Opportunities and Feasibility of Urban Freight Consolidation

A Case Study in the Event Area of Gothenburg

Master's thesis in Supply and Operations Management

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SUMMARY

With economic development and the growth of tourist-based event areas, urban freight transport faces significant challenges in terms of congestion and environmental impact. The freight activities in the event area of Gothenburg, especially Liseberg and Svenska Mässan, are characterized by fragmented shipments, seasonal fluctuations and spatial constraints, leading to logistical inefficiencies. This study combines stakeholders' interviews, freight trip generation (FTG) analysis and cost-based modeling to examine current delivery patterns in the event area, analyze the potential for freight consolidation, and assess the feasibility and sustainability of implementing consolidation strategies with an urban consolidation center (UCC). The results show that there is a strong need for freight consolidation in the area due to fluctuating, small-volume, frequent, and low-loading-rate deliveries, and that approaches such as multi-stop deliveries and receiver-led consolidation can significantly reduce delivery costs and traffic flows. Finally, the study provides actionable recommendations for stakeholders, including suppliers, logistics service providers, receivers, and public authorities, to advance consolidation strategies. This research contribute to the REDIG project's goal of developing scalable, fossil-free logistics solutions that improve urban transport efficiency and support sustainable urban freight in Gothenburg and beyond.

Keywords: Urban freight logistics, Urban consolidation center (UCC), Receiver-led consolidation, Gothenburg event area, Freight trