule and allow limited overlap of the attribute levels in the same choice tasks to detect the impact of other attributes on choice behaviour.

Accordingly, the experimental design produced 18 choice tasks to be presented to each

participant, which could be excessive and time-consuming for in-store staff for survey respondents. Consequently, the final choice scenarios were assigned to two balanced blocks of 9 choice scenarios, which are shown in Table 3.4.

Table 3.4. Final Choice Task Generated by the Experimental Design for the SP Survey

		Block A			Block B		
Choice Task	Attribute	Choice#1	Choice#2	Choice#3	Choice#1	Choice#2	Choice#3
	Time-Window	19:00-21:59	09:00-15:59	05:00-08:59	09:00-15:59	22:00-04:59	19:00-21:59
1	Reduction	25%	50%	33%	25%	50%	75%
	Service*	UN	TS	PR	RT	PQ	TS
	Updates**	Real-time	Fixed	No Update	No	No	Fixed
	Time-Window	22:00-04:59	19:00-21:59	09:00-15:59	16:00-18:59	19:00-21:59	22:00-04:59
2	Reduction	50%	33%	75%	25%	67%	75%
	Service	RT	UN	PR	PR	UN	RT
	Updates	Fixed	No	Real	Fixed	Real	No
	Time-Window	09:00-15:59	05:00-08:59	22:00-04:59	19:00-21:59	09:00-15:59	05:00-08:59
3	Reduction	50%	25%	75%	25%	33%	50%
	Service	PQ	RT	TS	TS	PQ	PR
	Updates	Fixed	Real	No	No	Fixed	Real
	Time-Window	19:00-21:59	05:00-08:59	09:00-15:59	16:00-18:59	19:00-21:59	09:00-15:59
4	Reduction	33%	67%	67%	75%	33%	67%
	Service	PR	UN	TS	PR	PQ	UN
	Updates	Fixed	Real	Fixed	No	Real	Real
	Time-Window	09:00-15:59	16:00-18:59	22:00-04:59	05:00-08:59	19:00-21:59	16:00-18:59
5	Reduction	67%	75%	25%	67%	50%	50%
	Service	PQ	RT	PR	TS	RT	UN
	Updates	No	Real	Real	Real	Real	Fixed
	Time-Window	19:00-21:59	05:00-08:59	16:00-18:59	22:00-04:59	09:00-15:59	05:00-08:59
6	Reduction	75%	67%	25%	33%	67%	75%
	Service	TS	PQ	UN	PQ	RT	UN
	Updates	No	Fixed	Real	Real	Real	Fixed

	Time-Window	22:00-04:59	05:00-08:59	09:00-15:59	05:00-08:59	16:00-18:59	19:00-21:59
7	Reduction	33%	50%	25%	33%	25%	67%
	Service	TS	PR	UN	TS	RT	RT
	Updates	Real	No	No	No	Real	Fixed
	Time-Window	09:00-15:59	16:00-18:59	05:00-08:59	16:00-18:59	19:00-21:59	09:00-15:59
8	Reduction	75%	25%	33%	25%	25%	33%
	Service	UN	PQ	RT	TS	UN	RT
	Updates	Real	No	Fixed	Real	Fixed	Real
	Time-Window	19:00-21:59	16:00-18:59	22:00-04:59	09:00-15:59	22:00-04:59	05:00-08:59
9	Reduction	75%	50%	67%	50%	75%	67%
	Service	RT	UN	PR	PR	TS	UN
	Updates	Real	Real	No	No	Fixed	No

* Services: ***RT***-Receiver time-specific delivery, ***UN***-Unpacking & waste removal, ***TS***-Temporary Storage, ***PQ***-Product Quality & Quantity check, ***PR***-Product Return.

** Updates: ***Real***-real-time update, ***Fixed***-time-fixed update (e.g. once a day), ***No*** – No Updates

The survey instrument was web-based, and computer-assisted personal interviewing was used to conduct the survey at the premises of the receivers using a mobile tablet. Each respondent was presented with 9 randomised choice tasks that included three different consolidated delivery choices that described how the consolidated delivery may be performed. The following measures were applied to enhance the validity and quality of the responses. The sequence of the choice tasks and the order of the choices in each task were randomised for the respondents in each block to reduce the dominance of certain choices or selecting choices based on recency. A pilot test of the survey was carried out with five receivers to examine the survey's design and measure its efficiency, clarity and relevance from the perspective of the respondent. Accordingly, any completed responses in less than 7 minutes were discarded as the pilot test of the survey suggested that the participant needed about 45-60 seconds to complete each choice scenario. Fig. 3.7 presents an example of a choice scenario that was presented to the respondents.

Which one of these consolidated delivery options would be the most suitable for your business?			
	Delivery Option A	Delivery Option B	Delivery Option C
Delivery Time Window	09:00 – 15:59	16:00 – 18:59	05:00 – 08:59
Your Existing Daily Number of Separate Deliveries Will be reduced by	75%	25%	33%
New Service Offered for a Minimum Charge	Unpacking & Waste Removal	Product Quality & Quantity Check	Receiver Time-Specific Delivery
Delivery Information Status	Real-Time Update	No Update	Time-Fixed Update (e.g. once a day)
	CHOOSE	CHOOSE	CHOOSE

Figure 3.7. An Example of Choice Scenario Presented in the SP Survey

3.4.3. Sampling Strategy and Response Rate

It was important to ensure the potential sample for the survey involved more representation and inclusion of sub-industries of the various receivers that operate in the inner-city. Accordingly, the sample for the survey was derived using a stratified random sampling technique with the strata representing the ANZSIC level 4 classifications. This sampling technique facilitated acquiring a sample that was highly representative of the population being investigated as well as ensuring that these strata were not over-represented (Saunders et al. 2009). The potential participants were sourced using the Census of Land Use and Employment (CLUE) database. The CLUE, which is conducted and provided online by City of Melbourne, provides detailed establishment information including the address, establishment size and ANZSIC level 4 classification for all establishments in Melbourne CBD. Fig. 3.8 displays the share of each sub-industry from the total sample for the potential receivers that were invited to participate in the SP survey.

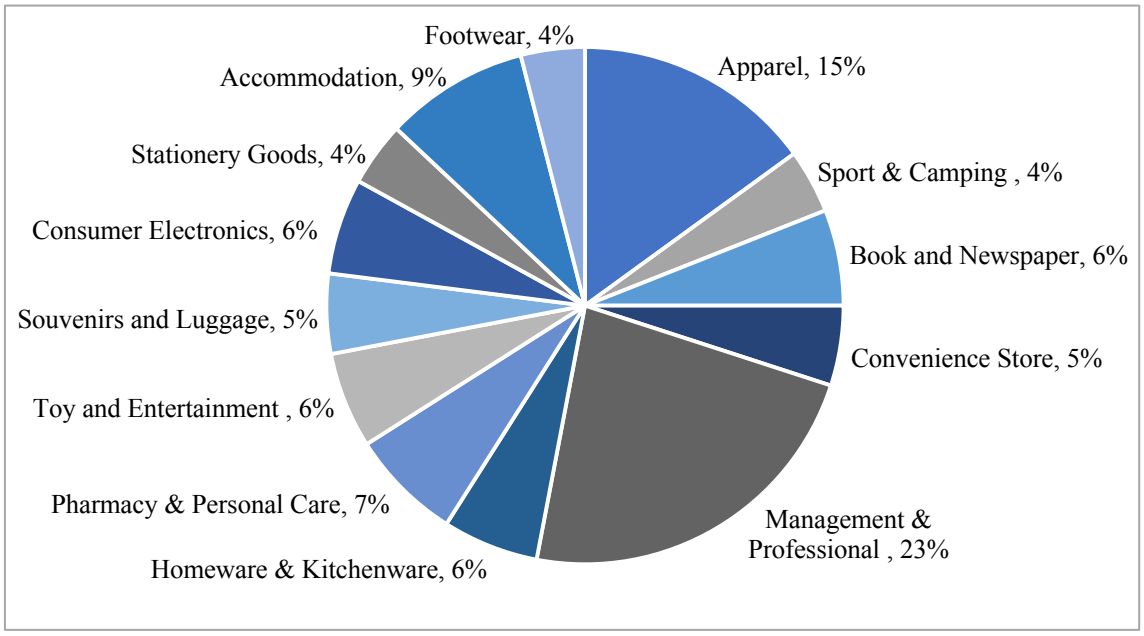


Figure 3.8. Share of Businesses in the 13 Sub-industries in the Survey Sample

A total of 255 completed responses were collected from receivers representing 13 different sectors. The total collected responses represent about 15% among all businesses in the sample. While the response rate could be considered somewhat low; however, this is expected in freight behavioural studies due to the high cost, time-consuming and confidentiality concerns associated with acquiring behavioural responses from businesses (Ellison et al. 2015). Moreover, this study achieved an acceptable total response size compared to other receiver-focused behavioural studies as highlighted in Table 2.3 in the Literature Review Chapter with an average of 196 responses.

3.5. 4th Stage: Multi-Criteria Spatial Evaluation Approach for Optimal Location of Central City Consolidation Facility in the Inner-city

The location of the consolidation facility in the urban area plays an important role in success of the consolidation policy and its effectiveness to attract participation from freight carriers. More emphasis should be also paid to the spatial suitability aspect of the optimal location of the facility to incorporate real geographic datasets in optimising the selection of suitable sites for the consolidation facility. Furthermore, the impacts of locating the facility on the surrounding sensitive users need to be considered as many previous studies overlooked the relationship between land-use and freight transport.

To the best knowledge of the researcher, no previous study has incorporated GIS models and multi-criteria decision-making (MCDM) methods in the locational selection of a freight consolidation facility in the inner-city area. Accordingly, this stage developed an integrated fuzzy GIS-MCDM approach to model and optimise the selection of the most suitable location among candidate sites for the proposed CCCF in the inner-city area based on a set of defined criteria with their priority weights determined by key stakeholders. The key phases in the proposed approach included the following six stages as displayed in Fig. 3.9: selection of decision criteria; application of the fuzzy Analytical Hierarchy Process (F-AHP) method to assign weights to the decision criteria; mapping of weighted decision criteria using geoprocessing tools in ArcGIS software; performing land suitability analysis of the study area and determining the candidate sites; applying the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to rank and select the most suitable candidate site for the facility in the inner-city area.

The six stages of the developed GIS-MCDM approach are described below:

- **1st Stage:** Identify Decision Criteria (C_i) for location assessment.

Key experts from the local government and relevant trade representatives from the freight industry in Melbourne were identified as the most significant stakeholder groups for this stage. The local government plays a key role in the solving conflicts between private stakeholders and simultaneously ensuring the sustainable development of the city. Local government authorities are responsible for setting the regulations to offer suitable industrial and commercial land to establish logistics facilities. Freight carriers are important stakeholders as they provide services for the movement and storage of goods in the city. The freight industries insights obtained from an extensive literature review on challenges and solutions of facility siting were coupled with feedback from key experts to identify 11 decision criteria for the location selection of the proposed consolidation

facility. The 11 decision criteria are shown in Fig. 3.10.

These criteria fall in one of three groups: Logistics land-use and attributes, Accessibility indicators and Suitability indicators. Critical operational parameters were included in the decision criteria to support the delivery activities of the participating freight carriers and the operator of the facility. This stage attempted to incorporate and pay more attention to the factors and aspects that in fact influence and reflect how various stakeholders would interact, cooperate and utilise the proposed facility. This would facilitate efficient operations to deliver the consolidated parcels to the receivers in the inner-city area.

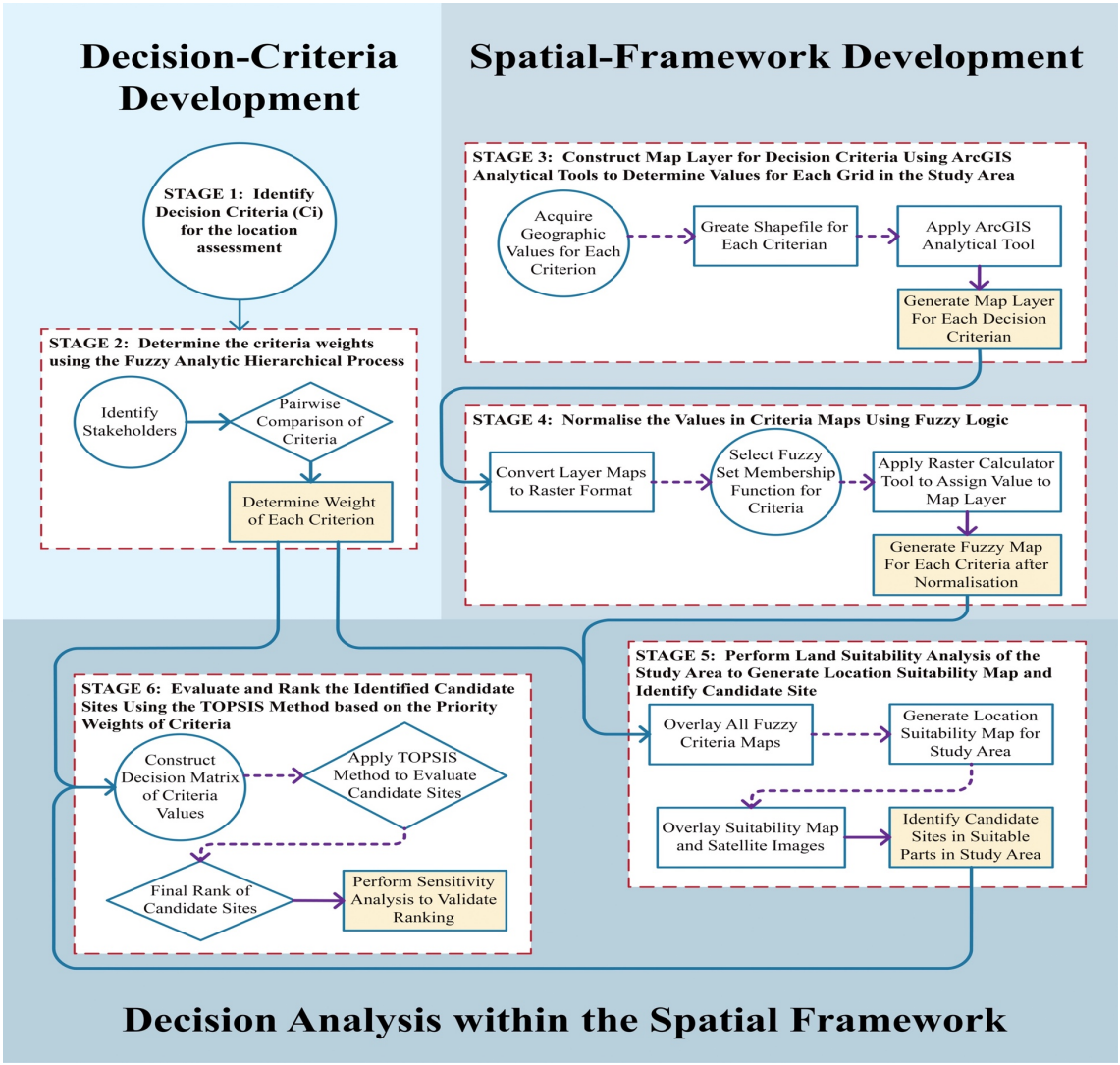


Figure 3.9. Stages of the GIS-MCDM Approach to Select the Most Optimal Location for the Proposed Consolidation Facility

A detailed description of each criterion is provided below. The potential impact(s) of each criterion is also explained, together with preferred objective of the criterion based on surveys from the stakeholder groups.

1) Logistics land-use and attributes

- *CR01 Existing warehouses*: Several wholesalers and trade companies (shippers) operate distribution centres/warehouses in some parts of the inner-city. Establishing the consolidation facility in these zones would facilitate the expeditious inbound transfer of the shipments into the facility. This criterion aims to locate the facility in an area with a high density of warehouses of other shippers and freight carriers.
- *CR02 Parking infrastructure*: The number of vehicles that the proposed facility can accommodate at once during peak hours may be limited. Thus, it is important to provide incoming freight vehicles with temporary parking space while awaiting entrance into the proposed facility. This criterion aims to locate the facility in an area with a high density of on-and-off street parking infrastructure.
- *CR03 Demographic attributes*: Residential areas with favourable demographic attributes such as higher household income and targeted age group (millennials) would attract/generate larger volumes of express parcel and online shopping deliveries. Establishing the proposed facility within these zones might encourage the express couriers to transfer the last leg of the delivery in the residential areas to the facility operator. This criterion aims to establish the facility in an area with higher household income and millennials age group.
- *CR04 Primary land-use zones*: Establishing the facility in freight land-use zones would minimise negative impacts on sensitive surroundings. This criterion aims to locate the facility in an area with existing industrial and commercial land-use zones.

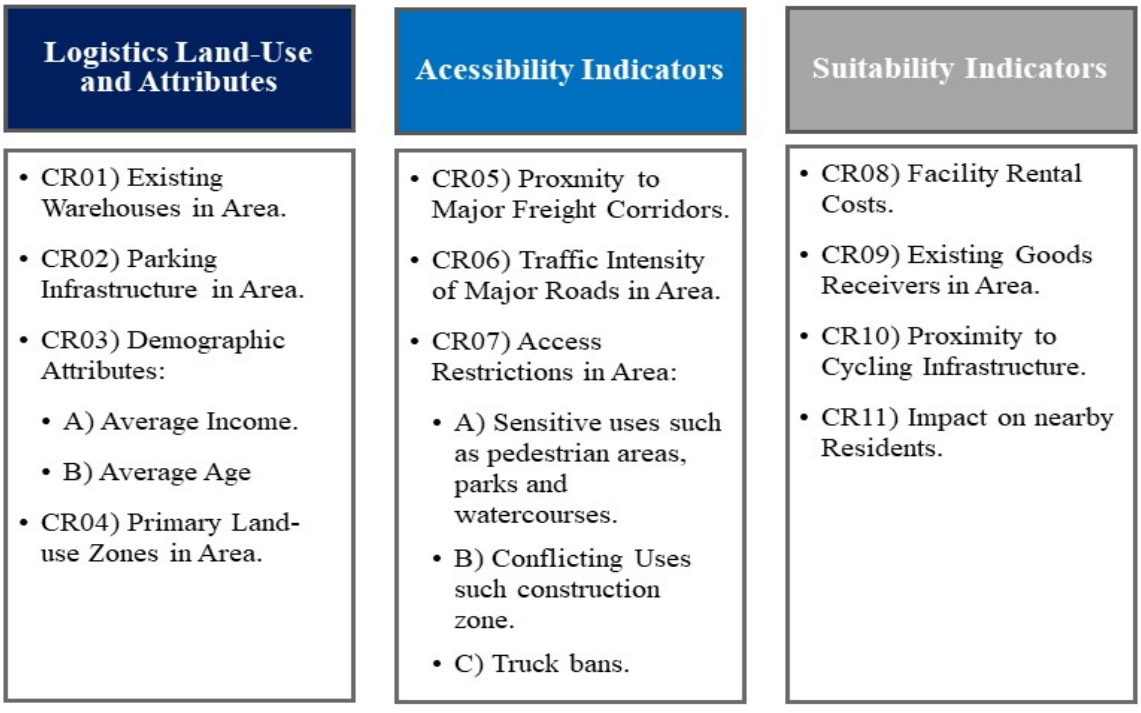


Figure 3.10. Decision criteria used in Evaluation of Most Optimal Location of consolidation facility in the inner city

2) Accessibility Indicators

- *CR 05 Proximity to major freight corridors:* Establishing the proposed facility in an area with excellent connectivity to freight corridors facilitates quick access for

the in-bound freight vehicles to reach the facility. This results in minimising the total travelled distance between their warehouses and the facility. This criterion aims to minimise the distance between the facility and major freight corridors.

- *CR 06 Traffic intensity of major roads in the area:* Freight carriers might be discouraged to transfer their parcels to the facility if their vehicles travel into heavily congested areas to reach the facility. The traffic congestion would result in lost time that adversely impact their freight vehicles. Average traffic intensity of the area is indicated by annual average daily traffic passing on major roads in the area. This criterion aims to locate the facility in areas of low traffic intensity.
- *CR 07 Access restrictions in area:* Being too close to areas with access restrictions such as parks, watercourses, truck bans and pedestrian areas would negatively impact the efficiency of the facility users to get in/out. These access restrictions might make it more difficult for in-bound freight vehicles to adhere to their prescribed transfer schedule into the facility and for the facility operator to offer reliable delivery time-window for their receivers. This criterion aims to maintain suitable distances between the facility and access restrictions or conflicting uses.

3) Suitability Indicators

- *CR08 Facility rental costs:* The facility rent represents a significant proportion of the overall cost of the facility. This criterion aims to establish the facility in an area with a competitive rental price to reduce the cost of the proposed facility.
- *CR09 Existing Goods Receivers in Area:* A location close to major receivers (office buildings, retail, commercial and education establishments) in the city centre facilitates a more reliable delivery time-window and quick consolidated delivery for the facility operator. This criterion aims to establish the facility in an area with a high density of goods receivers.
- *CR10 Proximity to Cycling Infrastructure:* As the proposed facility attempts to encourage using eco-friendly transport modes, being close to major bike lanes would encourage the facility operator to utilise cargo bikes. This criterion aims to establish the facility close to major cycling infrastructure.
- *CR11 Impact on nearby Residents:* It is necessary to establish a buffer zone between the facility and major residential areas to minimise the negative impacts of the freight vehicles that use the facility. This criterion aims to establish the facility in areas with low population density.

- **2ND Stage:** Determine the criteria weights using the Fuzzy AHP based on direct responses from key stakeholders in last mile delivery.

This stage applied the Chang EAM F-AHP approach to calculate the fuzzy weights of the decision criteria. Various key actors from local authorities and freight carriers in Melbourne participated in a questionnaire to select the related linguistic variables to determine the importance levels of the 11 decision criteria. Each set of two criteria were paired and the stakeholders were asked to indicate "which criterion was more significant for the optimal location of the consolidation facility in the inner-city area?" based on the linguistic scale of importance. This process was repeated to pair each criterion with all other criteria to create an evaluation matrix.

- **3RD Stage**: Construct Map Layers for Decision Criteria Using ArcGIS Analytical Tools to Determine Values for Each Grid in the Study Area.

Geographic and quantitative values were collected from different sources to prepare the attribute values for the layer map for each criterion as a shapefile in ESRI ArcGIS 10.2 software. The input data for the 11 criteria were all victor-based that represent the attribute by using points, lines and polygons. Fig. 3.11 displays the workflow and processes of the ModelBuilder tool in ArcGIS that were used to generate and analyse the map layers of the 11 decision criteria to perform the spatial analysis of study area.

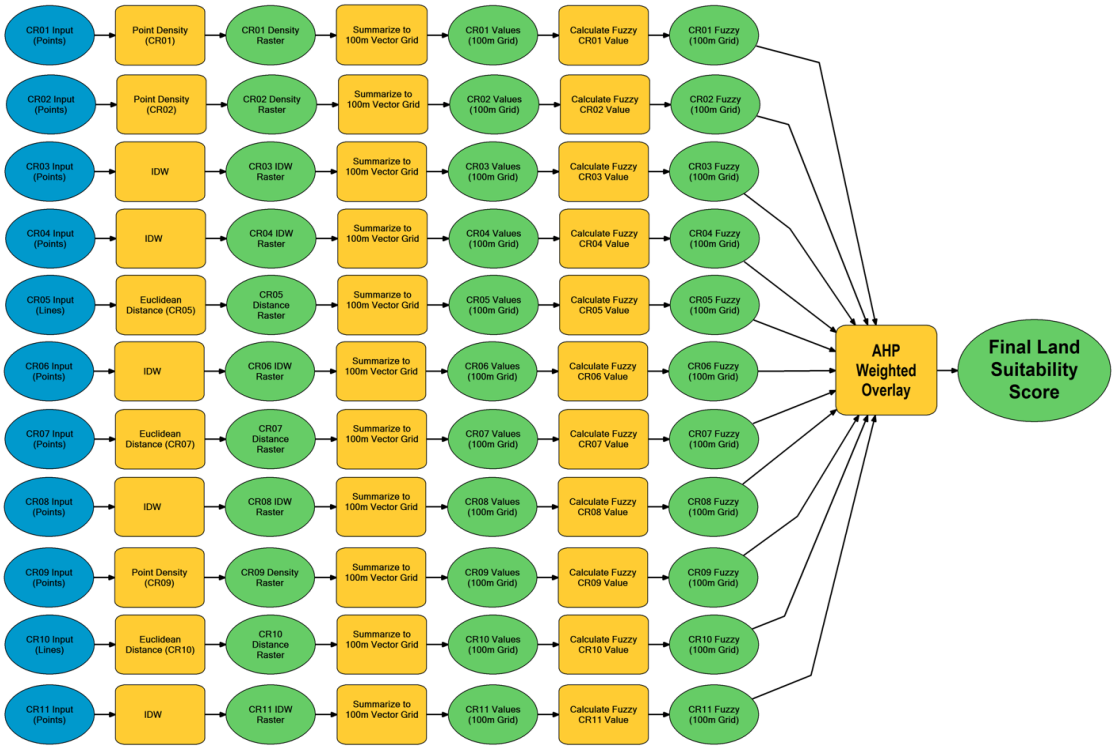


Figure 3.11. Workflow diagram for The ArcGIS ModelBuilder Processes and Analytical Tools

Table 3.5 describes the data type and the ArcGIS analytical tool applied to create raster layers for each criterion. Multiple predictor variables/parameters were compiled within ArcGIS based on a 100m x 100m cell size. These were based on the following classes: (1) density-based clustering, (2) distance-based clustering, and (3) attribute-based clustering. Density-based clustering operations using the Point Density tool was performed on point data such as warehouses and parking locations. This tool estimates a magnitude per unit area from point features that fall within a neighbourhood around each cell. The Euclidean distance tool was applied to data that contained proximity information such as the proximity to major roadways. The Euclidean distance analysis calculates the Euclidean distance of each point to the closest source to describe each point's relationship to the source. Attribute-based clustering was performed by first assigning attributes to each 100 m grid cell across the study area and then applying inverse-distance weighting (IDW) interpolations on those values. The IDW interpolation calculates the degree of relationship between near and distant points. For each criterion, the applicable clustering

tool produced a value within each grid across the study area. All criteria values were then reclassified to the 100 m grid cells by calculating average criterion value within the cell.

Table 3.5. Input data, analytical tools and fuzzy value functions used in ArcGIS software

Criterion	Input Data Type	Data Source	Analysis Tool	Fuzzy Value Function
CR01: Warehouses	Vector – point layer	Commercial Real-estate Directories	Point Density	Linear (increasing)
CR02: Parking Sites	Vector – point layer	Census of Landuse & Employment	Point Density	Linear (increasing)
CR03: Demographic attributes	Vector – grid polygon layer	Australian Bureau of Statistics	Inverse-distance Weighting (IDW) Interpolations	Linear (increasing)
CR04: Land-use zones	Vector – grid polygon layer	Land Victoria	IDW	Sigmoid (increasing)
CR05: Major roads	Vector – line layer	VicRoads	Euclidean Distance	Sigmoid (decreasing)
CR06: Traffic intensity	Vector – grid polygon layer	VicRoads	IDW	Sigmoid (decreasing)
CR07: Access restrictions	Vector – point layer	City of Melbourne	Euclidean Distance	Linear (increasing)
CR08: Facility rental costs	Vector – grid polygon layer	Commercial Real-estate Directories	IDW	Sigmoid (decreasing)
CR09: Major Receivers	Vector – grid polygon layer	City of Melbourne	Point Density	Linear (increasing)
CR10: Bike Lanes	Vector – line layer	City of Melbourne	Euclidean Distance	Sigmoid (decreasing)
CR11: Impact on residents	Vector – grid polygon layer	Australian Bureau of Statistics	IDW	Sigmoid (increasing)

- 4TH Stage: Normalise the Values in Criteria Maps Using Fuzzy Logic.

As the measurement unit and values for each criterion are different, the fuzzy logic technique was applied to standardise the unit for each criterion to make the various criteria comparable (Cheng and Thompson 2016). This technique enables classifying each grid cell in the study area by fuzzy functions in bytes scale (0-255) based on its fuzzy set membership function (Aliniai et al. 2015). This technique was deemed more suitable as each grid cell in the inner-city area might have completely different criteria values than surroundings cells. There are four membership functions in ArcGIS environment: Sigmoidal, J-Shaped, Linear and User-defined with sigmoidal being the most commonly used membership function in fuzzy set theory (Eastman 2003). In order to apply fuzzy functions in ArcGIS environment, all map layers were converted to a raster format. Then, cell values of each raster datasets for each criterion were converted to fuzzy scores using

the Raster Calculator tool to a common scale by assigning values (0-255) to each cell in the study area based on membership function. This was done along a low-high gradient where fully unsuitable parts were assigned values close to 0 while most suitable parts were assigned values closer to 255. Two membership functions were specified for the fuzzy logic calculations, as shown in Table 3.5: (1) linear or (2) S-shaped (sigmoid) functions.

- 5th Stage: Perform Land Suitability Analysis of the Study Area to Generate Location Suitability Map and Identify Candidate Sites.

After the normalisation by fuzzy logic, the map layers were overlayed to perform the land suitability analysis of the study area. The 11 fuzzy criteria maps generated in previous step were used as input raster data in the weighted Fuzzy AHP overlay in ArcGIS as shown in Fig. 3.9. The location suitability analysis was performed using the fuzzy logic overlay and Eq. (3.7) where sum of the product between the fuzzy value for each criterion and its priority weight produced a location suitability map as follows:

$$LS = \sum_{i=1}^{n} cf_i \times \omega_i \qquad \text{(eq. 3.7)}$$

where:

LS is location suitability

n equals the number of criteria (11 in this case),

i is the criterion,

cf_i is the criterion fuzzy value,

ω_i is the criterion weight

This process generated a land suitability score for each cell in the study area. The suitability map was colour-coded (classified) using the 0-255 scale to visually highlight suitable areas based on the above calculated score. This allowed focusing on the suitable parts in the study area to identify candidate sites for evaluation and selection.

- 6th Stage: Evaluate and Rank the Identified Candidate Sites Using the TOPSIS Method based on the Priority Weights of Criteria.

The last stage in the ArcGIS analysis facilitated identifying the list of the candidate sites for the proposed consolidation facility in the study area. It was important to evaluate and rank these candidate sites using a systematic approach that considered the priority weights of the decision criteria. Accordingly, this stage applied the TOPSIS method to evaluate and rank the candidate sites for the optimal location of the consolidation facility. The TOPSIS method is one of the most commonly used approaches in evaluation and ranking of transport solutions (Aruldoss et al. 2013). The following steps were performed to apply the TOPSIS method (Behzadian et al. 2012):

- 1st step: Constructed the decision matrix of the decision criteria' values (C_i)
- 2nd step: Normalised the decision matrix of the decision criteria (C_i)

As the unit for each decision criterion might be different, it was important to convert the criteria dimensions into non-dimensional attributes to make the criteria comparable. This

was performed by dividing each criterion value by root of sum of square of all values for that criterion as follow:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad j = 1,2,\dots,n; \quad i = 1,2\dots,m \qquad \text{(eq. 3.8)}$$

- *3rd step: Calculated the weighted normalised decision matrix*

This was performed by multiplying the normalised criterion value by its associated criterion weight (ω_i) obtained in the 2nd stage of GIS-MCDM. The weighted normalised value (V_{ij}) was obtained as follows:

$$V_{ij} = n_{ij} \times \omega_i \quad j = 1,2,\dots,n; \;\; i = 1,2,\dots,m \qquad \text{(eq. 3.9)}$$

- *4th step: Determined the positive-ideal solution (PIS) and negative-ideal solution (NIS) as follow:*

$$A^+ = \{V_1^+, V_2^+, \dots, V_i^+\}$$
$$= \left\{\left(\max_j V_{ij} \,\middle|\, i \in I'\right), \left(\min_j V_{ij} \,\middle|\, i \in I''\right)\right\} \qquad \text{(eq. 3.10)}$$
$$A^- = \{V_1^-, V_2^-, \dots, V_i^-\}$$
$$= \left\{\left(\min_j V_{ij} \,\middle|\, i \in I'\right), \left(\max_j V_{ij} \,\middle|\, i \in I''\right)\right\} \qquad \text{(eq.3.11)}$$

where I' was the index set of beneficial criteria, i.e. the positive solution was the maximum value, and I'' was the index set of distance or cost criteria, i.e. the positive solution was the lowest value.

- *5th step: Calculated the separation distance from the PIS and NIS. The separation distance from the positive-ideal solution (S_i^+) and the negative-ideal solution (S_i^-) for each alternative were calculated using the n-dimensional Euclidean distance as follows:*

$$S_i^+ = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^+\right)^2} \quad j = 1,2,\dots,n; \;\; i = 1,2,\dots,m \qquad \text{(eq.3.12)}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^-\right)^2} \quad j = 1,2,\dots,n; \;\; i = 1,2,\dots,m \qquad \text{(eq.3.13)}$$

- *6th step: Calculated the relative closeness or performance score to the ideal solution. The relative closeness (P_i) to the ideal solution was determined as follows:*

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad i = 0,1,\dots,m; \;\; 0 \le P_i \le 1 \qquad \text{(eq.3.14)}$$

7th step: Ranked the alternatives

$$P = \left\{v_i \,\middle|\, \max_{1 \ll i \ll m} (P_i)\right\} \qquad \text{(eq.3.15)}$$

The higher the value of P_i, the better the performance of the alternatives.

The full results of the spatial suitability and multi-criteria analysis are described in section 7.2. Moreover, a sensitivity analysis was conducted to assess the effect of modifying the criteria weights on the ranking of potential locations.

3.6. 5th Stage: Examining the Financial Viability of the CCCF

Many previous consolidation initiatives were deemed not self-sustaining from the financial perspective without government subsidies. It could be argued that a major reason for this failure was that the long-term financial viability of the consolidation facility was not comprehensively examined in the early stages of planning and decision-making of the initiative. Hence, it was also imperative that the proposed freight consolidation facility is evaluated not only from the operational and environmental aspects, but also from the business perspective in a systematic and rigorous approach. Appraising the consolidation policy using business analysis and cost models facilitate identifying and evaluating the business aspects and processes that contribute to generating sufficient revenue to cover the operational costs of the facility, which would make the facility financially viable. Fig. 3.12 illustrates the various approaches and models that were applied in the 5th stage to examine the financial viability of the proposed consolidation facility.

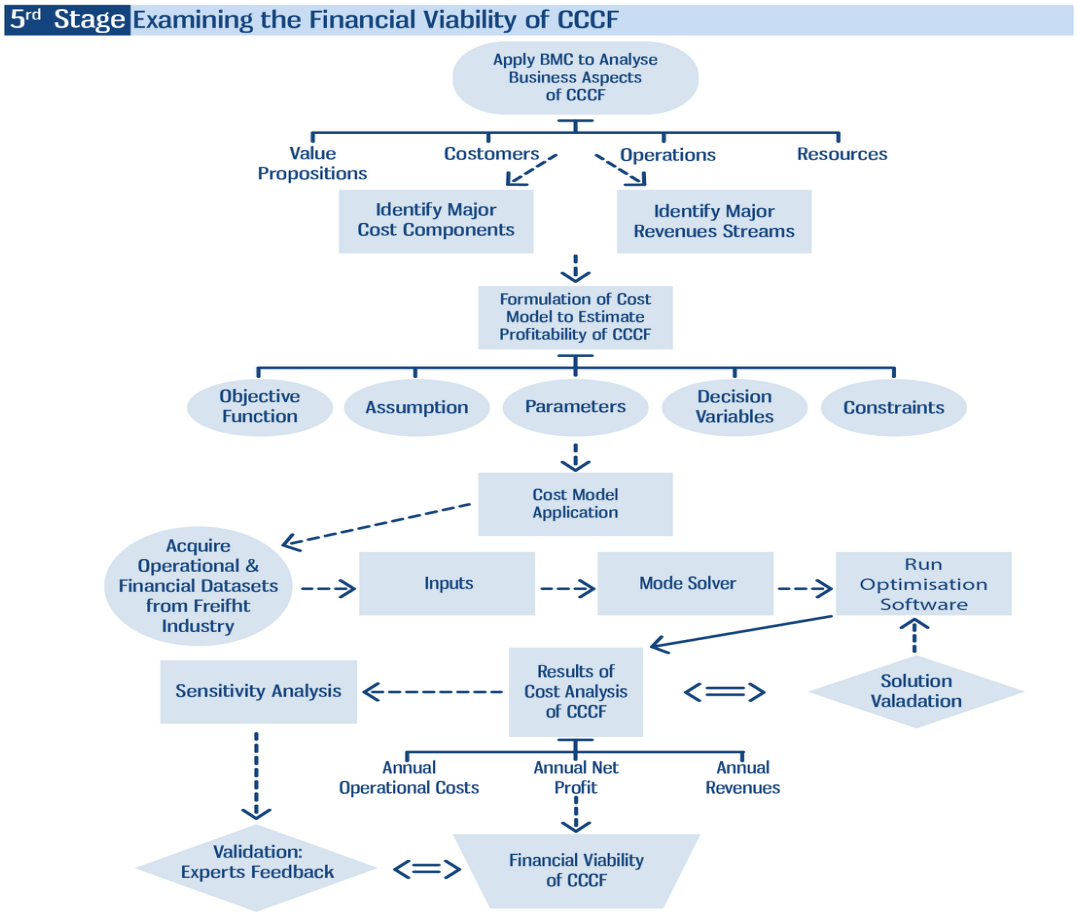


Figure 3.12. Overview of the Applied Models in the 5th Stage to Examine the Financial Viability of the CCCF

3.6.1. Appraising the Business Aspects of the Freight Consolidation Policy

Most city logistics measures are more concerned about sustainability, liveability and amenity of society and urban environment to alleviate the negative impacts of urban freight transport. However, it is necessary for the solution to generate profit or financial benefits for its stakeholders to achieve self-sustaining status without depending on public subsidies. Thus, the proposed freight consolidation policy must be examined from the business case perspective and put under a definitional microscope to dissect its various processes and operations using a more profit-oriented business approach. Accordingly, this phase applied the principles of the Business Model Canvas (BMC), which was introduced by Osterwalder and Pigneur (2010), to analyse the key business and operational aspects of the freight consolidation policy and determine how it could contribute to better value propositions for participating users. The BMC facilitated determining the value proposition, infrastructure, customers and finance of the proposed consolidation facility. The following aspects were included in the business modelling as shown in Fig. 3.13, which is adopted from TURBLOG (2011):

- Operations (the three Left-Blocks in Fig. 3.10): It involved the components required to deliver the proposed service and maintain the customers relationship including the key resources consumed, key partners used, and key activities undertaken.
- Customer (three right-blocks): It identified customer segments for the offered service, channels to reach the customers and type of relationships with the customers.
- Value Proposition (Upper middle block): It determined how the operations undertaken could contribute value for the customer.
- Externalities (Lower middle Block): It determined how the operations undertaken could contribute value for society and address the externalities produced by last mile delivery (environmental and social impacts).
- Financial Aspects: (Two lower blocks): It analysed the cost structure and revenue streams for the logistics solution.

Key Partners	**Key Activities**	**Value Proposition**	**Customer Relationships**	**Customer Segments**
- Who are the key partners and to create the service? - Which partners are essential to ensure more success?	- What key activities do our value propositions, customer relationships and revenue streams require?	- What distinctive value does the company deliver to the customer? - What problems does the company help to solve? - Why should these customers do business with our company?	- What type of relationship is established between the company and the customer? - What type of relationship does each of the customer segments expect?	- What specific customer group does the company want to service? - What are their needs?

Key Resources - Which resources are important to create the value propositions, to maintain customer relationships, to get new customers?	**Externalities** - which social and environmental impacts does the logistics solution contribute to society?	**Channels** - How does the company reach the customers about services offered? - How are the channels integrated?
Cost Structure - Which costs are important to ensure that the business will work? - Which resources and key activities are most expensive? - Which costs are fixed and which are variable?		**Revenue Streams** - For what value are the customers willing to pay? - How does the company earn money? - How are they paying? - How can it develop supplementary sources of income?

Figure 3.13. Business Model Canvas for Evaluation of the Freight Consolidation Policy

3.6.2. Estimating the Financial Viability of the Central City Consolidation Facility

3.6.2.1. Background

As there are many cost variables associated with the consolidation facility that might impact its profitability, it was important to include a comprehensive dataset of all major and minor costs in the cost estimation. Furthermore, assessment of the financial viability of the consolidation facility should also quantify the revenue streams, profit margin and efficiency utilisation levels. As the consolidation policy involves parcel transfer from participating freight carriers, there is a high uncertainty and risk associated with the unknown demand for the consolidated delivery service. Thus, random demand scenarios were included in estimation of the operational costs and revenue calculations to account for the stochastic nature of the daily operations of the proposed consolidation facility. It could be argued that addressing the financial viability using a deterministic modelling approach based on the assumptions of fixed and known operational variables overlook the notion that consolidation initiatives are highly dependent on demand services of external users, which could be highly volatile and unknown.

3.6.2.2. Problem Definition

This phase formulated a mixed integer linear programming (MILP) model to optimise the profitability of the consolidation facility by maximising all major and minor costs associated with operating the facility and performing the consolidated deliveries as well as all the revenues generated from various services offered by the facility. The formulated MILP cost model is presented in section 8.3. The operational setup of the facility and suggested parameters of the costs and revenues were based on the insights acquired in the surveys with the freight carriers in the 1st stage of the integrated framework. The delivery fleet of the consolidated delivery in the developed cost model incorporated the optimal solution of eco-friendly delivery vehicles, which was decided in the 2nd stage. The developed cost model addressed the profitability of the consolidation facility from the perspective of the facility operator to derive a profitable consolidation facility.

3.7. Chapter Summary

This chapter described the approaches and methods developed and applied in the five stages of the integrated framework. Incorporating the various operational requirements, objectives and concerns of all the stakeholder groups in the developed framework facilitates proposing a consolidation scheme that is practical, sustainable and suitable for the current challenges and issues of express deliveries in the inner-city. The following chapters present the application and results of each stage of the integrated framework using real datasets from the City of Melbourne to assess its suitability and rigor in establishing a suitable, effective and sustainable consolidation facility for Melbourne CBD as follows:

- Chapter 4 presents and analyses the results of the primary data collected from freight carriers to provide a detailed description of last mile delivery in the inner-city as well as the proposed design of the Central City Consolidation Facility.
- Chapter 5 presents and discusses the results of multi-stakeholder approach to select suitable consolidated delivery fleet based on objectives of all stakeholder groups.
- Chapter 6 analyses and discusses the econometric results of the behavioural responses collected from receivers to estimate their willingness to participate and pay for the consolidated delivery service.
- Chapter 7 presents and discusses the results of the application of the spatial-based multi-criteria approach to select the most optimal location for the proposed consolidation facility in the inner-city area.
- Chapter 8 analyses the results of the business model canvas to evaluate the business aspects and analyses and discusses the results of the solution of the MILP model to estimate the financial viability of the consolidation facility.

Chapter 4

1st Stage: Design of the Central City Consolidation Facility

4.1. Introduction

As highlighted in section 2.5.2 in the literature review, there is a limited knowledge on the delivery practices and operational challenges of last mile delivery activities inside the congested inner-city area. Hence, this chapter analyses and discusses the results of primary data collected from freight carriers using the observational study and surveys about the utilisation of the delivery vehicles and operational practices of their delivery inside the inner-city. Furthermore, the acquired knowledge is incorporated in the proposed design of the Central City Consolidation Facility in this chapter. The developed design of the consolidation facility in this research builds on issues and aspects discussed in section 2.3.6.2 that contributed to the failure of previous freight consolidation facilities.

The sections of this chapter are described below:

- Section 4.2 analyses the results and policy implications of the observational study on the use of on-street loading zones by freight vehicles in Melbourne CBD. The observation study is described in section 3.2.1.1.
- Section 4.3 analyses and discusses the results and policy implications of the responses collected in the semi-structured interviews and survey with freight carriers in Melbourne to characterise their delivery trips inside the inner-city area. A full description of the interviews and survey as well as the sample selection and response rate were presented in section 3.2.1.2.
- Section 4.4 describes the proposed design of the Central City Consolidation Facility to consolidate the last leg of deliveries to receivers in the inner-city.
- Section 4.5 provides a concluding summary of the chapter including limitations of the two studies and future research directions.

4.2. Observational Study of the Use of On-street Loading Zones (OLZs) in Melbourne CBD

4.2.1. Analysis of the Results of the Observational Study

A total of 385 parking events were observed at the selected OLZs during the 9-day observational study. Table 4.1 displays the distribution of vehicles during the observational study. It is estimated that about 89% of the freight vehicles are light vehicles (LCV and light trucks) while heavy trucks represented about 11% of the observed freight vehicles. It was observed that the majority of deliveries to office buildings and retailers were performed by LCVs. Furthermore, it was observed that service vehicles (e.g.

plumbers and electricians) used the OLZ for 16% of the parking events even though they are not designated as legal users of the OLZ according to VicRoads guidelines. They parked for 33 minutes on average at the observed OLZs, which further reduced availability of parking spaces for freight vehicles. Due to illegal parking by private cars, availability of loading bays for freight vehicles was reduced by 13%. It was observed that a loading bay was available for the freight vehicle at the time of arrival for 63% of the parking events. The unavailability of loading bays forced some freight vehicles to park illegally, wait and create traffic problems or circulate to look for another OLZ.

Table 4.1. Distribution of Vehicles at the Observed OLZs in Melbourne's CBD

Vehicle Type	**%**	**Freight Vehicle Type**	**%**	**Delivery Address (On- vs. Off-Street)**
Freight Vehicle	71%	LCV	70%	On: 36%
				Off: 54%
Private Car	13%	Light Truck	17%	On: 76%
(Illegal Parking)				Off: 24%
Service & Maintenance	16%	Medium Truck	11%	On: 72%
				Off: 28%
		Utility Vehicle	2%	On: 20%
				Off: 80%

**Light Truck*: Less than 4.5 Tonnes Gross Weight. *Medium Truck*: Over 4.5 Tonnes.

Fig. 4.1 illustrates the distribution of freight vs non-freight vehicles throughout the observation period. The number of non-freight vehicles were much higher in the early morning hours due to the absence of parking enforcement officers. It was observed that a very limited number of medium trucks performed deliveries in the afternoon compared with early morning. Most of the deliveries by medium trucks were conducted in the early morning hours. This further raises the need to promote policies that encourage receivers to redistribute deliveries throughout the day especially in the off-peak hours to take advantage of the available capacity at the on-street loading zones. Heavy trucks encountered more difficulties to find available and suitable loading spaces as they are required to park close to the receivers due to the heavy loads they carried. They needed up to 3 minutes on average to load/unload the products from their trucks using hand trolleys. Furthermore, the loading spaces did not facilitate easy parking and manoeuvrability for heavy trucks. This suggests that there should be different guidelines for the on-street loading zones based on industry-specific requirements.

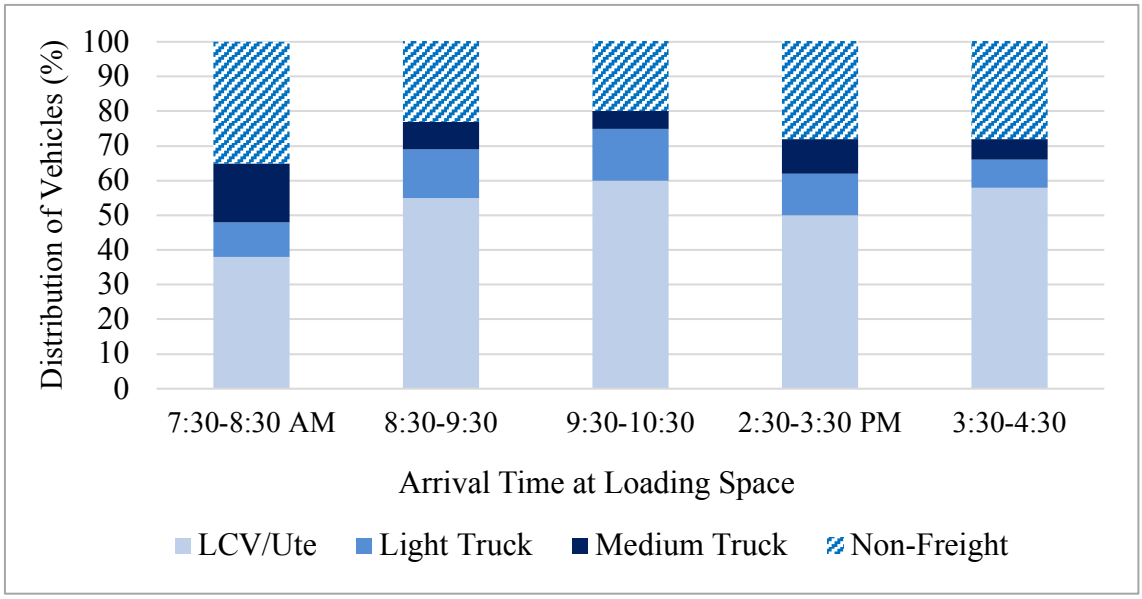


Figure 4.1. Distribution of Vehicle Types per Arrival Time Segment at the Observed On-Street Loading Zones in Melbourne CBD

Fig. 4.2 displays the parking duration for each freight vehicle's class at the observed OLZs. It was observed that about 50% of LCVs stayed less than 15 minutes at the OLZs as 23% and 26% of the LCVs parked 5-9 and 10-14 minutes respectively. Conversely, the majority of light trucks stayed more than 20 minutes and the majority of medium trucks stayed more than 25 minutes at the observed OLZs. Furthermore, the black checkered bar in Fig. 4.1 indicates the percentage of vehicles for each vehicle class that complied with the allowable time (a maximum of 15-minute or 30-minute) at the observed OLZs. LCVs did not overstay the allowable time as almost 66% of the LCVs adhered to the allowable parking time whereas only 49% and 34% of light trucks and medium trucks did not overstay the allowable time. Conversely, private cars and service & maintenance vehicles significantly overstayed the allowable time as only 29% and 21% complied with the allowable time. It was observed that about 46% of deliveries were for receivers located within 40 metres from a loading zone where the freight vehicle parked while 29% of deliveries were for receivers located more than 60 metres from the loading space. The breakdown of type of activities performed by the freight vehicle was 83% deliveries vs 17% pick-ups during the observation period. Most express couriers performed pickup activities in the late afternoon hours.

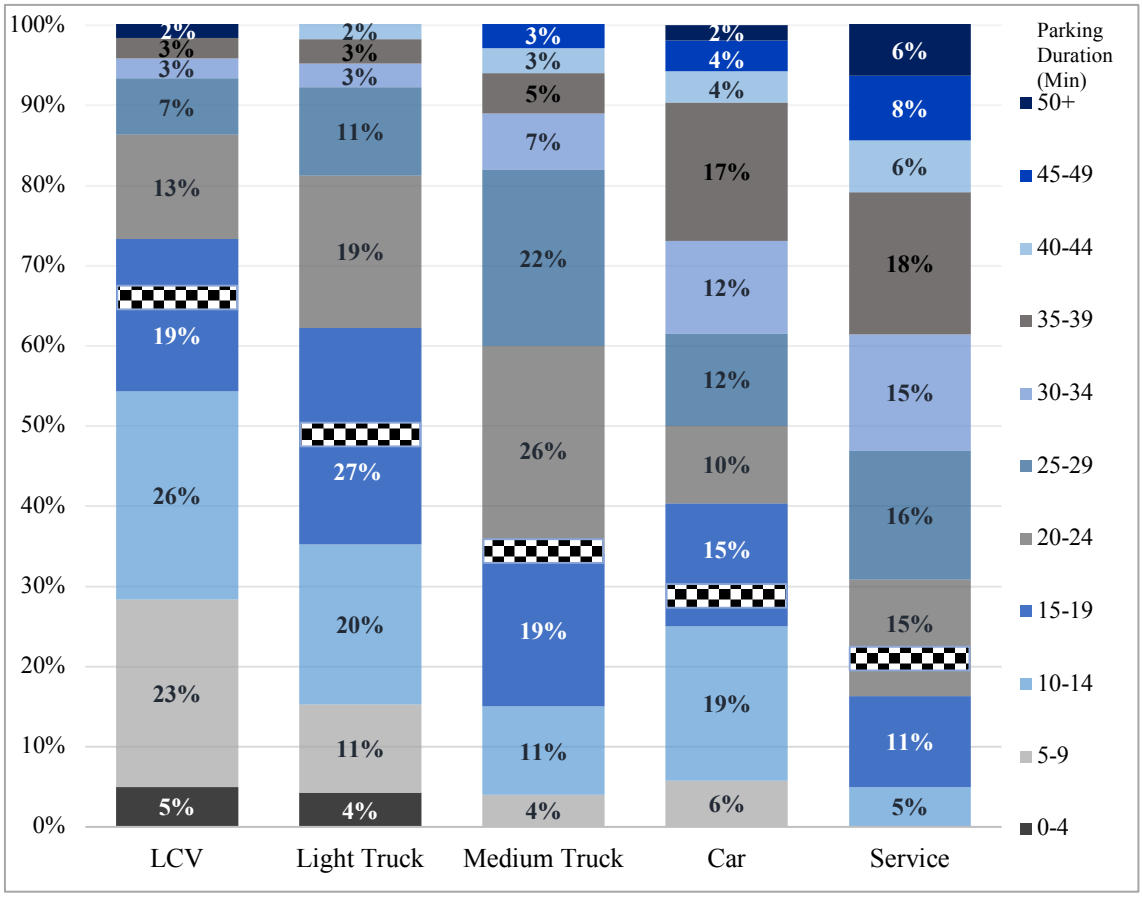


Figure 4.2. Parking Duration at the Observed On-Street Loading Zones for Each Freight Vehicle's Class

Fig. 4.3 presents the most common type of products that were delivered from the observed OLZs based on the packaging of the delivered parcel or the business name of the delivery company. The red dashed-line represents the percentage of each product category during the observation period. Food, express parcels and apparel & footwear accounted for 34%, 27% and 11% of the total freight that was delivered or picked up by the observed freight vehicles at the on-street loading zones in Melbourne CBD. As can be seen in Fig. 4.3, the majority of express parcel deliveries were completed in 10-15 minutes while food deliveries required about 15-20 minutes. Express parcel deliveries to office buildings were mainly conducted using LCVs in a very short time. Due to the large number of HoReCa businesses, food deliveries represented the largest number of deliveries followed by express parcels deliveries. Furthermore, medium trucks were used more often to deliver food in areas with concentration of food outlets especially large restaurants while small food outlets received deliveries more often via LCVs.

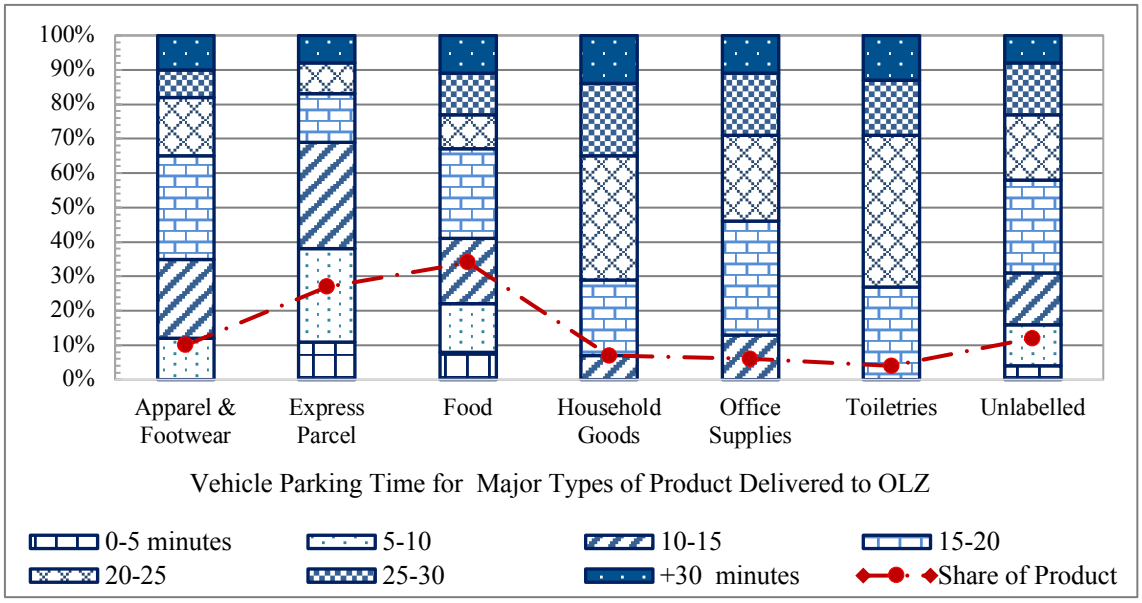


Figure 4.3. Breakdown of the Type of Product Delivered to Receivers from the Observed On-Street Loading Zones in Melbourne's CBD

4.2.2. Inferential Analysis of the Variables of the Observational Study

Spearman's rank correlation and Kruskal-Wallis H test, which are non-parametric tests, were utilised to assess the relationship between the variables of the observational study (vehicle types, product types and parking time). Spearman's rank correlation was used to determine the strength of relationship between variables (ρ indicates the degree of correlation from -1 to 1) (Washington et al. 2010). A positive correlation coefficient (ρ) indicates a positive relationship between the two variables while a negative correlation coefficient indicates a negative relationship. Furthermore, Kruskal-Wallis H test was deemed appropriate in evaluating the relationship of the variables in question. This test is useful because it can efficiently compare several categories of data at one time. The test compares the mean rank of the categories in the independent variable and determines whether differences in the mean rank are statistically significant. The Kruskal-Wallis H test rejects the null hypothesis (H_o: all the mean ranks of the variables are equal) if the H_{score} is greater than the critical value of χ^2 for the degree of freedom (df) used.

There were two notable relationships discovered in the Spearman's rank correlation in both the morning and afternoon datasets. The full correlation coefficients are illustrated in Table 4.2. In the morning dataset, vehicle type and parking time were correlated at 0.47, arrival time and parking time were correlated at -0.24, and vehicle type and arrival time at -0.13. It seems reasonable that vehicle type and arrival time are negatively correlated. It is possible that freight carriers prefer to deliver larger loads first thing in the morning and fill rest of the day with smaller loads due to increased availability of OLZ. That could be the case because larger trucks make more deliveries in the morning, and thus make bigger deliveries earlier in the day. The relationship between vehicle type and parking time, as well as the relationship between vehicle type and arrival time, are consistent in both datasets.

Table 4.2. Spearman's Rank Correlation of Relationship between Variables

Spearman's rank correlation - Morning				
	Vehicle Type	Product	Parking Time	Arrival Time
Vehicle Type	1.00			
Product	0.30	1.00		
Parking Time	0.47	0.22	1.00	
Arrival Time	- 0.13	- 0.04	- 0.24	1.00

Spearman's rank correlation - Afternoon				
	Vehicle Type	Product	Parking Time	Arrival Time
Vehicle Type	1.00			
Product	0.02	1.00		
Parking Time	0.49	0.16	1.00	
Arrival Time	- 0.14	0.03	- 0.06	1.00

The Kruskal-Wallis H tests uncovered several relationships between the variables which provides insight into how OLZs are used. While there were statistically significant relationships in both the morning and afternoon observations, the relationships were not necessarily consistent between the two samples. One relationship that did remain consistent between morning and afternoon observations was the relationship between vehicle type and parking time. This relationship is consistent with what was found in Spearman's rank correlation – larger vehicles take longer to make deliveries than smaller vehicles. The average duration of delivery by vehicle was also consistent in both samples – 15 minutes for LCV, 18 minutes for light trucks, and 23 minutes for medium trucks. Table 4.3 summarises results of the KW-H tests. We can reject the null hypothesis that vehicle types all have the same duration of delivery as the H_{score} is greater than χ^2.

Table 4.3. Results of Kruskal-Wallis H tests for Relationship between Variables

Variables	**Vehicle Type vs Parking Time**		**Vehicle Type vs Product**	**Product vs Parking Time**	
Period	Morning	Afternoon	Morning	Morning	Afternoon
H_{score}	29.61	9.93	26.68	21.49	13.65
df	2	2	6	6	6
P	0.05	0.05	0.01	0.05	0.05
χ^2	5.991	5.991	16.812	12.592	12.592

Another relationship was also noted between the products being delivered and the vehicle type making the delivery, although this relationship was only present in the morning sample. Vehicle types were translated from qualitative data to ordinal data where the LCV, light truck, and medium truck were described as 1, 2, and 3, respectively. The P-value for these variables is less than 0.05, which denotes that the relationship is statistically significant. Table 4.4 displays the average vehicle type and average parking

time for the different product categories. It is difficult to translate that information into which trucks deliver which products, but there are marginal differences in the average vehicle type that can lead to a theoretical answer to that question. Household goods, office supplies, and toiletries all have relatively high average vehicle type, suggesting that they are more likely to be delivered by light and medium trucks than other products. Express parcels are on the other end of the spectrum, suggesting that express parcels are more likely to be delivered by LCV than trucks. Furthermore, there appears to be a significant variance among products in the time it takes to deliver those products. This relationship is statistically significant in both the morning and afternoon. However, the order of parking time is not necessarily consistent between the two samples.

Table 4.4. Average Vehicle Type and Average Parking Time of All Product Categories

Product/Variable	Apparel & Footwear	Express Parcel	Food	Household Goods	Office Supplies	Toiletries
Average Vehicle Type 1 = LCV, 2 = LT, 3 = MT	1.38	1.08	1.54	2.44	2.12	1.92
Avg. Parking Time - Morning (Min)	16.71	12.15	16.21	23.60	21.60	21.33
Avg. Parking Time - Afternoon (Min)	18.50	11.24	17.90	21.22	19.10	17.75

4.2.3. Discussion and Policy Implications

The results of the observational study provided relevant insights on the utilisation of OLZs by freight vehicles in the city centre. The study confirmed the significant dependence on LCVs for delivery and pick-up activities in the central city area. Higher use of light freight vehicles was observed in this study (89%) compared to the figure reported in another Melbourne-based study (81%) (Casey et al. 2014). This could be attributed to difficulty of making deliveries using heavy freight trucks in OLZs compared to the other study that included also off-street loading facilities. This study supported claims by freight carriers about the inefficiency of existing OLZs that Melbourne CBD does not provide adequate and efficient parking and loading spaces for the 10,000 freight vehicles that perform deliveries in Melbourne CBD.

This observation study reported different figures with respect to the primary delivered products compared to the observational study performed by Thompson and Flores (2016), which focused on an off-street loading dock of a commercial tower in Melbourne CBD. It was reported that about 34% and 11% of deliveries to businesses in the commercial tower were express parcels and food deliveries. However, this study revealed that express parcels and food deliveries represented about 27% and 34% of total deliveries. Both studies confirmed that there was a significant relationship between the vehicle type and parking duration. Alternatively, this study reported that there was no significant relationship between the arrival time and product type whereas Thompson and Flores (2016) reported that there was a significant relationship (at the 10% significance level)

between the arrival time and product type especially for the food, flower and express parcel deliveries.

The improper existing local regulations with respect to the OLZs do not differentiate between the parking and loading requirements for the different classes of freight vehicles and sub-industries of receivers located in the city centre. For instance, setting a 15-minute OLZ in an area with clustering of food outlets that receive deliveries via light and medium trucks illustrates the fact that local authorities treat all freight trucks as equal. The average time a light or medium truck spends unloading the products into the hand trolley and making the deliveries is significantly different and sometimes longer than a light parcel on a delivery van. This is further validated by the higher percentage of light and medium trucks overstaying the allowable time of the OLZ compared to LCVs. Moreover, the long walking distance between the observed OLZs and the receivers adversely affect the efficiency of the couriers especially for drivers that performed multiple deliveries. It was estimated only 29% of deliveries were for receivers located more than 60 metres from the OLZ compared to the average distance of 105 metres reported in the London-based study (Allen et al. 2018a). Parking far away from the receivers negatively affected the size of the loads that the drivers could carry to the receivers, which resulted in multiple walking trips and consequently increased the parking times and delivery costs.

As the exclusive use of on-street loading zones to only freight vehicles could not be systematically enforced, local authorities need to consider setting regulations that facilitate better use of existing OLZs. Moreover, the regulations and allocations of the on-street loading spaces need to be updated to reflect the changes in practices and activities of freight carriers in the city centre. Local authorities might argue that there are enough loading spaces for freight vehicles in the city centre. However, they are not efficiently managed and distributed as illegal users are increasingly parking at these loading spaces. The OLZ policies should take into consideration the various parking requirements for the different classes of freight vehicles and receivers' sub-industries. In addition, it might be necessary to convert some OLZ in busy locations to serve as temporary staging areas for freight carriers especially in dense retail and business precincts.

4.3. Description of Delivery Trips and Practices of Freight Carriers in the Inner-city

4.3.1. Analysis of the Delivery Network of CEP Service Providers (Responses of the Semi-Structured Interviews)

The interviewed transport managers of the ten CEP service providers offered detailed description of the last mile delivery network of CEP services providers and the operational practices to handle, sort and deliver the parcels. For large CEP service providers, the majority of inter-state and intra-state consignments are transported to the depot in suburban parts of the city using heavy rigid trucks with large use of tautliner (curtain-sider) semi-articulated trucks. For the rigid trucks, the parcels are loaded and stored into the truck using roller containers. However, the tautliner trailer has curtains on both sides that can be pulled up and down to offload the parcels. The parcels are stored in steel cages that are loaded and strapped into the curtain-sided trailer using forklifts through the sides or rear of the trailer. Depending on the size of the truck, it can transport

up to 25 cages with each cage carrying large number of parcels. These trucks usually arrive at the depot between midnight and before dawn.

At the depot, large CEP service providers use advanced and fully-automated handling and sorting systems that utilise automated conveyer systems to scan, weigh and transfer the parcels from the incoming trucks to the sorting and handling area. The parcels are then moved on specific parcel loading chutes that are designated for each major delivery zone to be loaded into out-going delivery vehicles. However, there are some couriers that still use forklifts to offload the parcels from the trucks and transfer them in mesh containers to the handling and sorting area. In some facilities, manual pickers might be staffed to pick and sort the parcels into the containers. The parcels are sorted and moved based on their barcodes to mesh containers designated for each zone in the inner-city. These containers include parcels addressed to receivers in that particular zone. Consequently, the containers are transferred to loading bays of the delivery vans or truck.

Each major block of buildings in the inner-city area is usually covered by an assigned delivery vehicle that services all customers within that particular zone. Delivery vans are mainly used in the city centre and residential areas while trucks are used sometimes in suburban areas and for deliveries to commercial receivers. For instance, a logistics manager of the largest CEP service provider indicated that they divide Melbourne CBD into 8 different delivery zones with each zone covering up to 4 blocks. On a typical day, more than 40 delivery vans and 20 trucks perform the delivery and pickup services for that particular CEP service provider in Melbourne's CBD. However, 8-12 delivery vans usually service the inner-city of Melbourne for other CEP service providers. Using advanced routing and scheduling software, the daily delivery routes and rounds are determined for each delivery van. The sequencing of the deliveries (drops) is usually decided based on either the routing software or the personal experience of the driver. The CEP service providers typically schedule between 2-3 daily delivery rounds (waves) for each delivery van. The first delivery round starts at 7 AM. As the courier makes high number of stops, it is important for drivers to leave space in the cargo area to be able to quickly pick up parcels at each delivery stop. Most delivery vehicles use on-street loading spaces for delivers to receivers in the city centre, which is associated with high uncertainty about the availability of these parking spaces when the vehicle arrives. Furthermore, the traffic conditions, vacancy of parking spaces and availability of receivers adversely affect the efficiency of the delivery round. Any changes to these conditions would result in altering the sequence of delivery stops, which makes further complicate optimising this dynamic process. This is why it is operationally difficult for delivery vans to leave their depot more than 60% loaded. A fully loaded vehicle will make it difficult to offload the various parcels going to large number of receivers as the courier would spend unproductive and unnecessary time for placing and re-adjusting the parcels in the cargo area in the vehicle due to changes in the sequence of the receivers. For the second delivery round, delivery vans would leave the depot at 12 PM and around 40-50% loaded. Large CEP companies schedule the third delivery round to leave the depot around 3 PM.

CEP companies usually apply different approaches with respect to scheduling parcel pick-up jobs. Large CEP companies schedule pick-up jobs for delivery vans in busy zones in the afternoon hours. The delivery van would complete all delivery jobs in the morning hours. However, there are some CEP companies that schedule delivery and pick-up jobs to be conducted during both the morning delivery round and the afternoon delivery round.

Pick-up jobs usually represent around 10-15% of all distribution activities for the delivery van. Moreover, a delivery van performs daily about 100-120 stops (drops) daily in the inner-city area for a large CEP service area while a medium-sized CEP courier attempts to complete daily around 75-85 drops. A single drop to a receiver typically contains between 1-3 packages while a single delivery to a large receiver sometimes includes more than 5 packages. Conversely, a light truck usually performs between 40-60 stops in the inner-city area. Moreover, couriers usually deliver 5-8 parcels/stop when using trucks. Undelivered parcels are returned to the depot and rescheduled for delivery the following business day.

CEP service providers apply different vehicle ownership structures for their delivery vehicles. Most of the logistics managers revealed that their companies do not own the delivery vehicles and depend on driver-owner couriers to perform their delivery and pickup jobs. Many CEP service providers establish franchising agreement with the driver-owner especially in non-premium parts of the inner-city area. The franchisee operates their own delivery vehicle within an exclusive territory to deliver and collect parcels for the CEP service providers in that particular area. Alternatively, some companies that still own a proportion of the delivery vehicles usually rent these vehicles to couriers to perform the delivery services for a contractual fee per parcel especially in the busy city centre.

4.3.2. Characteristics of the Delivery Practices of Freight Carriers in the Inner-city Area (Responses of the Survey)

4.3.2.1. Descriptive Analysis of the Delivery Trips and Operational Issues of the Freight Carriers

This section provides a detailed analysis of the response received from freight carriers regarding their delivery practices, delivery fleet and challenges impacting their operations in the inner-city. The responses highlight that freight carriers utilise light commercial vehicles (LCVs) to perform the majority of delivery and pickup activities to retailers and businesses in inner Melbourne. It was reported that 65% of freight deliveries were carried using LCVS whereas light trucks (less than 4.5 tonnes gross weight) and medium trucks (more than 4.5 tonnes gross weight) were used in 22% and 13% of the delivery activities, respectively. However, the survey respondents expressed that the share of LCVs in freight deliveries in Melbourne CBD exceeded 80% due to the difficulty to perform multiple deliveries and parking issues in the city centre. Fig. 4.4 displays the delivery fleet configurations that are mostly operated by the respondents to cover the daily delivery operations to business receivers in inner Melbourne. It was reported that about 43% of the respondents (24 freight carriers)typically operate up to 7 LCVs whereas 13% (7 freight carriers) and 9% (5 freight carriers) of the respondents utilise up to 3 light trucks and 3 medium trucks, respectively. In contrast, about 9% (5 freight carriers) of the respondents indicated that they operate more than 10 LCVs to perform freight deliveries in the area. It is worth noting that these participants are express couriers that typically divide Inner Melbourne into distinct delivery zones.

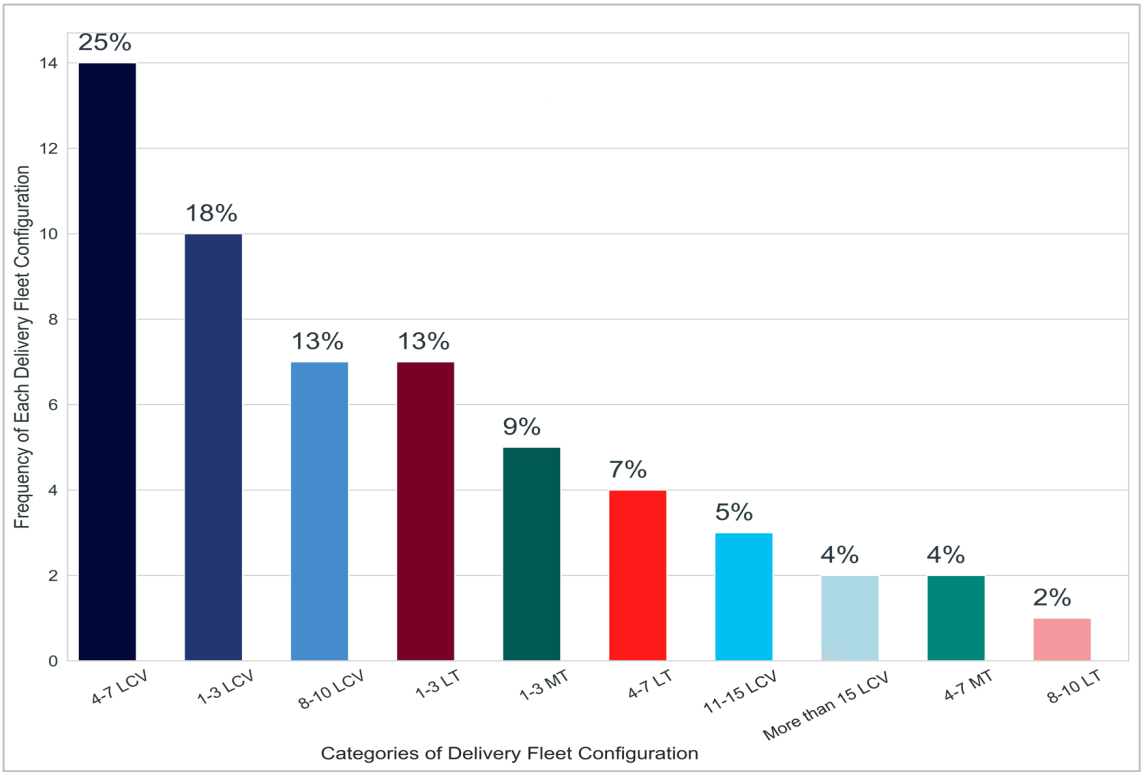


Figure 4.4. Distribution of the Operated Delivery Fleet Configurations to Perform Freight Deliveries in inner Melbourne

Additionally, the rate of successful delivery on 1st attempt is highly influenced by the type of receiver (business versus home delivery). The participants suggested that 70-80% of B2B deliveries are successfully delivered on 1st attempt while less than 60% of B2C deliveries are delivered on 1st attempt. The participants pointed out that express parcel B2B deliveries achieved a lower rate (around 70%) versus B2B deliveries to retailers/food outlets (more than 80%). The freight carriers were asked to elaborate on their decision-making with respect to the order of stops. For 53% of the participants (23 freight carriers), the driver usually sorts and sequences the parcels in the vehicle for receivers based on their experience and knowledge of the delivery area and customers' locations while 16% (9 freight carriers) reported that the order is decided by the depot manager. On the contrary, only 31% (17 freight carriers) responded that the order of stops is assigned by a routing and scheduling software and automatically sent and uploaded to the driver's handheld device.

With the respect to the average vehicle fill rate, the freight vehicles were utilised differently by freight carriers. It was highlighted that delivery vehicles of 19 freight carriers (35% of respondents) leave their depot around 40-50% loaded. In contrast, 9 freight carriers (16% of respondents) indicated that their vehicles are more optimised as the vehicle rate exceeds 70%. Alternatively, 15 freight carriers and 12 freight carriers reported that their vehicles were usually 50-60% and 60-70% loaded, respectively. Additionally, the vehicle fill rate varied based on the vehicle class. The average vehicle fill rate of most LCVs was around 50-70% whereas the average fill rates of light trucks and medium trucks were less than 60% and 50%, respectively. Furthermore, about 60% of the respondents (33 freight carriers) expressed their vehicles typically perform a single

daily delivery round while 31% (17 participants) expressed that their vehicles usually conduct a morning and afternoon delivery round. However, 9% (5 express couriers) highlighted that their delivery vans carried out three daily rounds, which are two delivery rounds (early morning and midday) and a single pickup round around 4 PM.

Fig. 4.5 illustrates the distribution of the daily number of stops for each vehicle class. It can be seen that the range of delivery stops performed by delivery vans is more diverse than freight trucks. The majority of freight carriers reported that delivery vans typically perform less than 80 stops depending on the type of products as 63% of respondents indicated the number of delivery stops was around 40-80 stops. Delivery vans usually perform more than 60 delivery stops to food outlets whereas deliveries to clothing and consumer electronics were performed in around 50 and 60 delivery stops, respectively. Alternatively, delivery vans perform around 60 delivery stops for deliveries to commercial establishments in high-rise towers including cleaning products and office supplies. Moreover, delivery vans typically perform around 65-75 daily stops for express parcel deliveries to commercial and residential receivers. However, some large express couriers perform more than 100 delivery stops on delivery vans. For light and medium trucks, the number of stops is significantly much lower as most freight trucks typically perform less than 40 stops in central Melbourne. This is in contrast to delivery vans that more commonly perform higher than 40 delivery stops. The respondents mentioned that most deliveries using medium trucks were for office supplies and food outlets, which required large number of bulky parcels at each stop. Some of these medium trucks performed only 20-40 stops for these receivers. Moreover, most medium trucks performed around 20 stops for deliveries of appliances and homeware. Additionally, deliveries to large food outlets were carried out by medium trucks in less than 20 delivery stops. It can be summarised that the average number of stops for a delivery van in the inner-city area is 55-60 stops while a light truck and medium truck typically perform 40-45 stops and 25-30 stops respectively.

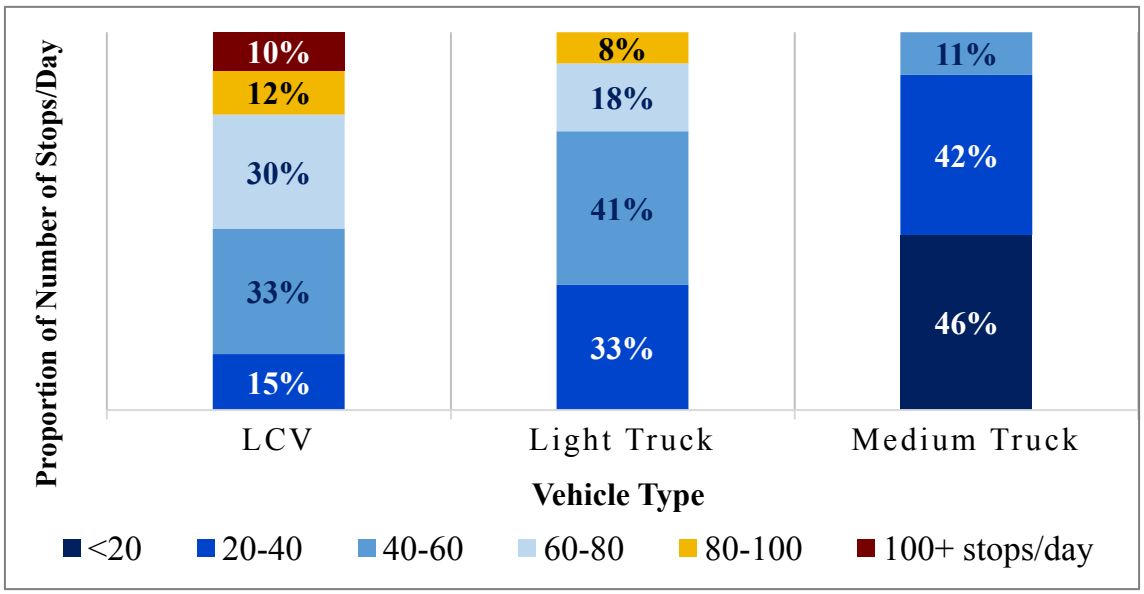


Figure 4.5. The Share of Number of Stops for Each Class of Freight Vehicles Performing Delivery and Pickup Activities in Inner Melbourne

Fig. 4.6 illustrates the 100-point allocation assigned to the operational issues based on their influence on the efficiencies of the carriers' activities in the inner-city. Issues related to parking and loading infrastructure, which are shown in dark blue colour, received the highest rating by respondents. Finding parking received the highest rating (29%) while regulations of OLZs was rated as the 3rd most negative issue (13%). This high rating highlights the negative impacts of the improper planning and the unavailability of on-street loading infrastructure. Issues related to traffic congestion and physical design of the city centre, which are shown in blue colour, were viewed as the second most negative aspects as traffic congestion received a rating of 24% whereas street design received a rating of 5%. Traffic congestion negatively impacts the reliability of the delivery and pick up services. Issues arising from street design was almost irrelevant for most freight carriers except for medium trucks (only 5%). A striking observation was that express couriers did not report traffic congestion to be a significant negative impact as compared to other types of freight carriers. This could be attributed to these couriers delivering to designated delivery zones, which increase their awareness of the area and allowing them to avoid heavy traffic. However, freight carriers using medium trucks expressed that these two issues have more considerable influence on their efficiencies as traffic congestion and physical constraints such as narrow lanes and street closures exerted significant pressure on their drivers to perform their operations.

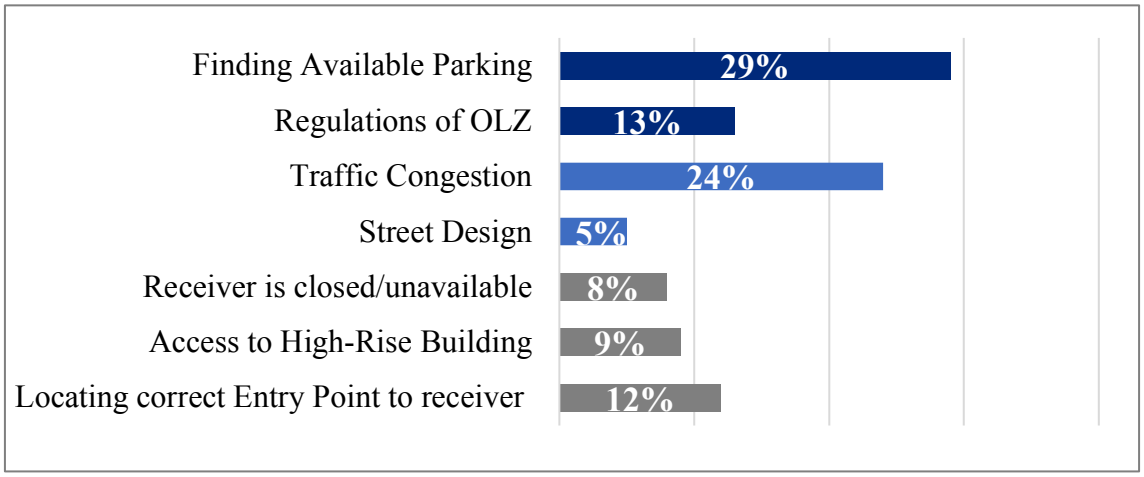


Figure 4.6. Rating of the Operational Challenges and Issues Based on Their Influence on The Efficiency of Freight Carriers in the Inner-city Area

Moreover, issues related to receivers' accessibility and availability, which are shown in grey, were ranked fourth by the participants. As many retailers and businesses in the city centre are located in high-rise towers and laneways, many freight carriers encounter difficulties accessing these receivers and locating the quickest and proper entry point to deliver the orders. Some participants complained that many deliveries to these receivers are restricted through main entrances where couriers have to navigate through loading docks and elevators to reach the different receivers inside these buildings. Some freight carriers warned that this problem was further aggravated by the high driver turnover, i.e. rate of couriers leaving the job, that negatively affect the freight carrier as they continually need to inform their couriers on best approaches to reach the receivers in these constrained buildings. Moreover, some express couriers allocated almost 40 points to "access to high-rise towers" to highlight the difficulties that their drivers encounter to adhere to the strict

delivery polices imposed by the building management. They expressed their considerable displeasure of the excessive lost productivity due to the long time between parking the vehicle and completing the delivery or pick up activity.

4.3.2.2. Inferential Analysis of the Relationships between the Characteristics of Delivery Trips and Operational Issues

A series of inferential analyses was carried out using Kruskal-Wallis H and Spearman correlation tests to explore potential significant relationships between the vehicle types, characteristics of the delivery trip (fill-in rate, number of drops and number of parcels delivered per drop) and the operational issues. Only statistically significant results are presented in this section to enhance the readability of the report. Two Kruskal-Wallis H tests were performed to assess relationships between vehicle type vs characteristics of the delivery trip and vehicle type vs operational challenges. Furthermore, Spearman correlation test was performed to examine the strength and direction of the relationship between the operational challenges and number of drops variable.

The results of the first Kruskal-Wallis H test indicated statistically significant differences in all attributes of the delivery trip under examination between vehicle types. Table 4.5 summarises results of this KW-H tests. We can reject the null hypothesis that vehicle types all have the same characteristics of delivery trips of delivery as the H_{score} is greater than χ^2. Therefore, it could be extrapolated that the characteristics of delivery trip differ significantly between types of vehicles.

Table 4.5. Results of Kruskal-Wallis H tests for Vehicle Type vs Delivery Trip

Variables	Vehicle Type vs Fill-in Rate	Vehicle Type vs Number of Drops	Vehicle Type vs Number of Parcels/stop
H_{score}	15.28	19.63	9.13
df	2	2	2
P	<0.01	<0.01	0.017
χ^2	10.597	10.597	7.824

Particularly, it was shown that:

- LCV has a significantly higher fill-in rate than light trucks (LT) (p =0.068, r = .5) and medium trucks (MT) (p < .001, r = .59). LCV drivers reported a fill-in rate between 60% to 70%, whereas LT and MT drivers stated a fill-in rate of 50-60% and less than 40%, respectively.
- LCV performs a significantly higher number of drops than medium trucks (p < .001, r = .66). LCV made 40 to 60 drops, while medium trucks made 20 to 40 drops.
- Medium trucks deliver a significantly higher number of parcels per drop than LCVs (p = .026, r = -.40). Medium trucks deliver 8-10 parcels per drop whereas LCVs deliver between 1 to 3 parcels per drop.

Subsequently, the second Kruskal-Wallis H test was conducted to evaluate if there was a statistically significant difference in operational challenges between types of vehicle. The independent variable included three categories of vehicle types. The dependent variables were “finding available parking”, “access to high-rise building”, and “street design”. With

the p-value ≪0.05 and the H_{score} is greater than χ^2, we have sufficient statistical evidence that the impact of these operational issues is different for different vehicle types. Table 4.6 displays the results of the Kruskal-Wallis H test for this analysis.

Table 4.6. Results of Kruskal-Wallis H tests for Vehicle Type vs Operational Issues

Variables	Vehicle Type vs Finding Parking	Vehicle Type vs Access to High-rise Building	Vehicle Type vs Street Design
H_{score}	11.03	13.59	40.25
df	2	2	2
P	0.007	0.037	<0.001
χ^2	9.210	5.991	13.816

It can be inferred that:

- Couriers using medium trucks (MT) reported significantly higher difficulty in finding available parking than LCVs and somewhat light trucks (MT vs LCV: p = .006, r = .47; MT vs LT: p = .030, r = .56). Medium trucks had a rating higher than 30% for the influence of this issue, whereas LCVs and LTs stated a rating of 25%.
- Couriers using LCVs rivers have significantly higher difficulty in access to high-rise buildings than medium trucks (p = .033, r = .39). Couriers using LCVs reported a rating of 12.5%, whereas medium trucks couriers stated a rating of 0%.
- Couriers using light trucks and medium trucks have a significantly higher difficulty than LCVs as to street design (LT vs LCV: p = .001, r = -.54; MT vs LCV: p < .001, r = -.90). LCVs couriers reported a rating of 0%, while LT and MT couriers stated a rating of 10% and 20%, respectively.

Finally, a series of Spearman correlation analyses were employed to explore if there was a statistically significant relationship between the operational challenges and number of drops. Results indicated that there is a statistically significant strong and negative relationship between street design and number of drops, $r_s(53) = -.54$, $p < .001$, suggesting that freight carriers who were more affected from street design reported a lower number of drops. Concerning LCVs, a statistically significant strong and negative relationship between finding available parking and number of drops was identified, $r_s(32) = -.56$, $p = .001$, indicating that LCV drivers who were more affected from finding available parking mentioned a lower number of drops. Regarding medium size trucks, there was a negative relationship of medium strength between traffic congestion and number of drops, $r_s(10) = -.38$, $p = .32$, suggesting that couriers using medium truck carriers who were more affected from traffic congestion reported a lower number of drops. However, it should be noted that no significance was obtained for this relationship, despite the strength of it. No significant relationships for light trucks were observed.

4.3.3. Discussion and Policy Implications

Freight carriers are increasingly using delivery vans for inner-city freight deliveries rather than freight trucks, which are more cost-competitive per parcel due to the larger cargo area. The changing and often conflicting delivery requirements for the various receivers in the inner-city in terms of parcel size, product type, delivery frequency and preferred

time-window even among businesses in the same commercial sector further complicate the efficiency and delivery practices of freight carriers. Furthermore, the ineffective on-street loading spaces whether in availability or outdated regulations adversely affect the parking practices and operational efficiency of freight vehicles and push the vehicles to move between parking spaces to comply with the time-sensitive delivery requirements of the receivers. This is evidenced by the high rating assigned to issues related to parking infrastructure. A key criticism expressed by the transport managers was that local authorities mistakenly assumed that couriers could easily access and use off-street loading docks of commercial towers and shopping centres, and thus on-street loading spaces are not highly necessary for their loading activities.

The perspectives and operational parameters acquired in the interviews with the CEP service providers highlight that although their delivery operations are optimised, it is operationally difficult to achieve a highly loaded delivery vehicle. This could be attributed to the dynamic nature of their delivery trips and the significant number of delivery stops as some delivery vans perform more than 80 express parcel deliveries to inner-city business receivers. Furthermore, it is important to incorporate the different types of contractual agreements between the freight carrier and the courier when attempting to address last mile delivery issues as sometimes there might be a conflict of interest between the delivery company and the franchisee or driver-owner. It could be argued that many freight models incorrectly approached these express deliveries from the freight traffic perspective by attempting to optimise the delivery routes for the delivery vans before leaving the facilities; however, they overlooked the freight demand aspect in terms of delivery requirements and availability of receivers as well as the unpredictable nature of parking infrastructure. Optimising the delivery routes and sequence of delivery stops might be uncontrollably disrupted in case of sudden changes in delivery requirements by the goods receivers or unavailability of parking spaces. Moreover, the considerable rating assigned to receivers' availability and accessibility further suggest the importance of including goods receivers in freight solutions and measures.

The survey responses confirmed that freight vehicles are forced to perform a large number of stops using unoptimised delivery vans to fulfil the different delivery requirements of the various types of inner-city retailers and businesses compared to receivers located in suburban parts. Moreover, many freight carriers complained that these multiple stops were performed to neighbouring receivers. The majority of the distribution centres and warehouses of freight carriers and shippers are located and clustered in freight-intensive industrial precincts in suburban parts of the city. Hence, delivery vehicles of different freight carriers often travel over longer transport distances to distribute similar products from these suburban facilities to neighboring retailers and businesses in the inner-city. The high number of delivery stops does not only affect the operations and cost of the freight carriers, but also takes a physical toll on the well-being of couriers. It could be inferred that the delivery trips of the last leg of delivery to inner-city business receivers are highly different from the more optimised delivery trips to business receivers in other parts of the metropolitan area that are commonly performed using trucks in a fewer number of delivery stops. Moreover, the high dependence on the driver to decide the order of the stops and customers in the delivery route could be problematic. The efficiency of the route and sequence selection could be adversely impacted by human factors and personal experiences. It does not take advantage of real-time traffic status and updates, which might result in additional travelled distance and bias in order of customers.

With respect to the characteristics of the delivery trips in the inner-city, the survey responses indicated somewhat different figures from similar studies performed in Europe and USA. For instance, the delivery route and sequence of delivery stops are decided more often in this study (53% of responses) than the Torino-based study, which indicated about 36% of deliveries were planned by drivers (Pronello et al. 2017). Furthermore, it could be inferred from the high number of stops for express parcel deliveries that most couriers perform a single delivery service to receivers in high-rise towers. This is similarly reported in a Seattle-based study that found 72% of couriers performed a single delivery to a high-rise building downtown Seattle (Kim et al. 2018). Alternatively, the average number of delivery stops for a delivery van in the London-based study (37 stops) (Allen et al. 2018b) is much lower than the average number reported in this study (about 55-65). The findings of the observational study (section 4.2.1) suggested that couriers had to walk less than 60 metres from the on-street parking space in about 70% of deliveries to receivers in the Melbourne CBD, indicating a shorter walking distance compared to the reported distance of 105 metres per customer stop in the London-based study. While the number of delivery stops is highly dependent on the operational practices of freight carriers and delivery requirements of receivers as indicated earlier, other urban factors such as clustering of receivers, layout of the city centre and freight land-use regulations could also affect delivery practices. It could be speculated that couriers perform a larger number of delivery stops in Melbourne's CBD than the London-based study due to the lower drop density as also suggested by the shorter walking distances. However, both studies estimated that a delivery van delivers about 100 parcels on average to inner-city receivers. Additionally, the average delivery size to shops and retailers (5 parcels) reported in a Parma-based study (Tozzi et al. 2013) is similar to the estimated number of parcels per delivery stop (407) reported in this study.

4.4. Design of Central City Consolidation Facilities

The following section describes the operational and the organisational design of the proposed consolidation facility including: the potential users of the proposed consolidation facility, the transport operator to perform the consolidated deliveries, the operational activities as well as supporting regulations and policies required for the establishment of CCCF in inner-city area.

4.4.1. Description of the Central City Consolidation Facility

The Central City Consolidation facility (CCCF) can be set up inside an existing parking infrastructure or a suitable building in the inner-city area. The facility works as a transshipment and micro-consolidation point and accommodates receiving light non-perishable freight deliveries from warehouses of various shippers and freight carriers via light and/or heavy freight vehicles. The out-bound distribution activities out of the CCCF will be carried out by a selected transport carrier from the Courier, Express and Parcel (CEP) industry. The CCCF operator will combine and bundle incoming light parcels (less than 30 kg) from participating freight carriers into optimised loads in consolidated delivery trips addressed to neighbouring receivers. This will deliver larger quantities in the same vehicle trip and reduce number of vehicles compared to using multiple carriers.

It is essential for the facility to have a high floor-to-ceiling height to accommodate receiving deliveries from participating freight carriers on heavy rigid trucks. This

operational capability would enable other carriers to bring the parcels on pallets using heavy freight vehicles instead of unoptimised and inefficient delivery vans. Depending on the size and volume of parcels, each pallet could contain up to 50 units. The palletisation of parcels facilitates higher vehicle fill-in rate and total number of parcels on the incoming freight vehicles into the consolidation facility. These benefits would enable any participating freight carrier to operate a single rigid truck to transfer the parcels to the consolidation facility compared to the original case of multiple delivery vans operated in the inner-city. Hence, the transport cost per parcel from the warehouses of the participating freight carriers to the consolidation facility are lower for palletised parcels on rigid trucks than the transport cost for individual shipments on unoptimised delivery vans. It is worth noting that if the facility does not accommodate large freight vehicles and the incoming parcels are broken in individual shipments, there might not be considerable cost saving and operational gains for the freight carriers, which would make the consolidation facility unattractive for the other freight carriers to transfer their parcels.

As the last leg of the delivery is considered the most problematic and most expensive link in the urban freight network, participating freight carriers could benefit from not having to deliver inside the inner-city. Furthermore, the CCCF operator could offer an additional pick-up service to the participating freight carriers to collect their delivery consignments from customers in the inner-city back to the consolidation facility where the freight carriers would take the parcels back to their warehouses. This service enables freight carriers to avoid pick-up activities in the congested inner-city area. These operational gains and cost reduction in the transport cost of parcels to the inner-city could facilitate offsetting the additional distribution costs for the freight carriers, which might encourage them to transfer their parcels to the proposed consolidation facility.

Furthermore, the operational configuration of the facility should facilitate easy ingress, manoeuvring and egress of the large freight vehicles without any restriction as well efficient and quick transfer and unloading of the incoming parcels from other freight carriers to the loading area inside the facility. All unloading, sorting and loading activities of the parcels are performed inside the facility to minimise any impact on surrounding sensitive uses. The facility should include ancillary spaces for temporary storage, operational equipment as well as an office and staff break room. The consolidation facility needs to be efficiently and sustainably integrated to cohabit with surrounding residential and commercial uses. The facility should be soundproofed and fireproofed. Proper lighting fixtures and locations should be selected inside and outside the facility to minimise light pollution as much as possible. Pedestrian and cycling paths should be constructed as well as creating an open space outside the facility in order to make the interface between the facility and the surroundings more sustainable.

Furthermore, the proposed freight consolidation initiative should attempt to attract small and independent retailers and businesses located in retail and commercial precincts in the city centre to consolidate their daily deliveries and offer value-added services. Receiving deliveries from multiple freight carriers is a repeated and time-consuming in-store process that takes the establishment's staff away from their core business activities. Accordingly, receivers that are interested in consolidating their deliveries through the CCCF could request their suppliers to deliver their parcels to the CCCF instead of their businesses. Furthermore, the CCCF operator will offer pre-retailing and recycling services that would improve the in-store processing of deliveries for the businesses. The existing commercial relationships between receivers and their freight carriers need to be preserved to

successfully encourage receivers to participate in the consolidation scheme. The CCCF operator must ensure the efficient system integration between information systems of the CCCF and participating freight carriers. The enterprise system of the CCCF should facilitate seamless and secure transfer of parcels from the freight carrier to CCCF operator by providing real-time status information of the parcel. It is essential for participating freight carriers to receive instantaneous proof of delivery from the CCCF operator upon delivering the parcel to the receivers inside the inner-city area.

The consolidated delivery fee charged by the CCCF operator to deliver the consolidated loads from the facility to the receiver's address would be covered mainly by the participating freight carriers. The freight carriers are expected to cover the larger share of the consolidated delivery charges as they would recover partial costs in their overall distribution costs of the parcels through improved utilisation of their delivery vehicles and operational gains by not delivering in the congested and time-restricted city centre. Hence, the consolidated delivery fee per parcel for the freight carrier may become less than the transport cost of direct delivery on the freight carrier's own vehicle from their warehouses to receivers inside the inner-city area.

4.4.2. Supporting Regulations and Technologies

The use of the CCCF will be on a voluntary basis for freight carriers operating in the inner-city. The CCCF operator will be responsible for all costs associated with the setup and operation of the consolidation facility. However, local authorities need to assess the merits and associated costs of establishing a Public Private Partnership (PPP) with the CCCF operator due to the potential social and environmental benefits of the micro-consolidation initiative. The PPP could provide the required and supporting measures that would facilitate the success of the consolidation initiative and overcome some of the regulative and external issues that the CCCF operator has no authority to change. Accordingly, local authorities should set through the PPP agreement clearly defined objectives and requirements to be met by the CCCF's operator with respect to the sustainability and efficiency of the consolidated deliveries. The PPP agreement should clearly stipulate the use of eco-friendly freight vehicles and promote performing the consolidation deliveries in off-peak hours as operationally as possible as well as efficiently integrate the facility with sensitive surroundings. Furthermore, city planners should utilise the Context Sensitive Solutions (CSS) collaborative approach in the formulation of the PPP agreement to set supportive measures that regulate how the facility is established by the potential operator. Consequently, city planners should apply suitable performance-zoning codes that set the land-use zone of CCCF based on performance standards that minimise negative impacts on surrounding uses.

Through the PPP agreement, local authorities need to set supporting regulations for the use of cargobikes on the city's bike lanes as well as on-street loading spaces by the freight vehicles of the consolidation facility. Local authorities could issue a favourable delivery scheme within the inner-city to the CCCF operator for longer delivery-windows and exclusive use of dedicated OLZs that are located close to participating receivers. Local authorities should consider setting industry-specific regulations for the new dedicated loading zones to incorporate delivery requirements of receivers from various industries. It might be necessary to apply structural changes to the on-street loading spaces to

facilitate easy parking, manoeuvring and loading/unloading for the CCCF freight vehicles such as bevelled edge sidewalk and inclined plane for enhanced material handling.

As a part of the PPP agreement, local authorities could utilise mobile communication technologies to provide a mobile application that enable the CCCF operator to reserve the dedicated on-street loading space and send booking details to receiving businesses. The mobile application will enable CCCF operator to notify only the receivers located close to the selected loading zone to prevent misuse of the dedicated loading zones and ensure compliance with the set regulations as part of the formulated PPP. Various time-slots will be available for booking during off-peak and peak hours. The mobile application will enable the drivers to report to local authorities (via pictures and submitted complaint) any illegal parking by unregistered commercial vehicles or private cars to ensure compliance with the rules. Furthermore, local authorities could also take advantage of advancements in Internet of Things technologies, license plate recognition and Smart Occupancy Signs to implement adaptive displays that establish virtual on-street loading zones that become active only when there is a booking by the CCCF operator. These smart displays will display the booking details (reserved timeslots and the license plate of the CCCF freight vehicle).

4.5. Chapter Summary

This chapter presented detailed understanding of the operational practices of freight carriers to perform their delivery and pickup services within the inner-city area to addresses *Research Question #1*. The acquired industry insights depict an accurate picture of the current state of last mile delivery in the inner-city area for scholars, policy makers and transport planners. The results of the observational study and survey corroborate the high dependence on LCVs for delivery and pick up activities in the inner-city. The findings of the survey confirm that majority of couriers perform a large number of stops to neighbouring receivers using delivery vans with underutilised load capacity. Hence, the efficiency and cost-effectiveness of the last leg of last mile delivery in the inner-city for freight carriers are adversely exacerbated due to inefficient loading and parking infrastructure, high number of stops with low number of delivered parcels, failed and repeated deliveries.

In accordance with the 1st objective of the research project, the design of the Central City Consolidation Facility presented in this chapter built on the acquired insights as well as the factors and aspects that impacted the success or failure of previous freight consolidation facilities. The aim was to incorporate the current operational practices of freight vehicles and sustainable freight land-use regulations into the design of the consolidation facility to ensure making the facility operationally and economically attractive for freight carriers to transfer their parcels to the facility operator, which addressed *Research Question#2*. Accordingly, the proposed consolidation initiative is centred around providing a delivery service to the participating freight carriers that would be more efficient and cost-effective to transfer their parcels instead of performing unoptimised delivery trips using LCVs in the inner-city area. The proposed design of the CCCF presented in this chapter is further applied in the following chapters to achieve the other aims of the research.

The results of the observational study might have some limitations due to the non-participation nature of the observation study and reliance on appearances and personal interpretation of the observed loading activity. Nonetheless, the comprehensive data collected in this study provided first-hand and actual representation of the use of on-street loading activities by freight vehicles that was limited to the Australian perspective. It is recommended that a future study attempts to collect similar parking and loading activities by freight vehicles in off-street loading docks of high-rise commercial and residential towers to facilitate comparison of the efficiency of on-street vs. off-street loading spaces in the city centre for freight vehicles. Another research direction could be to apply freight generation demand models to investigate freight trip generation and attraction at receiving establishments around the observed OLZs in the city centre to visually match and map the intensity level of the parking and loading activities of the OLZs.

There are certain limitations with the freight carriers survey study. One of these is the number of total collected responses as the relatively low response rate indicates there might be other groups of freight carriers excluded from the analysis. However, the difficulty of involving and reaching a larger number of transport managers of freight carriers could be expected due to the extremely busy and challenging business environment for the freight industry coupled with the fact that this study presented valuable insights that were not available for the last leg of delivery in the inner-city. Another issue of the survey is that the focus was on the delivery trips for the entire fleet which did not allow collecting a detailed and individualised vehicle trip journey for each individual vehicle route inside the inner-city for particular freight carriers. Hence, it is recommended that a future study apply the GPS survey technique using GPS and smart sensors to complement this study and collect actual vehicle trip diaries including vehicle routes and dwell times from selected freight carriers in the city centre. Moreover, another future study could formulate a bi-level optimisation model to select the optimal locations for on-street loading spaces in the city centre based on the actual characteristics of the delivery trips and utilisation of OLZs presented in this chapter.

Chapter 5

2nd Stage: Multi-stakeholder Approach for the Most Suitable Delivery Fleet for the Consolidated Deliveries

5.1. Introduction

The design of the CCCF presented in section 4.4 focused on the organisational structure and operational configuration of the freight consolidation initiative involving the participating freight carriers, goods receivers and the potential operator of the proposed facility. The 2nd stage of the integrated framework focused on assessing and selecting the most suitable delivery fleet to perform the consolidated delivery service to receivers in the inner-city area. The type and mix of freight vehicles and modes used in the delivery fleet are very integral to the efficiency, acceptability and sustainability of the freight consolidation policy. As highlighted in the literature review in section 2.3.1, the primary focus in the evaluation of eco-friendly freight vehicles was on assessing their environmental and economic benefits and merits. As many freight consolidation facilities were initiated by local authorities as reported in the section 2.3.2, most of these trials and projects attempted to promote or utilise soft transport modes and eco-friendly freight vehicles. However, it is important to focus on the requirements and objectives of all the stakeholders in the assessment and selection of the delivery fleet for the consolidated deliveries. Based on the literature review in section 2.4.1, the MAMCA approach provides a systematic and stakeholder-based evaluation approach that facilitates involving all stakeholders throughout the planning and decision-making process. This chapter presents and discusses the results and analysis of the application of the MAMCA approach using responses collected from key actors representing all stakeholder groups in Melbourne. Fig. 5.1 displays the steps of MAMCA approach that were applied to select the most suitable delivery fleet for consolidated deliveries to receivers in the inner-city.

The sections of this chapter are described below:

- Section 5.2 presents the results and analysis of the MAMCA application. A full description of the questionnaire with stakeholders for the pairwise comparison as well as sample selection and response rate were presented in section 3.3.
- Section 5.3 discusses the results of the MAMCA application and describes the implementation plan for the most optimal delivery fleet configuration.
- Section 5.4 provides a concluding summary of the chapter including the study limitations.

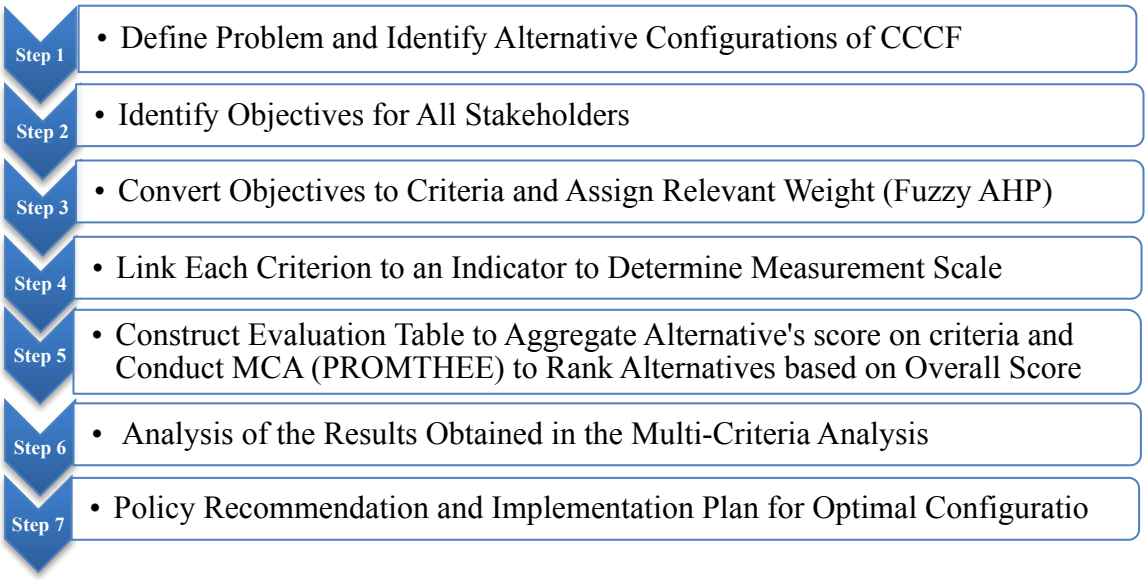


Figure 5.1. Overview of the Steps in the MAMCA Approach (Adopted from Macharis 2007)

5.2. Case analysis: Application and Results of MAMCA Framework

Using responses collected from key stakeholders in Melbourne, Australia, the MAMCA framework was applied to assess and select the most optimal and sustainable consolidated delivery fleet for the consolidated delivery in the inner-city area. The following sections describe and analyse the results of the MAMCA application.

5.2.1. Determining the Priority Weights of the Criteria Using Fuzzy AHP Method

The identified objectives of the six stakeholder groups were converted to decision criteria and their priority weights were calculated using the Fuzzy AHP method based on the primary responses collected from key experts in Melbourne. Table 5.1 displays the final objectives of all the stakeholders and the weight of the criteria for each stakeholder group obtained by the F-AHP method.

Cost of delivering/receiving the parcel represented the most important criterion for the logistics service providers (LSP) and receiver stakeholder groups with respective weights of 27.03% and 35.17%. These stakeholders are very interested in reducing the transportation cost of delivering and receiving the consolidated loads. For shippers, the most important criterion was **receiver satisfaction** with a weight of 35.39%. This could be attributed to shippers aiming to provide high-level service to their customers (the receivers). **Delivery lead time** was considered a very important criterion for both LSP and shippers as these stakeholders aim to minimise the total duration between picking up and delivering the consolidated shipments as much as operationally possible. **Consistent exchange of delivery documents and updates** represented the 4th most important criterion for receivers and shippers. This criterion might affect the likely participation of freight carriers and receivers in the delivery consolidation policy as it impacts the service level between these stakeholders. Receivers expressed high importance for **delivery punctuality** as this criterion represented the 2nd most important criterion for this group.

For local authorities and citizens, **liveability of the inner-city area** represented the most important criterion with respective weights of 35.52% and 47.19%. These stakeholders are very interested in improving the amenities of the inner-city area and the large presence of freight vehicles is a key issue. This was supported by **urban accessibility** and **traffic safety** being the 2nd most important criterion for these two stakeholder groups. For the logistics property providers (LPP) stakeholder group, "**profitability**" was the most important criterion with a weight of 44.74% as this stakeholder group aims to maximise profit of the commercial property leased as a consolidation facility. Surprisingly, this stakeholder group indicated a high importance on the sustainable integration of the commercial property with surrounding uses in the area. This could be attributed to companies in this stakeholder group aiming to reduce negative impacts on urban environment and enhance the corporate social responsibility of the company. Low importance was assigned to connectivity and utilisation of transport infrastructure by participants from local authorities and LPP, which might be expected as these stakeholders were more interested in sustainability and profitability, respectively. The inconsistency ratios (CRs) of all the pairwise comparison matrices in this study were all smaller than 0.1, which indicates that the participants performed consistent evaluations and the criteria weights were randomly assigned.

Table 5.1. Calculated Criteria Weights Using F-AHP Method for All Stakeholder Groups

Stakeholder	Objective	Criteria	F-AHP Weights
Logistics Services Providers *(No. of Participants = 17)*	Provide high service level to shippers and receivers	Service Level	0.1648
	Minimise total duration between picking and delivering product	Delivery Lead Time	0.2148
	Utilisation of other freight transport modes	Multi-modality	0.0351
	Reducing cost of collecting and delivering products	Transport Cost	0.2703
	Optimised vehicle capacity to utilise vehicles properly	Vehicle Fill-Rate	0.1270
	Efficient integration between information system of consolidated delivery's carrier and other carriers to provide delivery updates	System Integration	0.0814
	Reduce damage and theft of delivered products	Delivery Security	0.1066
Receivers *(No. of Participants = 20)*	Maintain receiving frequent deliveries on time.	Delivery Punctuality	0.2462
	Reducing the cost of receiving parcels	Parcel Receiving Cost	0.3517
	Receive continuous delivery status updates	Delivery Status Updates	0.1214
	Deliveries during non-busy operating hours to avoid disrupting staff activities	Convenient Deliveries	0.0634
	Attractive Shopping environment with minimum freight vehicles	Business Environment Attractiveness	0.0841
	Ensure the safety and security of delivered products	Delivery Security	0.1332
Shippers	Maintain low cost of delivering product to receiver	Delivery Cost	0.2648

(No. of Participants = 10)	Quick pick-up of products upon request and expedite delivery to receiver	Quick Delivery	0.2104
	Updated exchange of delivery documents (parcel pick-up and delivery window, waybill and proof of delivery)	Delivery Documentation	0.1130
	Ensure successful and on-time delivery to receiver	Receiver Satisfaction	0.3539
	Carrier's Accessibility and Readiness for Delivery	Carrier's Availability	0.0579
Local Authorities *(No. of Participants = 8)*	Liveable city for citizens with limited nuisance (less noise, emissions and accidents)	Liveable City	0.3552
	Implement low-cost measures to enhance the freight transport network and urban environment.	Low-Cost Measures	0.1910
	Enhance the utilisation of existing infrastructure	Network Utilisation	0.0701
	Reduce the number of freight vehicles and reduce congestion near homes and shopping areas	Urban Accessibility	0.2515
	Reduce the negative impacts of the facility on sensitive surrounding uses	Impact on Surroundings	0.1322
Citizens *(No. of Participants = 10)*	Prevent accidents near homes and shopping areas and reduce number of freight vehicles	Traffic Safety	0.3191
	Attractive environment for residents and shoppers with limited nuisances (noise, emission and congestion)	Quality of Life	0.4719
	Continuous supply of products and services in shops	Product Availability	0.2090
Logistics Property Providers *(No. of Participants = 5)*	High return on investment and lease facility to LSP at a competitive price.	Profitability	0.4474
	Reduce the repair & maintenance cost of the facility and minimise damage and deterioration to the facility	Repair & Maintenance Cost	0.1273
	Integrating the Facility to coexist with other surrounding uses	Harmonious Integration	0.2563
	Being Close to Major Freight Corridors and receivers.	Location Accessibility	0.1690

5.2.2. Analysis and Ranking of The Four Scenarios:

5.2.2.1. Mono-Actor Analysis

The following four scenarios were evaluated using the MAMCA software based on the PROMETHEE method and the priority weights of the decision criteria and the measurement indicators in the 5th step of the MAMCA approach.

- ***Scenario #1 "Cargobike":*** The consolidated delivery trips are conducted using only cargobike with parcel carry component.
- ***Scenario #2 "Eco-friendly LCV + Truck (Only Off-Peak Hours)":*** The consolidated delivery trips are conducted using eco-friendly LCVs in all times and trucks only during off-peak hours.

- ***Scenario #3 "Eco-friendly LCV + Cargobike":*** The consolidated delivery trips are conducted using eco-friendly LCVs and cargobikes with dedicated on-street loading zones in the inner-city area.
- ***Scenario #4 "BAU":*** Business-as-usual (BAU) where consolidated deliveries are performed using fossil-fuelled LCVs and trucks.

Valuable insights can be obtained from the mono-actor analysis for each stakeholder group with respect to their individual views on the scenario's performance on each criterion. Fig. 5.2 illustrates the evaluation scores of each scenario for the **Logistics Service Providers (LSP) group** with respect to each criterion. The scenarios are indicated by the four coloured lines while the criteria weights are represented by the vertical bars shown on the horizontal axis. The scale in the left vertical axis indicates evaluation scores of the scenarios while the right vertical axis displays the criteria weights. It is noteworthy that the BAU scenario performed significantly higher with respect to vehicle fill-rate, transport cost and delivery security criteria while it was viewed poorly with respect to the multi-modality and delivery lead time criteria. Transport cost was the most important criteria for LSP, which might explain why the BAU received higher overall evaluation score by LSP compared to the other stakeholder groups.

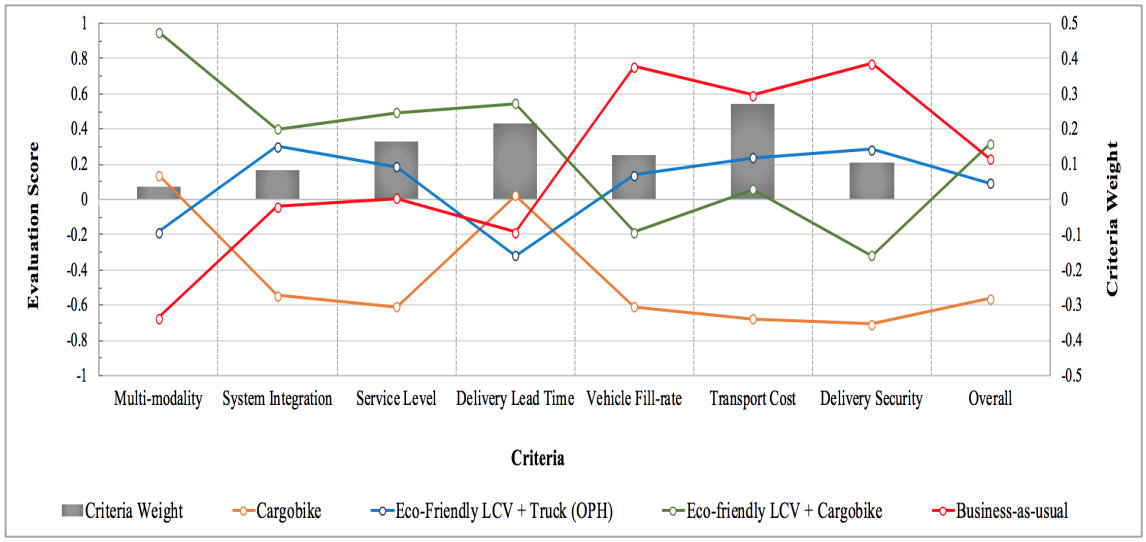


Figure 5.2. Results of the Mono-Actor Analysis for the Logistics Services Providers Stakeholder Group

On the contrary, the 3rd scenario was viewed poorly with respect to vehicle fill-rate and delivery security criteria even though this scenario received the highest overall performance score for LSP. This might be a result of its superior performance on the delivery lead time and service level, which were the 2nd and 3rd most important criteria for this group. The mono-actor analysis explains why the LSP group might be reluctant to use cargobikes due to their negative impact on service levels, efficiency and cost of their delivery activities. This is further supported by the higher evaluation score of the 2nd scenario compared with 3rd scenario with respect to the vehicle fill-rate, transport cost and delivery security criteria as the 3rd scenario included cargobikes. However, these two scenarios were viewed more favourably compared with the BAU scenario with respect to the service level criterion as the utilisation of eco-friendly LCVs for the consolidated delivery might satisfy the sustainability interest of the receivers and shippers. Another

advantage of the 3rd scenario compared to other scenarios was that it promotes multi-modality. It could be summarised that the BAU scenario is more favourable for the LSP stakeholder group from the economical and operational aspects while the 3rd scenario is more suitable from societal and sustainable aspects.

Fig. 5.3 illustrates the evaluation scores of each alternative for the **Receivers group** with respect to each criterion. The 2nd scenario was viewed more favourably compared with the other two scenarios with respect to the parcel delivery cost, which was considered the most important criterion for receivers. This explains the high overall evaluation score for this scenario for the group even though this scenario was not viewed as favourably with respect to other criteria. Receivers believe that the use of cargobikes in the consolidated delivery might negatively impact the delivery security and increase the delivery cost. However, the high evaluation score for the 3rd scenario with respect to the delivery punctuality criterion, which was the 2nd most important criterion, suggested that receivers believe utilisation of cargobikes facilitate quicker and more efficient deliveries in the congested inner-city area. In contrast, the 2nd and BAU scenario received very low scores for this criterion. This could be attributed to the difficulty of finding parking and loading spaces for trucks near receivers, which would negatively impact the efficiency and punctuality of the operator of the consolidated service.

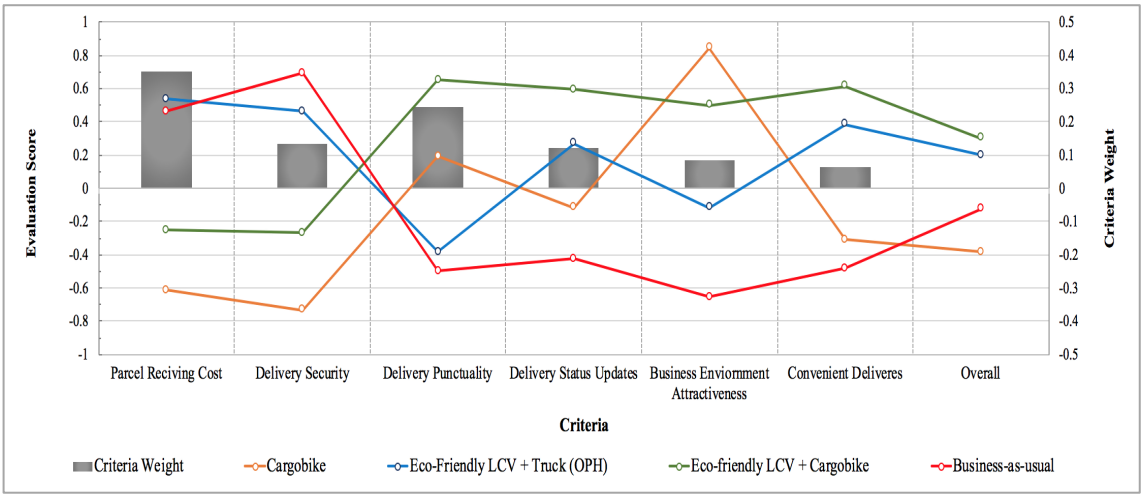


Figure 5.3. Results of the Mono-Actor Analysis for the Receivers Stakeholder Group

Moreover, the 1st and 3rd scenarios received high scores from the receivers for the business environment attractiveness since they facilitate reducing the presence of freight trucks. An interesting observation was the high evaluation score assigned to the 3rd scenario compared to the low score assigned to the Cargobike scenario for the delivery status criterion. This could be attributed to the fact that eco-friendly LCVs can deliver larger volumes of parcels in the consolidated delivery compared with cargobikes and result in a fewer number of delivery services, which contributes to more efficient tracking and delivery updates. As the 2nd scenario promotes the use of trucks during off-peak hours, receivers viewed this scenario more favourably with respect to the convenient delivery criterion, which encourages performing the consolidated delivery during off-peak hours to avoid disrupting staff's activities. The Cargobike and BAU scenarios received similar overall evaluation scores by the receivers even though they were viewed completely different with respect to each criterion as can be seen in the peaks and roughs in Fig. 5.3.

While the 3rd scenario received low score for the parcel delivery cost and delivery security criteria, this scenario might be the most suitable scenario for receivers due to its superior performance in other criteria.

Fig. 5.4 displays the evaluation scores of the alternatives for the mono-actor analysis for the **Shippers group**, which revealed slightly different views on the scenarios as their evaluation scores were much closer except for the Cargobike scenario. It was expected that the BAU scenario would receive high evaluation score for the delivery cost criteria, which represented the 2nd most important criteria for this group. However, it was remarkable that shippers ranked this scenario as the best option for the carrier's availability criterion, which might suggest that shippers have doubts on cargobikes' ability to provide continuous supply for the vehicles of the consolidated delivery. Similarly, the 3rd scenario and the BAU scenarios were ranked as the best two scenarios for the quick delivery criterion, which was the 3rd most important criterion. The time-limited use of trucks only during off-peak hours in the 2nd scenario contributed to the low rank for this scenario in the delivery lead time and carrier's availability criteria. Furthermore, shippers ranked scenarios that utilise cargobikes (1st & 3rd scenarios) quite favourably for the receiver satisfaction criteria, which was the most important criterion. As this criterion was highly important for the shippers group, the BAU scenario overall evaluation score was not high even though this scenario received higher scores in the other group's criteria. For the delivery documentation criterion, 3rd and 2nd scenario received very high scores compared with the cargobike scenario and BAU scenario. It can be summarised that the 3rd scenario was viewed quite favourably as indicated by the high overall evaluation score while 2nd, BAU and 1st scenario received slightly similar overall evaluation scores.

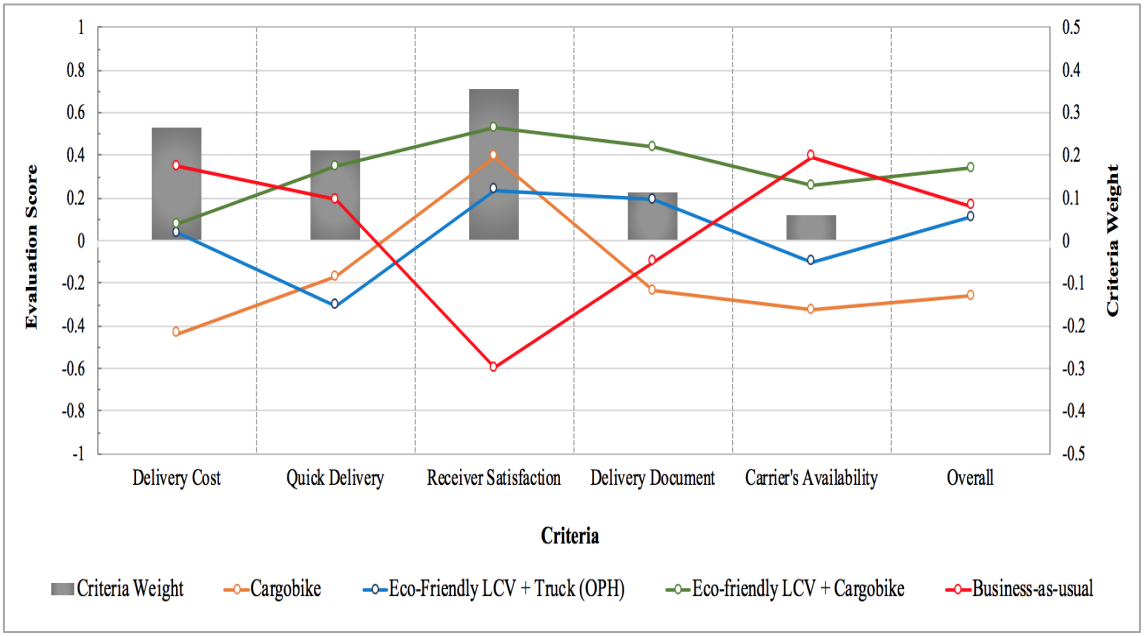


Figure 5.4. Results of the Mono-Actor Analysis for the Shippers Stakeholder Group

The results of the mono-actor analysis for the **Logistics Property Providers group** is illustrated in Fig. 5.5. As profitability represented the most important criterion for this group, scenarios that utilised eco-friendly LCVs (2nd and 3rd scenarios) were ranked quite

highly while the BAU scenario was ranked as the worst for this criterion. This high ranking could be attributed to the notion that using eco-friendly LCVs for the consolidated delivery would make the facility more accepted by businesses and societal stakeholders, which would increase the attractiveness and leasing opportunity for the facility. Furthermore, the 1st and 3rd scenarios received high evaluation scores with respect to the R&M cost and harmonious integration criteria as they reduce the presence of freight trucks, which would minimise damage and deterioration to the consolidation facility. It is noteworthy that the BAU scenario was ranked high for the location accessibility criterion. For this criterion, the LPP aim to have the facility closer to major freight corridors, which are more suitable for freight trucks than cargobikes. However, satisfying this objective would not guarantee excellent connectivity to the cycling infrastructure as well. This is validated by the low ranking of the 1st and 3rd scenario, which involve cargobikes, compared with the high ranking for the 2nd scenario with respect to this criterion. It is clear scenarios that address environmental aspects, which were the 1st, 2nd and 3rd scenarios, were viewed favourably by this stakeholder group compared with the BAU scenario.

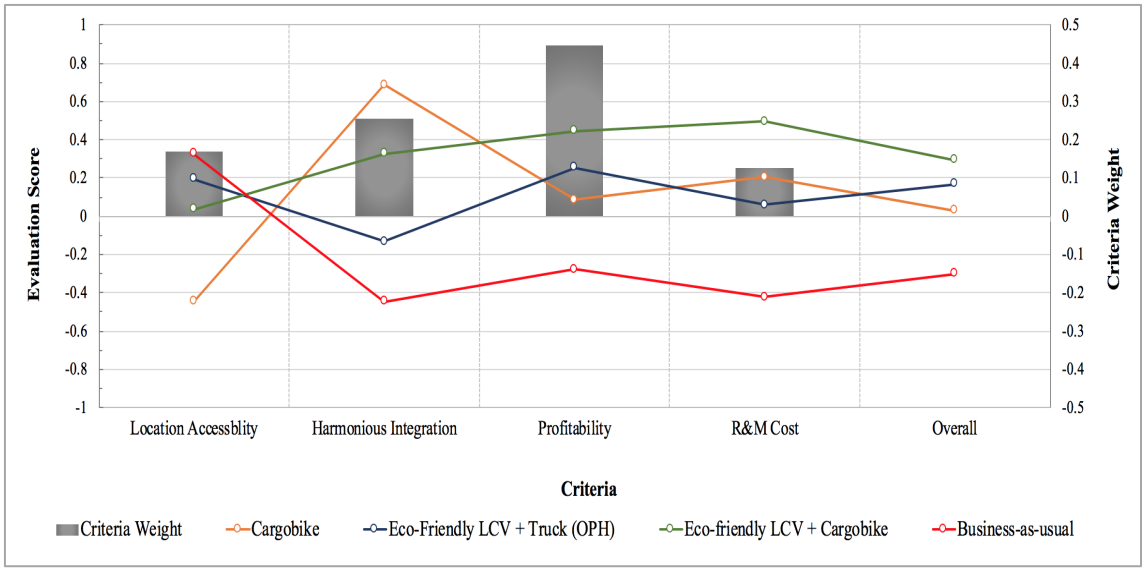


Figure 5.5. Results of the Mono-Actor Analysis for the Logistics Property Providers Stakeholder Group

The scenarios that addressed the socio-environmental concerns were ranked very high by the **Local Authorities group** as can be seen in the results of the mono-actor analysis illustrated in Fig. 5.6. The 1st and 3rd scenarios, which facilitate eliminating freight trucks in the inner-city area, received very high evaluation scores for the urban accessibility, liveable city and impact on surroundings criteria. The inclusion of the cargobikes in the 3rd scenario contributed to this scenario, being ranked 2nd preferred scenario for the impact on surroundings criterion. Since the 2nd scenario involved trucks during the off-peak hours, it was not viewed favourably by this stakeholder group with respect to that criterion. On the contrary, it was striking that the 2nd and BAU scenarios were ranked as the 1st and 2nd best alternatives with respect to the network utilisation criterion for local authorities. This could be attributed to the concerns of local authorities that cargobikes might place more pressure on the cycling infrastructure that is already used by residents

whereas the 2nd and BAU scenarios could use major roads for the consolidated delivery. However, it is worth noting that the 2nd scenario was ranked higher than 3rd scenario for the low-cost measure criterion, which was the 3rd most important criterion. This was unexpected, and it could be attributed to the notion that setting up the infrastructure for the 2nd scenario would be less costly than the 3rd scenario since freight carriers already utilised freight trucks whereas cargobikes would require enhancing the cycling infrastructure. For this stakeholder group, the Cargobike was clearly the most preferred scenario, followed by the 3rd scenario.

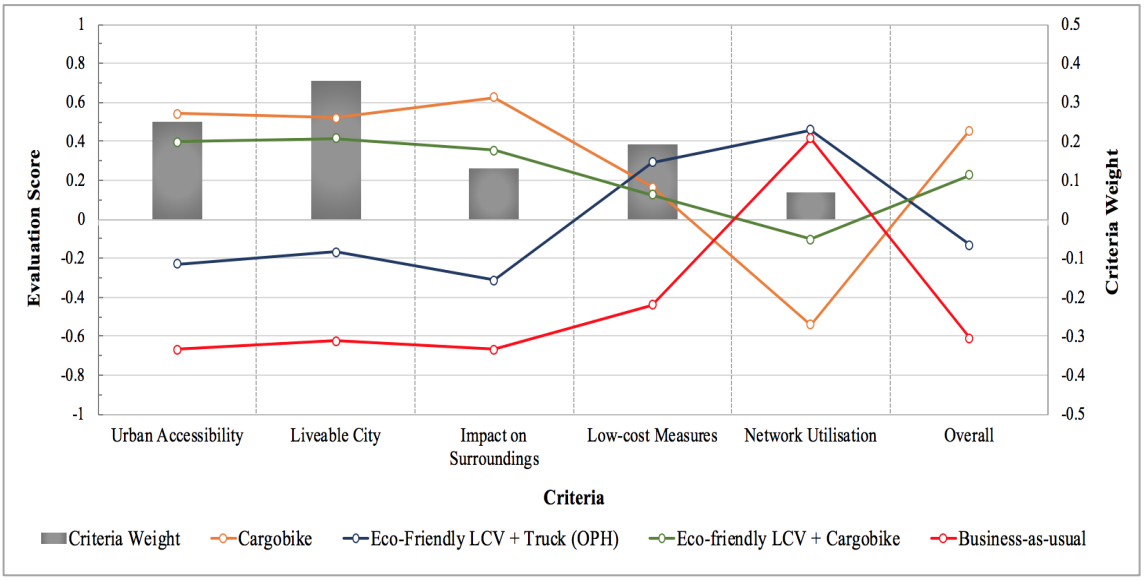


Figure 5.6. Mono-Actor Analysis for the Local Authorities Stakeholder Group

Fig. 5.7 clearly illustrate the superiority of the Cargobike scenario in satisfying the objectives of the **Citizens** group. For the quality of life criterion, which was the most important criterion for this stakeholder group, this scenario achieved a very high evaluation score and was followed by the 3rd and 2nd scenarios, respectively. The views were similar for the traffic safety criterion, which was the 2nd most important for this group. The BAU scenario received a very low evaluation score for these two criteria as expected. Residents and workers prefer the consolidated delivery to be performed with very limited presence of freight vehicles to enhance the amenity of the inner-city area. Furthermore, the mono-actor analysis revealed that the preference margin between the Cargobike scenario versus the 2nd and 3rd scenarios are quite wider than the results indicated by other stakeholder groups. It was striking that the Cargobike scenario was ranked as the 3rd best for the product availability criterion after the 3rd and 2nd scenarios. This suggests that this stakeholder group might believe it would be operationally difficult for the operator of the consolidation facility to maintain delivering products using only cargobikes. Similar to the local authority group, the most preferred scenario for the citizen group was the Cargobike scenario followed by the 3rd scenario.

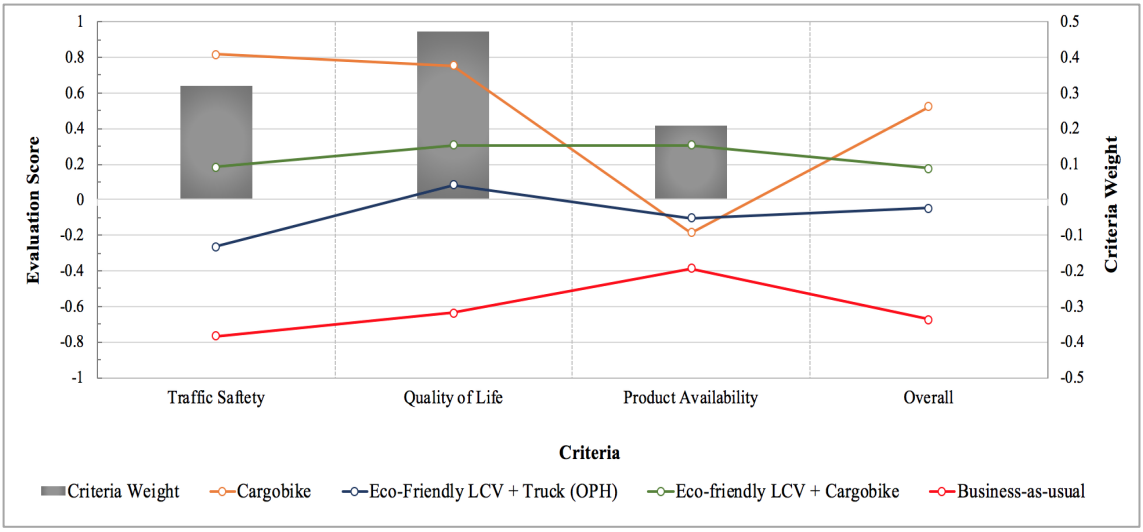


Figure 5.7. Results of the Mono-Actor Analysis for the Citizens Stakeholder Group

5.2.2.2. Multi-Actor Perspectives

The multi-actor view of the alternative configurations of the consolidated delivery is displayed in Fig. 5.8. The multi-actor analysis facilitates examining the overall performance of each scenario collectively for each stakeholder group. It provides a visual comparison based on the evaluation scores of the scenarios for all the stakeholder groups. The Eco-friendly LCV + Cargobike (***3rd***) scenario has achieved a relatively high evaluation score by all the stakeholder groups. The Eco-friendly LCV + Truck (***2nd***) scenario obtained good evaluation scores by the LPP, receivers and shippers while citizens and local authorities did not view this scenario as favourably due to the inclusion of trucks. The Cargobike (***1st***) scenario received significantly different views by the six stakeholder groups. This scenario achieved the highest evaluation score for citizens and local authority. However, it achieved the lowest evaluation score for LSP, receivers and shippers as it would negatively impact the profitability and the service level of the operator of the consolidation facility due to the restricted capacity of the cargobikes compared with freight vehicles. This is in contrast with the BAU scenario as it was viewed very poorly by the citizens and local authorities. It is interesting that the LSP stakeholder group viewed this scenario much more favourably than the 1st and 2nd scenarios. This could be justified due to the additional transport cost resulting from the exclusive use of cargobikes for the consolidated delivery and the time-restricted use of trucks only during off-peak hours in the 2nd scenario. Moreover, LSPs preferred the 3rd scenario over the 2nd scenario as the time-restricted use of trucks would impact the efficiency and reliability of the consolidated delivery since receivers might not welcome off-peak deliveries without any incentives.

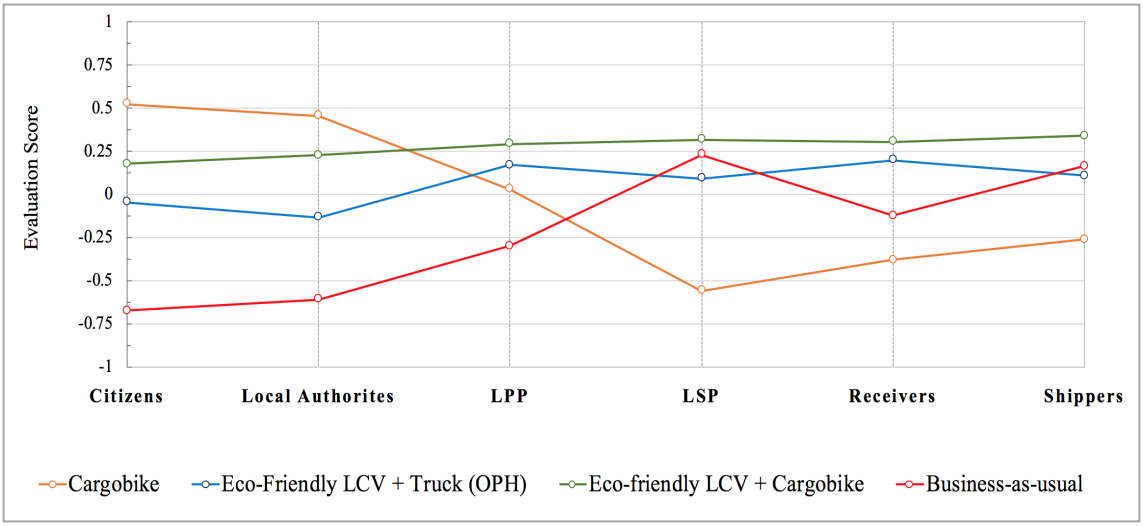


Figure 5.8. Results of the Multi-Actor Analysis of Alterative Configurations for Consolidated Delivery Fleet for the Consolidated Delivery

Another perspective of the multi-actor analysis is displayed in the Box and Whisker chart shown in Fig. 5.9. The box plot displays the distribution of evaluation scores of the four scenarios through their quartiles. Variation in the box plot is helpful in displaying the consistency of the evaluation scores for the four scenarios among the six stakeholder groups. A scenario with a median value above the zero line is considered an acceptable scenario by the majority of stakeholder groups while a scenario with median value below zero line is not well received by majority of the stakeholder groups. It can be seen that Eco-friendly LCV + Cargobike scenario has a comparatively short box plot with a higher mean value with less variation than the other three scenarios, which indicates a high level of consistent evaluation scores. However, the comparatively tall box plots of the Cargobike and BAU scenarios indicate that stakeholder groups hold quite diverse viewpoints on these two scenarios with respect to the decision criteria. Moreover, the uneven sections of the box plot for the Cargobike scenario underline the highly conflicting viewpoints among the six stakeholder groups with respect to this scenario. This is further validated by the whisker (vertical lines) of these two scenarios which highlight the high variability in the evaluation scores outside the upper and lower quartiles.

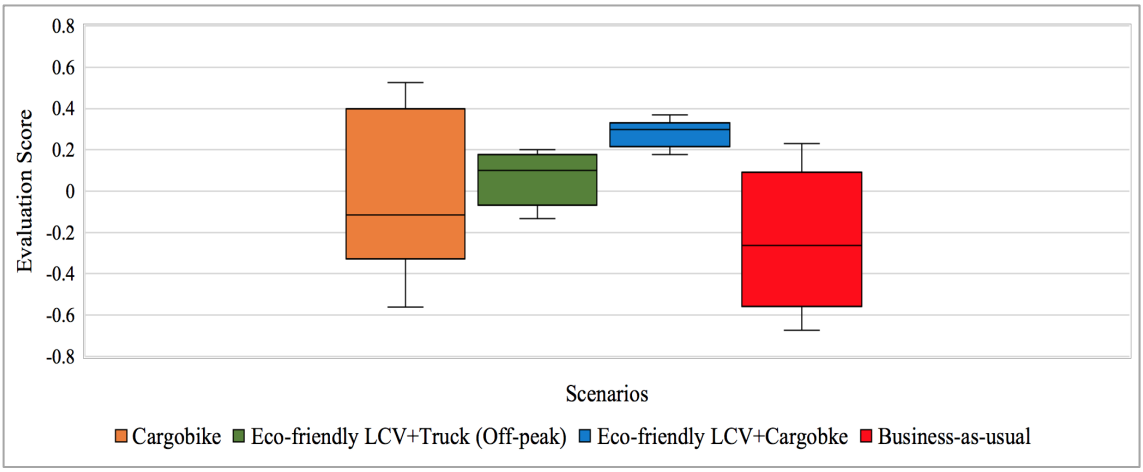


Figure 5.9. Box and Whisker Chart for the Multi-actor Analysis of the Four Scenarios

5.2.2.3. Sensitivity Analysis

A sensitivity analysis was performed to examine the significance of modifying the criteria weights on the ranking of the four scenarios and validate the robustness of the results. The priority weights of several criteria for the six stakeholder groups were changed moderately (about 10% increase or decrease) to facilitate including more perspectives and significance for the specific criterion by the stakeholder group. Table 5.2 highlights the changes that were applied to the criteria weights for each stakeholder group and the resulting changes on the ranking and evaluation scores of the alternatives.

Table 5.2. Summary of the Changes in Criteria Weights for the Sensitivity Analysis

Stakeholder	**Criteria**	**Original Weight**	**Modified Weight**	**Changes on the Ranking or Evaluation Score**
LSP	Transport Cost	27.03%	34%	No change
	Delivery Lead Time	21.48%	26%	
Receivers	Delivery Punctuality	24.62%	30%	No change
	Convenient Deliveries	6.34%	12%	
Shippers	Delivery Cost	26.48%	30%	No change
	Receiver Satisfaction	35.39%	28%.	
LPP	R&M Cost	12.73%	20%	Slight drop in evaluation score of Cargobike scenario
	Location Accessibility	16.9%	20%	
	Harmonious Integration	25.63%	15%	
Local Authorities	Low-cost measure	19.10%	28%	No Change
	Network Utilisation	7.01%	18%	
Citizens	Product availability	20.90%	30%	Slight drop in evaluation score of Cargobike scenario

For the LSP group, criteria weights of “Transport Cost” and “Delivery Leadtime” were changed to reflect the potential higher value that freight carriers might place on these critical operational factors. For the receivers group, criteria weights of “Delivery Punctuality” and “Convenient Deliveries” were changed as some receivers might view on-time and convenient deliveries as important as cost of the consolidated delivery. For the shippers group, the criteria weights of “Delivery Cost” and “Receiver Satisfaction” were changed as some shippers might place more importance on delivery costs than

receiver satisfaction. However, the ranking and evaluation scores of the four scenarios did not change for the three groups even with changes to priority weights of the above-mentioned criteria.

For the LPP group, criteria weights of "Repair & Maintenance Cost", "Location Accessibility" and "Harmonious Integration" were changed as some commercial property providers might not view the sustainable utilisation of the facility as important as profitability of the facility. The only noticeable change was a slight drop in evaluation score of Cargobike scenario. This could be attributed to the Cargobike scenario receiving the highest score for the "Harmonious Integration" criterion. For the local authority group, the criteria weights of "low-cost measure" and "Network Utilisation" criterion were changed as some local authorities might place more importance on the cost of the transport projects and enhanced utilisation of the transport network in their planning and decision-making. However, the ranking and evaluation scores of the four scenarios were consistent with previous results for the local authority group. For the citizens group, the criterion weight of the "product availability" was changed to reflect the importance of product availability to other members in the citizens stakeholder group. There was a slight decrease in the overall evaluation score for the Cargobike scenario. This could be attributed to the concern that cargobikes might impact product availability.

5.3. Discussion and Policy Recommendations

5.3.1. Discussion of the Multi-Stakeholder Analysis

The results of the multi-criteria analysis of the four scenarios highlighted the strengths and weaknesses of the four scenarios with respect to their performance on the stakeholders' criteria. The sensitivity analysis validated the robustness of the results as altering the criteria weights for the stakeholder groups did not significantly change the ranking and evaluation scores of the four scenarios. Different and conflicting rankings of the four scenarios by the different stakeholder groups were observed in the mono-actor analysis compared to the multi-actor analysis. For instance, while the overall evaluation scores displayed in Fig. 5.8 for the Eco-friendly LCV + Cargobike and BAU scenarios with respect to the LSP group are very close, the evaluation scores of these two scenarios on each criterion are quite different as displayed in Fig. 5.2. Hence, the discrepancies in the preferences of the scenarios and viewpoints of the stakeholder groups underline the importance of utilising a holistic approach in the planning and decision-making of freight solutions to enable decision-makers to delve deeper in examining the suitability of the alternatives rather than making the decision based on the preferences of dominant key actors.

The high overall evaluation score for the BAU scenario by the LSP group suggests that while they might be interested in eco-friendly freight vehicles in the consolidated delivery, they still prefer the current situation of using LCVs and trucks due to their competitive delivery cost. Moreover, the mono-actor analysis of the LSP group provided further explanation for the rejection of cargobikes due to their significantly inferior performance with respect to most decision criteria for this stakeholder group. This is in contrast with the view of the citizens and local authorities as they push to change the current situation and use cargobikes. This disagreement highlights the need for planners

and policy makers to set supporting policies and measures that address the operational and economic concerns of freight carriers in proposed freight consolidation policies.

While receivers and shippers might be attracted to the environmental benefits of cargobike deliveries, they might be concerned about safety of the parcels and additional transport costs. As shippers are primarily concerned about satisfying the receivers, it was striking that they had very similar overall evaluation score for the Eco-friendly LCV + Truck and BAU scenarios. This could be explained by their high interest in reducing the delivery costs to receivers. For the LPP group, Eco-friendly LCV + Cargobike was preferred over the Cargobike scenario. This might be attributed to the notion that there might be a financial risk with investing and setting up a facility only for cargobikes that might not be suitable for other potential commercial users. The Eco-friendly LCV + Cargobike scenario received more positive and consistent preferences among all stakeholder groups. The use of eco-friendly LCVs and cargobikes addresses the sustainable interests of citizens, local authorities and the LPP while presenting the LSP, receivers and shippers with a delivery fleet that serves their operational requirements in a balanced approach.

The application of MAMCA approach in this stage included a more comprehensive breakdown of the stakeholder groups than other studies as it focused on logistics property developers, which were overlooked in previous studies. Moreover, this stage incorporated different categories for stakeholder objectives as more attention was paid to operational criteria than similar studies. The criteria weights obtained from the stakeholders as illustrated in Table 5.1 revealed somewhat contrasting views compared with similar criteria in previous European studies that utilised the MAMCA approach for freight projects. For instance, transport costs were considered as the most important criterion in this study for LSP group while high level service and viability of investment were the most important criterion in studies conducted in Thessaloniki (Macharis et al a. 2014), Brussels (Verlinde et al 2014) and Amsterdam (Macharis et al a. 2016). However, delivery cost was viewed more importantly by the receivers group in the Thessaloniki and Brussels studies (61% and 47% respectively) than the 35% allocated to this criterion in this study. A relatively different view was that the LSP group in most of the European studies paid more attention to employee satisfaction and green concerns than the LSP group in this stage. For the shippers group, the views were consistent with other studies as offering high service value to receivers was also viewed as the most important criterion. For the local authorities group, it was interesting to observe that the cost of the measure was not viewed as importantly in other studies by local authorities, which paid more attention to the quality of life criterion.

Furthermore, the multi-actor evaluation of the four scenarios achieved somewhat different rankings and views than similar scenarios in other studies. For example, the LSP group in the Brussels' study and this study had high evaluation score for the BAU scenario while the LSP group in the Amsterdam study had very low preference for that scenario. The eco-friendly scenario in the Amsterdam study was not viewed as favourably by the local authorities and citizens groups as they viewed water deliveries more useful. It is important to highlight that other studies attempted to evaluate different freight policies. Nonetheless, it can be argued that comparing the results of this stage to the results of other studies further highlights the heterogeneity of stakeholders' views and complexity of decision-making with respect to freight policies.

5.3.2. Implementation Plan and Policy Recommendation

The results of the MAMCA framework suggest that the Eco-friendly LCV + Cargobike scenario is very likely to receive overall support from all stakeholders. Accordingly, this section, which represents the last step in application of the MAMCA approach, presents a suitable implementation plan that allows the decision makers to select the most suitable type of eco-friendly LCVs and cargobike as well as the required policies to support their utilisation by the operator of the proposed Central City Consolidation Facility (CCCF). Furthermore, a proposed layout of the operations of the facility is presented in this section, which is based on the design of the CCCF described in section 4.4. There are several vehicle technologies for the eco-friendly LCV that could be used including battery electric, hybrid electric and natural gas-powered delivery vans. Table 5.3 displays the main features of the top eco-friendly LCV available in global markets.

Table 5.3. Operational Characteristics of Leading Electric and Hybrid LCVs in the Global Market (Own Setup; Ayre 2017; Hubbard 2017)

Vehicle	**Uses**	**Driving Range (Km)**	**Battery Capacity (kWh)**	**Battery Charge Time - 100% (hour)**	**Battery Charge Time - 80% (min.)**	**Load Capacity**	**Price ($USD)**
Battery Electric LCV (BEV)							
Nissan e-NV200	Harrods (UK), FedEx (UK), Coca-Cola (Japan)	170	40	7.5	40	770 Kg, 4.2 m^3	26,000
Renault Kangoo ZE	La Poste (France), Gnewt Cargo (UK), Australia Post	190	33	6	60	650 Kg, 4.0 m^3	27,000
Citroen E-Berlingo	La Poste (France)	170	22.5	8	30	695 Kg, 4.1 m^3	29,000
Peugeot Partner Electric		165	45	7.5	30	636 Kg, 4.1 m^3	26,000
Voltia eNV200 Maxi	Gnewt Cargo (UK), TNT (Czech Republic),	170	40	6	30	600 Kg, 8.0 m^3	39,000

	DPD (Slovakia)						
StreetScooter Work L	DHL (Europe)	118	60	8	60	960 Kg, 8.0 m^3	64,000
Mercedes eVito	Released 2018	150	41	6	45	1,073 Kg, 6.6 m^3	49,000
Renault Master ZE	Released 2018	120	33	6	60	1,110 Kg, 11 m^3	60,000
Mercedes eSprinter	Available Mid-2018	150	41	6	45	1040 Kg, 10.5 m^3	-
Volkswagen e-Crafter	Available Mid-2018	160	35.8	5.5	45	1,709 Kg, 10.7 m^3	-
Hybrid Electric LCV							
Workhorse E-GEN	UPS (USA)	90 Km (Battery)	60 kWh battery			1,370 Kg, 14 m^3	25,000
Ford Transit Custom PHEV	Available Late-2018	50 Km (Battery)				1,000 Kg, 8.3 m^3	-

As the delivery vehicles for the proposed consolidation policy would not travel over large area in the inner-city area, the limited driving range of the BEV's battery would not be a major concern. Consequently, it is recommended that the operator of the CCCF utilise battery-electric delivery van (BEV) for the consolidated delivery. The Voltia eNV200 Maxi is an excellent vehicle for the small-medium LCV range due its superior loading capacity and relatively competitive price. Fig. 5.10 displays the Voltia eNV200 Maxi. For the large LCV range, the Renault Master ZE represents a suitable option even though its purchase cost is quite high. However, its large loading capacity will enable delivering larger number of parcels in a single delivery round compared with a smaller BEV.

Figure 5.10. Voltia eNV200 Maxi (Source: Voltia Website)

The utilisation of Voltia eNV200 Maxi requires many operational, technological and infrastructural changes and measures by the CCCF operator and local authorities. The parcel volume and receivers' delivery requirements need to be balanced with the limited load capacity of the BEV to ensure maintaining a high service and efficient distribution activities by the delivery vehicles of the facility. Consequently, the delivery rounds should be planned more efficiently to ensure that the consolidation and distribution cost per parcel would not be high. Similarly, the recharging schedule of the vehicles needs to be managed efficiently to minimise disrupting the fleet operations. Due to the close proximity of the proposed CCCF to the receivers in the inner-city, depot-based slow charging stations should be established at the facility to enhance the efficiency and reliability of the BEVs. Fast charging stations might present a quick charging option at the depot. However, their infrastructure is significantly more expensive than slow charging stations. Furthermore, it is important to schedule full recharge of these vehicles during the inactive period to ensure that the vehicles are always ready for distribution activities. Due to the advanced technologies of the vehicle, the drivers need to be trained properly on the recharging of the battery as well as the operational constraints of the vehicle. Thus, potential drivers of the vehicles should be more technology-savvy and qualified than drivers of traditional delivery vans.

Furthermore, local authorities are recommended to consider providing financial and non-financial incentives to the operator of the consolidation facility to promote use of Voltia eNV200 Maxi. Financial incentives could include purchasing subsidies and lower registration fees to reduce the purchase cost, exemption from toll charges and congestion charges. Moreover, local authorities should consider setting supporting policies that would enhance the efficiency and reliability of BEVs in the inner-city area. These supporting policies include establishing publicly accessible charging stations, prioritised use of parking and loading on-street spaces and longer access time-windows. Public charging stations in the inner-city area would enhance the usability of BEVs and reduce the risk that vehicles might stop their activities due to low battery levels. The favourable access policies would make the distribution activity of the delivery fleet more efficient and compensate some of the operational constraints of the BEV.

Moreover, there are different types of cargobikes that can be utilised for consolidated delivery including front-loading long-wheelbase bike, box or trike bike, electricity-assisted four-wheeled bike. It is important to select the cargobike that facilitate larger load volume and more efficient delivery rounds. Hence, the four-wheel electricity-assisted cargobike represents the most suitable cargobike. The Velove Armadillo E-Cargobike, which is displayed in Fig. 5.11, has an attached container that can carry loads up to 150 kilograms or 1 m^3. The cyclist can comfortably ride this bike daily up to 50 km to deliver parcels in the inner-city area. These cargobikes would complement and assist the Voltia eNV200 Maxi. They present the operator of the CCCF with reliable and quick access to receivers in very congested parts in the inner-city area where BEVs might have operational difficulties. Moreover, the carrier could utilise these cargobikes for deliveries during restricted time-windows for the BEV.

Figure 5.11. Velove Armadillo E-Cargobike (Source: Velove Website)

Fig. 5.12 illustrates the proposed layout of the Central City Consolidation Facility that incorporated the most optimal delivery configuration based on the MAMCA results. Furthermore, the proposed layout was discussed with experts from leading freight carriers to ensure reflecting the operational requirements and best practices of the local freight industry. It is recommended to separate the parking bays designated for freight vehicles of participating freight carriers in the facility from the loading bays of the Voltia eNV200 Maxi and cargobikes. This facilitates easy ingress and egress and efficient traffic flow of the vehicles within the facility. The number of parking bays for the Voltia eNV200 Maxi and Velove Armadillo would depend on the facility daily throughput (number of parcels/day) and the configurations of the delivery rounds for the consolidated delivery services to receivers in the inner-city. The handling and sorting area for the incoming parcels should be adjacent to both zones of parking/loading bays to facilitate efficient and quick transfer of the incoming parcels. The inner-city area would be divided into number of delivery destination zones. Each BEV and cargobike would be assigned to a specific delivery destination zone within the inner-city area, which they deliver to on a daily basis. This would help the drivers get familiar with the area and the receivers. The number of delivery rounds for each BEV and cargobike would depend on the load capacity of the vehicle, delivery volume and requirements of the receiver as well as the operational practices and safety regulations of the local freight industry.

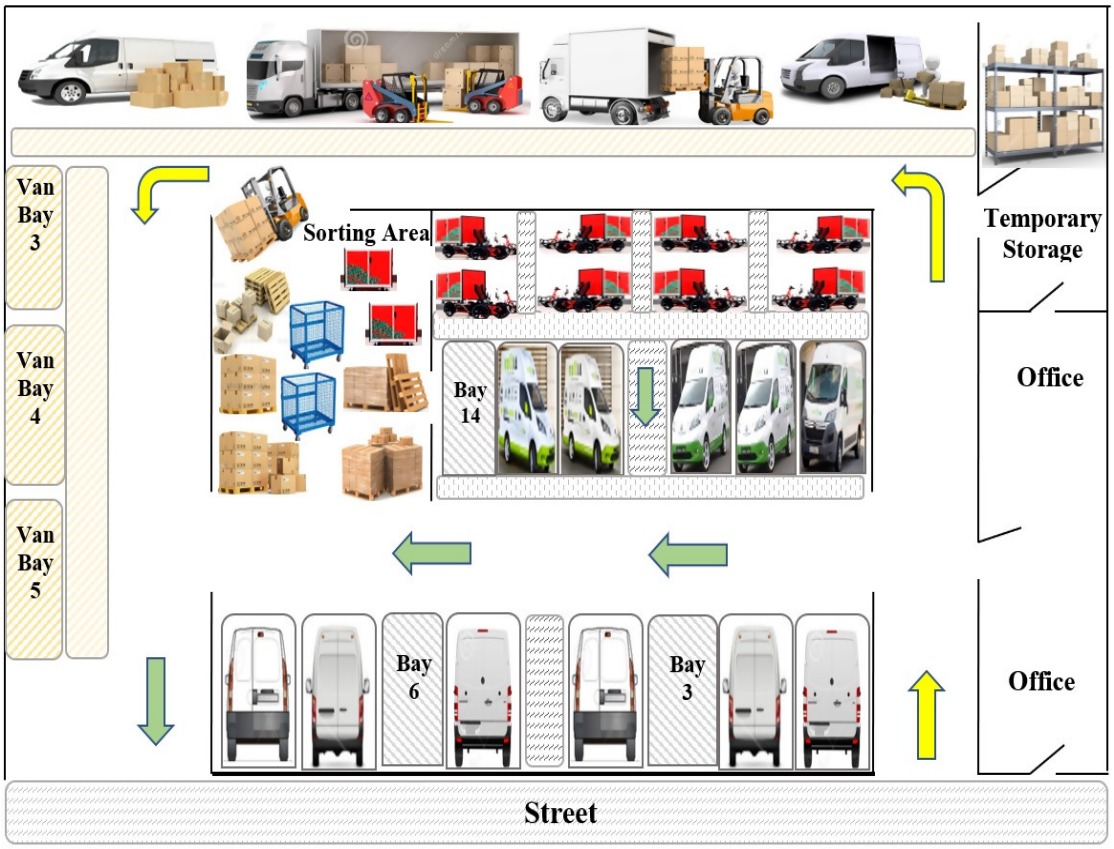


Figure 5.12. Schematic of the Proposed Layout of the Consolidation Facility

The participating freight carriers would bring their parcels to the proposed CCCF preferably during the early morning hours. The incoming parcels would be offloaded and transferred to the handling and sorting area using forklifts and/or jack pallets. The parcels are sorted and bundled for each designated delivery zone and moved to loading bays of the BEVs and cargobikes using cage trolleys or containers. Each cage trolley contains bundled parcels for a specific BEV or cargobike that are addressed to neighbouring receivers within their designated delivery zone. Consequently, the driver of the BEV or the cargobike would sort and sequence the parcels into their vehicle from the transferred cage trolley or containers for each delivery round. Moreover, the hand-held scanning devices used by the driver should allow instant connectivity and information transfer to enable real-time tracking of the parcels and facilitate efficient delivery updates for both freight carriers and receivers. Fig. 5.13 illustrates the proposed consolidated delivery scheme using the BEVs and cargobikes to receivers in the inner-city area.

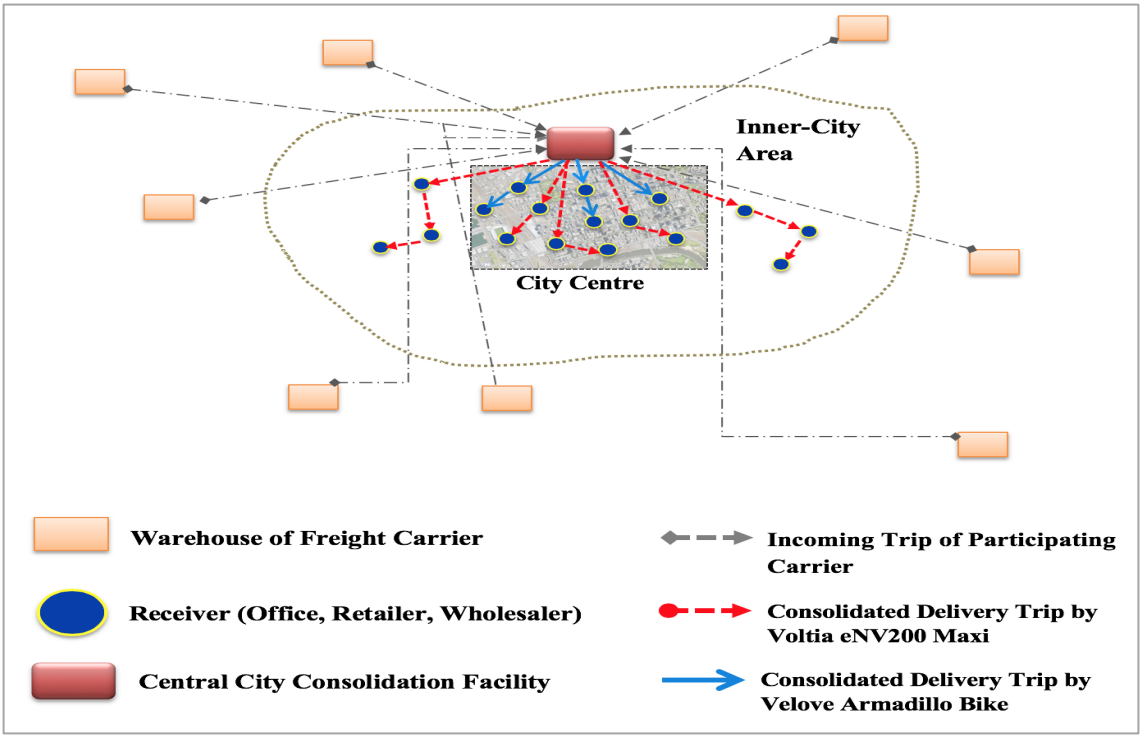


Figure 5.13. Illustration of the Consolidated Delivery Trips using Battery-Electric Delivery Vans and Cargobikes

5.4. Chapter Summary

The optimal configuration for the consolidated delivery fleet should address the sustainable, societal, economic and operational objectives and requirements by all the stakeholders in a balanced approach. This chapter analysed the application results of the MAMCA approach for the optimal delivery fleet to perform the consolidated deliveries in the inner-city based on the various objectives of all stakeholders, which addressed *Research Question #3*. Accordingly, the findings of the multi-actor analysis suggest that the combined use of battery-electric delivery vans (BEV) and electricity-assisted cargobikes represent the delivery fleet configuration with the best chance of receiving consensus based on all the stakeholders' preferences in accordance with the 3rd research objective. It offers a sustainable delivery fleet that addresses the concerns and requirements of all stakeholder groups. Performing consolidated deliveries in the inner-city area using BEVs and cargobikes could contribute to reducing emissions, noise and traffic congestion around receivers especially in heavily dense and congested areas. This enhances the amenity and quality of life for customers, retailers and residents.

The insights and perspectives from the six stakeholder groups on the four scenarios in this chapter provide local authorities and transport researchers with valuable information that could be used to formulate suitable and sustainable freight solutions and policies to address the challenges and negative impacts of last mile delivery in the inner-city area. The multi-criteria analysis produced a ranking of the four scenarios as well as in-depth understanding of how each alternative was viewed by each stakeholder group. The allocated criteria weights by the various stakeholder groups highlighted how stakeholders differed in their perspectives on the optimal delivery fleet for the consolidated deliveries.

Different stakeholder groups assigned conflicting scores for shared objectives. This explained why and how the objectives of the six stakeholder groups resulted in different and clashing views of each alternative. However, some criteria were prevalent for most stakeholders primarily the transport cost and service level for business stakeholders and liveability for societal stakeholders. This chapter attempted to delve more into the mono-actor analysis than other studies that utilised the MAMCA framework to acquire more individual perspectives from clashing stakeholders. An important lesson is that there is no single solution that could address or satisfy all the objectives of all the various stakeholders. This further raises the need for researchers and policy makers to avoid focusing only on most visible or influential stakeholders in last mile delivery and ensure incorporating the objectives and requirements of all stakeholders.

Due to the participatory nature of this study, there are a few limitations that should be noted. While every effort has been made to identify the most important decision criteria that contribute to selecting the most suitable and sustainable delivery fleet for the consolidated delivery, other objectives not included may also be influential to the respective views and preferences of stakeholders. The calculated criteria weights are sensitive and dependent on views of the key actors that participated in pairwise comparison. However, the inclusion of a sufficient number of actors from each stakeholder group ensured that different and representative views were sourced for the pairwise comparison. The multi-actor analysis was primarily performed using qualitative indicators, which might limit the generalisability of some of the results presented. There are few future research directions that could complement the findings presented in this chapter. For instance, with recent advancement in autonomous delivery robots and vehicles, it is recommended a future study apply the MAMCA approach to examine the efficacy of these unmanned delivery technologies in addressing the viewpoints and preferences of all stakeholders with respect to performing consolidated delivery in the inner-city area.

Chapter 6

3rd Stage: Exploring the Receivers' Interest in Participating in the Freight Consolidation Service

6.1. Introduction

If goods receivers find the freight consolidation service beneficial with respect to the efficiency and reliability of their deliveries, they might be willing to coordinate and request their supplies and freight carriers to transfer the shipments to the proposed consolidation facility. However, the interests and preferences of receivers towards the consolidated delivery service are not fully appraised and understood as highlighted in section 2.4.2.2 in the Literature Review. Moreover, most previous freight consolidation projects initiated the planning and decision-making of the consolidation service through the freight carriers as highlighted in section 2.3.3.1. It is necessary to thoroughly investigate the on-site delivery activities of the receivers to efficiently and optimally formulate holistic freight consolidation policy levers. Accordingly, this chapter analyses and discusses the econometric modelling results of the behavioural responses collected using the stated-preference survey from businesses representing 13 sub-industries in Melbourne CBD towards the receiver-led consolidated delivery (RLC) service. Detailed descriptions of the design of the stated-preference survey, sampling strategy and response rate were provided in section 3.4.2 and section 3.4.3, respectively. The four attributes of the consolidated delivery service in the survey were as follows:

1. **Time-Window of Consolidated Delivery:** 05:00 – 08:59, 09:00 – 15:59, 16:00 – 18:59, 19:00 – 21:59, 22:00 – 04:59.
2. **Reduction in Existing Number of Deliveries:** 25%, 33%, 50%, 67%, 75%.
3. **Value-added Services:** Receiver time-specific delivery (*RT*), unpacking & waste removal (*UN*), temporary storage (*TS*), product quality & quantity check (*PQ*), and product return (*PR*).
4. **Delivery Status Updates:** Real-time updates, fixed updates, e.g. once a day, and no updates.

The sections of this chapter are described below:

- Section 6.2 presents a descriptive analysis of the receivers' delivery activities collected in the 1st part of the survey.
- Section 6.3 analyses and discusses the modelling results of the ordered logit model to examine the influence of the receivers' delivery characteristics that could drive willingness to participate in the RLC service.

- Section 6.4 analyses and discusses the modelling results of the mixed logit model to estimate the receivers' willingness to participate and pay for the RLC service based on the RLC service attributes.
- Section 6.5 provides a concluding summary of the chapter including the study limitations and future research directions.

6.2. Descriptive Analysis of the Receivers' Delivery Characteristics

This section presents a descriptive analysis of the responses that were collected in the 1st part of the SP survey. The responses were collected from receivers representing 13 different sectors. Fig. 6.1 displays the distribution of the receivers' daily delivery attributes (number of deliveries and pick up services, number of delivery companies that receivers deal with on a daily basis and most frequent delivery time). It was reported that the majority of respondents received on average more than two deliveries per day as 34% of the businesses received 2-4 deliveries/day while 22% of the businesses received 5-7 deliveries/day. Moreover, 21% of the respondents indicated that they received on average more than 8 deliveries/day whereas only 23% of the respondents received on average a single delivery/day.

On the contrary, 67% of the receivers required on average a single collection service per day while 22% of the receivers reported that their number of daily pickup jobs was 2-4 collection services. Moreover, the responses revealed that the majority of these deliveries and pickups were performed by different delivery companies. It was reported that 35% of the receivers on a daily basis deal with 2-4 delivery companies while 24% of the respondents receive deliveries from 5-7 delivery companies on a typical day. In comparison, 14% of the receivers indicated that more than 8 delivery companies perform their delivery and pickup services on a typical day. However, only 27% of the respondents indicated that are typically serviced by a single delivery company on a daily basis. The large number of daily deliveries, which are usually performed by different delivery companies, negatively impact the efficiency of these receivers.

Moreover, the current delivery times for receivers were examined to shed more light on the receivers' most frequent delivery times as illustrated in Fig. 6.1. It was revealed that most deliveries were performed during peak hours as 53% of deliveries were performed during 9:00-11:59 while 20% of deliveries were conducted during 12:00-15:59. However, around 14% of the deliveries were conducted during early morning hours (5:00-8:59). It is important to highlight that most of these deliveries were to receivers from book & newspaper and pharmacy & personal care sub-industries. It is worth noting that only 7% of deliveries were performed during off-peak hours (after 7 PM), which were to receivers from accommodation and convenience store sub-industries. The very limited number of deliveries during off-peak hours suggest that receivers might not be very willing to participate in the proposed consolidation scheme if their delivery times are significantly changed.

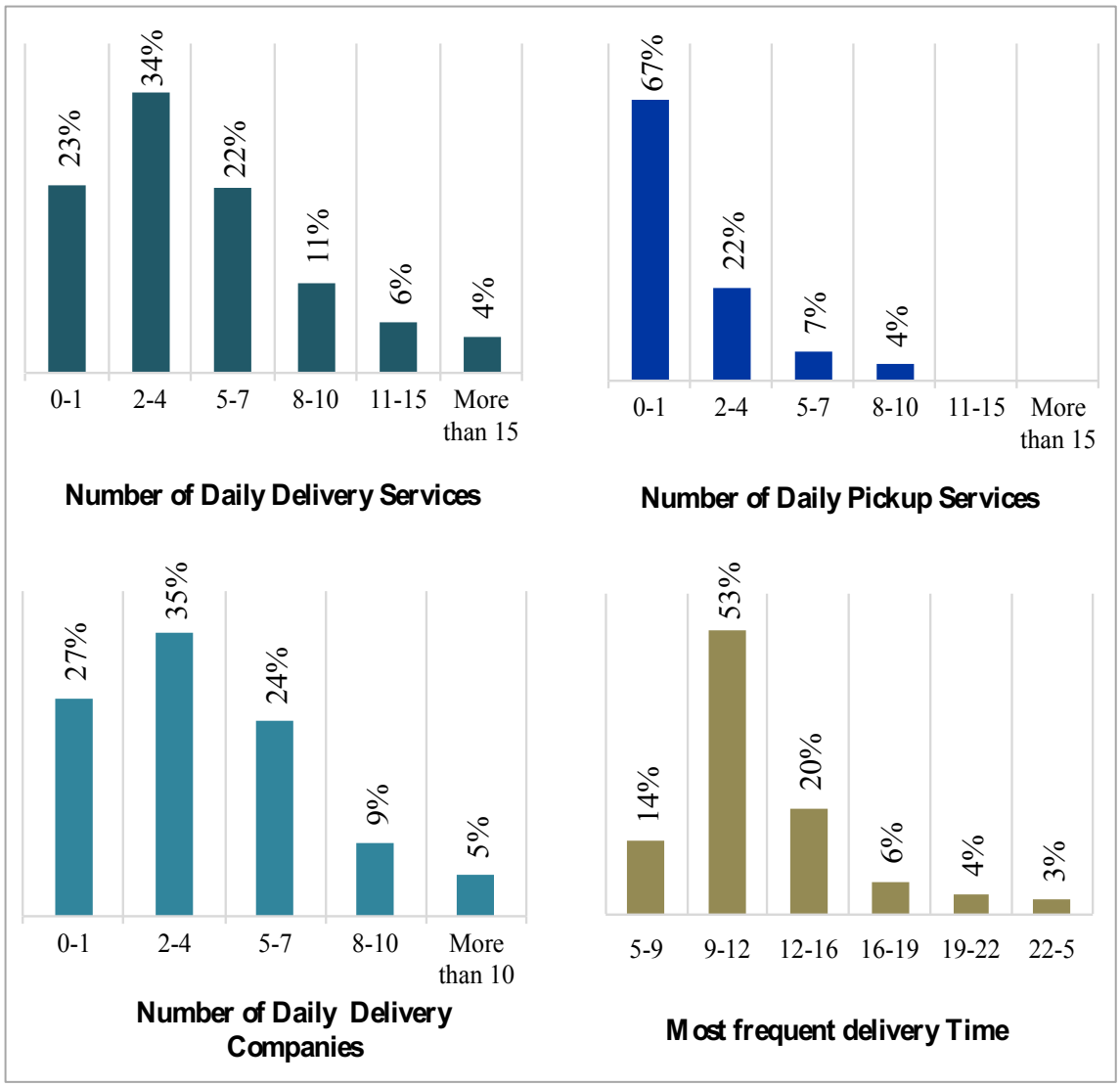


Figure 6.1. Characteristics of Receivers' Delivery Activities

Furthermore, analysis of the responses revealed valuable insights about the downtime that receivers lose on accepting and processing each delivery into their premises. It was reported that 17% of respondents spent on average more than 20 minutes to accept and process a single delivery service. This is striking when coupled with the large number of daily deliveries received from multiple delivery companies. Furthermore, 42% of receivers indicated that they spent on average between 10-20 minutes to process a single delivery. In contrast, only 19% of receivers indicated that they spent on average less than 5 minutes to process a single delivery. It is worth mentioning that most of these receivers were from the management & professional services, which were mainly express mail and office supplies.

Fig. 6.2 illustrates the receivers' willingness to participate from each sub-industry. The light blue circle indicates the proportion of each sub-industry among all 13 sub-industries that participated in the survey. Overall, 24% of the receivers from all sub-industries indicated that they were very willing to request their suppliers to deliver to the proposed consolidation facility instead of directly to their businesses. The homeware &

kitchenware (44%) and book & newspaper (42%) sub-industries reported the highest interest in the proposed consolidation scheme as more than 40% of their receivers revealed they were very willing to participate. Similarly, receivers from the management & professional services, apparel and pharmacy & personal care sub-industries expressed somewhat high interest in the concept as almost 30% of their respondents reported that they were very willing to participate. Similarly, 25% of the respondents from the accommodation sub-industry indicated that they were very willing to participate. In contrast, receivers from stationary goods, footwear, sport & camping and convenience store sub-industries indicated the least interest to participate as their "very willing" interest was below 10%. Respondents from these four sub-industries represented 20% of the total responses from all 13 sub-industries. Moreover, it can be argued that more receivers from the accommodation and apparel sub-industries might be interested in the initiative if the right policy is implemented as 28% and 27% of their respondents indicated that they were somewhat willing to participate, respectively.

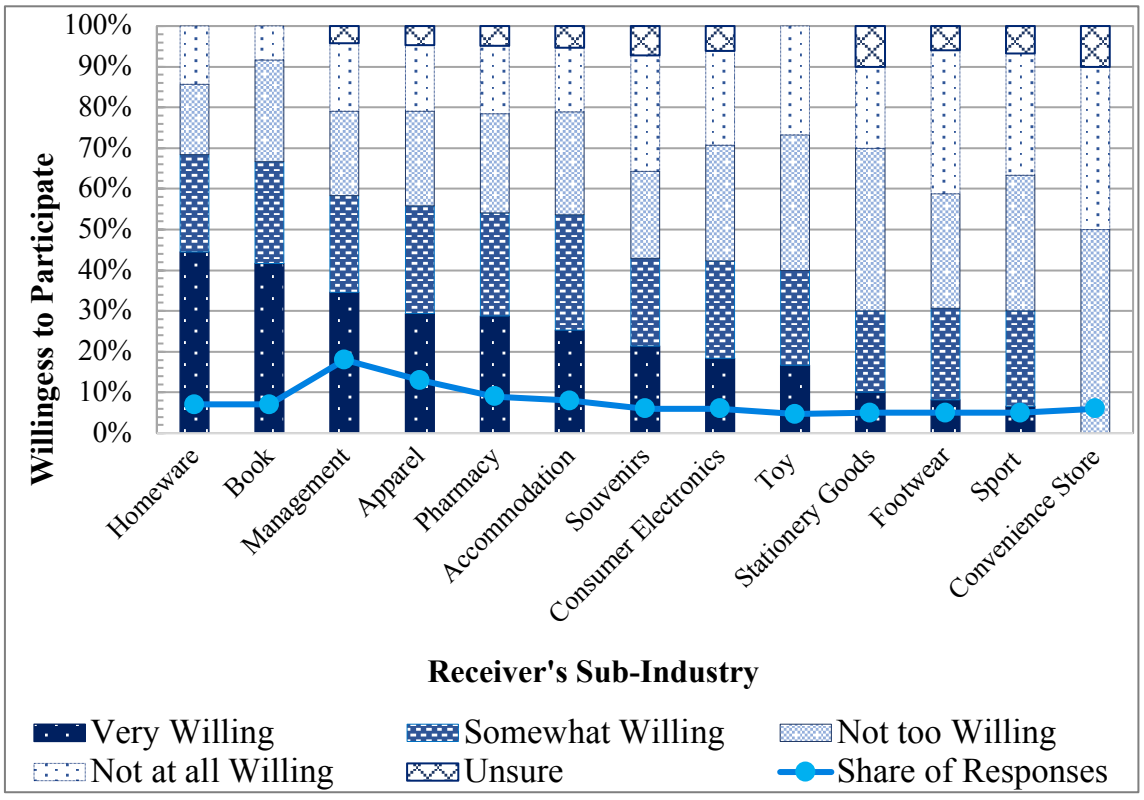


Figure 6.2. Receivers' Willingness to Participate in the Proposed Freight Consolidated Delivery Scheme from 13 Sub-industries

6.3. Estimating the Receivers' Willingness to Participate in the RLC Service based on Receivers' Business Characteristics

In this section, the behavioural responses of receivers were estimated using an ordered logit model to investigate the influence of receivers' business characteristics on their willingness to participate in the RLC service. This enabled identifying which receivers from various sectors might be highly interested in participating in the RLC service and

determining which delivery characteristics to focus on in order to spur receivers to influence their freight carriers to transfer parcels to the proposed facility.

6.3.1. Ordered Logit Model Specification

The independent variables were the attributes of the receivers and RLC policy variables. The dependent variable (the willingness to participate) of interest was ordinal with higher number indicating higher willingness. It was coded as a variable with four levels: not at all willing (level 1), not too willing (level 2), somewhat willing (level 3) and very willing (level 4), with an additional option for unsure. There is a natural and clear ordering to these options, with the exception of unsure. However, these options do not have cardinal value. Treating the dependent variable as cardinal would introduce undesirable assumptions and require us to determine the cardinal value of the different options.

Based on the nature of the dependent variable, it was more suitable to apply the ordered logit model to estimate the willingness to participate of receivers. An ordered regression model allows for the ordinal properties of the dependent variable to be maintained in a way that is parsimonious and similar to linear regression as well as greater detection power and flexibility (Agresti 2010). We structured the analysis in the framework of random utility modelling (Domencich and McFadden 1975). We assumed that each business i has a linear utility function that depends on the features of the consolidated delivery option on offer and the attributes of businesses.

$$U_i = X_i\beta + \varepsilon_i \quad \text{(eq. 6.1)}$$

where X_i is a vector of consolidated delivery choice and business attributes relevant to business i, β is a vector of preference parameters, and ε_i is a random disturbance. U_i, the business's utility for the consolidated delivery choice, is an unobserved latent variable.

We observed the response to the willingness question Y, which has four levels $Y_i \in \{0,1,2,3\}$. The ordered logit model makes use of three threshold parameters μ_1, μ_2, μ_3, These parameters define cutoffs in the unobserved latent variable, such that:

$$\begin{aligned} &Y_i = 0 \text{ if } U_i < \mu_1 \\ &Y_i = 1 \text{ if } \mu_1 < U_i < \mu_2 \\ &Y_i = 2 \text{ if } \mu_2 < U_i < \mu_3 \\ &Y_i = 3 \text{ if } \mu_3 < U_i \end{aligned} \quad \text{(eq. 6.2)}$$

Since the model likelihood is invariant to an additive shift in the latent variable, the model is unidentified unless one of the threshold parameters is fixed. Many applications normalise $\mu_1 = 0$. We instead normalise the constant term in the linear model to 0, which is equivalent. μ_1, μ_2, and μ_3 are estimated in the ordered logit estimation process. These are the three parameters shown in Table 6.1.

For a business with attributes X_i, the predicted probability of selecting a given willingness level is then:

$$\begin{aligned} &\Pr(Y_i = 0) = F(\mu_1 - X_i\beta) \\ &\Pr(Y_i = 1) = F(\mu_2 - X_i\beta) - F(\mu_1 - X_i\beta) \end{aligned} \quad \text{(eq. 6.3)}$$

$$\Pr(Y_i = 2) = F(\mu_3 - X_i\beta) - F(\mu_2 - X_i\beta)$$

$$\Pr(Y_i = 3) = 1 - F(\mu_3 - X_i\beta)$$

where $F(\mu_x - X_i\beta)$ is the cumulative distribution function for the logistic distribution.

The resulting model has several desirable properties. The coefficients β can be interpreted as the effect of the attribute on the underlying business's utility for the consolidated delivery option, and the sign of each coefficient corresponds to the sign of the effect of that attribute on the willingness to participate response. Further, the effect of each attribute can be converted into a probabilistic statement by calculating the marginal effect of the attribute. The marginal effect of a given binary attribute x on the probability of selecting $Y = j$ is the difference in probability of selecting $Y = j$ when that attribute $x = 1$ compared to when $x = 0$.

$$Marginal\ Effect\ of\ x\ on\ j = \Pr(Y = j|x = 1) - \Pr(Y = j|x = 0) \qquad \text{(eq. 6.4)}$$

Since in this study all attributes are categorical variables, each marginal effect is interpreted relative to a reference category and consequently the $x = 0$ in the equation above is equivalent to "the attribute is in the reference category." Therefore, the marginal effect of a given categorical attribute x being in category k is

$$Marginal\ Effect\ of\ x\ on\ j = \Pr(Y = j|x = k) - \Pr(Y = j|x = Reference) \qquad \text{(eq. 6.5)}$$

where $Reference$ is the reference category for the attribute.

There are several reasons to focus on the marginal effects as a way of interpreting the ordered logit regression results. One advantage is ease of interpretation as a change in the probability of selecting a given level of willingness is easy to understand. Moreover, because the marginal effects are calculated for a combination of attribute and willingness level, they show the impact of a given attribute not just on the underlying latent variable, but how that attribute affects each level of the observed variable separately.

The Pseudo-ρ^2 measure used is based on Maddala (1983). This measure bases its understanding of R^2 on a comparison of the log likelihood of the model to the log likelihood of a model without any predictors. It is closely related to the log-likelihood joint test of all variables in the model. It is intended to be similar in interpretation to ρ^2, and can be thought of as roughly the proportion of choice activity that can be explained by the explanatory variables.

6.3.2. Estimating the Characteristics of the Most Interested Businesses to Participate in the RLC Service

The full sample of 255 behavioural responses was estimated using the ordered logit model to predict the "willingness to participate" variable that recorded responses about how willing the respondent is to participate in the consolidated delivery service. This estimation was performed twice. The 1st specification controlled for respondent's characteristics (sub-industry, number of daily deliveries, number of delivery companies, current delivery time) to predict the effect of these variables on the receivers' willingness to participate. The 2nd specification controlled only for the respondent's sub-industry to identify sub-industries that are most likely to participate unconditional on other business's

attributes. This allowed for an analysis of preference heterogeneity across sub-industries and enabled identifying which sectors are most likely to participate.

As shown in Table 6.1, which displays results of the ordered logit model, there are few differences between businesses with different attributes in their willingness to participate. For the sub-industry variable (1st run), the modelling estimation revealed that the coefficients of all the subindustries are insignificant compared to the reference sub-industry (footwear), indicating that the difference between each subindustry and footwear is not statistically significant ($p>0.05$). We can also statistically test the differences between the coefficients of various subindustries against each other. The aim here is to determine which subindustry has a high-willingness than other subindustries. The only significant difference ($p<0.05$) between subindustries in the 1st run column was found between the most-willing industry, book & newspaper, and the least-willing industry, convenience Store. However, the differences between all other sub-industries are not statistically significantly different in column 1 (1st run). Thus, these tests showed that there were no significant differences between the subindustries in terms of willingness, once we controlled for other variables. Only one of the differences was significant.

Businesses that currently receive deliveries during the 9:00-11:59 time-window might be more willing to participate (β = 2.1660, t-stat = 2.8031, $p < .05$). However, there were no other considerable differences between the businesses with respect to the current delivery windows except for the 9:00-11:59 time-window relative to 19:00-21:59, which indicates that these respondents might be somewhat willing to participate.

Businesses with 5-7 daily deliveries were most interested in the service (β = 4.1535, t-stat = 4.6572, $p < .01$), as well as those with 2-4 (β = 2.2204, t-stat=3.0179, $p < .05$). The negative coefficient for businesses with more than 10 deliveries suggest that these businesses might be least interested compared to 0-1 deliveries. The estimation results suggest that the number of deliveries is important. Compared with businesses being serviced by a single delivery company, businesses with 5-7 delivery companies are more willing (β = 3.5048, t-stat = 3.3190, $p < .01$). However, there is a statistically significant drop off in willingness for businesses with 8-10 and more than 10 delivery companies compared with 5-7 delivery companies ($\beta = 3.5048 > \beta = 0.1149 > \beta = -1.8604$).

Table 6.1. Results of Ordered Logit Model to Predict Willingness to Participate

Variable	1st Run		2nd Run	
	Willingness to Participate		Willingness to Participate	
	Coeff.	t-stat	Coeff.	t-stat
Sub-industry				
Footwear	(Ref.)		(Ref.)	
Book & Newspaper	1.6451	1.9759	1.9112***	3.1448
Homeware & Kitchenware	1.4738	1.8081	1.6260***	2.9767
Management & Professional Services	1.1668	1.7794	1.3568***	2.51458
Apparel	0.9835	1.5735	1.2963**	2.2815
Accommodation	0.9467	1.2104	0.7159	1.2020
Pharmacy & Personal Care	0.6071	1.5170	0.9013	1.6829
Souvenirs & Luggage	0.5943	0.5041	0.3143	0.8559
Consumer Electronics	0.3821	0.3581	0.5168	0.8610
Toy & Entertainment	0.2196	0.2573	0.3810	0.5525

Stationary Goods	0.1713	-0.0907	0.2249	0.3064
Convenience Store	-1.2512	-1.1764	-1.3230	-1.6078
Sport & Camping	0.0957	0.1253	-0.4679	-0.8491
Number of Daily Deliveries				
0-1	(Ref.)			
5-7	4.1535***	4.6572		
2-4	2.2204**	3.0179		
8-10	0.3915	0.5239		
11-15	-1.1002	-1.6171		
More than 15	-1.4002	-1.4134		
Number of Delivery Companies				
One	(Ref.)			
5-7	3.5048***	3.3190		
2-4	1.4301*	1.9777		
8-10	0.1149	0.8320		
More than 10	-1.8604	-1.9857		
Current Delivery Time				
5:00-8:59	(Ref.)			
9:00-11:59	2.1660**	2.8031		
12:00-15:59	1.6393*	1.4762		
22:00-4:59	0.2429	0.4684		
16:00-18:59	0.2170	-0.3225		
19:00-21:59	-1.4348	-1.5651		
Parameters				
$\mu(1)$	1.3815*	1.8474	-0.6513	-1.3929
$\mu(2)$	3.6588***	4.6412	0.7134	1.5270
$\mu(3)$	5.5170***	6.6298	1.8774***	3.9207
Goodness-of-fit				
Number of Observations	255			
Pseudo-R^2	0.265			
Log-Likelihood	-325.63			

*** p<0.01, ** p<0.05, * p<0.1

The results of the 2nd run revealed that book & newspaper (β = 1.9112), homeware & kitchenware (β = 1.6260), management & professional services (β = 1.3568) and apparel (β = 1.2963) sectors have a positive and significant coefficient compared to the footwear sector. Conversely, the sport & camping (β = -0.4679) and convenience store (β = -1.3230) have a negative coefficient compared to footwear and are statistically different from the most-willing industries. The 1st run shows that business attributes contain important information that explain part of *why* particular subindustries are likely to be willing. On the basis of the ordered logit estimation, these four sectors are selected as the most willing to participate sub-industries.

Comparing the 1st and 2nd run models, the effects of subindustry are suppressed in the 1st run. This suggests that the business characteristics such as number of daily deliveries and delivery companies are important drivers of why particular subindustries report high willingness to participate. Once these characteristics are controlled for, the effect of subindustry becomes somewhat smaller. The most-willing subindustries appear to be willing because they have business characteristics that, on their own, predict high

willingness, rather than there being something unique and unmeasured about their subindustry. This result is important because it allows for directed exploration of willingness outside of the given list of subindustries. In considering whether subindustries not on this list might also be willing to participate, the results of the 1st run suggest that a good place to start would be looking into whether those other subindustries have the attributes associated with high willingness here.

All in all, we find the ordered logit model has a goodness of fit (pseudo-R^2 of 0.265), indicating that a considerable portion of the variation in willingness to participate is explained by the business's attributes and captured by the relatively small number of predictors included in the ordered logit model. One assumption of the ordered logit model is the proportional odds assumption, which requires that the independent variables have the same effect on the latent variable U_i at all levels of the dependent variable. We tested this assumption using the Brant test (Brant 1990). The test checks whether the coefficients are statistically different between models, which would indicate a violation of the proportional odds assumption. Of the 25 coefficients compared in the 1st run of the model, one (8-10 daily deliveries) varied significantly at the 10% level and one (2-4 daily deliveries) varied significantly at the 5% level. This is about the number of significant differences we would expect if indeed proportional odds were not violated, given the number of tests performed. Furthermore, the results of the Brant test for the 2nd run illustrated that none of the compared coefficients varied significantly. The results of the Brant test indicate that the proportional odds assumption is not too restrictive.

In addition to the analysis of the goodness of fit metrics considered earlier, another way to examine goodness of fit for the ordered logit model is by comparing the observed and predicted probabilities of respondent's willingness to choose within different business's attributes. The predicted willingness level probabilities of RLC participation based on the ordered logit model is shown in Table 6.2. The average absolute error by group, calculated from Table 6.1, is moderate. For number of daily deliveries, the average absolute error is 6.7%, meaning that, on average, the difference between the observed proportion choosing a given consolidated delivery option and the actual proportion choosing that option within each number of daily deliveries group is 6.7%. For number of delivery companies, the average absolute error is 7.5% and for current delivery time, it is 8.4%. These figures indicate that the model is capable of predicting willingness somewhat accurately for businesses of a given set of attributes, erring on average by about 7 percentage points. Further, the average absolute error within willingness levels varies considerably. The average absolute error for not at all willing is 5.7%. For not too willing, somewhat willing, and very willing, the average absolute error is 11.2%, 5.5%, and 2.7 %, respectively. The model is least accurate in predicting the proportion of a group that will select not too willing.

Table 6.2. Observed and predicted probabilities of RLC participation

Attribute	Willing to Participate							
	Very willing (%)		Somewhat willing (%)		Not too willing (%)		Not at all willing (%)	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
Number of Daily Deliveries								
0-1	2.5%	0.0%	9.4%	1.8%	35.0%	53.6%	53.1%	44.6%
2-4	36.1%	39.6%	33.8%	32.1%	22.1%	20.1%	8.0%	8.2%
5-7	51.2%	55.6%	31.4%	32.5%	13.4%	8.3%	4.8%	3.6%
8-10	23.8%	25.6%	26.6%	19.7%	35.7%	40.1%	13.9%	14.6%
11-15	8.4%	7.6%	12.7%	9.4%	40.7%	50.6%	38.2%	32.4%
More than 15	6.4%	4.3%	10.5%	7.5%	42.3%	51.9%	40.7%	36.3%
Number of Delivery Companies								
One	1.9%	0.0%	8.3%	1.8%	36.0%	49.1%	53.8%	49.1%
2-4	23.7%	27.0%	37.4%	33.7%	30.7%	27.0%	8.2%	12.3%
5-7	53.2%	51.7%	33.1%	33.6%	9.2%	8.0%	4.5%	6.7%
8-10	20.2%	22.3%	21.1%	23.6%	28.3%	26.7%	29.4%	27.4%
More than 10	5.4%	6.7%	16.2%	6.7%	31.2%	40.0%	47.2%	46.7%
Current Delivery Time								
05:00 - 08:59	19.2%	26.1%	26.7%	21.7%	30.8%	21.7%	23.3%	30.4%
09:00 - 11:59	34.0%	37.4%	26.1%	24.2%	24.2%	23.1%	15.7%	15.3%
12:00 - 15:59	31.6%	32.3%	26.2%	29.5%	25.1%	22.7%	17.1%	15.5%
16:00 - 18:59	19.2%	17.1%	31.4%	27.3%	31.2%	39.3%	18.2%	16.3%
19:00 - 21:59	7.3%	10.0%	19.4%	20.0%	32.9%	20.0%	40.4%	50.0%
22:00 - 04:59	15.5%	13.2%	29.0%	26.9%	37.5%	46.2%	18.0%	13.7%

The marginal effects of the 2nd run, which are shown in Table 6.3, illustrate how a change in a given sub-industry, on average, affects the probability of choosing the consolidated delivery service, relative to the reference sub-industry. As highlighted in Table 6.3, the probability of the four most willing sectors being very willing to participate in RLC program is 18-28 % higher than the reference sub-industry (footwear). Furthermore, their probability to be somewhat willing to participate are higher than other sub-industries. Alternatively, the considerable and negative probability of these four sub-industries being "not at all willing" suggests that they are almost 15-24% less likely to reject the RLC policy than the reference sub-industry. These results imply that the difference by sub-industry shown in Table 6.1 are meaningfully large.

We can also observe in Table 6.3 how the subindustries vary in their specific distributions. In particular, among the most-willing industries, the biggest differences are at the extremes. Compared to footwear, the marginal effect of being in book & newspaper is a rather large -12% on not too willing and positive 7% on somewhat willing. But the marginal effects on not at all willing and very willing are huge -24% and 28%, respectively. Results are similar for the other most-willing subindustries. The aspect that defines these sub-industries is not a slightly higher rate of tepid "somewhat willing" responses – it's a shift to the extreme "very willing" end. That is, the subindustries that are more willing than others to participate are not only marginally more willing than others, but display heavy positive responses, indicating strong willingness.

Table 6.3. Estimated Marginal Effects of the Ordered Logit Model (2nd Specification)

Variable	Willingness to Participate							
	Very Willing		Somewhat Willing		Not too willing		Not at all Willing	
Sub-industry								
Footwear	(Ref.)							
Accommodation	0.14	(0.11)	0.04	(0.03)	-0.06	(0.05)	-0.12	(0.10)
Apparel	0.18*	(0.10)	0.05*	(0.03)	-0.08*	(0.04)	-0.15*	(0.08)
Book & Newspaper	0.28**	(0.13)	0.07**	(0.04)	-0.12**	(0.06)	-0.24**	(0.11)
Consumer Electronics	0.11	(0.13)	0.03	(0.03)	-0.05	(0.05)	-0.09	(0.11)
Convenience Store	-0.15	(0.14)	-0.04	(0.04)	0.06	(0.06)	0.13	(0.11)
Homeware & Kitchenware	0.27**	(0.11)	0.07**	(0.03)	-0.12**	(0.05)	-0.23**	(0.10)
Management & Prof. Services	0.21**	(0.10)	0.06**	(0.03)	-0.09**	(0.04)	-0.18**	(0.08)
Pharmacy & Personal Care	0.16	(0.11)	0.04	(0.03)	-0.07	(0.05)	-0.14	(0.09)
Souvenirs & Luggage	0.11	(0.13)	0.029	(0.03)	-0.05	(0.05)	-0.09	(0.11)
Sport & Camping	-0.03	(0.12)	-0.01	(0.03)	0.01	(0.05)	0.03	(0.10)
Stationary Goods	0.04	(0.14)	0.01	(0.04)	-0.02	(0.06)	-0.04	(0.11)
Toy & Entertainment	0.07	(0.13)	0.02	(0.03)	-0.03	(0.05)	-0.06	(0.11)

*** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses.

These results can be combined and contrasted with the results from Table 6.2. In particular, Table 6.3 found that the most-willing subindustries displayed not just higher general levels of willingness; but also, they were particularly likely to select very willing. One potential concern with these results is that the finding about very willing responses may simply be a marker that the model is miscalibrated and is over-predicting very willing responses. However, Table 6.2 finds that the model is in fact most accurate in predicting very willing responses, offering reassurance about the findings in Table 6.3.

6.3.3. Discussion and Policy Implications

The results of this investigation both confirm earlier findings in the freight behavioural literature and extend knowledge in new ways. First, we confirm that there is some interest in the freight consolidation initiative among receivers. In their behavioural choice model conducted in New York City, Holguín-Veras and Sánchez-Díaz (2016) found that around one-quarter of businesses were willing to participate in receiver-led delivery consolidation policy. Results from the Melbourne CBD (24%) confirm this figure. We do note, however, some differences in willingness to participate by sub-sector between the current study and the New York study. The modelling results suggest that book & newspaper, homeware & kitchenware, management & professional services and apparel sectors are the sub-industries that are most willing to participate in the RLC service. This is somewhat different from the most willing sectors reported in the New York study,

which are retail establishments (building material, furniture stores, and food and beverage stores), accommodation and wholesale electronic markets. These observations suggest that business sectors cannot be homogenised across geographical settings and may help to contribute to understanding about why consolidation concepts that are successful in certain contexts are not necessarily transferable to others.

While the ordered logic model found that sub-industry does remain an important explanatory predictor of willingness to participate in RLC policy, comparison of the full and suppressed models suggests that certain sub-industries are more willing to participate in the policy as a consequence of characteristics such as number of daily deliveries and the number of delivery companies. The results suggest that key determinants of willingness to participate in the policy are the number of daily deliveries and the number of delivery companies interacted with on a daily basis. Businesses that receive between 2 and 7 deliveries per day are likely to be more willing to participate than businesses who receive a higher number of deliveries. *Prima facie*, these observations seems to be counterintuitive, especially in light of the notion that suggests that receiving a higher number of deliveries and working with large number of delivery companies exert an injurious impact on business efficiency. However, it is possible that these businesses are concerned about the difficulty to efficiently consolidate a large number of deliveries from multiple companies. An alternative possibility is that the efficiency gains of consolidated delivery is not well understood by these businesses. It is suggested that more effort should be exerted to encourage this group of respondents to participate due to the large number of deliveries this group of respondents receive.

Some implications for policymakers can be inferred from the observations made above. First, policymakers should observe that there are differences in willingness to participate in consolidated delivery initiatives according to delivery characteristics. Businesses in certain sectors such as convenience stores and the sports & camping sectors do exhibit a lower willingness to respond positively to the RLC policy compared to businesses in sectors such as homeware & kitchenware and books & newspapers, but this is likely explained by their different delivery characteristics. The estimation of the delivery characteristics provides valuable insights on the size of the receivers that might be useful in proposing a suitable RLC policy. Businesses that that receive more (but not most) deliveries per day, and which interact with many (but not most) delivery companies are more likely to be willing to accept the RLC service than those that receive a lower number of deliveries and who work with just a few delivery companies. Policy planners would therefore do well to develop a more sophisticated understanding of the distinct needs and characteristics of businesses with alternative characteristics before designing and developing RLC solutions, in order to ascertain the drivers of positive responses by sector and delivery characteristics.

In addition to developing interventions that consider the different delivery characteristics of businesses, policymakers should also consider differences in willingness to participate in RLC schemes according to business sub-industry. Both this study and others undertaken in different contexts found there to be differences in the willingness of businesses to be positively receptive to the consolidated concept depending on the sector in which they operate. However, and given the limited amount of research that has expressly considered sub-industry as a driving factor in preferences, it is recommended to pay attention to the geographical setting in which the businesses are located. For

example, there were differing levels of willingness to participate in an RLC initiative between businesses in the accommodation sector in this study (undertaken in Melbourne) and in the New York City study. It is possible that there is some interaction between the sector of business and the locale which drive differing levels of willingness. Moreover, businesses' perceptions towards the consolidation concept may be driven by the extent to which they are surrounded by businesses in a similar sub-industry, and thereby with similar needs. The results of this study suggest that policymakers would do better in promoting acceptance of RLC policy if they developed heterogeneous strategies that are driven by the needs of businesses in specific industries, rather than if they offered a one-size-fits-all policy solution.

6.4. Investigation of the Receivers' Willingness to Participate and Pay for the RLC Service Based on the Service Attributes

In this section, the behavioural responses of the receivers were estimated using a mixed logit model to characterise the influence of the RLC service attributes on the receivers' willingness to participate and quantify willingness to pay (WTP) for the RLC service.

6.4.1. Description of The Empirical Model

6.4.1.1. Mixed Logit Model Specification

This study used the collected 2,295 observations to estimate a mixed logit model to investigate the trade-offs between different attributes of the RLC services. The mixed logit model is a flexible model that can approximate any random utility model (McFadden and Train 2000). This model has a hedonic formulation that permits random parameters to represent variations in tastes across individuals and unrestricted substitution patterns that allow estimated coefficients to vary with each respondent, which obviates the limitations of other common logit models (Revelt and Train 1998, Train 2009). Because of these advantages, the mixed logit model is increasingly used in advanced discrete choice studies.

This mixed logit model assumes a utility function for business i that is a function of service attributes:

$$U_{ij} = \beta' X_{ij} + \varepsilon_{ij} \,, \qquad \text{(eq. 6.6)}$$

where X_{ij} is a vector of j services, such as the delivery time-window or the new service offered, β is the vector of coefficients of business-specific preference parameters, and ε_{ij} is the error term distributed according to the generalised extreme value distribution. Under this distributional assumption, the probability of choosing a given attribute k of the service j in the mixed logit model is:

$$P_{ik} = \int \frac{\exp(\beta' X_{ik})}{\sum_{j \neq k \in J} \exp(\beta' X_{ij})} \,, \qquad \text{(eq. 6.7)}$$

where $f(\beta|\theta)d\beta$ is the density function of β.

All effects-coded coefficients are set to follow a normal distribution in the main analysis. The sign of the coefficients freely allows respondents to show positive or negative

preference for each attribute. This freedom allows for capturing heterogeneous preferences and avoids the need to test for independence of irrelevant alternatives.

We first estimated the mixed logit model for the full sample of 2,295 observations. Using the estimated model coefficients, we predicted the probabilities of each respondent choosing different services options to determine the marginal effect of a change in a given attribute. We predicted the probability of choosing each option separately for each of the levels of the attribute. Then, we compared the predicted probabilities for each service attribute to the predicted probability for the reference service attribute. The resulting difference is the marginal effect of switching from the reference service attribute.

6.4.1.2. Calculation of Respondents' Willingness to Pay (WTP) and Net Program Benefits

The standard way to infer respondents' WTP for RLC programs is by calculating the ratio of the estimated coefficients on program attributes and costs (Train and Weeks 2005; Sillano and de Dios Ortúzar 2005). However, since the stated-preference survey did not include a cost attribute to characterise the RLC service cost, an alternative approach was applied to infer WTP using structural econometric methods. This approach has an important advantage as it allows for quantifying WTP without including cost attributes in survey design and thus avoids complications outlined in section 3.4.2. The important caveat of using this approach lingers on the assumption that respondents are both rational and know (or can accurately determine) the costs of RLC program attributes. If these assumptions are violated, the WTP estimates should be interpreted with caution. The WTP for the RLC program equals the marginal benefit, or the change in the respondent's utility U_{ij} with and without participating in the RLC program. That is,

$$WTP_i = U_{ij}(\beta' X_{ij} | y_i = 1) - U_{ij}(\beta' X_{ij} | y_i = 0), \quad \text{(eq. 6.8)}$$

where y_i is the observed respondent's willingness to participate in the RLC the program (1 = "Yes") and $\beta' X_{ij}$ is the linear combination of estimated coefficients and program attributes. Combining equation (6.8) with equation (6.7) calculates WTP as the following.

$$WTP = \begin{cases} y_i(\beta' X_{ij}) + (1 - y_i) \ln\left[\left(\frac{1 - \Pr(y_i=1)}{\Pr(y_i=1)}\right) \exp(\beta' X_{ij})\right] & \text{if } y_i = 1 \\ y_i(\beta' X_{ij}) + (1 - y_i) \ln\left[\left(\frac{\Pr(y_i=1)}{1-\Pr(y_i=1)}\right) \exp(\beta' X_{ij})\right] & \text{if } y_i = 0 \end{cases} \quad \text{(eq. 6.9)}$$

Observe that WTP calculated from eq. (6.9) measures the utility change, whereas tractable estimates of the WTP should be in terms of the money metric equivalent. Finding the value of WTP in dollar terms assumes that the respondent finds it optimal to participate in the RLC program if the WTP equals or exceeds the marginal cost (MC) of program participation. If the unit cost of the RLC program is determined in terms of parcels, Q, then the

$$MC = \frac{d(pQ)}{dQ} = p\,, \quad \text{(eq. 6.10)}$$

where p is the known constant marginal price, i.e. the service fee per consolidated delivery that the receiver would pay to the operator of the consolidation facility for the additional services offered with the consolidated delivery service. These assumptions allow ranking each respondent's calculated WTP and finding the 'marginal' respondent who chooses to

participate in the RLC program but holds the lowest willingness to pay for it (excluding outliers). Setting the WTP of the marginal respondent (WTP_0) to observe marginal cost of that respondent (p_0) can determine the money metric equivalent of the WTP:

$$WTP_{\$} = \frac{WTP}{WTP_0} p_0. \quad \text{(eq. 6.11)}$$

Finally, the net benefit of the RLC participation, NB, calculates as the difference between the dollar value of the WTP and the price of the RLC program attributes:

$$NB = WTP_{\$} - p. \quad \text{(eq. 6.12)}$$

6.4.2. Estimation of Receivers' Willingness to Participate Based on RLC Service Variables

6.4.2.1. Receivers' Perceptions and Stated Responses to Receivers-Led Delivery Consolidation

The results of mixed logit model facilitate determining the influence of the RLC service variables on the behavioural responses of receivers towards the RLC service. Table 6.4 displays the estimation results of the mixed logit model. Estimated coefficients are shown in the 1st column while t-statistics are shown in 2nd column. The 3rd column reports the marginal effects showing how a one-unit change in each attribute affects the probability of choosing a given option relative to the reference attribute. The data of Table 6.4 show that time-specific delivery service holds the greatest potential to sway receiver support or opposition to delivery consolidation. Among new services under consideration, the time-specific delivery service shows the greatest magnitude of interest (β = 0.6811), highest confidence over 99% (t-stat of 4.881), and largest marginal effect on participation (8.95%).

Table 6.4. Results of the Mixed Logit Model for the 13 Sub-industries

Attribute	(1) Coefficient	(2) t-stat.	(3) Marginal Effect
Consolidated Delivery Time-Window			
05:00 – 08:59		*(Ref.)*	
09:00 – 15:59	0.518***	3.853	7.77%
16:00 – 18:59	-0.011	-0.107	-0.15%
19:00 – 21:59	-0.670***	-5.624	-8.20%
22:00 – 04:59	-1.938***	-8.300	-19.26%
Reduction in Existing Number of Deliveries			
25%		*(Ref.)*	
33%	0.116	1.002	1.54%
50%	0.147	1.251	1.94%
67%	0.174	1.510	2.30%
75%	0.134	1.053	1.80%
New Service			
Product Quantity & Quality		*(Ref.)*	

Product Return	-0.004	-0.029	1.22%
Time-Specific Delivery	0.681***	4.881	8.95%
Temporary Storage	0.020	0.139	1.48%
Unpacking & Waste Removal	0.394**	2.104	4.82%
Delivery Information Update			
None		*(Ref.)*	
Real-Time Update	0.341**	2.263	5.46%
Fixed-Time Update	0.082	1.027	1.08%
Goodness-of-fit			
Observations	2,295		
Log Likelihood	-1980.29		
Pseudo-ρ^2	0.235		

*** p<0.01, ** p<0.05, * p<0.1

We find considerable differences in interest in the RLC service across the time-window variable. Businesses express strong interest in convenient time windows and stronger opposition to the most inconvenient ones. Respondents on average prefer the midday delivery time-window as shown by the large and statistically significant coefficient for the 9:00-15:59 delivery window (β = 0.5181, t-stat = 3.8533, $p < .01$). Businesses express aversion to consolidation schemes if the policies push deliveries into inconvenient time windows, as negative coefficients indicate for late off-peak hours of 19:00-21:59 (β = -0.6702) and 22:00-4:59 (β = -1.9385). These results make intuitive sense in that small and independent businesses do not commonly staff second and third shifts, so accepting deliveries during these time windows would require hiring new employees or paying overtime. The marginal effects illustrate how a change in a given attribute, on average, affects the probability of choosing the consolidated delivery service, relative to the reference category of that attribute. For example, the choice of a 9:00-15:59 time window would be 7.77% more likely selected compared to the reference 05:00-8:59 time window. There is no noticeable difference between choosing consolidated deliveries in the early morning hours (5:00-8:59) and late afternoon hours (16:00-18:59) as the probability change is almost zero (-0.15%). However, receivers are almost 20% less likely to participate in RLC if the consolidated delivery would be performed during midnight off-peak hours (22:00-4:59) than in early morning hours.

Beyond the fundamental interest in the time-specific service, businesses find unpacking & waste removal appealing (β = 0.3942, t-stat = 2.1048, $p < .05$). Including this additional service in the RLC service would make the consolidated service 4.82% more preferred by respondents as compared to the reference "product quantity & quality check" service attribute. However, there is strong preference heterogeneity for additional services. There is also a preference for real-time updates (β = 0.3410). Compared to a fixed-time update or no update, having real-time update increases the respondents' probability of participating in RLC by 5.46%. For other attributes, there are fewer clear preferences and significant differences across the respondents. Model coefficients are small, and t-statistics are insignificant for both product-return and temporary-storage services. Receivers do not view the reduction in number of deliveries as a significant attribute, as indicated by no significant differences in preferences across the different levels of reduction in the existing number of deliveries (*t*-stat of 1.51 and less). This insignificance

might be because receivers perceive the reduction of deliveries as an implicit outcome of other consolidation policies, such as new services and real-time delivery status updates. Simply consolidating the time window of deliveries tells business owners and managers that receiving shipments will require a known amount of employee time daily regardless of the number of deliveries.

6.4.2.2. Robustness Checks for the Mixed Logit Model

The model's overall goodness-of-fit is acceptable with the Pseudo-ρ^2 value of 0.235. Another way to examine the goodness of fit for the mixed logit model is to compare observed and predicted probabilities of respondents' willingness to choose different RLC options. Observed probability comes from the ratio of willing versus unwilling sectors as declared in the 1st part of the SP survey while the predicted probabilities were calculated using estimated coefficients from eq. (6.7). Table 6.5 juxtaposes the observed and predicted probabilities. Overall, the results of the z-test for proportions revealed that the differences between the observed and predicted probabilities for all attribute levels in Table 6.5 are not statistically significant (p-value for all attribute levels are considerably higher than 0.05). Hence, the null hypothesis is accepted, i.e. there is no difference between the observed and predicted probability. Accordingly, it could be inferred that all predicted probabilities are accurate and validate the robustness of the econometric model in terms of scenario analysis. Furthermore, Table 6.5 shows no considerable differences greater than 3% between the observed and predicted probabilities for most of the delivery time-window, reduction in existing delivery and delivery information updates. However, the model tends to over-predict respondents' choices of receiver time-specific delivery (49% vs. 54%) and under-predict respondents' choices of the 19:00 – 21:59 delivery window (20% vs 16%), temporary storage (26% vs. 22%) and time-fixed updates (33% vs. 26%). Thus, results for these choices should be interpreted with scrutiny: the model might introduce error, a hidden variable might exist, or respondents might have provided illogical responses due to inaccurate understanding of how the situation might affect their businesses.

Table 6.5. Observed and predicted probabilities of RLC participation attributes

Attribute	**Mixed Logit**		
	Yes (%)		Z-test
	Observed	Predicted	p-value
Time Window			
05:00 - 08:59	39.81	42.07	0.6525
09:00 - 15:59	48.24	46.13	0.4776
16:00 - 18:59	37.93	40.32	0.5863
19:00 - 21:59	20.36	16.46	0.2534
22:00 - 04:59	10.42	7.44	0.2162
Reduction in Existing Number of Deliveries			
25%	29.55	32.92	0.2946
33%	31.27	31.08	0.9238
50%	37.52	35.23	0.5810
67%	34.32	33.14	0.7790

75%	34.04	33.73	0.9255
New Service			
Product Quantity & Quality	18.13	17.56	0.9079
Product Return	23.24	20.18	0.3891
Receiver Time-Specific Delivery	48.93	54.16	0.2561
Temporary Storage	26.07	22.45	0.3516
Unpacking & Waste Removal	40.46	38.72	0.3737
Delivery Information Update			
No Update	31.94	30.43	0.7743
Real-Time Update	40.47	43.88	0.4196
Time-Fixed Update	32.73	25.84	0.1979

6.4.3. Analysis of the Most Willing Sub-Industries to Participate

6.4.3.1. Estimating the Willingness to Participate of Most Interested Sub-industries

Launching the RLC service should target and focus on sub-industries that are highly inclined to participate as the unwilling sub-industries might complicate the effort and success of the consolidation initiative regardless of its likely benefits. This facilitates formulating a suitable policy for offering the version of the consolidated delivery service that contains the attributes most preferred among the likely target market. The ordered logit estimation (the 2nd run column in Table 6.1) highlights that the book & newspaper, homeware & kitchenware, management & professional services and apparel sectors have a positive and significant coefficient, which suggests that they are more inclined to participate in the RLC service compared with the other nine sub-industries. Accordingly, responses of these four sectors are further investigated in this section in order to estimate the preferences of these four sectors towards the RLC service using the mixed logit model. Table 6.6 displays their estimated coefficients and marginal preferences.

Table 6.6. Mixed-Logit Results for Sub-Industries Most Willing to Use RLC Service

Attribute	Sub-industry							
	Book & Newspaper		Home & Kitchenware		Management & Pro Service		Apparel	
	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.	Coeff.	Marg. Eff.
Consolidated Delivery Time Window								
5:00 – 8:59	(Ref.)		(Ref.)		(Ref.)		(Ref.)	
9:00 – 15:59	0.814**	10.52%	0.463	5.24%	0.816***	13.21%	0.979***	16.32%
	(1.805)		(1.289)		(4.003)		(4.546)	
16:00 – 18:59	-1.185**	-14.23%	-0.608	-6.92%	0.293	4.83%	0.395*	6.43%
	(-2.411)		(-1.582)		(1.422)		(1.870)	
19:00 – 21:59	-2.152***	-25.61%	-1.582***	-18.83%	-0.368	-5.84%	-0.793***	-12.46%
	(-3.810)		(-3.958)		(-1.623)		(-3.226)	
22:00 – 4:59	-3.224**	-29.54%	-4.758*	-38.46%	-1.980***	-22.86%	-1.241***	-18.87%
	(-2.253)		(-1.723)		(-3.478)		(-3.032)	
Reduction in Existing Number of Deliveries								
25%	(Ref.)		(Ref.)		(Ref.)		(Ref.)	
33%	-0.408	-2.26%	-0.662	-4.28%	-0.072	-0.77%	-0.067	0.84%
	(-0.762)		(-1.145)		(-0.186)		(-0.183)	
50%	0.219	1.47%	-0.358	-2.46%	-0.070	-0.68%	0.174	2.54%
	(0.871)		(-0.844)		(-0.238)		(0.713)	
67%	0.376*	4.56%	0.246	2.14%	0.048	0.43%	0.429*	4.96%
	(1.295)		(0.658)		(0.292)		(1.869)	
75%	0.166	2.13%	0.132	1.65%	0.023	0.36%	0.200	3.21%
	(0.314)		(0.347)		(0.178)		(0.826)	
New Service+								
PQ	(Ref.)		(Ref.)		(Ref.)		(Ref.)	
PR	0.612	6.54%	-0.628	-7.46%	0.045	0.72%	0.232	3.75%
	(1.252)		(-1.315)		(0.178)		(0.933)	
RT	1.562***	14.46%	0.893	7.43%	1.937***	22.34%	1.703***	15.66%
	(2.663)		(1.785)		(5.472)		(3.535)	
TS	0.937**	10.72%	0.171	2.18%	0.605*	7.41%	-0.034	-0.67%
	(1.334)		(0.415)		(1.702)		(-0.131)	
UN	2.007***	27.24%	1.763***	20.81%	0.845**	9.24%	1.274**	11.82%
	(3.031)		(3.704)		(2.173)		(2.420)	
Delivery Update++								
None	(Ref.)		(Ref.)		(Ref.)		(Ref.)	
Real	0.220	5.84%	0.142	1.78%	0.608***	11.62%	0.537**	10.76%
	(1.388)		(0.527)		(2.439)		(1.842)	
Fixed	-0.148	-0.97%	0.162	1.94%	-0.332	-1.28%	-0.151	-1.34%
	(-0.628)		(0.748)		(-1.176)		(-0.668)	
Goodness-of-Fit								
Observations	108		189		432		387	
Log Likelihood	-174.620		-289.188		-468.390		-370.780	
Pseudo-ρ^2	0.212		0.241		0.223		0.264	

t-stat in parenthesis, *** p<0.01, ** p<0.05, * p<0.1

The four sub-industries maintain the established preference for the 09:00-15:59 time window. It has the largest positive coefficient for all subindustries. Calculated marginal effects show that the probability of receivers in the book & newspaper, management & professional services and apparel sub-industries selecting a consolidated delivery option during normal business hours (09:00-15:59) is more than 10% higher than choosing early morning hours. Apparel and management & professional services are the only sectors

expressing higher preference (6.43% and 4.83%, respectively) for early evening (16:00 – 18:59) rather than early morning hours. Receivers from the management and apparel sectors reveal a higher preference for real-time updates (β = 0.608 and β = 0.537). This result differs from the full-sample analysis, where the full group of receivers indicate a lower preference for the real-time update service (β = 0.341). In contrast, there is no considerable probability change for the book & newspaper and homeware & kitchenware sectors with respect to selecting real-time updates compared to no updates.

Preferences towards the additional services are different across the selected sectors. The time-specific delivery service is highly preferred among receivers from the management & professional services, apparel and book & newspaper sectors. Businesses from these three sub-industries are 22%, 15% and 14% respectively more likely to select a delivery option with time-specific delivery than another delivery option with the product quality and quantity service. Furthermore, these three sectors reveal a stronger preference for this service compared to the full sample as shown in Table 6.4 (β = 0.681). Additionally, receivers in the book & newspaper and homeware & kitchenware sectors indicate a significantly high preference (β = 2.007, t-stat = 3.031 and β = 1.763, t-stat = 3.704, $p < .01$) for the unpacking and waste removal service. Businesses from these two sub-industries are 27% and 21% more likely to select a delivery option with the unpacking service than a delivery option with product quality and quantity check. The apparel sub-industry has a positive coefficient (β = 1.274, t-stat = 2.420, $p < .05$) for this service as well. Overall, these three sectors show even stronger preference for this service than the coefficient of the full sample as shown in Table 6.4 (β = 0.394).

Otherwise, receivers in book & newspaper and management & professional services show a high preference for temporary storage service (10.72% and 7.41% marginal effects respectively). Unlike receivers from other sub-industries, book & newspaper sector show a high preference for the product return service (β = 0.612, t = 1.252, $p < 0.1$). However, the book & newspaper and apparel sectors are the only sub-industries to show relative preference for reduction in existing number of deliveries (β = 0.376, t = 1.295 and β = 0.429, t = 1.869, $p < .1$). This study set a baseline at a 25% reference reduction in existing deliveries, but book & newspaper and apparel sub-industries might increase RLC participation by 5% if deliveries can be reduced by 67%. Receivers in management & professional services and homeware & kitchenware indicate positive but smaller effects; however, insignificant *t*-statistics leave this finding inconclusive for these two sectors.

6.4.3.2. Scenario Analysis of the Most Preferred Choices in the Most Willing to Participate Sub-industries

Results of the mixed logit model estimation can be used to draw useful insights about preferences of receivers in the most willing sub-industries towards the RLC service attributes. Specifically, a scenario analysis was performed using 14 different attribute mixes to examine the effects of choosing a certain attribute mix by the most willing sectors. These mixes were identified by focusing on the most commonly selected delivery choices by the four most willing sectors in the SP survey. We compared each of the selected attribute combinations to a random mix of alternate options in the sample and predicted the probability of choosing the attribute mix of interest in the most wiling sectors. These percentages can be evaluated against the baseline choice probability of 33% i.e., the probability of randomly choosing a given attribute mix between the possible

3 delivery options in a choice task in the SP survey. An attribute mix with a choice probability higher than 60% is considered highly preferred while an attribute mix with a choice probability below 33% is dismissed. The model assigned low predicted probabilities to 6 attribute mixes out of the initial 14 mixes. Consequently, Fig. 6.3 displays the final 8 delivery choices and the predicted choice of RLC service in each sector.

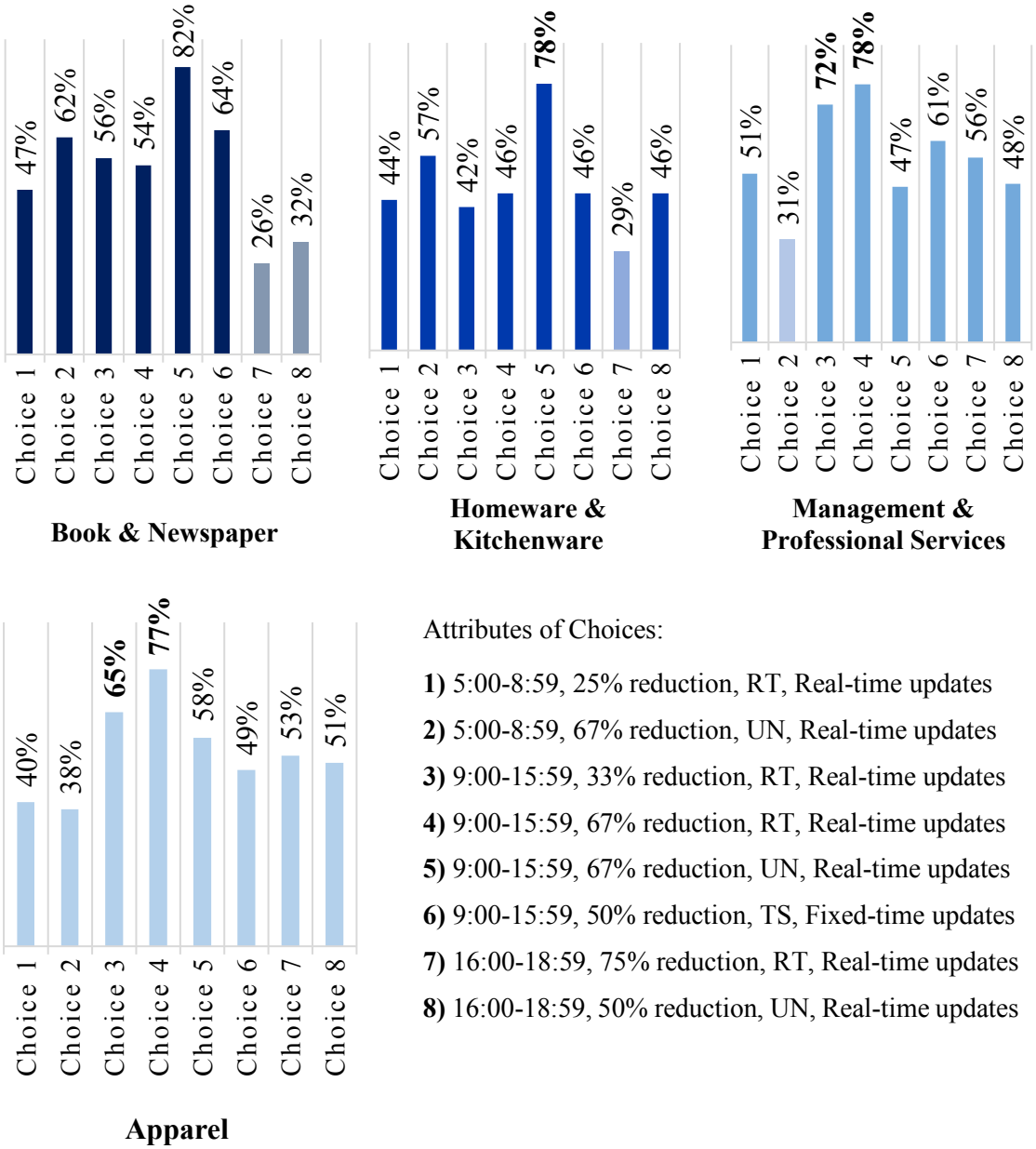


Figure 6.3. Predicted Demand Probability of Selecting Proposed Delivery Options for Most Willing Sub-industries

The scenario analysis shows that choice 4 has the highest choice probability as it exceeds 77% for management & professional services and apparel sectors. The RT service might be more valuable to receivers from these two sectors due to the improved efficiency and added convenience accrued from knowing ahead of time when deliveries are expected to arrive. Choice 3 has the same attributes except for smaller reduction in deliveries. This

option also has a high choice probability exceeding 65%. Other scenarios result in significantly lower predicted choice probabilities. For example, changing the delivery window to 5:00-8:59 (choices 1 and 2) lowers average choice probability to 40%, and changing the delivery window to 16:00-18:59 (choices 7 and 8) results in an average choice probability of 52%. Overall, the model predicts that delivering during standard business hours (9:00-15:59) with the RT service will increase demand probability for these receivers by almost 20% compared with the other two delivery windows. Offering the unpacking & waste removal or temporary storage services instead of RT service (choices 5 and 6) also reduces the probability of participating in RLC, although to a lesser extent. These findings demonstrate that a combination of early daytime deliveries, the RT service and the real-time update is particularly effective in increasing willingness to participate in the RLC program for these two sub-industries.

Predicted participation probability exceeds 78% for book & newspaper and homeware & kitchenware sectors when offered choice 5, which includes the 9:00-15:59 time-window and the UN service. It can be argued that these receivers are more interested in the UN service due to the large volume of industry-specific packaging waste coupled with limited waste disposal services offered to on-street stores. A similar option (Choice 2) with earlier time-window of 5:00-8:59 comes as the second choice for both sectors (62% average). Overall, it is predicted that having a 9:00-15:59 delivery-window along with the UN service will increase the demand probability for these receivers by almost 15% compared with the 5:00-8:59 delivery-window. However, choice 7, which includes the 16:00-18:59 time window and the RT service, is the least preferred choice in both sub-industries with predicted probability below the baseline probability of 33%. It was predicted that only the book and management sectors might be interested in the TS service (choice 6) with predicted demand probability exceeding 60%. The higher predicted demand for these sectors could be attributed to the limited in-store storage area that is further complicated by the wide range of goods that they sell or receive.

6.4.4. Cost-Benefit Analysis and the Willingness to Pay for the RLC Service

Figs. 6.4 – 6.6 illustrate the calculated WTP and net benefits of RLC participation for three main characteristics of the respondent (sub-industry, most common delivery time and number of daily deliveries). It is important to note that the marginal price used in the WTP estimation is based on the service fee per consolidated delivery that the receiver would pay for the RLC additional services. The average WTP is about AU $1.05 and the average net benefit of the RLC participation is about AU $0.15. Both WTP and the net benefit vary significantly across surveyed sectors (Fig. 6.4). The largest WTP is in the pharmacy & personal care (AU $1.25), the homeware & kitchenware (AU $1.24) and the apparel (AU $1.23) sectors, while the smallest WTP is in the footwear (AU $0.93), convenience stores (AU $0.81) and accommodation (AU $0.78) sectors. The net benefit is positive in all sectors, except for the accommodation (AU $-0.08) and the footwear (AU $0) sectors, which means these two sectors might require additional incentives to motivate them to participate in the RLC policy. The net benefit is the largest in the sport & camping (AU $0.32), souvenirs & luggage (AU $0.31), and pharmacy & personal care (AU $0.26) sectors.

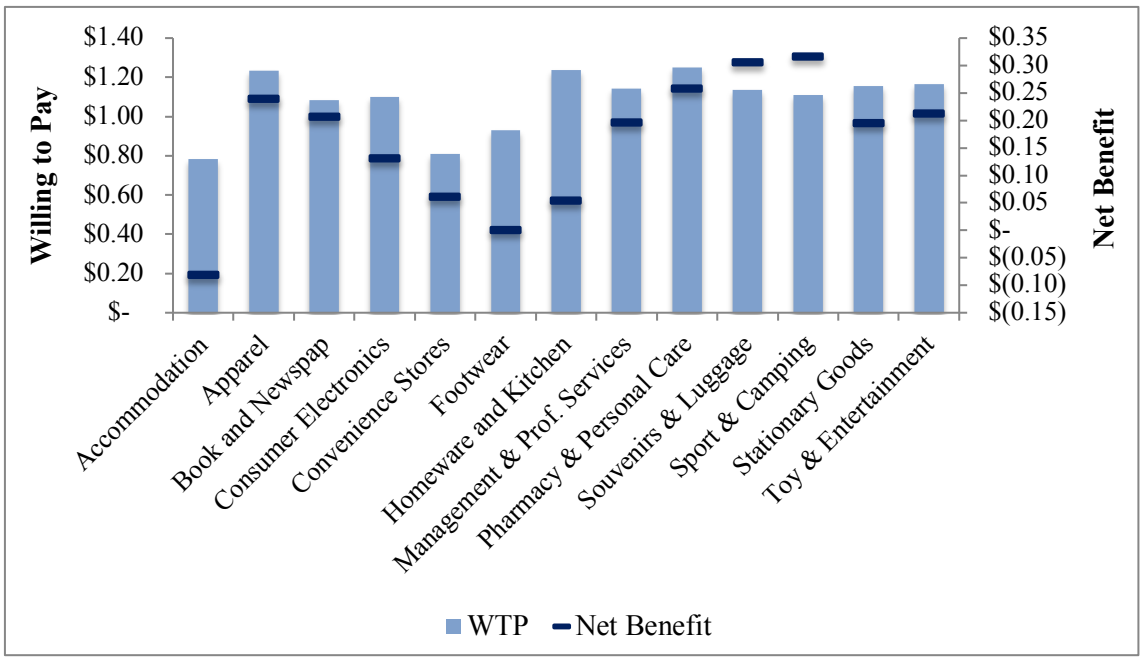


Figure 6.4. WTP and Net Benefit by Sub-industry

WTP and the net benefit also vary across the respondents' current delivery characteristics such as their most frequent delivery time and the number of daily deliveries they receive. Both WTP and net benefit appear to be the largest for businesses with most frequent delivery time during normal peak hours (9:00-19:00) (Fig. 6.5). One possible reason for this interest might be the higher operational problems for store staff in peak-hour deliveries. Thus, these businesses might be willing to pay higher due to the added benefits and efficiencies accrued from the RLC consolidated deliveries as they lead to less delivery traffic interference with shoppers and fewer stoppages to process deliveries during business hours. On the other hand, the WTP diminishes and the net benefit turns negative for businesses that have most of their deliveries during the night. It can be argued that businesses currently receiving night-time deliveries are not as adversely impacted by operational problems and inefficiencies as perhaps their staff are not busy with customers, and there are likely to be fewer traffic and parking problems. Thus, this cohort might not benefit as much from the consolidated deliveries, which might explain the negative net-benefit for this time-window.

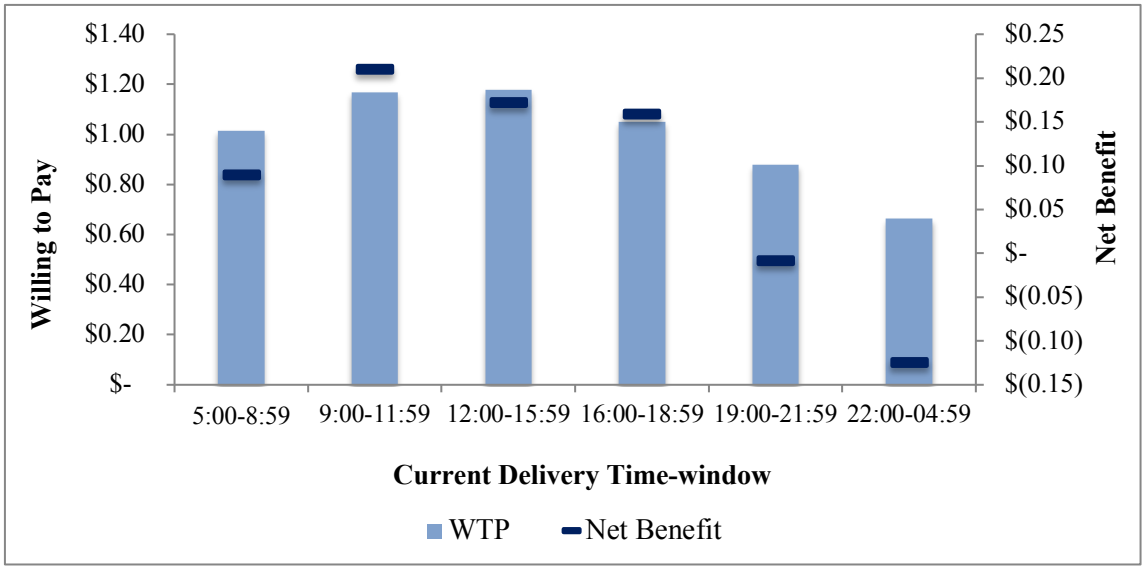


Figure 6.5. WTP and Net Benefit by Common Current Delivery Time

The WTP tends to be larger for businesses that receive about 2 to 7 deliveries per day compared to large number of deliveries (10+) as illustrated in Fig. 6.6. This finding refines the earlier result showing that reduction in the number of deliveries does not affect most respondents' willingness to participate in RLC. The high WTP for businesses receiving between 2 and 7 deliveries could be attributed to their concern that receiving many deliveries from multiple freight carriers is an unproductive process. These businesses do not receive enough deliveries to justify creating new internal systems and operations to accommodate heavy receiving activity, but external services might be welcome.

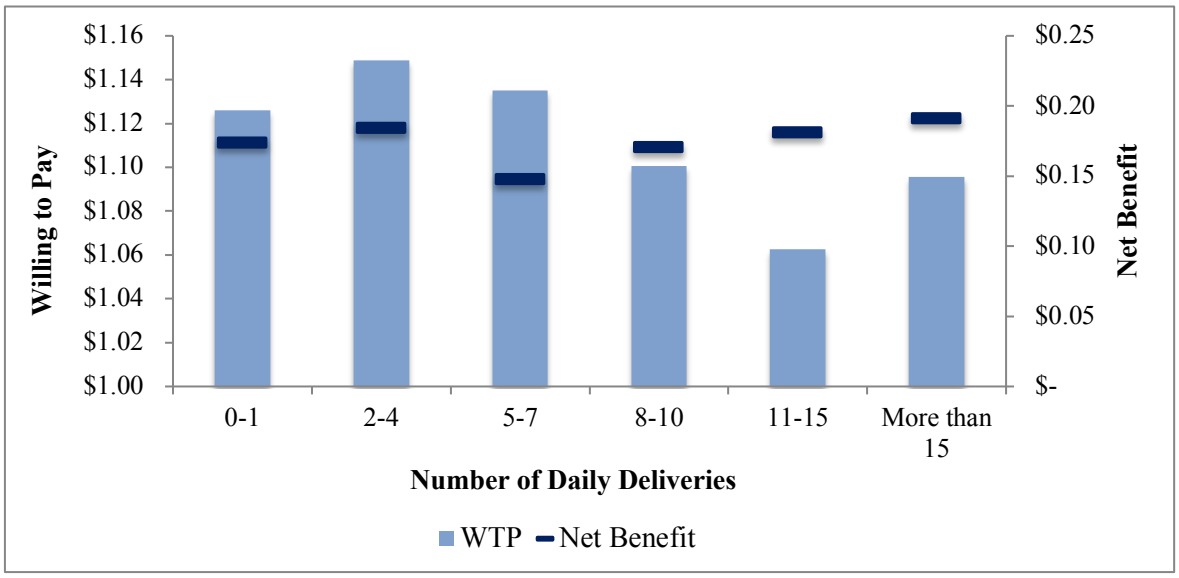


Figure 6.6. Willingness to Pay and Net Benefit by Number of Daily Deliveries

The net benefit increases for businesses with more than 7 deliveries, but willingness to pay for consolidation decreases. Businesses with numerous daily deliveries have likely developed business operations to make receiving efficient, so external contributions to

efficiency might be perceived less advantageous. Receivers with significantly large number of deliveries might alternatively feel reluctant to pay more for RLC deliveries because of their concerns about the difficulty of consolidating a large number of deliveries from multiple companies. Most respondents with high number of daily deliveries are from the accommodation, convenience stores and stationary goods sectors. They display high preferences for the lower-cost delivery attributes including off-peak hours and no delivery-status updates, which reduces the cost of consolidated delivery services.

6.4.5. Discussion and Policy Recommendations

6.4.5.1. Main Lessons for Transport Researchers and Local Authorities

The modelling results of the mixed logit model facilitate shaping a vision of what a freight consolidation scheme might entail, focusing on sub-industries indicating the most willingness to participate. One key finding is that most receivers might be reluctant to accept changes to their current delivery times. This assertion is validated by the significantly positive coefficient for the 9:00-15:59 time-window and the strong negative coefficients for off-peak hours as the results of the mixed logit model for the full sample shows (Table 6.4). There is a statistically significant rejection of off-peak hour delivery (22:00-4:59) by most receivers regardless of sub-industry with the one exception of the accommodation sector. This is similar to the results reported by dell'Olio et al. (2017): retailers in Santander and Barcelona were more inclined to the UCC policy than off-hour deliveries. Moreover, receivers prefer certainty in the management of their businesses to the largest extent possible. This is supported by the high coefficients for the RT service and real-time tracking attributes, which indicate that survey respondents highly value the potential improvements in delivery reliability resulting from the consolidated delivery service. Therefore, RLC delivery schemes should take this into account and be implemented in such a way to incorporate them easily into establishments' existing processes.

The WTP estimation results suggest that independent businesses might be willing to contribute financially to the cost of a consolidated delivery service, and almost all industries, on average, will find it optimal to participate. WTP and net benefits are smaller for respondents whose main deliveries occur in the evening. WTP tends to be higher for respondents with a small or medium number of daily deliveries; however, the net benefit of RLC participation increases for receivers with a large number of deliveries. As Fig. 6.4 indicates, respondents with the highest WTP do not necessarily gain the most from RLC participation because they are also more likely to choose RLC attributes with higher costs. For instance, the apparel sector, which has a relatively high WTP at $1.23, displays a high preference for higher-cost delivery attributes such as the RT and UN services as well as real-time tracking. The expected net benefit for apparel-sector businesses ($0.24) is lower than for those in the souvenirs & luggage sector ($0.31) even though this sector has a much lower WTP at $1.14. Similarly, the sport & camping sector displays a high preference for lower-cost delivery attributes such early morning delivery (5:00-9:00) and no delivery updates, which contributed to their higher expected net benefit.

Sub-industries with lower WTP for the RLC service may gain more by choosing lower-cost delivery service attributes. These results indicate that for at least some sectors, choosing lower cost RLC attributes yields higher net gains as the utility gain from the

more expensive RLC attributes is outweighed by their costs. Moreover, the city centre includes many accommodation establishments and convenience stores that generate and attract many freight deliveries. For instance, it is estimated that a hotel might receive daily 5 times the number of deliveries of a large supermarket (Dablanc and Rodrigue 2014). Thus, local authorities should consider offering incentives (such as subsidises) to reduce the overall cost of the consolidated deliveries during off-peak hours for the consolidation facility operator and these establishments.

The key high-level findings of this study are as follows

- Policy makers should design consolidation schemes to minimise disruption to current business processes. The 9:00-15:59 time slot is the most preferred.
- Receivers' willingness to participate in a RLC service is greatly affected by the consolidated delivery time-window and additional services, but not by the expected reduction in existing deliveries.
- Most sub-industries strongly prefer the time-specific delivery services and real-time status updates. This highlights the great value on time placed by respondents.
- Estimation results confirm heterogeneity of preferences of receivers across the various sub-industries with respect to policy variables that affect their willingness to participate in the freight consolidation scheme.
- Fundamentally, the WTP estimation suggest that independent businesses are willing to pay for services.
- Higher willingness to pay for the RLC service does not necessarily imply the highest net benefit for participating sectors.

6.4.5.2. Recommended RLC Policy Levers for Most Willing Sub-industries to Participate

Through an investigation of preferences for, and the optimal mix of the attributes of consolidated delivery service, the most effective consolidated delivery policy levers can be brought into focus with respect to the receivers' preferences. Assessing RLC schemes requires rigorous analysis of the key outputs from the stated preference survey shown in the previous sections. This includes examination of: 1) sub-industry segments that indicate a high willingness to participate; 2) the relative importance of each attribute by industry sub-segments; and 3) specific preferences for specific levels within each attribute that might inform a scheme.

Table 6.7 lays out the most preferred RLC policy variables based on the modelling results and the scenario analysis for the most willing sub-industries. The consolidated deliveries should be conducted preferably during early normal business hours (09:00-12:00). Moreover, afternoon hours (12:00-16:00) should be particularly promoted to serve industries with both highest willingness to pay and highest net benefit from choosing RLC services. This time-window also satisfies the high interest of receiver time-specific delivery service as most receivers are interested in 09:00-15:59 time-window and the RT service. Value-add services make delivery consolidation more appealing to receivers. Unpacking and waste removal offer improved utilisation of space in-store and an efficient and sustainable waste management solution for businesses, especially retailers with a

large number of deliveries and limited access to disposal areas. Real-time delivery status updates enable receivers to manage processing their daily deliveries efficiently. Local policy makers should focus on these variables to formulate appropriate RLC policy levers tailored towards the respective requirements and preferences of each sub-industry in order to foster their participation without the need for added financial incentives. The proposed freight consolidating policy should target businesses from sub-industries that typically receive 2-4 deliveries daily, as these industries have the highest willingness to pay for and derive high net benefit from choosing RLC services.

Table 6.7. Most Suitable Receiver-Led Consolidated Delivery Policy for the Most Willing Sub-Industries

RLC Policy	Sub-Industries	Delivery Time Window	Additional Services	Delivery Update
Policy A	Management & Professional Services Apparel	09:00 – 16:00	Receiver Time-Specific Delivery	Real-Time
Policy B	Homeware & Kitchenware Book & Newspaper	09:00 – 16:00	Unpacking & Waste Removal	Real-Time

6.5. Chapter Summary

In accordance with the 2nd objective of the research project, this chapter analysed the modelling results of the behavioural responses to explore the degree to which retailers and other businesses in the inner-city are willing to participate in receiver-led delivery consolidation service. The 2nd stage of the integrated framework has sought to examine the receivers' delivery characteristics and RLC service variables that could drive positive behavioural change in this critical group of stakeholders to address *Research Question #4*. Moreover, the chapter has characterised freight receivers' willingness to pay for the RLC service. Accordingly, this chapter addressed the clear gap in knowledge about investigating the factors and policy variables that influence receivers' willingness to exercise their market power to adopt RLC initiatives.

The chapter findings underline that it is business characteristics such as number of daily deliveries and delivery companies that seem to be the most important drivers of why particular subindustries report high willingness to participate. Businesses that receive multiple numbers of deliveries and who work with multiple delivery companies daily seem especially willing to accept an RLC policy. Furthermore, the modelling results show that the time-window of consolidated delivery and availability of relevant value-added services significantly influence receivers' willingness to participate. The results of the WTP calculation suggest that while there might be net benefit for receivers to pay for services, delivery characteristics of receivers, such as their sub-industry type, highly influence WTP.

The segmented nature of the study among sub-industries also revealed that future freight consolidation should be optimised by sub-industry and should accommodate as closely

as possible the current delivery practices that businesses use. If the RLC service can be offered in multiple configurations, different sub-industries will choose to adopt different options of the service. Knowing how sub-industries differ with respect to preferences towards various RLC service attributes aids policymakers in selecting the most interested businesses for targeting new consolidation initiatives. This knowledge also helps identify specific attributes to highlight in the scheme and the proposal of suitable and optimal consolidated schemes tailored for the preferences of sub-industries most willing to participate based on their parameter estimates.

There are a few limitations of the econometric models and findings that should be noted. Firstly, as with any choice-based approach to assess program attributes, the confines of a survey cannot accommodate all factors that might influence behavioural responses and decisions. Secondly, the collected sample size and the share of some sub-industries in the survey, while in line with that of other freight behavioural studies, might not be relatively large. Finally, this study's findings might have specific geographic relevance (the inner-city). The results might only allow inferences in similar areas. Other types of commercial areas might view this study as a model template for conducting area-specific studies involving in-depth analysis of receivers' behavioural responses towards a RLC delivery service. Nevertheless, by adopting a discrete choice approach and using data from a representative sample of receivers in an urban centre, this chapter presents a robust response to earlier calls for more receiver-cantered freight behavioural research that better understands receivers' needs and likely responses to delivery consolidation policy.

The findings suggest future research in a few areas. This investigation shows that the RLC policy needs to consider not merely the extrinsic motivations for accepting the consolidated delivery model, but also the intrinsic needs of receivers. A future direction for research could involve the construction of a multilevel model that builds in and considers interactions between both demand drivers (i.e. delivery characteristics) and supply drivers (i.e. incentives) on receivers' likely responses to an RLC policy. Given the large concentration of management and professional services businesses operating in large office buildings in the city centre, further research should appraise their willingness and preferences to exert influence on their building managers and delivery companies to consolidate their deliveries. This segment of central-city commercial activity can provide further insight into policies that could be focused specifically on this sub-industry.

Chapter 7

4th Stage: Multi-Criteria Spatial Evaluation Approach for Optimal Location of CCCF in the Inner-city

7.1. Introduction

The location of the consolidation facility in the urban area plays an important role in the success of the consolidation policy and its effectiveness to attract participation from freight carriers and receivers. As highlighted in section 2.4.4.1 in the Literature Review, most previous location studies assessed and selected the optimal location for freight consolidation facilities using decision support models that were performed by numerical computations or multi-criteria analysis without enough input from spatial analysis. Spatial suitability is an important aspect of location analysis with the goal of optimising the selection of suitable sites for facilities. Accordingly, this chapter presents and discusses the results and analysis of the application of the developed fuzzy GIS-based Multi-Criteria Decision-Making (GIS-MCDM) approach to locate and rank optimal sites for the proposed Central City Consolidation Facility in the inner-city area as follows: calculating the priority weights of 11 decision criteria using the Fuzzy AHP method; performing land suitability analysis of the study area using geoprocessing tools in ArcGIS to evaluate and identify suitable candidate sites; rank and select the candidate sites using the TOPSIS method. The integration of GIS technologies and MCDM approach allows the appropriate location to be quantitatively determined and visually examined in a highly intuitive manner. This allows decision makers to not only apply value-decisions at the onset of the process, but also allows for understanding and visualisation of the results and of the importance of chosen criteria in the decision-making process. Fig. 7.1 displays the steps that were applied in GIS-MCDM approach to select the most optimal candidate site for the CCCF. A full description of the fuzzy GIS-MCDM approach is provided in section 3.5.

The sections of this chapter are described below:

- Section 7.2 presents the results and analysis of the application of the GIS-MCDM approach to identify and select the most optimal candidate sites for the proposed consolidation facility in Inner Melbourne.
- Section 7.3 discusses the implications of the results with respect to the siting freight consolidation facilities and the contributions of the proposed spatial-based evaluation approach.
- Section 7.4 provides a concluding summary of the chapter including the study limitations and future research directions.

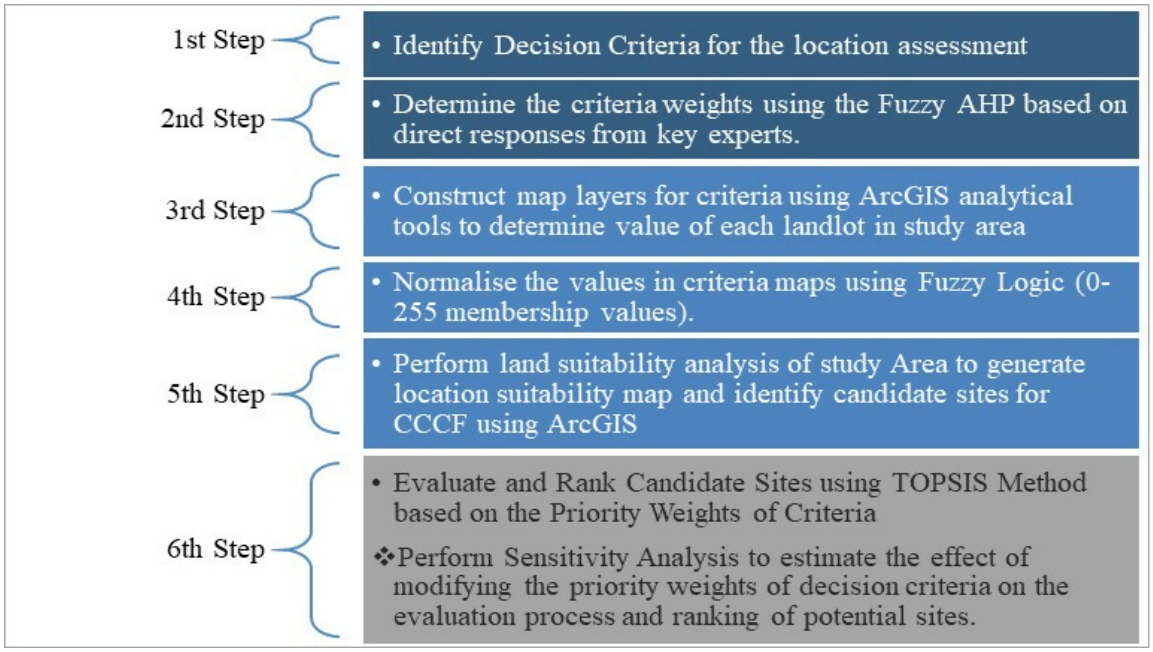


Figure 7.1. Illustration of the GIS-MCDM Approach to Assess and Select the Most Optimal Candidate Site for the CCCF in the Inner-City

7.2. Application of Fuzzy GIS-MCDM Approach for Assessment and Selection of The Optimal Location in the Inner-city

The results of the GIS-MCDM application to select the most optimal location to establish the proposed consolidation facility in Inner Melbourne are presented in this section. The study area is introduced and then the results of the ArcGIS spatial analysis and land suitability analysis are described. Finally, the identified candidate sites in the most suitable parts in Inner Melbourne are evaluated and ranked using the TOPSIS method.

7.2.1. Overview of the Study Area (Inner Melbourne)

The study area is located in Inner Melbourne, Australia within an area of approximately 49.5 km^2 (9 km x 5.5 km) as shown in Fig. 7.2. The study area was divided into 100m x 100 m grid cells. This area covers the trade, government and employment hubs of Melbourne including the Central Business District (CBD), Docklands, Southbank and St Kilda Road as well education and health precincts in Parkville and Carlton. The area includes more than 5,200 retail and business establishments with AU $ 11.2 billion annual economic output (Melbourne Retail Hospitality Strategy Report 2017). On a typical day more than 982,000 residents, workers, students and visitors are present within the study area.

The study area experiences a significantly large presence of freight vehicle movements as more than 10,000 freight vehicles perform deliveries and more than 20,000 freight vehicles pass through the area (Casey et al. 2014). However, the study area offers very limited supply of industrial and commercial lands for logistics facilities as the allocated industrial/commercial land lots within this area representing only 4% of the total industrial land in Greater Melbourne (Urban Development Program 2015). Furthermore, storage and transport facilities make only 1% of all built up space in Inner Melbourne

(Last Kilometre Freight Plan 2016). Due to the location of Port of Melbourne, which is the largest containerised and general cargo port in Australia, there is a large presence of wholesale and transport businesses in the western part of the study area in West Melbourne and North Melbourne as well as the industrial suburb of Port Melbourne in the south of the study area. There are no existing consolidation facilities in the study area as most warehouses are run by different logistics companies and operated as distribution or forwarding facilities.

Figure 7.2. Map of the Study Area (Inner Melbourne) Relative to Greater Melbourne (in Inset)

7.2.2. Identification and Calculation of Criteria Weights using Fuzzy AHP

Key experts from freight carriers and local authorities were surveyed and the results were used to perform the fuzzy pairwise comparison to calculate the priority weights for the decision criteria. Fig. 7.3 displays the priority weights calculated by the Fuzzy AHP for the CR01-CR11 decision criteria. The size of each block in the tree map reflects the weight of each criterion with respect to the total weight of all decision criteria (100%).

The suitability (grey colour), accessibility (blue colour), and logistics land use/attributes (dark blue) criterion groups account for 51.29%, 27.89%, and 20.82% of the weights, respectively. Among the suitability indicators, the facility rental cost (CR08) and the proximity to major receivers (CR09) are considered the two most important criteria and had a weight of 19.71% and 18.06%, respectively as indicated by the two largest blocks in Fig. 7.3. Road network connectivity had a weight of 15.97%. This is followed by the presence of existing distribution centres/warehouses in the area (CR01) and traffic intensity (CR06), which had weightings of 11.99% and 8.60%, respectively.

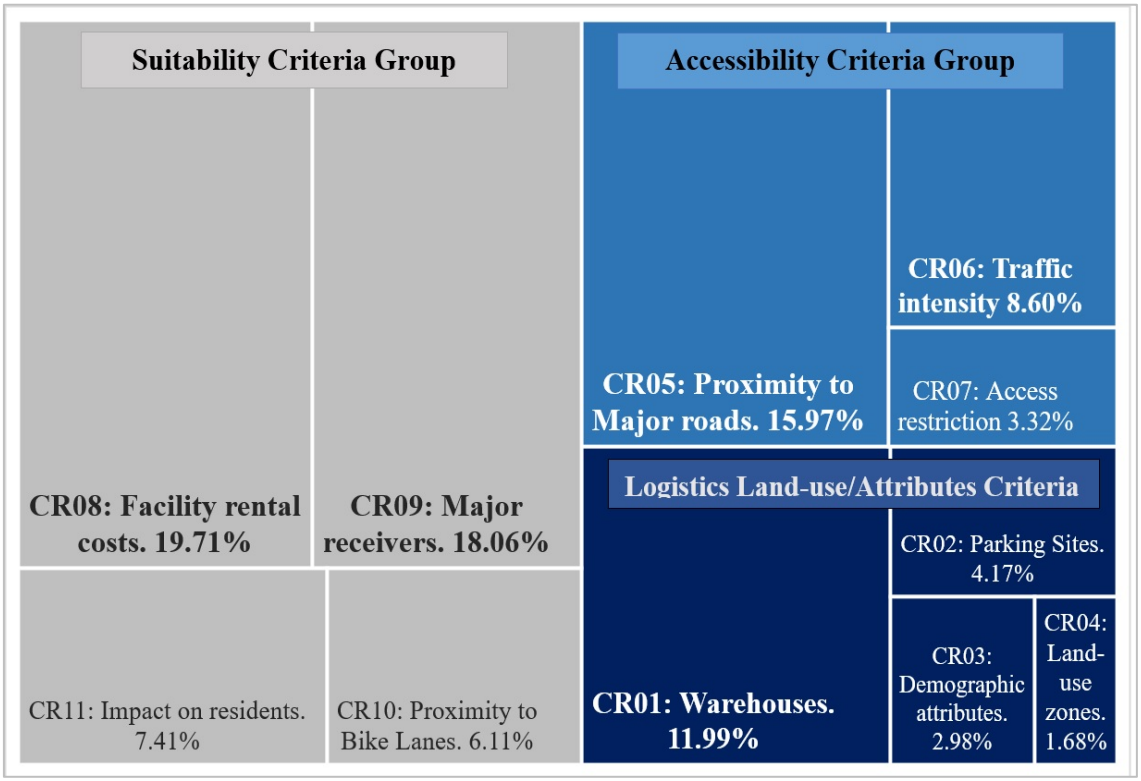


Figure 7.3. Priority Weights of Decision Criteria Calculated by Fuzzy AHP Method

From another perspective, the criteria could be categorised based on their functions. The criteria that attempts to reduce the travel distance of the consolidated delivery (CR01, CR03, CR05 and CR09) collectively had a total weight of 49%. This high weight illustrates the substantial importance assigned to accessibility to the supplier, the consolidation facility and the market due to their direct influence on the transport costs and efficiency of the consolidated trips. The hierarchy of the weights derived through F-AHP is consistent with the stakeholder's objectives to integrate the consolidation facility with existing infrastructure and networks. The high weight for this group along with facility rental costs (CR08 with a weight of 19.71%) is consistent with one key objective of the stakeholders – reduce costs and maximise profits. Furthermore, the social and environmental criteria (CR04, CR07, CR10 and CR11), which attempt to minimise the impacts on the environment and residents, had a lower collective weight of 18.52%.

An alternative approach would involve grouping the criteria based on their related functions. The criteria that attempt to reduce the travel distance of the consolidated delivery (CR01, CR03, CR05 and CR09) collectively had a total weight of 49%. Together, these four criteria account for nearly half the overall weightage, highlighting the importance of accessibility while selecting the location of the consolidation facility. Being accessible to shippers and businesses directly influences transport costs and the efficiency of consolidated delivery trips. The hierarchy of the weights derived through F-AHP is consistent with the stakeholder's objectives to integrate the consolidation facility with existing infrastructure and networks. The high weight for this group along with the facility rental costs (CR08 with a weight of 19.71%) is consistent with one key objective

of the stakeholders – reduce costs and maximise profits. Furthermore, the social and environmental criteria (CR04, CR07, CR10 and CR11), which attempt to minimise the impacts on the environment and residents, had a lower collective weight of 18.52%. Clearly, the location of the freight consolidation facility plays a key part in improving efficiency and reducing cost of the delivery service. Therefore, the following section focuses on understanding how spatial analysis can be employed to improve the location selection process for the proposed consolidation facility.

7.2.3. Suitability Analysis of the Study Area Using GIS Models

The spatial analysis of geographic data obtained provided valuable insights on the suitability of the study area with respect to each individual criterion. Fig. 7.4 shows the fuzzy maps obtained after normalising each decision criterion. The colour ramp from blue to burgundy shows the suitability of each location for the consolidation facility for each decision criterion. Zones in blue are most suitable while those in burgundy are least suitable based on the spatial analysis. The various zones in the study area received different suitability scores for the decision criteria as indicated in Fig. 7.4. For instance, the map for CR09 (proximity to receivers) displays that the suitable parts are located in the middle of the study area only, as most receivers are located on either inside or around the Melbourne's CBD area. On the other hand, the map for CR08 (facility rent) depicts a completely different picture, showing the middle part of the study area is entirely unsuitable due to the significantly high rent. The south-eastern part of the study area is ranked entirely different with respect to CR03 and CR04. This part is considered highly suitable with respect to the demographic attributes as this is the place where high-income residents live. However, few industrial-land zones are available in this area. The conflicting suitability scores of the different decision criteria for the same zone underline that selection of the optimal location should not be entirely decided based on an individual criterion nor the preferences of only key stakeholders. As a result, it is essential to comprehensively and collectively evaluate all important key and relevant criteria in the evaluation and selection of the optimal locations of consolidation facilities.

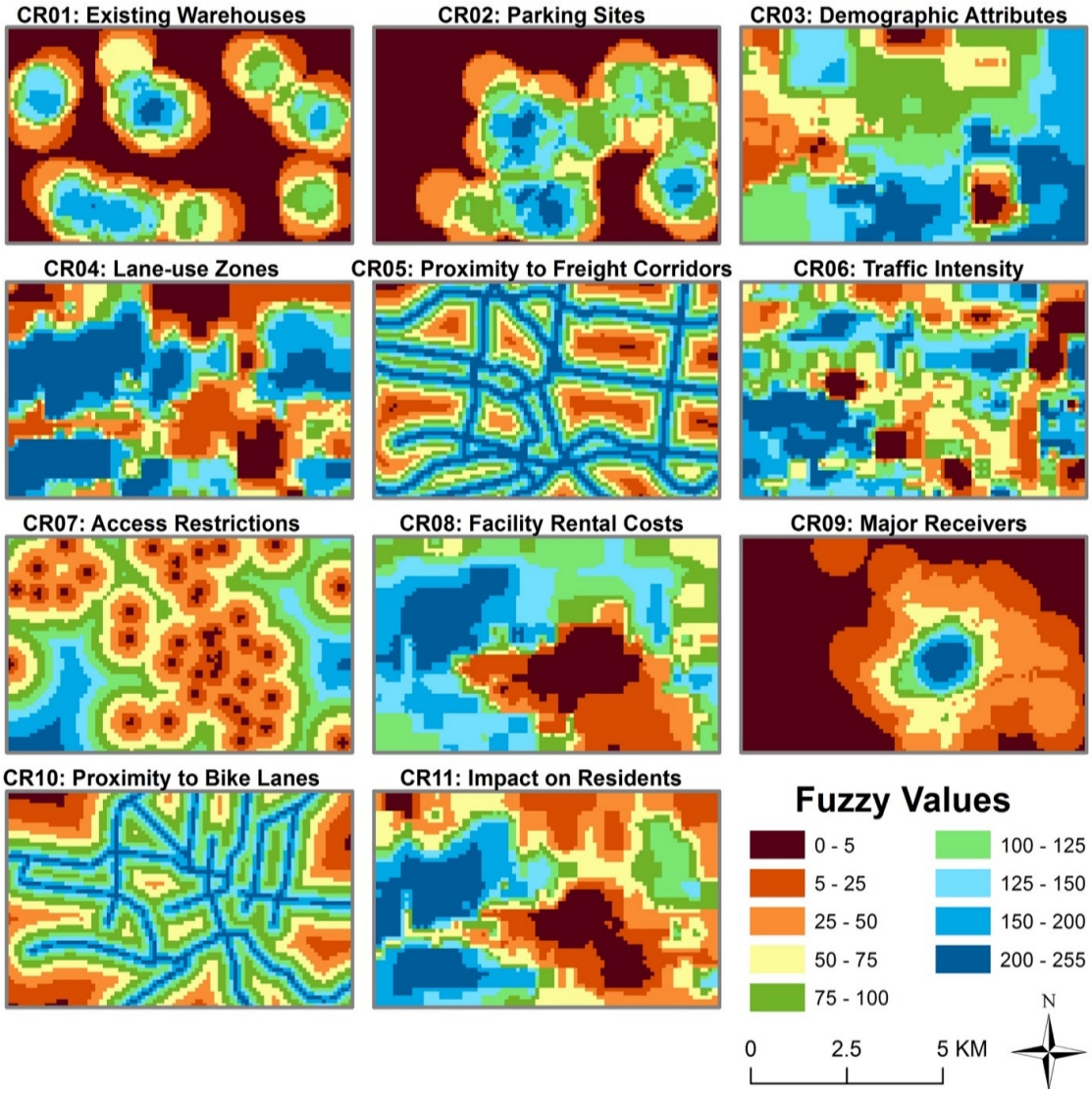


Figure 7.4. Fuzzy maps created for CR01-CR11

The final suitability map (Fig. 7.5) was created by overlaying the weighted 11 criteria maps. The suitability map shows that the most suitable locations in the study area are located in zones with affordable industrial land and superb access to receivers and major roads, which are shown in black lines in Fig. 7.5. The most suitable parts to establish the consolidation facility are in the north-western parts of the study area (West Melbourne and North Melbourne suburbs) and south-western parts (Port Melbourne). All these areas have quite a few very affordable industrially-zoned land lots with superior accessibility to major freight corridors. Furthermore, the industrial suburbs of West Melbourne and Port Melbourne include many operational warehouses from many light industries. Port Melbourne also includes many depots of express couriers. West Melbourne houses many small distribution centres and storage facilities for large freight carriers that depend on the nearby Port of Melbourne.

On the other hand, Fig. 7.5 shows that the south-eastern area is the least suitable region to establish the consolidation facility. This area includes the Melbourne's CBD, Docklands and Southbank. This could be attributed to the negative influences of traffic

congestion, high rental price, and population density. Moreover, East Melbourne and South Yarra have high facility rental costs and many parks, making this area unsuitable for establishing a consolidating facility. Another unsuitable pocket is located on the top northern parts of the study area. These areas are filled with highly populated residential zones, sensitive land-use zones (parks, public-use zones, health and education precincts) and have limited industrial facilities.

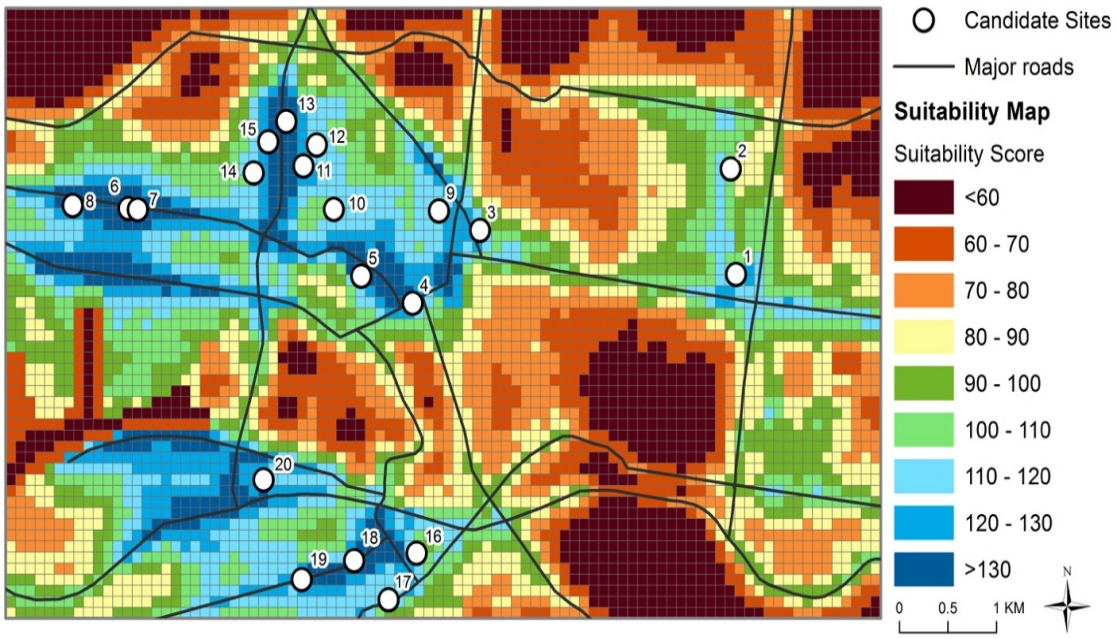


Figure 7.5. The Generated Final Suitability Map for the Optimal Locations of the Consolidation Facility in the Study Area with the Identified Candidate sites

We further removed any potential sites that fell within defined sensitive areas such as watercourses, pedestrian zones and parks through examining a high-resolution satellite image of our study area. Subsequently, we identified the top 20 candidate sites, which are shown in Fig. 7.5, with 18 clustering in the western and only two in the eastern parts of our study area. Thirteen of the candidate sites are located in the north-western part of the study area. The predominance of suitable locations on the western part of the map reflects the higher weighting by stakeholders on lower rental costs (CR08) and larger road network connectivity (CR09). The clusters of the candidate sites in the north-western and south-western regions mimic the patterns observed for CR01 (higher density of existing warehouses/distribution centres) as shown in Fig. 7.4.

7.2.4. Evaluation and Ordered Ranking of Identified Candidate Sites Using the TOPSIS Method

The 20 unranked candidate locations shown in Fig. 7.5 were evaluated and ranked using the TOPSIS method. A decision matrix containing the criteria values for each criterion was defined and then normalised. The positive-ideal solution (PIS) and negative-ideal solutions (NIS) were calculated, and the Euclidean distance of each alternative to these ideal solutions was calculated. Finally, the alternatives are ranked based on their relative closeness to the ideal solution. The weighted normalised decision matrix for the candidate

site locations is provided in Table 7.1. The PIS and NIS for each candidate site were calculated. These scores were then used to calculate the performance score and subsequently the ranking of the sites (Table 7.2).

Table 7.1. Weighted normalised decision matrix for the 20 candidate sites

	Criteria										
Site	**CR01**	**CR02**	**CR03**	**CR04**	**CR05**	**CR06**	**CR07**	**CR08**	**CR09**	**CR10**	**CR11**
S1	0.3005	0.1071	0.1715	0.1453	0.1605	0.2177	0.2032	0.4250	0.6048	0.1243	0.1367
S2	0.1493	0.1032	0.1783	0.1003	0.7967	0.1787	0.2212	0.5172	0.1077	0.2385	0.0618
S3	0.1538	0.1109	0.2276	0.1172	0.0586	0.1405	0.1151	0.5685	1.0084	0.0226	0.1312
S4	0.3195	0.1403	0.1459	0.1585	0.0440	0.2423	0.0990	0.3923	0.6335	0.1526	0.1559
S5	0.4641	0.1742	0.1610	0.1657	0.1164	0.2551	0.1061	0.3859	0.4183	0.2334	0.2039
S6	0.4189	0.0323	0.1726	0.1996	0.1872	0.1510	0.1502	0.3632	0.1507	0.0317	0.2519
S7	0.4130	0.0369	0.2406	0.2012	0.1068	0.1355	0.1547	0.3626	0.2091	0.0151	0.2573
S8	0.0488	0.0077	0.0751	0.1676	0.3776	0.2507	0.0570	0.3786	0.0285	0.0364	0.1885
S9	0.3296	0.0993	0.2040	0.1712	0.3309	0.2218	0.1239	0.5094	0.8616	0.0121	0.1657
S10	0.2493	0.1065	0.1172	0.1242	0.5598	0.2640	0.0322	0.4530	0.1155	0.1520	0.1542
S11	0.2259	0.0473	0.1290	0.1637	0.3814	0.1869	0.1106	0.4028	0.1108	0.0510	0.1644
S12	0.1235	0.0303	0.1256	0.1576	0.6193	0.2100	0.1295	0.4048	0.0594	0.2065	0.1504
S13	0.1788	0.0243	0.2004	0.1323	0.0488	0.1312	0.1448	0.3767	0.0666	0.0131	0.2059
S14	0.0665	0.0217	0.2044	0.1265	0.7064	0.1530	0.1303	0.3744	0.0533	0.0661	0.1392
S15	0.1083	0.0228	0.1157	0.1479	0.2910	0.1303	0.1378	0.4058	0.0369	0.1599	0.1514
S16	0.2792	0.1567	0.2869	0.1254	0.1172	0.1618	0.0455	0.4929	0.6295	0.1013	0.1398
S17	0.0658	0.1027	0.2492	0.1075	0.2130	0.2062	0.1299	0.5210	0.0640	0.2805	0.0847
S18	0.4176	0.1029	0.2808	0.1635	0.0446	0.1360	0.1102	0.4294	0.1692	0.1278	0.1515
S19	0.2105	0.1085	0.2691	0.1374	0.0426	0.2077	0.1002	0.5052	0.1073	0.0766	0.1563
S20	0.2219	0.0598	0.2587	0.1450	0.2848	0.1638	0.1408	0.4609	0.0571	0.1021	0.1365

According to the results of the TOPSIS calculations as shown in Table 7.2, candidate site 5 had the highest performance score (0.751) is the most suitable site for a potential consolidation facility followed by candidate site S7 (0.712) and candidate site S6 (0.680). The 5 most suitable sites according to the TOPSIS baseline rank are: S5, S7, S18, S6 and S4 respectively. Conversely, candidate site S2 had the lowest performance score (0.185) and is considered the least suitable location. Candidate sites S11, S12, S16 and S17 complete the list of the 5 least suitable sites.

As all the candidate sites were identified in the most suitable parts in study area, it is important to note that the scale of comparison in this section (higher or lower) for any criterion is only between the candidate sites not the entire study area. Lower real estate costs combined with proximity to major receivers in the city centre and proximity to major road networks played the biggest influence on the high ranking of candidate site S5. These criteria (CR08, CR09 and CR05) were the 3 most highly weighted in determining the hierarchy of decision criteria (Fig. 7.3). The high ranking of candidate sites S7 (Rank 2) and S6 (Rank 4) could be explained by low real estate costs, proximity to major roads and proximity to existing warehouses in the area. Candidate sites S6 and S7 are clustered together. Candidate site S18 is ranked 3th best. The high ranking for this

site may be due to proximity to major roads and warehouses as well as lower traffic intensity. Alternatively, candidate site S4 (Rank 5) shared similar suitable spatial attributes to candidate site S4 and are also clustered together. Candidate site S5 is ranked higher than candidate site S4 because of its more favourable spatial position to major receivers.

Conversely, candidate site S2 is the least suitable site. It is located in north-eastern part of the study area where it is in close proximity to residential zones with higher traffic intensity and inferior accessibility to major roads. The other least suitable sites tend to show clustering patterns. Sites S11 and S12 are in highly populated zones with higher traffic intensity and inferior proximity to major receivers while sites S16 and S17 are in areas with relatively higher facility rental prices and inferior access to major receivers.

Table 7.2. Final Ranking of the candidate sites using TOPSIS Method

Candidate Site	S^+	S^-	Performance Score	Rank
S5	0.049	0.105	0.751	1
S7	0.082	0.093	0.712	2
S18	0.088	0.090	0.680	3
S6	0.087	0.092	0.626	4
S4	0.068	0.089	0.605	5
S19	0.097	0.078	0.566	6
S20	0.101	0.087	0.531	7
S9	0.043	0.106	0.515	8
S3	0.104	0.063	0.503	9
S13	0.043	0.128	0.463	10
S15	0.109	0.070	0.445	11
S10	0.110	0.079	0.418	12
S8	0.117	0.054	0.392	13
S1	0.056	0.086	0.379	14
S14	0.102	0.058	0.361	15
S17	0.055	0.092	0.316	16
S16	0.111	0.042	0.276	17
S11	0.121	0.031	0.229	18
S12	0.125	0.037	0.205	19
S2	0.127	0.029	0.185	20

where: S^+ is the separation of the candidate site from the ideal best solution, S^- is the separation of the candidate site from the ideal worst site location.

7.2.5. Sensitivity Analysis

In the analysis above, multiple criteria and different weights were considered to identify the candidate sites. Both subjective and objective attributes were considered in this process. We adjusted the criterion weights in the three scenarios (Table 7.3) to identify the factors that most significantly influence the stability of candidate sites' rankings and test the robustness of the process and the confidence in the outcome as follows:

- In the 1st scenario, we placed higher emphasis on the importance of the criteria that are critical to the operations of freight industry stakeholders. As a result, weights of relevant criteria (CR01, CR05, CR08 and CR09) were increased and other criteria were assigned lower weights.
- In the 2nd scenario: we placed higher emphasis on the societal criteria (CR02, CR04, CR06 and CR11) that represent the environmental and social concerns of the local authorities and residents. These four criteria were assigned with higher weights and other criteria with lower weights.
- In the 3rd scenario, we assume all the criteria should be equally considered and therefore equal weights were assigned to each of the criteria.

Weights are adjusted within the following constraints:

- No decision criterion would have a 0% or a 100% weight.
- Weight adjustment started from the most important criterion for the respective stakeholder group and the aim mentioned in the scenario followed by the other important criterion that reflected the goal of the scenario.
- Weights were only moderately increased or decreased (less than 10%) to ensure changes were applied to all important criteria in the scenario to reflect their importance.

Table 7.3. Decision criteria weights used in the sensitivity analysis

Decision Criteria	**Criteria Weights (%)**			
	Baseline	**Scenario 1**	**Scenario 2**	**Scenario 3**
CR01: Warehouses	11.99	13.97^{+}	10.00^{--}	9.09
CR02: Parking locations	4.17	2.00^{--}	10.00^{+}	9.09
CR03: Demographic attributes	2.98	1.00^{--}	2.98	9.09
CR04: Land-use zones	1.68	1.68	11.61^{+}	9.09
CR05: Major roads	15.97	20.08^{+}	10.00^{--}	9.09
CR06: Traffic intensity	8.60	8.60	10.60^{+}	9.09
CR07: Access restrictions	3.32	3.32	3.32	9.09
CR08: Facility rental costs	19.71	23.00^{+}	10.00^{--}	9.09
CR09: Major receivers	18.06	22.35^{+}	8.00^{--}	9.09
CR10: Bike lanes	6.11	2.00^{--}	8.11^{+}	9.09
CR11: Impact to residents	7.41	2.00^{--}	15.38^{+}	9.09

+ indicates the weight of the criterion was increased in the scenario compared to baseline.

- indicates the weight of the criterion was decreased in the scenario compared to baseline.

The TOPSIS model was re-run to produce the performance scores and determine the ranking of each candidate site in the respective scenario. The ranks of each candidate site in the three scenarios are shown in Fig. 7.6 together with the baseline rank shown in Table 7.2. The ranks for each site were compared to identify whether weight changes in each scenario had any bearings on the ranking outcomes for the candidate sites. The black vertical line indicates the average rank for the candidate sites across the four scenarios.

It was seen that the rank for the least suitable sites, which are candidate sites S2, S12, S11 and S17 (rank 20,19,18, 17) remained almost unchanged under all scenarios. However, ranks for candidate sites S1, S3, S4, and S16 considerably improved under Scenario 1, indicating these sites are more sensitive to the operational requirements of freight carriers. The most significant rank changes were found for candidate site S4, of which the rank jumped from 5th to 1st, and candidate site S3, of which the rank jumped from 9th to 3rd. Sites S3 and S4 offer very excellent connectivity to major receivers and roads. Similarly, the jump of site S9's ranking from 8th to 6th could be attributed to this reason. Moreover, ranks of candidate sites S1 and S16 were improved from 14th to 8th and 16th to 10th, respectively. Improved ranks of these sites in Scenario 1 may be because they are close to major roads and existing warehouses, which significantly reduce operational costs, as well as the lower weights assigned to impact on residents. Although candidate sites S6 and S7 were ranked highly in this scenario, their rankings were lower than the baseline rankings due to the longer distance to major receivers. On the other hand, the ranking of candidate sites S13 and S19 experienced the highest drop compared to their baseline ranking. The ranking of candidate sites S10 and S14 did not change. The sensitivity analysis of Scenario 1 identified the following as the top 5 most suitable sites: S4, S5, S3, S18 and S7 respectively. The superior access to major roads, receivers and warehouses of these sites is beneficial to the efficiency of the consolidation facility operators and freight carriers, which compensates for the relatively high rental cost in these areas.

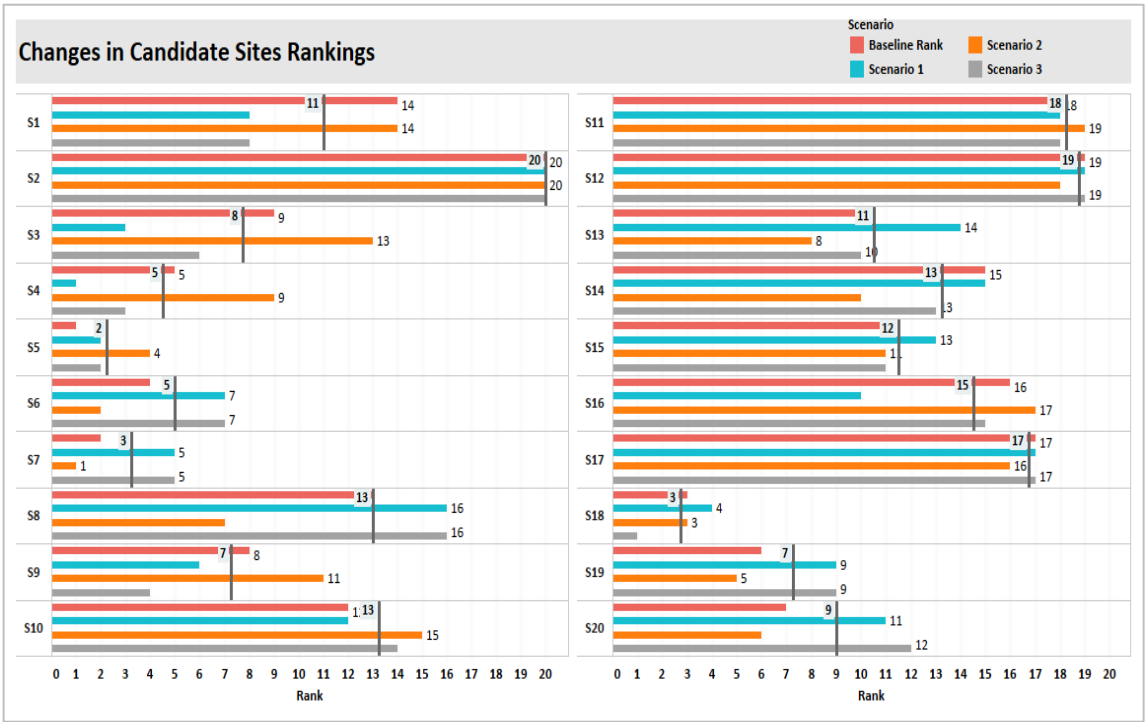


Figure 7.6. Rankings for Candidate Sites for the baseline and sensitivity analysis scenarios based on the TOPSIS calculations

Sensitivity analysis of Scenario 2 revealed the following as the top 5 most suitable sites: S7, S6, S18, S5 and S19 respectively. These sites are located in industrially-zoned land away from highly populated areas. This highlights the high concerns of local authorities and residents toward the consolidation facility being close to residential areas. The most significant rank change was found for candidate site S8, as its rank jumped from 13th to 7th. This could be explained by the lower weights assigned to connectivity to receivers and roads as well as the higher weight assigned to land-use zones. Similarly, the ranking of candidate site S14 improved from 15th to 10th, which could be attributed to the higher weights assigned to land-use zones and impact on residents. However, ranks of the majority of other sites in Scenario 2 were very similar to their baseline ranks. This indicates that, for the other candidate sites, the increased weights on social and environmental factors have no significant impact on the ranking, highlighting that these criteria might have lower impact on the rankings. Conversely, rankings of candidate sites S3, S4, S5 and S9 dropped in Scenario 2 due to their proximity to populated neighbourhoods, again showing the possible slightly negative attitude towards the consolidation facility from residents.

Scenario 3 identified the following as the top 5 suitable sites: S18, S5, S4, S9 and S7 respectively. The rankings of site S9 in this scenario is higher than the baseline rankings and is identical to its ranking in Scenario 1. This higher ranking could be explained by the lower weight assigned to facility rent and higher weights assigned to parking infrastructure and demographic attributes as these sites are very close to the CBD area. Ranks of other sites under Scenario 3 changed in comparison with the baseline ranking in response to the changed weights. Furthermore, the discrepancy of the rankings between Scenario 3 and Scenario 2 were much higher. This highlights the shortcomings of location studies of logistics facilities that assume equal weights of the decision criteria as this notion of equal weights overlook the heterogeneous nature of stakeholders' priorities and perspectives.

The results from the sensitivity analysis also indicate the confidence in the baseline rankings of the top suitable sites in the three scenarios. Furthermore, increased weights of the criteria concerned with accessibility (CR01, CR05 and CR09) from originally (46.33%) to 51% in Scenario 1 contributed to the most significant changes of the ranking of several candidate sites across the three scenarios. The results of the sensitivity analysis indicate that increasing the weights for the operational criteria and decreasing the weights for proximity to residential areas increases the rankings of sites located in areas with low real estate costs and more industrially-zoned parts, which are in favour of freight operation. As a result, the sensitivity analysis thus provides valuable insights for decision-makers and transport researchers on which criteria are more dominant or not important at all on the final ranking of candidate sites.

Further analysis was performed to rank candidate sites according to the travel distance and time to delivery zones of major receivers in the study area. The aim was to highlight the shortcomings of the studies that dedicated higher weight to transport distance to receivers on the evaluation and selection of the most suitable location for consolidation facilities. Fig. 7.7 displays the average travel distance and time between each candidate site and busy delivery zones that include many receivers in the study area. The abbreviated names of the delivery zones are shown in the figure legend, e.g. CBD NE indicates a delivery zone in northern part of the CBD area while CBD C1 indicates a

delivery zone in the central part of the CBD. The size of the circle in the chart area indicates the travel time in minutes between the candidate site and the delivery zone. The travel distance and time displayed in the figure reflect actual traffic conditions acquired from local geographic datasets for delivery trips between the candidate site and each delivery zone in the study area. According to Fig. 7.7, the top five candidate sites with the shortest overall transport distance are S3, S9, S4, S5 and S10 whereas the worst five candidate sites are S19, S20, S7, S6 and S8. These are based on estimated travel distance between the candidate site and the 20 delivery zones. While sites S7 and S6 have been ranked consistently high in the baseline and three sensitivity scenarios, they would be excluded from the top list of candidate sites if the decision-making was primarily influenced by the transport distance. Ranking and selecting the top candidate site entirely based on transport-related factors produced a completely different list for the top and worst candidate sites compared to the GIS-based analysis framework. This fails to capture and include the geographical and spatial relationships between key transport nodes as well as the dynamics of logistics land-use and commercial property costs in the selection of the most suitable sites.

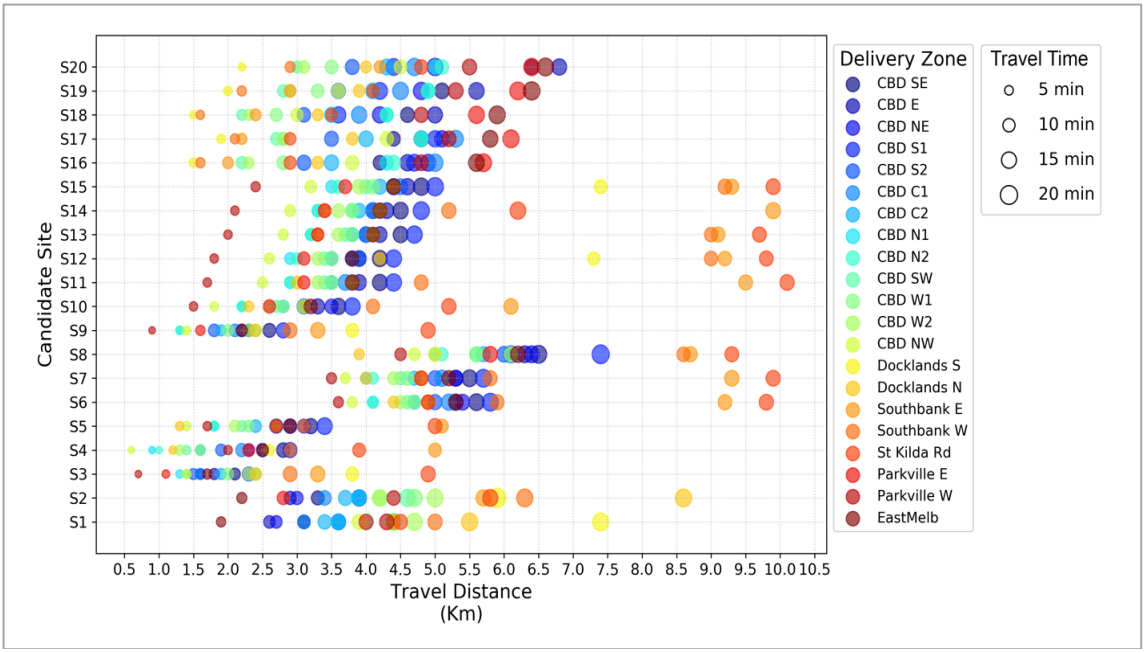


Figure 7.7. Travel Distance and Time Between the Candidate Sites and Major Delivery Zones in the Study Area

7.3. Discussion and Policy Implications

7.3.1. Discussion on the Most Suitable Locations for the Consolidation Facility in the Inner-city

The siting of the consolidation facility in the inner-city represents challenges for site optimisation due to the limited availability of low-cost industrial lands and clustering of residents. The ideal location sites need to maximise favourable criteria such as lower costs (thus maximising profits) while minimising environmental and social negative impacts such as being far enough away from residential areas to not cause a nuisance. The results

of the suitability analysis confirm that the optimal location of the consolidation facility should not be selected based on one individual criterion as the fuzzy criteria maps shown in Fig. 7.4 illustrate different suitability for each criterion, but rather a holistic decision as shown in Fig. 7.5.

On the question of the optimal location for the consolidation facility, the results indicate that most suitable sites in the study area are located in the zones with affordable industrial lands and with superb access to major roads and receivers. Additionally, two potential development nodes were identified in the western part of the study area, which are highly suitable for the consolidation facility (Fig. 7.5). Furthermore, the changes in the rankings of some candidate sites due to the higher or lower weights of the decision criteria between the three scenarios in the sensitivity analysis further illustrated the difficulty of reaching consensus among all stakeholders on the ranking of the optimal location. Alternatively, the optimal site location is the one that addresses the operational requirements of freight carriers and the social and environmental concerns of local authorities and residents in a balanced and reasonable approach. Hence, the sensitivity analysis corroborates that candidate sites S5, S18 and S7 are considered as the most robust and suitable sites and show little change in their ranks under all scenarios compared with the baseline as shown in Fig. 7.6.

In this study, the identified candidate sites were determined in the most suitable area as a result of the suitability analysis and their ranking scores unlike many similar location studies whereas the alternative locations were proposed by the decision-maker early in the evaluation process (Chen et al. 2014; Muñoz-Villamizar et al. 2014). Furthermore, the priority weights assigned to the decision criteria (Fig. 7.3) revealed somewhat contrasting preferences as compared with previous studies of urban consolidation centres. For instance, the facility rent cost (CR08) is considered the most important criterion (19.71%) in this study whereas it is reported as the 4th most important in the Bangkok study (Amchang and Song 2018) and the 2nd most important in Yogyakarta, Indonesia (Sopha et al. 2016).

Another contrast is observed when comparing the criterion weights from the geographical context of the facility – inner-city area (this study) versus suburban parts (freight villages and logistics centre studies). For instance, the impact on residents (CR11) is the 6th most important criterion (7.41%) in this study whereas it is reported as the 2nd most important (12.8%) in the Ankara study (Özceylan et al. 2016). Similarly, the proximity to major freight corridors (CR05) is the 3rd most important criterion in this study whereas it is reported as the top most important criterion in the Istanbul study (Yıldırım and Önder 2014). While these criteria were assessed by different stakeholders in different geographical settings; however, the different ratings indicate how the importance of these criteria could be perceived differently between the dense inner-city area compared to the wider metropolitan area. Moreover, this study included a comprehensive and suitable list of decision criteria for the dense and challenging inner-city that could be quantified and converted into a continuous surface in GIS using real geographic values. Some previous studies incorporated many qualitative decision criteria such security, labour conditions and conformance to government regulation (Rao et al. 2015; He et al. 2017; Amchang and Song 2018) in the MCDM evaluation. Such qualitative decision criteria could also be appropriately quantified in GIS and then subsequently included in the GIS-MCDM decision-making process.

Furthermore, the fuzzy weighted overlay process in GIS in this study facilitated assigning different criteria values and generating different evaluation scores for candidate sites that are very close to each other. This is extremely important when it is necessary to differentiate highly suitable sites from low suitable sites that are located within the same micro-zone in the study area. This is of great value in location studies for the inner-city area with highly compact zones and with various and competing decision attributes. For example, candidate site S14 has a lower baseline rank (15) compared to candidate site S13 (Rank 10) or S15 (Rank 11) even though they are located next to each other. This could be attributed to the higher density of warehouses as well as the closer distance to major roads and receivers, which contributed to a higher-ranking score for candidate site S13 compared to site S14. Similarly, the closer distance to major roads and lower population density in the grid of candidate site S15 resulted in a higher ranking compared to site S14.

The integration of GIS with fuzzy MCDM in this study produced an optimal location for the consolidation facility that achieved a more robust balance of the economic, operational, spatial and environmental requirements, which address the shortcomings and limitations of other approaches. For instance, the decision-making for the optimal location in the accessibility framework proposed by Olsson and Woxenius (2014) was fundamentally based only on the minimisation of travel time from the UCC to customers in Gothenburg, Sweden. Moreover, the AHP-based approach applied by Amchang and Song (2018) was more of an upper-level macro-analysis approach to identify the most suitable part for the UCC in Bangkok based on mainly operational criteria rather than determining exact location for the facility. Alternatively, the key premise of the optimal location in the optimisation model developed by Muñoz-Villamizar et al. (2014) was on selecting the location of the UCC that minimise the total cost/distance of the delivery routes to serve the customers without considering the objectives of other stakeholders.

7.3.2. Implications of the GIS-MCDM Framework for Siting Consolidation Facilities in the Inner-city

Gathering insights on suburban and inner-city context with respect to siting of logistics facilities support local transport decision making. However, transport researchers need to combine the data in ways that allow systematic site evaluation and comparison. This section describes methodological lessons learned and applied in this study that can guide site selection in future studies.

The impacts of logistics facilities on the built environment and society extend over a larger spatial extent than the physical location of the facility itself. In line with greater focus on sustainability and mobility, land use planning and allocation is the arena in which urban planners and policy makers exert their control and power to address the negative externalities caused by last mile delivery especially in the increasingly high-dense and congested inner-city area. However, conventional decision-making approaches of location studies for logistics facilities fail to accurately reflect and consider the complex interactions between land-use, freight movements and transport infrastructure. Moreover, it could be argued that the high reliance on numerical computation and disregard for spatial and land-use focus in the conventional approaches often result in location selection for the logistics facility that overlook the critical factors that influence freight trips and may not be optimal for all stakeholders involved in last mile freight.

The land use zoning regulations set by local authorities for the designation of public land especially in the inner-city directly influence the affordability and availability of industrial land for logistics facilities and act as push factors that affect where logistics facilities could be established. Moreover, local authorities could build on the insights outlined in this study for improved integration of freight transport and land-use planning to select the most suitable locations to preserve industrial lands for future consolidation facilities in the highly expensive inner-city. This could help offset the negative impacts of logistics sprawl, i.e. relocation of logistics facilities to suburban parts due to lack of industrial land in inner-city, by allocating industrial land in optimised location that could address the trade-off between limiting inefficient freight vehicles and increasing transport distance to reach customers in the inner-city. Moreover, local authorities could use the integrated approach as a lobbying tool to justify setting public policies that support establishing and operating freight consolidation facilities in the inner-city area. Residents have their opportunities in the consensus-led decision-support approach to express their concerns through the societal decision criteria about the site selection process and results.

The logistics real-estate providers can also use it to appraise the best optimal locations to invest and build suitable logistics facilities that might attract freight carriers and receive local government approval. The focus on the compatibility of the consolidation facility with sensitive surrounding uses in the location selection would enable the logistics real-estate industry to address the sustainable development concerns in their future property projects. More importantly, GIS models also make it possible to allow the freight industry to confirm whether a candidate site actually meets the business needs in terms of available size of the facility and operational requirements, if consolidation facility is actually built up. For instance, other optimisation approaches could indeed select an optimal location for the logistics facility with respect to transport distance or coverage. However, the layout of the surrounding roads and streetscape around the facility may not be operationally optimal whereas the GIS models enable satellite imagery to visually assess the operational environment of the candidate site. It is worth to mention that although it seems GIS models could be easily used as a tool to support the decision-making process, it is extremely important to ensure that all criteria are converted to GIS data layers without any spatial or thematic errors. Accordingly, the interdisciplinary collaboration between spatial modelling and urban freight experts should be strongly advocated so that the spatial decision support systems can expand their applications toward another field and the freight industry experts can be assured that location selection of the logistics facility is encompassing of all operational requirements.

More importantly, GIS also makes it possible to allow the freight industry to determine whether a candidate site actually meets the business needs in terms of available size of the facility, as well as the potential impacts on the local communities and business if consolidation facility is actually built up. It is worth to mention that though it seems GIS could be easily used as a tool to support the decision-making process, it is extremely important to ensure that all criteria are translated to GIS data layers without any spatial and thematic errors. As a result, the interdisciplinary collaboration between GIS and urban freight experts should be strongly advocated so that the GIS can expand its applications toward another field and the freight industry experts can be assured that the way they use GIS is scientifically solid.

7.4. Chapter Summary

The location of a consolidation facility critically impacts the costs and efficiency of the bundling and distribution operations. Locations too far from receivers and truck routes lead to long transport distances, high operational costs, low revenue per kilometre driven, and reduced operational capacity due to inefficient use of vehicles and drivers. Locations too close to populated or ecologically sensitive neighbourhoods often result in high mitigation costs or community rejection. Most previous facility-location studies have focused on consolidation facilities in suburban areas. This study uniquely addresses siting interests for inner-city consolidation facilities.

In accordance with the 3rd objective of the research project, this chapter analysed the application results of the multi-criteria spatial approach to identify and rank suitable locations for the proposed consolidation facility in the inner-city area. The findings of the spatial analysis and sensitivity analysis answers *Research Question #5* and confirm that most suitable candidate sites are candidate site S5, S18 and S7 as they are located in zones with relatively affordable industrial land and superior accessibility to major freight corridors and receivers in the inner-city area. The investigation of the optimal location for the consolidation facility has shown that while transport-related decision criteria are critical in the suitability of the location; however, freight landuse-related factors considerably influence the operational environment and suitability of the location especially with respect to affordability of the land and impact on sensitive surroundings.

The dense and congested inner-city inherently contains many people and many conflicting land uses near each other. The complex environments of the inner-city area require consideration of multiple and comprehensive criteria to reflect the various and conflicting views and objectives of all stakeholders when it comes to siting of consolidation facilities. The findings of the study highlight the challenges of identifying optimal location for the facility in the inner-city area as adjoining zones display completely different values of the decision criteria that complicate the decision-making of location selection. Selecting where to place a consolidation facility in the inner-city requires multiple levels of consideration due to the limited availability of low-cost industrial land and clustering of residents. The 4th stage of the integrated framework addressed the limitations of existing location studies of consolidation facilities by incorporating geographic datasets and fuzzy spatial modelling in the location selection process.

Because the stakeholders and their concerns come from the public and the public sector, a profit-oriented logistics operator cannot be expected to take on such effort. Economic-development planners in public agencies and chambers of commerce can take a proactive role in engaging stakeholders. This consensus-led decision-support framework can help formulate and justify incentive policies to attract logistics operations with the employment and tax base they represent. Urban planners can use the resulting findings to formulate freight land-use policies and guidelines to allocate industrial land for logistics facilities. Public agencies can then share data on stakeholder interests with logistics operators considering locating in the jurisdiction. A consolidation facility can fit well in a dense inner-city area, but the importance of sound site selection increases with neighbourhood complexity and the number of people affected. Although logistics operations bring neighbourhood challenges, commerce stops without logistics facilities. Properly siting a logistics facility to serve private and public interests will help all stakeholders maximise positive outcomes and mitigate neighbourhood challenges.

There are a few limitations of this study that should be noted. It is still a challenge to include all relevant decision criteria in the site selection process and further studies can expand the decision criteria by incorporating input for other stakeholders such as shippers and receivers. Another limitation could be the lack of operational metrics included to compare the reduction in environmental emissions between the candidate sites. It is also important to extend the multi-criteria approach to improve the confidence in the site selection results by applying other fuzzy MCDM techniques in the evaluation and ranking of the candidate sites in the last stage of the presented framework. More geoprocessing tasks in GIS models can be undertaken on the optimal site(s) to further consider any other constraints that may be missed in the site selection process. For example, network analysis could be performed on an existing consolidation facility to investigate its routing schemes to minimise the transportation cost and thus maximise potential profits. Moreover, the insights on the optimal location for the consolidation facility acquired by the GIS-MCDM in this study could be further extended by combining agent-based modelling and vehicle routing problem techniques. The integration of these models could further optimise the delivery routes of the consolidated delivery trips to receivers based on simulation of the behavioural interaction and perceived objective values between agents involved in the consolidated delivery service (the facility operator, freight carriers, receivers, local authorities and citizens).

Chapter 8.

5th Stage: Examining the Financial Viability of the Central-city Consolidation Facility

8.1. Introduction

The current literature on consolidation facilities have proven these facilities to be effective from both a social and environmental perspective as they deliver various benefits to the urban environment and society. However, it is necessary to also examine the consolidation initiative from the business perspective to assess its effectiveness and ability to create a business value for the stakeholders. The value propositions of the consolidation initiative need to be systematically evaluated in the early stage of planning prior to implementation of the concept. This is very critical in determining the long-term success and financial viability of the consolidation policy. Lack of utilisation of business models in the assessment of freight consolidation initiatives, which have been overlooked in previous studies as highlighted in Section 2.3.5, contributed to the failure of various consolidation initiatives as summarised in Section 2.3.6.2. Accordingly, this chapter analyses and discusses the application and results of the two-phase ex-ante profitability approach to examine the financial viability of the proposed consolidation facility.

The sections of this chapter are described below:

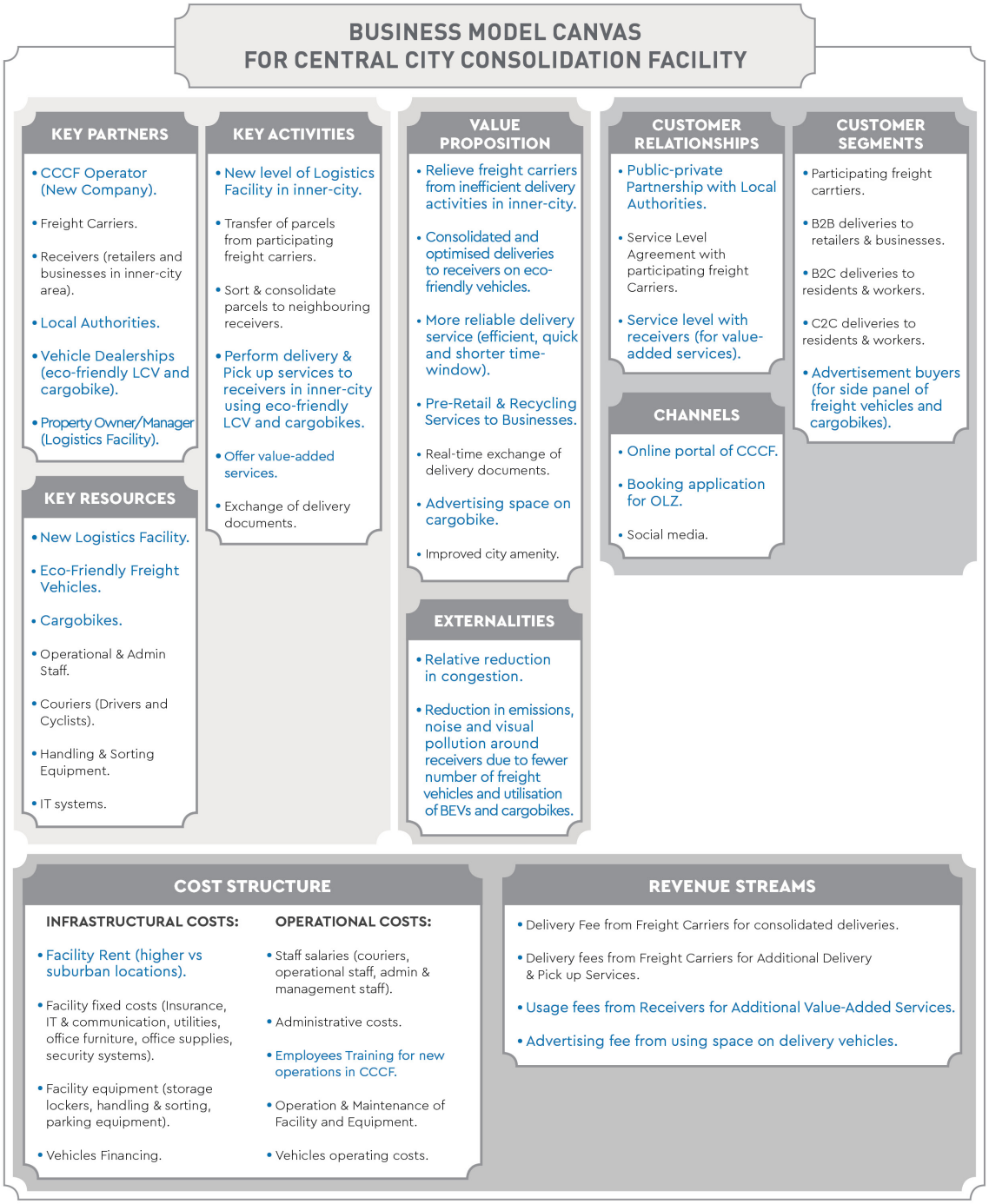
- Section 8.2 analyses the results of the business modelling using the Business Model Canvas (BMC) to assess the potential value propositions for the stakeholders of the proposed consolidation initiative.
- Section 8.3 presents the formulation of the mixed-integer linear programming (MILP) cost model to optimise the profitability of the facility.
- Section 8.4 describes the genetic algorithm (GA) solution for the formulated MILP cost model.
- Section 8.5 presents and analyses the computation results of the GA solution to estimate the operational costs and revenues of the proposed CCCF and determine the profitability of the facility.
- Section 8.6 discusses the findings and implications of the profitability assessment.
- Section 8.7 provides a concluding summary of the chapter including the study limitations and future research directions.

8.2. Assessing the Business Model of the Proposed Freight Consolidation Policy

The proposed consolidation initiative was evaluated using the principles of the Business Model Canvas (BMC), which was developed by Osterwalder and Pigneur (2010), to analyse the expected changes in key business and operational aspects and assess how these changes could contribute to improved value propositions for the stakeholders. Fig. 8.1 summarises the results of the business modelling for the proposed consolidation initiative.

Firstly, we examined the operational aspects of the consolidation scheme (left block in Fig. 8.1). The consolidation facility adds a new layer of logistics facilities in the shipper-freight carrier-receiver freight network. A new and significant player is added as the consolidation facility operator. Hence, operations of the delivery and pick-up activities to receivers are changed. Most commercial facilities in the inner-city are usually leased for other commercial uses such as a showroom or parking. Commercial property providers scarcely offer to lease facilities in the inner-city for warehousing activities as they could capitalise the return on investment by leasing them for other profitable commercial uses. Thus, commercial property owners are an important partner in the operational aspects and are involved here to ensure providing a suitable logistics facility for the operator of the consolidation initiative. The facility operator needs to also consult with IT systems providers to select the right information system to integrate and operate the warehouse system management, hand-held devices for couriers, online portal for the consolidation service and booking application for the dedicated on-street loading spaces. The in-bound transfer of parcels from participating freight carriers involves and requires efficient and high level handling and sorting of incoming parcels into trolleys designated for delivery zones. Moreover, the value-added services that would be offered by the facility operator also add more complexity to the in-house operational staff and couriers to ensure matching requested services to each receiver. The focus on eco-friendly freight vehicles results in acquiring new types of freight vehicles to perform the consolidated deliveries. Hence, the facility operator needs to consult with vehicle dealerships for battery-electric delivery vans and electricity-assisted cargobikes.

Secondly, we examined the changes that might occur to the customers involved in the proposed consolidation initiative (right block in Fig. 8.1). The consolidation initiative will not involve significant changes to the customers (participating freight carriers and receivers) as it is essential to preserve the current commercial agreements between these stakeholders. Although the participating freight carriers will not deliver directly to receivers, the facility operator will ensure maintaining the same delivery practices to receivers and a seamless sharing of delivery status updates. Receivers might notice some slight changes such as deliveries by cargobikes. Furthermore, receivers will be dealing with different couriers working for the facility operator than the original freight carriers. Thus, there might be some lost personal relationships or knowledge here. Receivers will be notified of delivery status updates using the IT system and booking application in more real-time status. Moreover, the public-private partnership between local authorities and facility operator introduces a new customer relationship in the proposed consolidation initiative as certain sustainable and societal concerns will be imposed on the operations of the consolidation scheme. The facility operator could offer the side panel of the BEVs and cargobikes for buyers advertising as the facility vehicles would offer an advertising opportunity visible to residents, workers and shoppers in the city centre.



*Legend: The elements that would be affected by the CCCF are highlighted in **blue**.*

Figure 8.1. Results of Business Modelling using Business Model Canvas for Evaluation of the CCCF

Thirdly, the value propositions (middle block in Fig. 8.1) of the consolidation initiative were investigated to determine if the previously mentioned changes would contribute to business improvements for stakeholders. Avoiding deliveries in the inner-city could be beneficial to participating freight carriers as they could better utilise their inefficient freight vehicles in other less congested parts of the urban area. The consolidated delivery

service would contribute to more reliable and efficient delivery and pick up services for receivers. Moreover, deliveries on cargobikes could be very useful and quick for urgent deliveries. Receivers could benefit from the time-specific deliveries to better manage the in-store processing of their deliveries. The temporary storage service could be beneficial to retailers with limited in-store areas. Other services such as unpacking & waste removal or product quantity & quality check could be cheaper for receivers to be conducted by the consolidation facility than premium retail spaces, which are more expensive with higher wages. The facility operator could capitalise on the added-advantage of the facility location with respect to accessibility to residents and small businesses in the inner-city to perform urgent and express deliveries through additional delivery services. The utilisation of BEVs and cargobikes would improve the amenity of the city centre for residents, shoppers and retailers through reduction of polluting freight vehicles.

Finally, the infrastructural and operational costs of the facility and the revenue streams (lower block in Fig. 8.1) were further analysed. There are four cost categories associated with operating and maintaining the facility as well as delivering the consolidated loads, which are the annual facility costs, annual equipment costs, annual personnel & administrative costs and annual delivery vehicles costs. The facility category includes cost functions related to the operation of the physical facility including facility rent, repair & maintenance, utilities, insurance, IT hardware & systems, office supplies and office furniture costs. The equipment cost category includes cost functions related to handling, sorting and storage of parcels including handling equipment hire (forklift and pallet jacks), equipment repair & maintenance, storage equipment, packaging materials and pallet hire. The personnel & administrative cost category covers cost functions related to remuneration of staff and costs of administrative processes such as accounting, legal, training and uniform costs. Finally, the vehicle cost category includes costs related to financing, operation and maintenance of the delivery vans and cargobikes that fall into two main groups: fixed vehicle costs (leasing, registration, insurance, tax and depreciation) and variable fixed costs (maintenance, repairs and tyres). Additionally, costs of the undelivered/returned parcels to the consolidation facility are included in the profitability estimation to ensure they are deducted from total revenue.

The four revenue streams are delivery fees from the consolidated delivery services, service fees from value-added services, service fees from additional delivery services and advertising fees. The facility operator would charge a delivery fee per parcel to the participating freight carriers. The value-added services are ancillary services and include product quality & quantity check, time-specific delivery, unpacking & waste removal, temporary storage and product return. They would be offered by the facility operator for a service fee per parcel, which would be paid by the receivers. The side panel of delivery vehicles would be offered to interested businesses to advertise their services for a service fee. Additional delivery services include the pickup-delivery (P+D) service and pick-up service. Businesses and residents would request express delivery through the P+D service to pick up light parcels from their address for delivery to other receivers inside the inner-city within a pre-defined delivery-window for a service fee per parcel. The participating freight carriers could request the facility operator through the pick-up service to collect their delivery consignments from customers in the area back to the facility where they would take them back to their facilities for final delivery. This service enables other freight carriers to avoid pick-up activities in the congested inner-city for a service fee per parcel.

Based on the business aspects discussed in the BMC analysis with the setting of the CCCF, this section further highlighted how the proposed consolidation initiative might contribute to useful value propositions for key stakeholders involved in the consolidated delivery services. Results of the business modelling were discussed with experts from local freight and retail industry to ensure the validity and relevance of the findings in assessing the business case of the consolidation initiative. Accordingly, various estimates were sourced from the local freight industry for the cost functions and revenue streams to estimate the profitability of the proposed consolidation facility using the formulated MILP cost model, which is presented in the 2nd phase of the profitability approach in the following section.

8.3. Estimating the Financial Viability of the Central City Consolidation Facility (Cost Model Development)

8.3.1. Problem Description

This study introduced stochastic optimisation into the financial viability estimation by taking into account the uncertainty in demand of the consolidation service from freight carriers. The uncertainty is presented by random parcel demand scenarios that simulate the number of parcels transferred to the consolidation facility on a given operational day. The cost model optimises the operational costs of sorting and combining the incoming parcels and performing the consolidated delivery services to maximise those revenue streams that contribute to a profitable consolidation facility. Accordingly, a mixed integer linear programming (MILP) cost model, in which four main cost categories and four revenue streams, is employed.

8.3.2. Mixed Integer Linear Programming (MILP) Model Development

Mixed integer linear programming (MILP) modelling has been used extensively to solve complex optimisation problems with discrete or continuous decisions in various engineering and transportation fields (Vielma 2015). The mathematical programming of MILP formulations seeks to find optimal values (either the minimum or the maximum value) of an objective function of a set of decision variables, which represent actions that can be taken in the problem being modelled. The limitations of the problem are considered as a set of constraints that are accounted for by restricting the decision variables to be equal to, not more than or not less than a certain numerical value (Smith and Taskin 2008). Thus, the modelling of the problem under consideration starts with defining the decision variables to represent the choices that should be optimised, followed by stating the system's constraints and defining the objective function, which assesses the quality of the solution.

There has been somewhat an increasing number of studies that presented mathematical models on the economic aspects of freight consolidation facilities. These studies examined the cost aspects from different perspectives including from the total transport cost perspective using location-routing problem (LRP) to optimise its location or delivery routes; multi-criteria decision analysis to prioritise the objectives of the stakeholders; traffic simulation to assess environmental, economic and social benefits. Most studies applied various mathematical optimisation techniques to minimise the total transportation cost and included the main cost components as a lump sum variable without specifying

what costs fall under the main cost variables. Additionally, most of the studies in the literature focused on the cost components rather than assessing the profitability of the consolidation facility. Winkenbach et al (2016) developed a MILP model to determine the cost-optimal network configuration for a profitable city distribution centre. Li et al. (2018) developed a MILP model to optimise the location of an urban distribution centre based on minimising the total costs, which includes economic, environmental and socio-economic costs. Simoni et al. (2018) formulated a MILP model to optimise the location and vehicle routing of UCC to minimise transport costs. Handoko et al. (2016) constructed a profit-maximising auction mechanism for consolidated deliveries via a UCC based on the MILP approach.

There are many cost variables associated with consolidation facilities including: *vehicle costs* including financing, insurance, maintenance, fuel; *facility costs* including rent, facility throughput, wages of operational staff operational cost of the facility; *operational parameters* including number of delivery rounds, vehicle capacity, working hours of driver, distance from the facility to customers, average stop time per stop, distance between stops (Otto et al. 2009; Kin et al. 2018). These cost components could be also classified based on the function: *the transportation cost* covers the cost to move products from one point to another, *the stop cost* represents the cost of loading and loading the products at stops, *the storage cost* includes facility rent, storage equipment and any maintenance costs related to storage of products, and finally *the waiting cost* resulting from cost of carrying the inventory over a certain period of time and the item value lost while waiting (Lin et al. 2016). Most cost models in the literature that have applied the discrete mathematical approach have paid more attention to cost components that are primarily related to the location of the facility's location. Additionally, the cost components in the economic assessment in these studies were represented as major cost blocks, without specifying and estimating the secondary cost variables that collectively make up the main cost function.

The purpose of the mathematical model in this section is to determine the most profitable facility type (size) among alternative configurations, as well as the resources (e.g. staff and number of vehicles) that optimise the operational costs and revenue of the proposed consolidation facility. All the decision-making processes are subject to the uncertain nature of the demand (the number of transferred parcels) and the model provides the optimum outputs in order to satisfy all the possible demand scenarios.

The model is developed based on a two-stage decision making process. The first-stage attempts to approximate realistic decision-making in the sense that the top-level of establishing a consolidation facility focuses on optimising the selection of the facility and personnel costs based on satisfying the demand and minimising facility costs before attempting to maximise the delivery operations and revenue. Thus, the key decision variables in this stage are the type of facility and the number of staff. These variables have a unique value for all the given scenarios, indicating that decisions are made independently of the parcel values in the scenarios. Consequently, the second-stage decision variables (number of vehicles, deliveries to be performed and the number of additional services to be provided per day) are scenario-dependent. In the second stage, the decision maker attempts to minimise vehicle costs subject to satisfying different demand needs for each operational day. Table 8.1 displays the indices used in the model

while Tables 8.2 and 8.3 summarise the parameters and the decision variables, respectively.

8.3.2.1. Assumptions

The following assumptions are made regarding the operations of the facility:

- Demand for every service is modelled per scenario for each of the 250 operational days. All the costs are assumed linear and known. The capacity of all the vehicle types and handling capacity of all the staff types are also known.
- The vehicle fill-in rate is assumed to be 70% of their full capacity to account for the operational practice to keep some spare space in the cargo area for easy pick up and movement of parcels.
- It is assumed that certain ratios of the total daily parcel demand include the value-added services demand and additional delivery services demand.
- It is assumed that certain ratios of total daily demand consist of small-size, medium-size, and large-size parcels to include different types and size of light parcels.

Table 8.1. MILP Model Indices

Symbol	Description
$i \in I$	Facility types (i=1 for 500m^2, i=2 for 700m^2, i=3 for 1,000m^2, i=4 for 1,300m^2, i=5 for 1,700m^2, i=6 for 2,000m^2 facility)
$j \in J$	Vehicle types (j=1 for delivery van, j=2 for cargo bike, j=3 for forklift truck)
$k \in K$	Staff types (k=1 for driver, k=2 for cyclist, k=3 for operational staff, k=4 for admin & support staff, k=5 for manager)
$l \in L$	Parcel sizes (l=1 for small-size parcel, l=2 for medium-size parcel, l=3 for large-size parcel)
$m \in M$	Additional delivery service types (m=1 for P+D service, m=2 for pick-up service)
$n \in N$	Value-added service types (n=1 for Q&Q check service, n=2 for time-specific delivery service, n=3 for waste removal service, n=4 for temporary storage service, n=5 for product return service
$t \in T$	Operational day (250 operational days in a year)
$s \in S$	Demand scenarios set (40 scenarios)

Table 8.2. MILP Model Parameters

Symbol	Description
ph_{st}	the number of transferred parcels per scenario s, per day t
$prob_s$	probability per scenario s
FFC_i	facility costs of facility type i per day t
PHC_i	parcel handling capacity of facility type i

FEC_i	equipment costs of facility type *i* per day *t*
AME_i	total administrative and management expenses for facility type *i* per day *t*
COS	handling capacity of an operational employee
CAS	handling capacity of an admin & support employee
CM	the number of staff that can be managed by a single manager
SS_k	salary cost of staff type *k* per day *t*
SEB_k	total employee benefit cost of staff type *k* per day *t*
RH	handling cost per undelivered parcel
VF_j	daily fixed costs of vehicle type *j*
VV_j	daily variable costs of vehicle type *j*
DD_j	maximum number of delivery rounds of vehicle type *j*
CH_j	parcel loading capacity of vehicle type *j* (number of parcels)
CPD_j	maximum number of P+D service capacity of vehicle type *j*
CP_j	maximum number of pick-up service capacity of vehicle type *j*
q_{lt}	ratio of parcel with size *l* in the parcels delivered per day *t*
tpd_t	ratio of daily delivered parcels from total transferred parcels at the facility per day *t*
ta_{nt}	ratio of value-added service *n* in the total parcels delivered per day *t*
tcs_{jt}	ratio of delivery vehicle with advertisement boards per day *t*
tad_{mt}	ratio of additional delivery service *m* in the total parcels delivered per day *t*
NEX	maximum number of days per scenario *s* allowed if ph_{st} exceeds vehicle capacity CH_j
MDF	maximum difference between ph_{st} and vehicles capacity CH_j on *NEX* days per scenario *s*
RD_l	delivery fee for consolidated delivery of parcel size *l*
RA_n	service fee of value-added service *n*
RAD_m	service fee of additional delivery service *m*
RCS_j	advertisement fee for side panel for vehicle type *j*

Table 8.3. MILP Model Decision Variables

Symbol	Description
x_i	$= \begin{cases} 1 & if\ facility\ type\ i\ is\ operated \\ 0 & otherwise \end{cases}$
o_{st}	$= \begin{cases} 1 & if\ ph_{st}\ exceeds\ vehicle\ capacity\ CH_j\ on\ day\ t\ for\ scenario\ s \\ 0 & otherwise \end{cases}$
z_k	the number of staff type *k* hired
y_{jst}	the number of vehicle type *j* operated per scenario *s,* per day *t*

pd_{st}	the number of parcels delivered per scenario *s,* per day *t*
ppr_{st}	the number of parcels returned back to the facility per scenario *s,* per day *t*
pa_{nst}	the number of value-added services *n* provided per scenario *s,* per day *t*
pad_{mst}	The number of additional delivery services *m* provided per scenario *s,* per day *t*
ca_{jst}	the number of delivery vehicles with advertisement boards per scenario *s,* per day *t*

8.3.2.2. Objective Function

The objective of the model is to maximise the total profit of the consolidation facility in terms of yearly revenue and operational costs.

The MILP model is specified as follows:

$$\max \sum_{s\in S} prob_s \{ [\sum_{l\in L}(\sum_{t\in T} RD_l * q_{lt} * pd_{st}) + \sum_{n\in N}(\sum_{t\in T} RA_n * pa_{nst}) + \sum_{m\in M}(\sum_{t\in T} RAD_m * pad_{mst}) + \sum_{j=1}^{2}(\sum_{t\in T} RCS_j * ca_{jst})] - (\sum_{t\in T} RH * ppr_{st}) - \sum_{j\in J}(\sum_{t\in T}(VF_j + VV_j) * y_{jst})\} - [\sum_{i\in I}(FFC_i * x_i) + \sum_{i\in I}(FEC_i * x_i) + \sum_{t\in T}(AME_i * x_i) + \sum_{k\in K}(SS_k + SEB_k) * z_k] \quad \text{(eq. 8.1)}$$

In the objective function (eq. 8.1), the first four terms cover the four revenue streams. The second-third line covers the operational costs related to handling costs of undelivered parcels, delivery vehicles, the facility, equipment and personnel & administrative tasks of the facility.

8.3.2.3. Constraints

Model constraints are represented by equations 8.2 to 8.22. The system of equations are as defined as follows:

Facility Selection:

- Ensures only one facility type (size) is operated.

$$\sum_{i\in I} x_i = 1, \quad \text{(eq. 8.2)}$$

Parcel Demand (per Operational Day t per Scenario s):

- Defines the maximum number of parcels delivered.

$$pd_{st} \le tpd_t * ph_{st}, \qquad \forall s,t \quad \text{(eq. 8.3)}$$

- Defines the maximum number of value-added services.

$$pa_{nst} \le ta_{nt} * pd_{st}, \qquad \forall n,s,t \quad \text{(eq. 8.4)}$$

- Defines the maximum number of additional delivery services.

$$pad_{mst} \le tad_{mt} * pd_{st}, \qquad \forall m,s,t, \quad \text{(eq. 8.5)}$$

- Defines the relationship between the number of transferred parcels, the number of delivered parcels, and the number of parcels returned to the facility.

$$ppr_{st} = ph_{st} - pd_{st}, \qquad \forall s,t \qquad \text{(eq. 8.6)}$$

Facility Capacity:

- Ensures that the number of transferred parcels handled at the facility cannot exceed the capacity of the facility that is being operated.

$$\sum_{i\in I} PHC_i * x_i \geq \sum_s prob_s * ph_{st}, \qquad \forall s,t \qquad \text{(eq. 8.7)}$$

Vehicle Capacity:

- Ensures there is enough vehicle capacity to handle the transferred parcels at the facility on usual days ($o_{st} = 0$) and the transferred parcels can exceed the vehicle capacity only by MDF parcels on NEX days ($o_{st} = 1$).

$$ph_{st} - \sum_{j=1}^{2}(DD_j * CH_j * y_{jst}) \leq MDF * o_{st}, \quad \forall s,t \qquad \text{(eq. 8.8)}$$

- Ensures that the number of P+D services provided cannot exceed the allocated capacity of the vehicles that are being used.

$$\sum_{j=1}^{2}(DD_j * CPD_j * y_{jst}) \geq pad_{1st}, \quad \forall s,t \qquad \text{(eq. 8.9)}$$

- Ensures that the number of pick-up services provided cannot exceed the allocated capacity of the vehicles that are being used.

$$\sum_{j=1}^{2}(DD_j * CP_j * y_{jst}) \geq pad_{2st}, \qquad \forall s,t \qquad \text{(eq. 8.10)}$$

- Ensures that the number of forklifts that are being used cannot exceed the capacity of the facility that is being operated.

$$CH_3 * y_{3st} \geq \sum_{i\in I} PHC_i * x_i, \qquad \text{(eq. 8.11)}$$

Workforce Availability:

- Ensures that the number of drivers is not smaller than the number of vans.

$$z_1 \geq y_{1st}, \qquad \forall s,t \qquad \text{(eq. 8.12)}$$

- Ensures that the number of cyclists is not smaller than the number of cargobikes.

$$z_2 \geq y_{2st}, \qquad \forall s,t \qquad \text{(eq. 8.13)}$$

- Ensures that the number of transferred parcels handled at the facility cannot exceed the total capacity of the operational personnel that are employed.

$$COS * z_3 \geq ph_{st}, \qquad \forall s,t \qquad \text{(eq. 8.14)}$$

- Ensures that the number of transferred parcels handled at the facility cannot exceed the total capacity of the administration & support personnel that are employed.

$$CAS * z_4 \geq ph_{st}, \quad \forall s,t \qquad \text{(eq. 8.15)}$$

- Ensures that there are enough managers to manage the other employed personnel.

$$CM * z_5 \geq \sum_{k=1}^{4} z_k, \qquad \text{(eq. 8.16)}$$

Delivery Vehicles Advertisement Availability:

- Ensures that at most a certain proportion of the delivery vehicles can have advertisement boards.

$$ca_{jst} \leq tcs_{jt} * y_{jst}, \quad j \in (1,2) \wedge \forall s,t \qquad \text{(eq. 8.17)}$$

Non-negativity Condition and Binary/Integer Variables:

- Ensures that there is no more than NEX days per scenario *s* when demand exceeds vehicle capacity.

$$o_{s,t} \in \{0,1\} \qquad \forall s,t \qquad \text{(eq. 8.18)}$$

$$\sum_{t \in T} o_{st} \leq NEX \qquad \forall s \qquad \text{(eq. 8.19)}$$

- Binary and integer constraints that are necessary due to the definition of the decision variables.

$$x_i \in \{0,1\} \; \forall i \in I, \qquad \text{(eq. 8.20)}$$

$$y_j, z_k, pa_{nst}, pad_{mst} \geq 0 \; and \; integer, \quad \forall j,k,m,n,s,t \qquad \text{(eq. 8.21)}$$

$$pd_{st}, ppr_{st}, ca_{jst} \geq 0 \; and \; integer, \quad \forall s,t \qquad \text{(eq. 8.22)}$$

8.4. Cost Model Solution

A case study of the proposed freight consolidation facility for Melbourne's CBD is presented in this section to solve the developed MILP cost model using a genetic algorithm and to demonstrate the feasibility and effectiveness of the formulated cost model.

8.4.1. Genetic Algorithm Solution

To solve the problem discussed in section 8.3.2, our approach decomposed the optimisation problem into sub problems, and thus a sequential nested genetic algorithm was applied in order to speed up the evaluation process. In this problem, demand scenarios for each day are independent, therefore dividing a problem into sub problems improves the efficiency of the genetic algorithm in terms of fitness function value (annual net profit), computational time and the number of generations. The schematic diagram in Fig. 8.2 displays the procedure for the sequential genetic algorithm. In the sequential GA, the optimisation problem is solved in two steps, step 1 solves a set of variables (x_i, z_1, z_2) using genetic algorithm 1 (GA1). GA1 has nested genetic algorithm 2 (GA2), which solves the rest of variables such as y_{jst} (j=1,2). A detailed description of proposed sequential nested genetic algorithm is given in the following section.

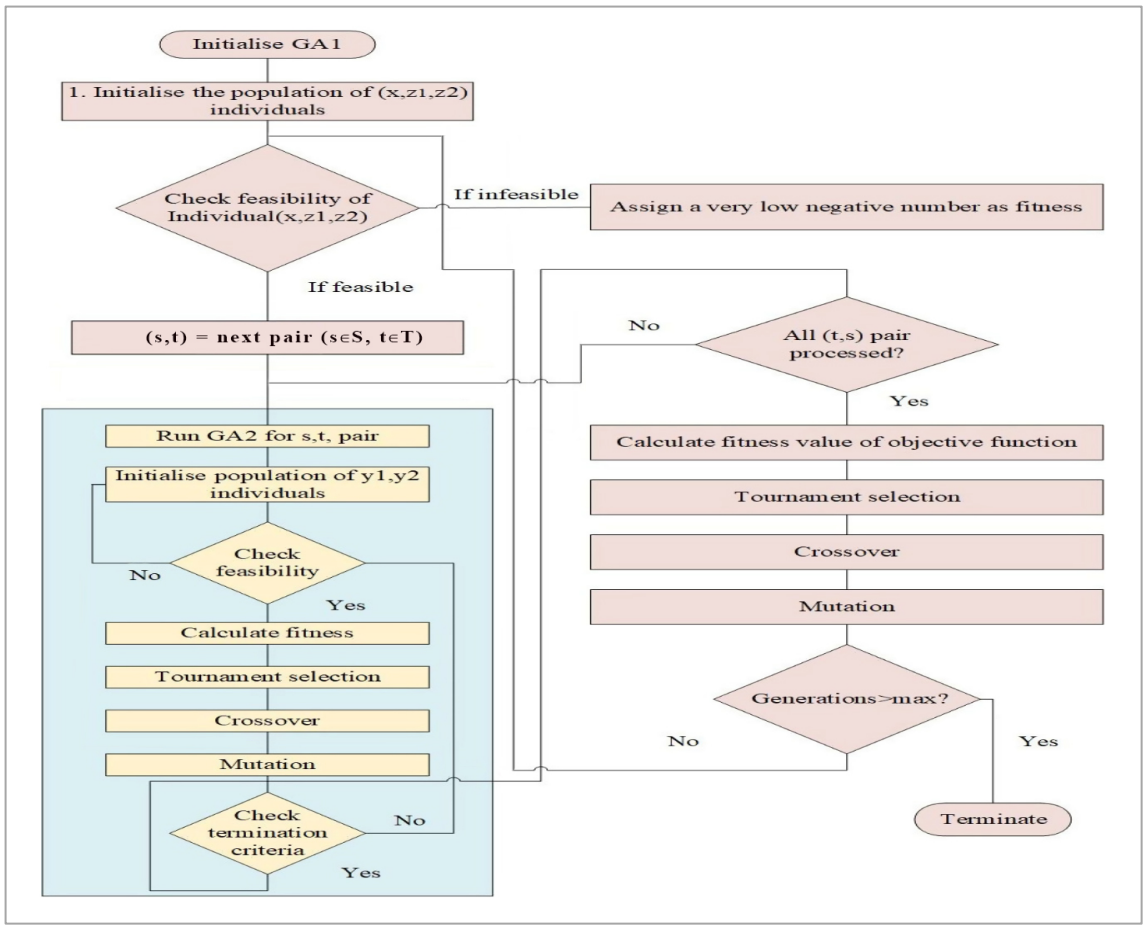


Figure 8.2. Flowchart of Sequential Nested Genetic Algorithm to Solve the MILP Model

8.4.1.1. Overview of the Sequential Nested Genetic Algorithm

The solution variable values obtained in GA1 are used in GA2 to get an overall best fitness function value in an acceptable time. In GA1, the solution space branches defined by x, z_1, and z_2 variable values are considered. GA2 is then used for each such branch to optimise the problem for variables y_{jst} (j=1,2). Once all pairs of y_{jst} (j∈ {1,2}, s ∈ S, t ∈ T) for a given branch are processed by GA2, then control is given back to GA1 which uses the obtained y_{jst} values to evaluate the overall objective function value associated with x, z_1, z_2 for the rest of the variables. The calculation of the objective function for each individual (x, z_1, z_2) requires running GA2 on max(s)*max(t) sub problems to optimise y_{jst}, (j=1,2). The ability to independently solve these problems greatly reduces the total time needed to find near-optimal values of y_{jst} (j=1,2) for given values of x, z_1, z_2. Solving such 10,000 subproblems provide an acceptable solution for a subset of solution space with given x, z_1, z_2. The objective function of this genetic algorithm (GA2) is equal to the best value of objective function (eq. 8.1) applied to the set of variables, x_i, z_1, z_2 that are defined by solution vector, values of y_{3st}, o_{st}, pd_{st}, pa_{nst}, pad_{nst}, ppr_{st}, ca_{st} are derived by formulae, y_{jst} found by applying GA2 to max(s) * max(t) sub problems (for each s,t combination given x_i, z_1, z_2 values are fixed). Solutions yielding the best objective function y_{jst} are remembered and returned at end of GA1. The calculated objective function value is cached to avoid having to recalculate it given the same individual appearing again during the run of the algorithm.

8.4.1.1.1. Genetic Algorithm 1 (GA1)

Genetic algorithm 1 starts with the initialisation of population for individuals x, z_1, and z_2. An individual is represented as a tuple of 3 integer numbers (x, z_1, z_2). X defines the facility being used (we use integer 1<=x<=6 here, instead of $x_i \in \{0,1\}$, $i \in I$ as in the MILP specification). Individual representation, crossover, and mutation for GA1 are shown in Fig. 8.3. In GA1, the population size was 20 individuals while crossover and mutation rate of 0.5 has been used. These parameters were decided based on a sensitivity analysis of GA parameter values to test and determine the right combination (population size, tournament size, number of generations, etc) to ensure finding a near-optimal solution. For the termination criterion for GA1, the exhaustion of number of allowed generations was used. Tournament selection is used for the fitness individual selection for next generations. Tournament selection compares the objective function values of individuals in pairs making sure each individual participates in the tournament at least once. The individual with higher objective function value is selected for inclusion into the next generation. The objective function value of infeasible individuals is set to a very low number, lower than any possible feasible solution, i.e. infeasible solution always loses to a feasible solution. Two sets of parents are returned by tournament selection to be used in crossover.

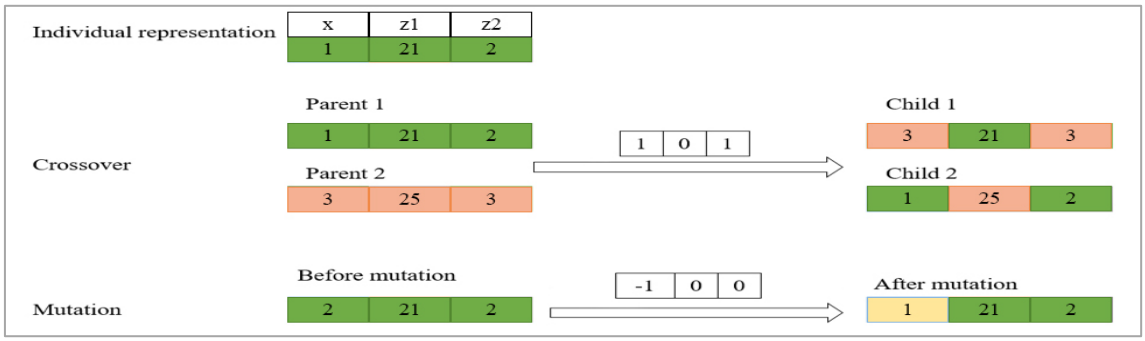


Figure 8.3. Individual representation, crossover and mutation in GA1

8.4.1.1.2. Genetic Algorithm 2 (GA2)

Genetic algorithm 2 is coded with integer coding. It uses tournament selection, one-point crossover and slow creep mutation. It defines an additional objective function for each subproblem and includes only the objective function components directly dependent on y_{jst} (j=1,2): the advertisement revenue from day s,t and the vehicle costs for day s,t.

$$Obj(y_{jst}) = \lfloor tcs_{st} * y_{jst} \rfloor * RCS - \sum_{j=1}^{2} y_{jst} * (VF_j + VV_j)$$

Initial population is generated randomly by assigning each individual's y_{jst} (j=1,2) a random integer number sampled from uniformly distributed 0 to z_j. Fig. 8.4 shows the individual representation, crossover and mutation for GA2. Crossover occurs by exchanging individual values between parents. The population size in GA2 was 50 and a crossover rate of 0.5 is used to generate diversity in the individuals. With a mutation rate of 0.8, we added the number sampled from a normal distribution to each variable, with parameters μ=0 and σ=1.8. This indicates that the mutation most often selects individuals close to the original one, but also has a possibility to select further individuals to ensure

both good exploration and good exploitation of solution space. The modified individual is then fixed in case it becomes infeasible: y_{jst} are forced to fit into diapason $[0, z_j]$ if a value is outside of its diapason, the closest value in the diapason is selected. Tournament selection is used for best individual selection.

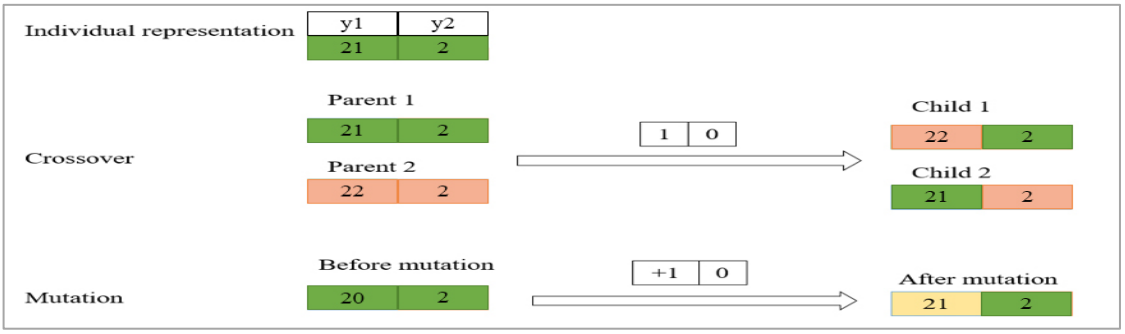


Figure 8.4. Individual representation, crossover and mutation in GA2

8.4.2. Generation of Parcel Demand Scenarios

In order to capture the uncertain nature of the number of parcels transferred from freight carriers, different demand scenarios of the likely transferred parcels need to be included to account for any risk associated with any incorrect information related to the demand. Hence, a baseline scenario for the daily number of transferred parcels was created based on actual operational parameters acquired from the local freight industry for an inner-city distribution facility. The baseline scenario incorporated weekday variability (Monday to Friday) for all peak and off-peak seasons during a typical annual operational year for light parcel deliveries. Consequently, 39 scenarios were generated using a Monte Carlo simulation approach, where the values of the daily transferred parcels are different in each of the generated scenarios. As the approach considered random sampling, the corresponding probability of the scenarios were set to be uniform. Fig. 8.5 displays all the 40 scenarios during the 250 operational days with a minimum daily demand of 1,009 parcels and a maximum of 3,140, indicating significant variability in demand scenarios.

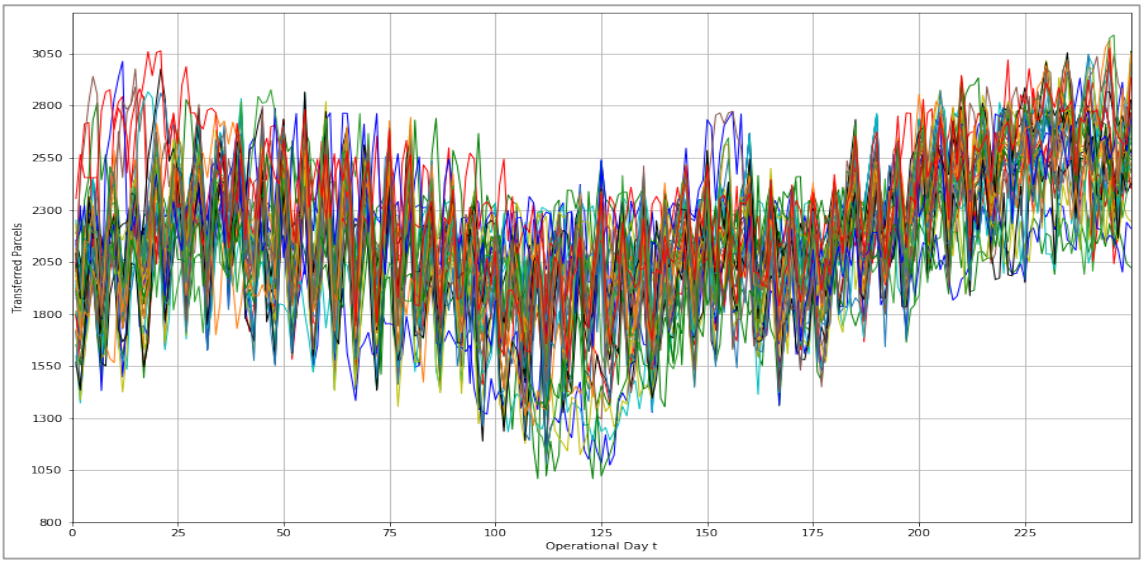


Figure 8.5. Daily Demand for Transferred Parcels to the Facility in 40 Demand Scenarios

8.4.3. Model Inputs

Operational datasets were acquired from the local freight industry in Melbourne for all parameters and variables. Table 8.4 displays the parameters inputs to solve the cost model. Based on the outcome of discussions with local facility managers, it was assumed that delivery vans and cargo bikes would be acquired through leases from commercial vehicle rental companies rather than investing in high capital costs to purchase the vehicles because leasing contracts are more cost-competitive for the facility operator. Different estimates for each operational day were applied for the second-stage operational variables due to the different demand scenarios. Hence, it is important to note that only average values for these variables are shown in Table 8.4, which are denoted by *avg*. Furthermore, the suggested service fees for consolidated delivery services for each parcel size were selected based on feedback from freight experts to ensure that they did not exceed the distribution cost for freight carriers inside the inner-city area.

Table 8.4. Parameter Values Sourced from Local Freight Industry for the GA Solution

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
Facility & Equipment Operational Parameters							
FFC_1	657	FFC_2	821	FFC_3	1,049	FFC_4	1,241
FFC_5	1,429	FFC_6	1,581	FEC_1	100	FEC_2	143
FEC_3	167	FEC_4	209	FEC_5	253	FEC_6	289
PHC_1	1,500	PHC_2	2,000	PHC_3	2,800	PHC_4	3,700
PHC_5	4,800	PHC_6	5,500	AME_1	51	AME_2	64
AME_3	76	AME_4	114	AME_5	150	AME_1	180
Personnel Operational and Remuneration Parameters							
COS	350	CAS	1,000	CM	40	RH	1.5
SS_1	152	SEB_1	27	SS_2	132	SEB_2	27
SS_3	152	SEB_3	16	SS_4	180	SEB_4	14
SS_5	300	SEB_5	28				
Vehicles Parameters							
CH_1	64	CH_2	21	CH_3	1,000	DD_1	2
DD_2	2	DD_3	-	CPD_1	20	CP_1	24
CPD_2	6	CP_2	10	CPD_3/CP_3	-		
$VF_{1,avg}$	30.14	$VV_{1,avg}$	16.624	$VF_{2,avg}$	28.132	$VV_{2,avg}$	3.36
$VF_{3,avg}$	23.2	$VV_{3,avg}$	14.976				
Parcels and Services Operational Parameters							
ph_{avg}	2,174	$prob_{avg}$	0.025	tpd_{avg}	0.96	tcs_{avg}	0.3
$q_{1,avg}$	0.711	$q_{2,avg}$	0.166	$q_{3,avg}$	0.123	$ta_{1,avg}$	0.061
$ta_{2,avg}$	0.09	$ta_{3,avg}$	0.081	$ta_{4,avg}$	0.071	$ta_{5,avg}$	0.053
$tad_{2,avg}$	0.063	$tad_{1,avg}$	0.065	NEX	25	MDF	330
Parcels and Services Pricing Parameters							
RA_1	1.1	RA_2	0.85	RA_3	0.75	RA_4	0.65
RA_5	0.6	RD_1	2.75	RD_2	3.40	RD_3	4.65
RAD_1	10	RAD_2	3.5	RCS	4.57		

8.5. Computational Results of the Genetic Algorithm Solution

8.5.1. Analysis of Computational Results of Genetic Algorithm Solution

This section presents the computational outputs obtained from the genetic algorithm to solve the MILP model. The settings described in the model outputs resulted in a problem that consisted of 130,005 integer variables, 10,005 binary variables, and 300,051 constraints. The experiments were performed using a personal computer with 2.60 GHz Intel i5-3329 4 core processor and 16 GB of RAM and the computation time for the GA solution took 216.59 CPU seconds on average.

Furthermore, ten trials of the algorithm were carried out to evaluate how consistently well the genetic algorithm performed on average and to determine the number of generations and computational time to achieve a satisfactory result in the different trials. To achieve the results, up to 47 sub-problem were performed, each one involved 10,000 runs of GA2 for same (x, z_1, z_2) for different (s, t) pairs to optimise y_{1st} and y_{2st} for a given (s, t). Fig. 8.6 displays the computational time for the 10 trails to reach the best fitness value. All runs were able to achieve the best value for objective function within 7 generations of GA1. The median time for reaching the best value is 101.49 CPU seconds. Thus, all 10 trials converged to the same best fitness function value within a reasonable computational time, which demonstrates the good performance of the genetic algorithm in reaching a satisfactory result.

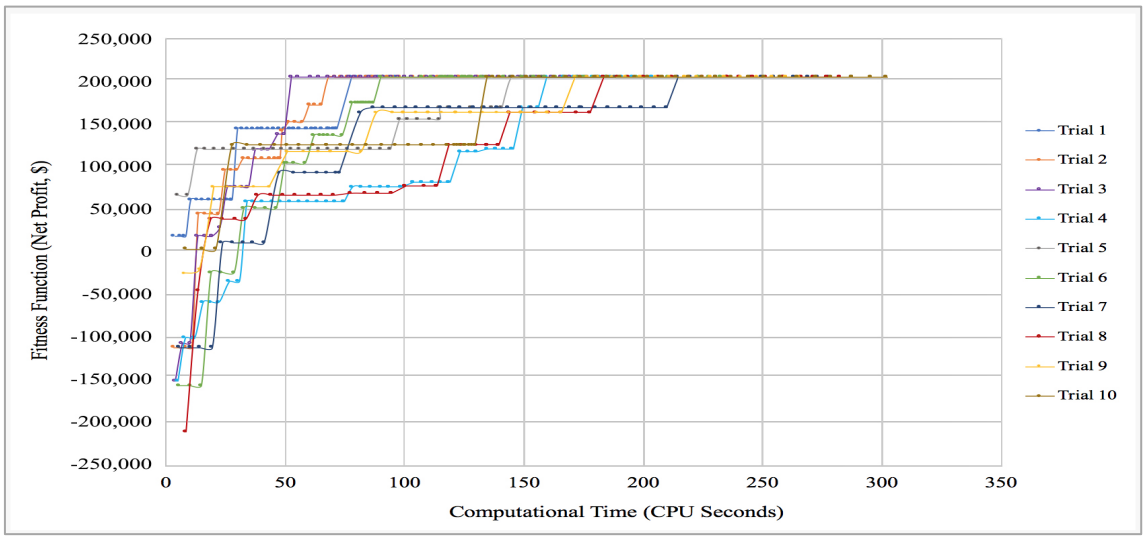


Figure 8.6. Progress (by Computational Time) of Best Fitness Achieved in Ten Trials of the Genetic Algorithm Solution

Additionally, GA1 converged in less than 10 generations as shown in Fig. 8.7, which displays the best fitness function (annual net profit) values for GA1 and GA2. The sequential GA provided the best results for maximum profit in a reasonable computational time with a reduced number of generations. It can be seen that same elite repeated in successive generations in GA2 and it did not further improve. The best and near optimal individual was found at the 20th generation. Overall, less than 70 generations were enough for GA2 to converge.

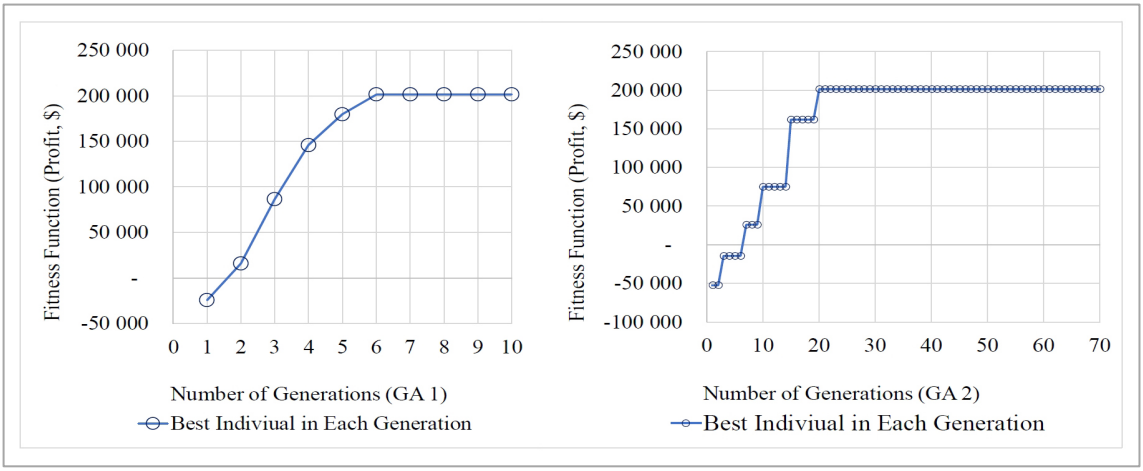


Figure 8.7. Best Fitness Function Achieved in Genetic Algorithm 1 and Genetic Algorithm 2 with Respect to Each Generation

Furthermore, Table 8.5 displays the key decision variables obtained by the GA solution with respect to the most profitable facility size and required number of staff and delivery vehicles as well as determining the number of services for the four revenue streams. Accordingly, the GA solution produced a detailed estimation of the total operational costs and revenue streams that enabled estimation of the net profit of the consolidation facility. The model outputs are further analysed in the following section to demonstrate the financial viability of the facility.

Table 8.5. Key Decision Variable Outputs of Genetic Algorithm Solution

Variable	**Model Output**	**Variable**	**Model Output**
Facility Size	1000 m^3		
Staffing		*Vehicles*	
Delivery Van Drivers	21	Delivery Vans	21
Cargo Bike Cyclists	2	Cargo Bikes	2
Operational Staff	8	Forklifts	2
Administrative & Support Staff	3		
Managers	1		
Parcel Outputs (Average Values in 40 The Scenarios)		*Value-added Services (Average Daily Requests in the 40 Scenarios)*	
Daily Number of Transferred Parcels	2,174	Q&Q Check	122
Daily Number of Delivered Parcels	2,117	Time-Specific Delivery	183
Daily Number of Returned Parcels	57	Waste Removal	169
		Temporary Storage	152
		Product Return	112
Additional Delivery Services (Average Daily Requests in the 40 Scenarios)		Number of Vehicles with Advertising	5
Pickup & Delivery Service	132		
Pick-up Service	126		

8.5.2. Analysis of the Profitability of the Consolidation Facility

8.5.2.1. Analysis of Operational Costs

Fig. 8.8 displays the annual operational costs and revenue associated with operating the facility and performing the consolidated delivery services. The total annual operating costs of the facility is projected to be AU $2.046 million. The largest contributor to overall cost is associated with personnel and administrative costs, representing 69% of total costs. Facility costs (15%) and vehicle & cargobike costs (13%) are similar while the component contributing the least to total costs is the cost of equipment (3%). From both a staffing and financial perspective, couriers represent the most critical piece of the operation as they make up almost 60% of total staff and their salaries alone account for 40% of total costs. However, other types of staff such as operational staff represent a relatively minor share (11%) to total facility costs. Similarly, staff who are responsible for managerial and administrative tasks such as supervising and performing order-related data entry and record keeping processes, represent a minor share (9%) of the total costs. Moreover, employee benefits, which account for other types of compensation provided to all staff such as overtime or annual leave, make up nearly the same share as management & admin staff costs. The model solution estimates the annual operational costs for undelivered parcels in terms of labour costs would represent less than 1% ($17,800) of total annual costs.

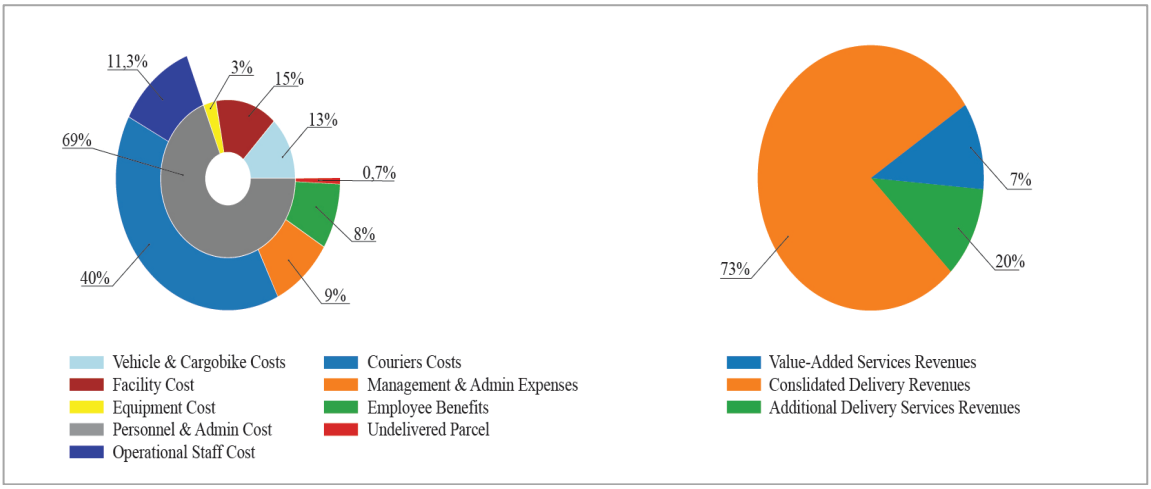


Figure 8.8. Model Results: Annual Operational Costs and Revenue of the Proposed Central City Consolidation Facility

Facility costs are driven by the annual rent, which accounts for about 60% of facility costs, followed by IT systems and utilities representing 17% and 9% of facility costs, respectively. A primary takeaway when reviewing the results of the cost model suggest that components contributing to total costs that may seem critical – such as the facility rent or the cost of vehicles – are in fact, not as critical. Furthermore, the model solution indicates the required number of delivery vans is almost 10 times greater than the number of cargobikes, which could be attributed

to the significantly smaller loading capacity of the cargo bike. It is estimated that the distribution cost per parcel using a cargo bike is almost three times higher than distribution cost using a delivery van. This illustrates that the per parcel cost of the cargo bike is very sensitive to the higher share of the cyclist's salary to the total costs and lower number of parcels delivered by cargo bike compared to the delivery van.

Vehicle costs are driven to a larger share by annual fixed costs of the vehicles. It is estimated that the costs of leasing the vehicles represent about 43% of the total vehicle costs. This cost is dependent on the financing option that the facility operator selects to source the vehicles and the geographical setting of the location of the facility. However, the annual vehicle costs might be significantly higher if the facility operator decides to purchase rather than lease the vehicle. For delivery vans, more than a third of annual costs are driven by variable costs (i.e. repair and maintenance) while cargobikes have lower variable costs, which makes a mere 10 % of total cargobike costs. The vehicles variable costs are relatively low due to the shorter travelled distance as a result of the facility being in the inner-city area and in close proximity to goods receivers.

8.5.2.2. Analysis of Revenue Streams

A breakdown of the share of each revenue stream for all services to the total revenue is displayed in Fig. 8.8. It is estimated that the total annual revenue from all services would be AU $2.247 million. The numerical solution suggests that the proposed consolidation facility would be profitable resulting in an annual profit of AU $ 201,000 (8% annual net profit margin). The largest contributor to total revenue is consolidated delivery fees (73%). The results indicate that additional delivery and value-added services are also critical to maintaining profitability. Service fees associated with additional delivery services are higher on a per unit basis, and therefore contribute a much higher percentage (20%) to total revenue compared with value-added services (7%). However, the model solution does not support offering the vehicles' side panel for advertisement as a revenue stream due to their revenue not exceeding 0.5% of total annual revenue.

The annual cost, revenue and net profit for the 40 scenarios are displayed in Fig. 8.9. The primary vertical axis displays the total annual cost, total annual revenue and annual net profit for each scenario while the secondary vertical axis displays the daily average of transferred parcels shown in the black line for each demand scenario. The model solution estimates that 8 scenarios with a daily average of 1,900 parcels would contribute to unprofitable facility with an annual net loss of $122,000 (5% net loss margin). The vehicle costs in these scenarios contributed a lower share of the total costs (9% vs overall 13% in the 40 scenarios) due to less operating vehicles on lower demand days. However, there was not enough revenue from the main services to compensate for the high personnel and admin costs in these unprofitable scenarios. In contrast, it is estimated that 10 scenarios with a daily average of 2,310 parcels would contribute to a highly profitable facility with annual net profit exceeding $400,000 (18% net profit margin).

Fig. 8.9 suggests that for the facility to break even, it is necessary for the daily facility throughput to average around 1,985 parcels per day throughout the operational year. This

value could be considered as the minimum threshold of daily transferred parcels from other freight carriers for a consolidation facility in the study area to start making a profit. Facility throughput has a direct impact on the other operational costs in the consolidation facility. At a lower number of parcels transferred per day, the facility profit margin could be eroded due to higher fixed costs relative to all other costs. The model solution estimates that a daily average of 2,050 - 2,100 transferred parcels would result in a low-profit facility (around 5% net profit margin) whereas a daily average of 2,180 - 2,230 and 2,260 - 2,300 parcels would contribute to a profitable facility (around 10% net profit margin) and a highly profitable facility (around 15% net profit margin), respectively.

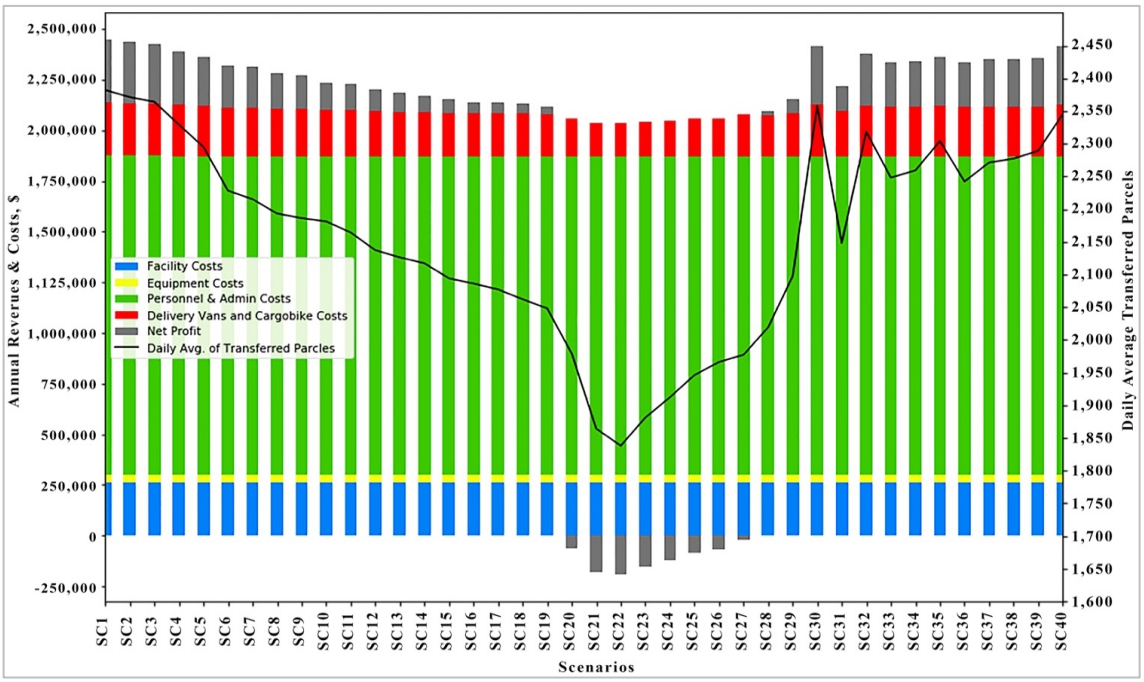


Figure 8.9. Illustration of Estimated Annual Profitability of the Consolidation Facility between the 40 Demand Scenarios

Fig. 8.10 delves deeper in the profitability of the facility to highlight the average revenue and costs per parcel. The primary vertical axis illustrates the daily average cost per parcel and daily net profit per parcel for the full operational year while the daily average of transferred parcels is shown in the black line across the secondary vertical axis. The model solution estimates an overall $4.26 revenue per parcel and $3.84 cost per parcel for a $0.42 net profit per parcel. Furthermore, it is estimated that the daily net profit of the facility would be around $807. It is important to note that the reported revenue per parcel is based on revenue generated from *all services* not the only the consolidated delivery fees. It is estimated that the cost per parcel would exceed the revenue per parcel for about 65 days especially during the very low-demand days (t: 101 - 123) with a $0.86 daily net loss (23% net loss margin) during this off-peak period. In contrast, it is estimated that the facility would be considerably profitable on more than 70 days with a daily net profit of more than $1.06 per parcel especially during the peak-demand season (t:208-240) with an estimated $1.52 net profit per parcel (30% net profit margin).

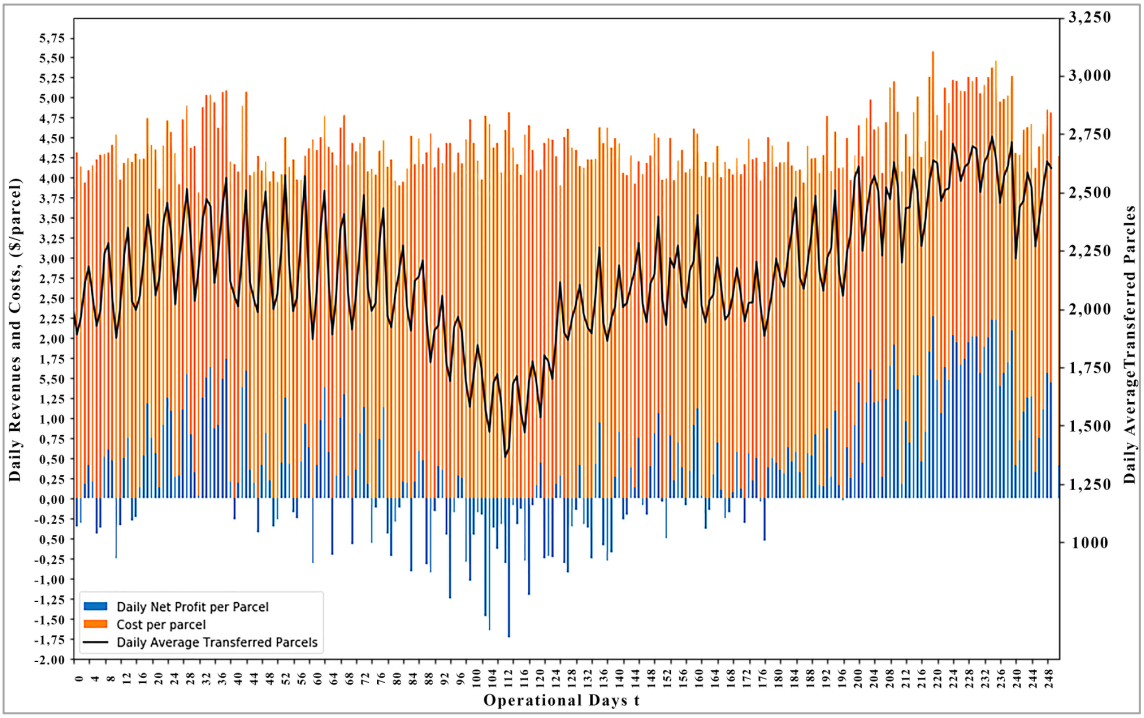


Figure 8.10. Illustration of Estimated Daily Profitability of the Consolidation Facility

8.5.3. Sensitivity Analysis

As the model parameters included various operational assumptions, it was necessary to perform a sensitivity analysis to examine the influence of any variations in the operational variables on the profitability of the consolidation facility. Accordingly, varying values of three operational variables were updated in the model inputs while keeping all other model parameters unchanged. The genetic algorithm solution was re-run for various values to generate the facility outputs for each iteration of the model inputs. The following section analyses the results of the model solution for the following operational variables with respect to the changes on the annual net profit margin of the facility:

- A) Vehicle Fill-in Rate (Load Utilisation)
- B) Vehicle size
- C) Manpower Efficiency

Fig. 8.11 displays results of the sensitivity analysis for three operational variables with respect to changes in the facility net profit margin. Changing the vehicle fill-in rate would alter the value of CH_1 and CH_2. The utilisation load of the freight vehicle capacity significantly influences the facility's profitability as illustrated in Fig. 8.11a. It is estimated that any load utilisation below 60% would make the facility unprofitable. This is critical to highlight due to the typically low load utilisation that freight carriers apply to perform delivery services to receivers in the inner-city. It is estimated that a 5% increase in vehicle load utilisation would contribute to 4 - 5% increase in the net profit margin. Although a maximum load utilisation such as 90% would be highly recommended as it would contribute to a significantly profitable facility (20% net profit margin), certain operational conditions are required such as optimising delivery routes

and lowering the number of receivers per delivery round in order to facilitate this high load utilisation. It is also estimated that performing three daily delivery rounds instead of two would exponentially increase the net profit margin of the facility and even obviate the need to increase the fill-in rate. For instance, the net profit margin for 3 delivery rounds at 40% load utilisation is close to 2 delivery rounds at 65% load utilisation. However, the benefits of increasing the number of delivery rounds needs to be compared against the additional costs and issues of drivers' operational conditions as well as the wear and tear on the vehicles.

Secondly, the influence of operating different classes of delivery vans on the facility's profitability are illustrated in Fig. 8.11b. The model inputs assumed CH_1 (64 parcels) for a large delivery van. However, the facility operator might consider using other classes such as a 2-tonne delivery van or a small light commercial vehicle such as a station wagon instead of the one-tonne van. A small delivery van, which typically has a capacity of about 30-35 parcels, would require almost double the number of delivery vans compared to a large van (64 parcels) or extra-large van (90 parcels). Given that the cost of drivers, and personnel costs in general, are the highest cost component, the influence of the vehicle size, and finding the optimal mix between carrying capacity and number of vehicles needed, has a substantial impact on profitability. Fig. 8.11b clearly indicates that vehicle size has a large impact on net profitability for the facility, given the wide range between the negative profit margin (loss) associated with a small van and the 21% positive profit margin (gain) associated with the extra-large van. However, it is important to take into consideration other operational parameters that could not be incorporated in the model inputs such as ease of parking and manoeuvrability in the congested inner-city when comparing the benefits of the different classes of delivery vans.

Finally, as the model inputs for the facility manpower included assumptions based on the handling capacity of the facility staff, it was necessary to apply different productivity levels of the facility staff to examine the effects of the manpower efficiency on the profitability. Hence, two additional cases (under and excellent utilisation) for the efficiency of the facility manpower throughputs in terms of number of parcels processed per staff (COS & CAS) were included in the sensitivity analysis for these operational variables. The results of the sensitivity analysis associated with the utilisation of the facility manpower (Fig. 8.11c) underline the observations made in the previous section regarding the influence of personnel costs. The negative impact of the manpower efficiency on the profitability is high in cases where facility staff are not efficient in handling the transferred parcels in the under-utilisation case. An effective consolidation operation requires well-trained staff for quick and efficient handling and processing of parcels to ensure that throughput rates are consistently above the point at which profitability can be realised. In fact, under-utilised facility staff will not only contribute to an unprofitable facility, but also discourage other freight carriers from transferring their parcels.

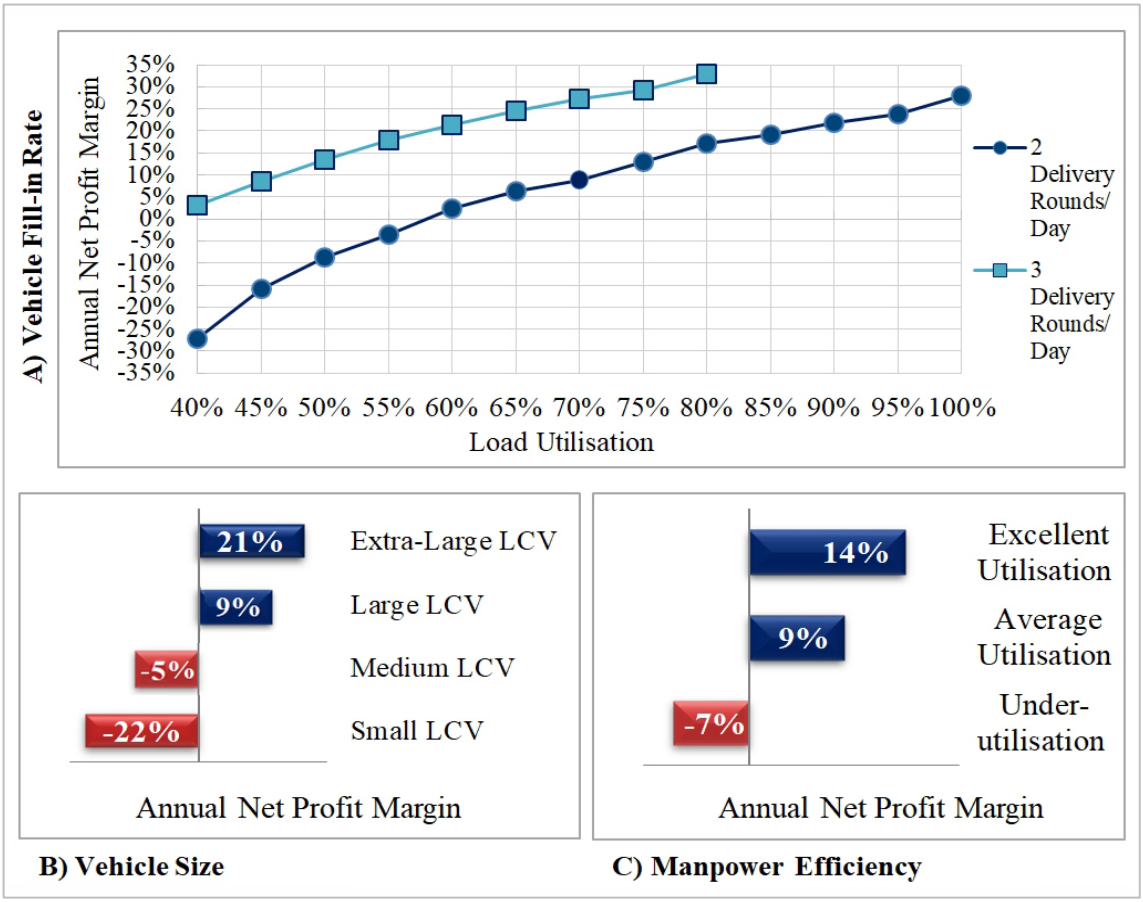


Figure 8.11. Sensitivity Analysis: Influence of the Operational Parameters (Vehicle Fill-in Rate, Vehicle Size and Manpower Efficiency) on Annual Net Profit Margin

Furthermore, we here delve deeper in the sensitivity analysis to examine how different operational conditions might influence the facility's profitability. Accordingly, three additional scenarios with different values of the key operational variables were created as shown in Table 8.6. Each scenario represents a different utilisation level of the facility's resources. Furthermore, changes to the additional delivery and value-added services were included as the fourth variable to assess the influence of increasing or decreasing the number of these services on the facility's profitability.

Table 8.6. Scenario Definitions for Sensitivity Analysis Comparison

	Operational Variables			
Case Scenario	Manpower Efficiency	Vehicle Load Utilisation	Vehicle Size	Additional Services
Lower-limit	Under	50%	Medium van	30% Drop
Average	Average	65%	Large van	5% Increase
Upper-limit	Excellent	95%	Extra-Large van	30% Increase

Fig. 8.12 illustrates the changes in the net profit margin based on incremental increases in the parameter values of the operational variables across the three scenarios. This facilitates determining the variables that the facility operator should focus on optimising in order to achieve the highest gains in the facility's profitability. The operational values associated with the lower-limit scenario contribute to an unprofitable facility (an annual net loss of more than 5%) with only one factor, additional services, suggesting a near break-even facility. However, the net profit of the 30% drop in additional services further highlight that the profitability is not highly dependent on these services. The vehicle load utilisation and manpower efficiency have a higher negative impact on the profitability than the vehicle size in this lower-limit scenario. The lower-limit scenario underlines the importance of the efficiency of facility staff in handling transferred parcels. Going from the lower-limit scenario to the average scenario increases the likelihood of profitability as all four operational variables contribute to a net profit margin of at least 7%. However, there are diminishing profitability gains moving to the upper-limit scenario, as the profit margins become less sensitive to changes in manpower efficiency and additional services.

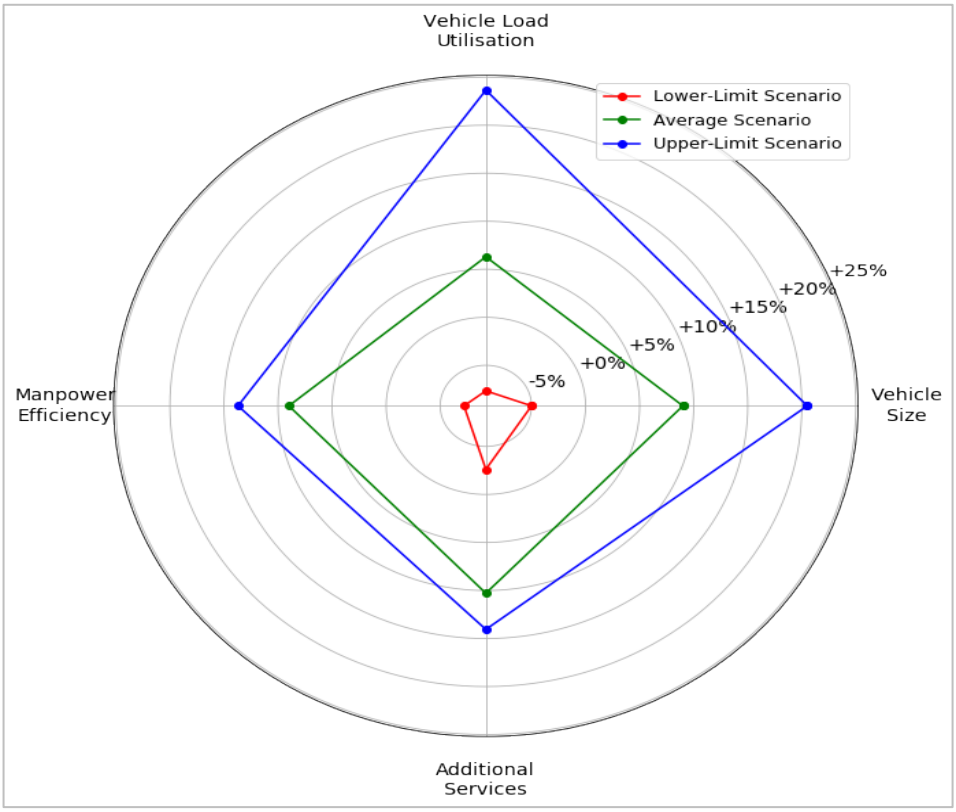


Figure 8.12. Summary of Sensitivity Analysis: Net Profit Margins of the Four Operational Variables across the Three Scenarios

Changes to the additional services variable, e.g. value-added services for retailers, exhibit the smallest variations in the range (difference in net profit) between the lowest performing scenario and the highest. The WTP estimation (section 6.4.4) indicated that retailers and businesses might be willing to pay for the proposed consolidated delivery service. However, the estimated monetary values for the retailers' WTP – AU $1.05 on average - is low compared to the service fee paid by the participating freight carriers or the total profit per parcel. As shown in Fig. 8.12, increasing the volume of additional services by 30% still does not highly impact to the profitability of the consolidation

facility as other variables. It can be mentioned that the low WTP for retailers is relatively important attribute for sustaining economic viability for the consolidation facility, albeit to a much lesser degree compared to other revenue streams. In contrast, the differences in net profit margin between the lowest and highest performing scenario for vehicle load utilisation are much larger as well as the vehicle size variable. Thus, Fig. 8.12 confirms that the vehicle load utilisation should command the greatest attention of the facility operator as the increase in profit generated by incremental improvements in that variable is greatest.

8.6. Discussion and Policy Implications

While delivery consolidation is often touted as a potential solution to congestion and other problems caused by the delivery of freight in urban areas, the extant literature has overlooked quantifying the financial viability of delivery consolidation facilities, or to consider the factors that might generate such profitability. By accounting for all costs and revenues associated with facility operation, the optimisation cost model provides insights into the potential profitability of a consolidation facility based on parameters established through local data and indicates that such a consolidation facility could be financially viable without government subsidies. Overall, the results indicate that a profitable consolidation facility is predicated on ensuring a minimum daily threshold for the parcel transfer from other freight carriers and successful operation and management of staff resources. This could be considered as the most important factor for maintaining the economic viability of the proposed consolidation facility. These cost components (particularly personnel costs and as revealed by the sensitivity analysis, the vehicle fill rate), have a much larger impact on the costs, revenues and profitability structure of a consolidation facility than the infrastructural costs of the facility, either in terms of fixed costs associated with rent or variable costs associated with maintenance. This result seems counter-intuitive since conventional wisdom suggests that location-related aspects of the facility may be perceived as critical.

Upon comparing the study findings with other studies that have investigated the financial viability of consolidation facilities, we find some key similarities. While the cost model was able to produce a profitable solution, as the sensitivity analysis demonstrates, to maintain profitability, the facility operator must focus their attention on personnel costs, training and retention efforts, and the optimal utilisation of operation resources. These findings are consistent with the findings reported in the Brussels study (Janjevic and Ndiaye 2017b) and Saint-Etienne, France study (Faure et al. 2016). The takeaway of this finding is that the profit margin of these facilities is difficult to maintain and can be impacted by small declines in factors to which profitability is quite sensitive. Another clear parallel between our study and the Brussels study is the cost of human resources as a primary contributor to overall costs (69% vs 75%, respectively). Moreover, the higher share of couriers' salaries relative to the total vehicle costs support the findings reported by Kin et al. (2018) that couriers' salaries are a considerably large cost component in the total cost of last mile distribution.

Additionally, the results of the cost model provided valuable insights on the challenges that need to be properly addressed by the facility's management in order to sustain the economic viability of the consolidation facility. Ultimately, the operations of handling and delivering the transferred parcels are labour-intensive, indicating that proper and

consistent staffing should be the highest priority. Proper training of staff in terms of enhancing processing the parcels and minimising time spent on each delivery would also be an important activity for facility management. The sensitivity analysis underlines that efficiency improvements to the vehicle load utilisation, which could be achieved through optimised delivery routes and sequence of stops as well as continuous training of couriers, would contribute to considerable profitability gains for the facility. The optimisation of vehicle use is contingent upon the facility operator having a constant and ongoing understanding of the receivers with respect to their specific operations and the types of services that they require to ensure an optimal mix of vehicle/cargobike use. Recognising the importance of courier staff to the profitability of the facility should motivate the facility operator to implement policies which seek to retain courier staff to the greatest extent possible. Therefore, employee satisfaction among couriers might be a key metric to focus on in the ongoing successful operation of the facility. Hence, facility management need to hire qualified staff to execute the administrative tasks to ensure their costs remain under control and do not adversely impact the efficiency and success of the facility.

Since the core function of the operation is the successful processing of parcels from freight carriers, cultivating and growing long-term relationships with these business partners is critical. However, as the cost model results indicate, additional efforts such as ancillary delivery services are also important. Both findings suggest that the successful facility manager should engage in a two-pronged strategy to mitigate the potential risk of being overly reliant on one customer base. The marketing strategy should be one of both maintenance and growth: maintaining freight carriers as core customers but also continually reaching out to new businesses in the city centre to leverage the provision of additional services and the revenue they bring. As the successful consolidation facility operation is contingent upon the level of retail trade activity, one key risk to the operations is outside of the purview of facility management. Declines in economic activity within the area will result in lower demand for consolidated delivery services, which consequently will have a direct impact on profitability. The model solutions highlight that scenarios with lower parcel demand would lead to an unprofitable facility as shown in Fig. 8.9. Hence, the facility management, to mitigate this risk, must have a good understanding of what is impacting local retail trends and ultimately, factors contributing to increased parcel deliveries. This could simply be an ongoing task of the facility manager to have continual assessment and knowledge of current economic activity among businesses/customer types and ideally, projected activity.

From a local policy perspective, the model results can provide a roadmap of sorts for local authorities for determining the most important aspects to focus on in the development of incentives schemes and measures that could support freight consolidation endeavour. For instance, some previous government policies provided project start-up funds or tax abatement for facility operators to set up a facility (rent and equipment) during the first year. However, the model results clearly indicate that location and costs of the physical space are less important to achieve profitability than are personnel costs. While the cost of a facility and infrastructure might be offset by tax abatement measures or start-up funding, over time, these policy levers will have a decreasing effectiveness as those costs do not disproportionately impact profitability. Hence, the study findings underline that these start-up support measures do not affect the efficacy of the consolidation facility to reach self-sustaining status as much as other critical operational parameters. More effective measures might focus on raising awareness among businesses in central

business districts (or market areas) to support facility operations and maintain a customer base large enough to achieve profitability. Conveying the benefits of the consolidation initiative with respect to utilisation of eco-friendly freight vehicles and improving the amenity of the city centre could help attract businesses and keep the demand pipeline active. Local programmes could also focus on ensuring an ample supply of labour available for the facility, and training programs that would seek to ensure the most efficient operations. Other potential policy measures might include favourable terms on vehicle infrastructure for the facility operator; technical assistance for facility operator; and, favourable terms for employee benefit programmes.

These findings may be transferrable to cities with a congested city centre that suffers from limited on-street parking infrastructure and heavy utilisation of delivery vans. Many local authorities are implementing more pedestrianisation policies to improve amenities in the city centre and promote active transport (walking and cycling). However, these pedestrian zones adversely affect the accessibility and efficiency of the freight vehicles to the large number of retailers inside the pedestrian zones. The increasing demand for express and fragmented deliveries to receivers coupled with the negative implications of logistics sprawl and inefficient loading infrastructure in the inner-city will further complicate the last leg of deliveries and make these activities operationally and economically cost-prohibitive for freight carriers. It is time to move from the critical oversight of past approaches of freight solutions focusing on societal stakeholders and environmental concerns while overlooking the operational challenges of freight carriers. Policy makers should bring goods receivers and freight carriers to the table to design suitable and profitable freight consolidation schemes that will meet their business and operational needs as well as set financial and non-financial incentives schemes that are optimised and highly influential in alleviating the contribution of freight to urban traffic congestion and its associated challenges.

8.7. Chapter Summary

There is a growing body of literature within transportation economics that focuses on the variables and factors influencing profitability of freight consolidation facilities. This chapter analysed the business model of the consolidation initiative to examine its business case and demonstrate the value propositions to the various users from participation to address *Research Question #2*. In accordance with the 4th research objective, a mixed integer linear programming (MILP) cost model was formulated to optimise the profitability of the proposed facility and determine the operational variables that influence its profitability in this chapter, which represents the 5th stage of the integrated framework. Accordingly, a genetic algorithm was applied to solve the formulated MILP cost model and demonstrate its suitability and practicality in optimising the operational costs and revenue of the consolidation facility as well as providing outputs describing the most profitable consolidation facility.

The solution of the MILP cost model revealed a scenario under which a consolidation facility could be operated profitably given local parameters. Contrary to the perspective in the literature that questions the feasibility of a consolidation facility to be profitable, this study provides evidence that these facilities could be financially viable without government subsidies. However, the cost model also does suggest that the profit margin is very tight, and that small changes in operating variables can have substantial impacts

on facility profitability. This outcome stresses the importance of ensuring the facility operator take an active role in monitoring the ongoing operational health. Based on the cost model results, we can highlight that a successful consolidation facility should focus on 1) ensuring a minimum daily throughput; 2) employing a strategy to effectively manage critical staffing resources; 3) ensuring vehicle fill rates are optimised; and 4) employing marketing strategies to both cultivate long-term partnerships with carriers while facilitating new relationships to drive demand for ancillary services. The overall results of the study portend that regulations seeking to support the operations of these facilities should focus on these key areas to increase the likelihood of profitability.

This study expands the value of cost models in the transport economics literature by accounting for all the various costs in detail associated with a consolidation facility. The holistic model is different from other studies in the literature as it incorporated uncertainty of freight carriers' interest in consolidated delivery services by applying various demand projections of the number of transferred parcels from other freight carriers. In addition, it focuses on the potential profitability of a consolidation facility given local data. Therefore, this proposed framework can be used in virtually any location to assess whether a consolidation facility will be profitable, in addition to informing the staffing and infrastructure needed to be operationally efficient. Moreover, the model offered an enhanced understanding and evidence for transport researchers, the urban freight industry and local authorities on the operational factors that significantly influence the financial viability of freight consolidation facilities.

This study is also not without its limitations. As the cost model is dependent upon the collection of local data, due diligence is required to ensure the quality of model inputs are as accurate as possible. The model outputs and resultant outcome of profitability are highly sensitive to the various assumptions applied for the operational parameters. Although the model inputs included different ratios across the operational days for additional delivery and value-added services, the values of these ratios were kept constant across the scenarios. While the cost model attempted to include a realistic operational perspective by including a ratio of the delivered parcels to total transferred parcels, another limitation of the cost model is that it did not incorporate a financial penalty for failing to deliver all the transferred parcels besides the lost revenue from the undelivered parcels. Finally, the cost model did not consider any potential impact of changes in prices on the facility profitability's, particularly over time.

Accordingly, it is recommended that a future study could focus on developing a more in-depth understanding of the impact of changes in prices of consolidated delivery services on the facility profitability. The cost model could be further expanded to include a decision variable that attempts to maximise the drop density of each delivery vehicle, i.e. increasing the number of delivered parcels at each stop, by incorporating freight generation demand models and vehicle routing problem optimisation techniques to optimise delivery routes and the number of freight vehicles. Another research direction could apply the cost model to evaluate the influence and effectiveness of various government incentive schemes on the facility's profitability such as start-up schemes (tax breaks or subsidies for real estate costs), operational schemes (subsidies for maintenance and repair of facility infrastructure and/or vehicles) or retailer-based schemes (inducing businesses to request their suppliers to transfer the parcels to the facility) to determine the optimal package to support the financial viability of the consolidation facility.

Chapter 9.

Conclusion

This chapter presents a summary of the major findings, main contributions of the research and practical applications of the integrated framework and findings for key stakeholders. This chapter concludes with a few suggestions for future research directions.

9.1. Research Summary

Ensuring efficient deliveries and streamlined relationships between freight carriers and receivers in the inner-city have never been more critical and challenging due to the time-sensitive delivery expectations, higher distribution costs, ineffective infrastructure and outdated regulations. Hence, the efficiency and transport costs of freight carriers' delivery activities are adversely exacerbated in the highly congested inner-city area. The freight consolidation policy offers an effective alternative for freight carriers to consolidate the last leg of parcel deliveries to the various types of receivers in the inner-city. Accordingly, this research project developed an integrated framework, which consisted of five stages, to establish an effective, sustainable and financially viable freight consolidation facility in the inner-city based on operational, social, environmental and economic requirements of all stakeholders. The integrated framework included five stages to address the research questions (section 1.3) and achieve the research objectives (section 1.4) as follows:

- *Firstly*, the 1st stage presented the design of a Central City Consolidation Facility based on analysis of delivery activities specifically in the inner-city and overcoming the shortcomings of previous consolidation initiatives. The analysis of operational parameters underlines that delivery trips inside the inner-city are significantly different from other parts in the metropolitan area with considerably higher use of delivery vans (more than 80% of delivery fleet), higher number of stops per vehicle (more than 50 daily stops) and lower vehicle fill-in (about 50% fully loaded), which addressed *Research Question#1*. The regulations of on-street loading spaces need to be updated. Accordingly, the design of the CCCF focused on including operational capabilities and efficiency gains such as accommodating incoming heavy freight vehicles, palletisation of parcels and an efficient system integration to make the consolidation initiative operationally- and economically-attractive for freight carriers to transfer their inner-city parcels to the consolidation facility operator. Moreover, the inclusion of sustainable freight land-use zoning in the design of the consolidation facility ensures the facility would be sustainably integrated to cohabit with sensitive surrounding uses. Thus, the design of the consolidation facility addressed *Research Question#2* and the 1st research objective.
- *Secondly*, the multi-stakeholder approach in 2nd stage selected the most suitable delivery fleet to perform the consolidated deliveries based on priority weights of 30

objectives from all six stakeholders groups to address *Research Question #3*. The multi-actor analysis suggests that the combined use of battery-electric delivery vans and electricity-assisted cargobikes would likely receive overall support from all stakeholders to address the 3rd research objective. Some criteria were prevalent for most stakeholders primarily the transport costs and service levels for business stakeholders and liveability for societal stakeholders. However, the conflicting criteria weights among the six stakeholders groups and evaluation scores of the alternatives in the mono-actor analysis vs. multi-actor analysis emphasised how stakeholders expressed different preferences on the most suitable delivery fleet. Accordingly, it is essential for decision-makers to realise that no single solution can achieve consensus or equally satisfy all stakeholders.

- *Thirdly*, the behavioural responses of retailers and business were analysed using econometric models in the 3rd phase to estimate the receivers' willingness to participate in the consolidation initiative in accordance with *Research Question #4* and the 2nd research objective. The findings reveal a general potential willingness to participate in the proposed consolidation initiative (24% of respondents). The estimation of the ordered logit model indicate that the receivers' business characteristics including the number of daily deliveries and delivery companies as well as commercial sector highly influence their willingness to participate. It is estimated that businesses that receive 2-7 daily deliveries and deal with 5-7 delivery companies are highly interested in the consolidated delivery service. The mixed logit estimations reveal that the time-window of the consolidated delivery specifically during 09:00-15:59 and value-added services specifically the time-specific delivery, unpacking and real-time status updates significantly influence receivers' willingness to participate. The WTP calculations highlight that while there might be a net benefit for most receivers to pay for the consolidated service, the receivers' business characteristics especially the sub-industry influence their WTP. Moreover, the modelling results confirm that most receivers are reluctant to accept changes to their current delivery times and prefer a consolidated delivery service that facilitates improved certainty and reliability of their deliveries. Hence, it is recommended that policymakers should design consolidation schemes to minimise disruption to current delivery processes as possible and formulate RLC service configurations that are driven by needs and preferred attributes of businesses in the most interested sub-industries, rather than offering a one-size-fits-all policy solution.

- *Fourthly*, the multi-criteria spatial approach in the 4th stage demonstrated how the integration of spatial modelling and MCDM methods facilitate identifying suitable locations for the consolidation facility, examining their suitability and producing a systematic ranking based on real geographic values of all criteria in a highly robust and adjustable approach in regard to *Research Question#5* and the 3rd research objective. The application results of the GIS-MCDM approach highlight that most suitable locations for the facility in the inner-city are in zones with affordable industrial land and superior access to major freight corridors and goods receivers. The spatial maps of the 11 decision criteria illustrated conflicting suitability score for adjoining zones in the study area, which highlight the challenges of identifying the optimal location for the facility in the highly expensive and dense inner-city.

- *Finally* in the 5th stage, the two-phase profitability assessment approach examined the profitability of the consolidation facility in accordance with *Research Question#2* and the 4th research objective. The business modelling of the consolidated initiative demonstrated its effectiveness in contributing to useful value propositions for stakeholders involved in consolidated delivery services. Moreover, the genetic algorithm solution of the MILP cost model confirm that the proposed consolidation facility could be profitable without government incentives. However, the estimated thin net profit (8%) is highly dependent on maintaining a certain threshold of transferred parcels from other freight carriers to ensure profitability and reaching a self-sustaining status. It is estimated that the largest contributor to overall facility cost is associated with personnel and administrative costs (69% of total costs) due to higher staff remunerations. The optimisation solution estimated the actual costs of delivery vehicles (13%) and facility costs (15%) to represent a minor share of the total costs. Furthermore, the sensitivity analysis indicates that optimising the vehicle fill-in rate of the consolidated delivery fleet would contribute to the highest gains in the profitability of the facility. Hence, it is recommended that the facility operator places a near singular focus on the human resource management of the operations, as this is a critical contributor to profitability.

In conclusion, successful delivery consolidation strategies could be a trade-off between transshipment costs, externalities, operational delivery requirements, stakeholders' interests and the formulation of supporting regulations. At the end, decision-makers need to take these aspects into consideration when assessing and selecting the right policy levers for consolidated deliveries in the congested inner-city area, which underlines the difficulties associated with freight consolidation policies. The direct insights acquired from freight carriers about their delivery trips and operational challenges and from receivers about their daily delivery activities in this thesis provide useful knowledge on freight deliveries specifically inside the inner-city area that was limited. Policymakers and transport researchers could build on the derived knowledge to propose freight solutions and formulate supporting regulations that are in fact relevant and suitable to the current state of last mile freight in the inner-city. The progress and outcomes of the five stages of the integrated framework have provided evidence that the focus on operational requirements, comprehensive stakeholders engagement, involving goods receivers, optimising the operational configuration and location of the facility and ex-ante assessment of all business aspects will facilitate establishing an effective, sustainable and profitable freight consolidation policy for the various stakeholders. From the numerous studies performed in this research project, the following key lessons can be drawn:

- Acquiring and applying relevant and updated operational characteristics and parameters from the urban freight industry plays an important role and a critical factor in the efficacy and likely acceptance of any proposed freight solutions.
- Increasing demand for express and fragmented deliveries to receivers coupled with the negative implications of logistics sprawl and inefficient loading infrastructure in the inner-city will further complicate last leg of deliveries and make these activities operationally and economically cost-prohibitive for freight carriers.

- It is essential to incorporate the notion of realistically attaining operational efficiencies and economic gains for business stakeholders in proposed freight solutions, not only the sustainable concerns of societal stakeholders.
- Involving selected actors from the urban freight industry does not constitute comprehensive stakeholder engagement. The focus should not be on a dominant key stakeholder group, but rather holistic representations of all the various stakeholder groups in the planning and decision-making of freight solutions. Moreover, the size and type of actors in the stakeholders involvement process should include large companies as well as small and independent businesses.
- It is time to move away from the critical oversight of past approaches of freight solutions that solely focus on and serve the needs of carriers and societal stakeholders. Policy makers should bring goods receivers to the table to design suitable and useful measures that will meet their business needs and alleviate freight's contribution to urban traffic congestion and its associated challenges.
- Government financial and non-financial incentives and measures should be optimised and allocated to the operational aspects that are highly influential in the productivity and success of the freight solution, not primarily during the start-up stage.

9.2. Research Contribution

The integrated framework to optimise establishing a freight consolidation facility and the derived insights presented in this research extended the theoretical and practical knowledge of the following aspects:

- **Characteristics of Delivery Trips for the Last Leg of Delivery in the Inner-City**:

  Presented a detailed and up-to-date description and characteristics of freight carriers' delivery trips inside the congested inner-city including: class and number of freight vehicles, average vehicle fill-in rate, number of daily stops per vehicle, and rate of successful delivery on 1st attempt as well as ranking of selected operational challenges on the efficiency of freight carriers' activities. The acquired freight industry insights expanded the limited knowledge on the current state of last mile delivery inside the inner-city area as highlighted in section 2.5.2. This contributes to proposing practical policy suggestions for balancing the competing needs for space and access for freight vehicles and liveability in the inner-city.

- **Operationally- and Economically-Attractive and Sustainable Design for the Proposed Consolidation Facility**:

  Operationalised the design of the freight consolidation facility based on sustainable freight land-use policies, actual operational requirements and societal concerns for all stakeholders involved in the last leg of the last mile delivery.

- **Modelling Freight Receivers' Willingness to Participate in and Pay for Receiver-led Delivery Consolidation Service:**

Estimated receivers' willingness to participate using freight behavioural models as follows: determine the delivery attributes that influence receivers' willingness to participate, identify the commercial sectors that are most likely to participate, examine which RLC policy levers are more influential in their willingness to participate and their willingness to pay for the service without the involvement of government financial subsidies. Knowledge derived from the econometric modelling results make a contribution to the limited knowledge on RLC policy as outlined in section 2.4.2.2. This knowledge could be used to shape a vision of what a freight consolidation scheme might entail, focusing on sub-industries indicating the most willingness to participate. Details regarding findings at a sub-industry level provide valuable insights that can be used to formulate a suitable and effective RLC scheme that is tailored for the most willing receivers.

- **Siting of Freight Consolidation Facilities in The Inner-City:**

  Presented a fuzzy Multi-criteria spatial evaluation approach to locate and optimise the selection of the most suitable location for consolidation facilities in the inner-city by combining spatial analysis, sustainable logistics land-use and stakeholder engagement. The fuzzy GIS-MCDM approach enables determining the optimal location for the facility while considering and addressing the various operational, spatial and economic requirements of freight carriers as well as the social and environmental objectives of local authorities and residents, which addresses the limitations of approaches applied in other location studies as highlighted in section 2.4.4.2. This provides transport researchers and local authorities with a holistic decision-support system for location studies of consolidation facilities based on an improved understanding of the various objectives of key stakeholders.

- **Quantifying the Profitability of The Freight Consolidation Facility:**

  Formulated a mixed-integer linear programming (MILP) cost model to optimise the profitability of the proposed facility and determine the operational parameters that contribute to a profitable and self-sustaining consolidation facility without government incentives. The optimisation cost model incorporates the unknown nature of parcel demand and enables assessing the financial health of the facility by quantifying the annual net profit margin and revenue streams. The model solution offers an enhanced understanding and evidence for transport researchers, the urban freight industry and local authorities on the operational factors and infrastructural costs that significantly influence the financial viability of the facility, which has been overlooked as highlighted in section 2.4.5.2.

9.3. Applications and Uses:

The data-driven decision-support framework presented in this thesis incorporated freight industry operational requirements as well as social and environmental concerns to optimise establishing a freight consolidation facility in the inner-city area. Hence, it would benefit and could be utilised by several stakeholders groups as follows:

9.3.1. Local Authorities:

- Local councils can benefit from the key findings to formulate land-use planning guidelines to allocate industrial land in the inner-city for logistics facilities that are optimal both in location and quantity.
- Local councils can apply the insights about utilisation of on-street loading spaces by freight vehicles to improve the allocation and regulation of OLZs and promote higher use of off-street loading docks in high-rise towers.
- Local councils may build on this robust and holistic approach as a lobbying tool to justify setting public policies that support the set-up and operation of suitable and sustainable freight consolidation facilities in the inner-city.
- Transportation planners could benefit from the mono-actor and multi-actor analysis to reduce impediments and act proactively to support freight carriers to utilise battery-electric delivery vans and cargobikes for deliveries in the inner-city.
- Urban planners may take a proactive approach to incorporate the knowledge on characteristics of delivery trips and proposed supporting regulations (section 4.4.2) in the local transport planning of the inner-city and set land-use ordinances for future logistics facilities for sustainable integration with sensitive surrounding uses.
- Urban planners can use the spatial approach to select most suitable locations to preserve industrial land for future logistics facilities in the highly expensive inner-city.
- Chamber of commerce and economic development agencies could use this study as a model to engage with potential receivers to identify areas of greatest geographic need and design a useful consolidation service that will meet their business needs.
- Local councils could use the WTP estimates and facility operational costs estimates to consider the level of public subsidies to promote freight carriers and receivers' participation in future consolidation initiatives.

9.3.2. Urban Freight Industry

- Freight carriers can utilise the knowledge presented on delivery trips to hold stakeholder meetings with local authorities to discuss and highlight the negative implications of the operational challenges on the efficiency of their operations.
- Freight carriers interested in setting up a consolidation facility can apply the proposed operational design and build on insights derived from mono- and multi-actor analysis to garner support from local authorities.
- Interested freight carriers can apply the proposed operational design of the consolidation facility to set up and operate an operationally- and economically-attractive facility to encourage other freight carriers to transfer their parcels.
- Interested freight carriers can apply the multi-criteria spatial approach to assess and confirm whether the operational environment of a commercial property actually meets the business needs in terms of facility size and operational requirements.
- Potential operators of future consolidation facilities can utilise the optimisation cost model to assess the facility's profitability and determine what operational

parameters to focus on in order to ensure achieving a self-sustaining status for the facility.

9.3.3. Logistics Real-Estate Providers

- Logistics property providers could utilise the proposed design to build logistics facilities that display improved functional, architectural and insulation quality that are compatible with surrounding residential and commercial uses in the inner-city.
- Interested providers could use the proposed facility layout to set up a consolidation facility that takes into consideration the operational requirements of freight carriers and the utilisation of a sustainable delivery fleet.
- Interested providers can use this framework to appraise the best locations in the inner-city to invest and build a suitable consolidation facility that will attract freight carriers and receive local government approval.
- Commercial property owners of commercial buildings and shopping centres could benefit from the insights about receivers' interest in the consolidation initiative to consider measures that facilitate improved management of incoming deliveries.

9.4. Future Research Directions

Given the nature of the research questions and time constraints of this research, the following research directions are proposed for further investigation, which are additional to the chapter-specific research areas highlighted in summary sections of Chapters 4-8:

- With recent advancements in autonomous delivery vehicles, internet of things, and warehousing robotics, a physical internet (Montreuil 2011) enabled consolidation facility could be realised to facilitate automated, multi-modal and cost-effective transfer, handling and distribution of standardised parcels in consolidated shipments from freight carriers to receivers in the inner-city. However, it is necessary to examine the required regulations and suitability of autonomous freight delivery robots for consolidated shipments in congested parts of the inner-city. Further research is necessary to determine the operational requirements and regulations to enable a standard size packet for parcels exchanged between various freight carriers involved in the consolidation scheme. Moreover, another study could examine the cost-effectiveness of utilising autonomous delivery robots and robotics warehousing in lowering the personnel costs associated with consolidation facilities.
- A future study could integrate freight generation estimates and sustainable freight land-use regulations in the land-use planning and building permit process of future commercial property developments. For example, a future study could investigate the necessary regulations and added benefits of incorporating a centralised off-street loading dock in future building permit approvals of adjacent high-rise commercial towers instead of an individual loading dock for each building.
- The integrated framework could be further applied to optimise the siting of construction consolidation centres especially with the large number of commercial and residential development projects in various city centres in the Australasian region. Many development projects are being constructed in adjoining sites in the

city centre and receive similar construction materials using under-utilised freight vehicles. With the increasing use of modular construction materials, a properly planned and designed construction consolidation centre could accommodate receiving optimised deliveries of construction materials on road trains, which include a prime mover truck pulling more than three trailers, with subsequent delivery to construction sites on articulated trucks. This could reduce the number of heavy trucks transporting construction materials into the inner-city area as well as utilising the heavy road trains for backhaul of construction waste.

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Appendix

Appendix A: Ethics Approval Letter

THE UNIVERSITY OF MELBOURNE

16 August 2017

A/Prof R.G. Thompson
Infrastructure Engineering
The University of Melbourne

Dear A/Prof Thompson

I am pleased to advise that the Engineering Human Ethics Advisory Group has approved the following Minimal Risk Project.

Project title: **An Integrated Framework for the Sustainable Establishment of Central City Transhipment Facility to Ameliorate Last Mile Freight**
Researchers: **A/Prof R G Thompson, K Aljohani**
Ethics ID: **1749808**

The Project has been approved for the period: **10-Aug-2017 to 31-Dec-2017.**

It is your responsibility to ensure that all people associated with the Project are made aware of what has actually been approved.

Research projects are normally approved to 31 December of the year of approval. Projects may be renewed yearly for up to a total of five years upon receipt of a satisfactory annual report. If a project is to continue beyond five years a new application will normally need to be submitted.

Please note that the following conditions apply to your approval. Failure to abide by these conditions may result in suspension or discontinuation of approval and/or disciplinary action.

(a) **Limit of Approval:** Approval is limited strictly to the research as submitted in your Project application.

(b) **Amendments to Project:** Any subsequent variations or modifications you might wish to make to the Project must be notified formally to the Human Ethics Advisory Group for further consideration and approval before the revised Project can commence. If the Human Ethics Advisory Group considers that the proposed amendments are significant, you may be required to submit a new application for approval of the revised Project.

(c) **Incidents or adverse affects:** Researchers must report immediately to the Advisory Group and the relevant Sub-Committee anything which might affect the ethical acceptance of the protocol including adverse effects on participants or unforeseen events that might affect continued ethical acceptability of the Project. Failure to do so may result in suspension or cancellation of approval.

(d) **Monitoring:** All projects are subject to monitoring at any time by the Human Research Ethics Committee.

(e) **Annual Report:** Please be aware that the Human Research Ethics Committee requires that researchers submit an annual report on each of their projects at the end of the year, or at the conclusion of a project if it continues for less than this time. Failure to submit an annual report will mean that ethics approval will lapse.

(f) **Auditing:** All projects may be subject to audit by members of the Sub-Committee.

Please quote the ethics registration number and the name of the Project in any future correspondence.

On behalf of the Ethics Committee I wish you well in your research.

Yours sincerely
George Buchanan
Dr George Buchanan - Chair
Engineering Human Ethics Advisory Group

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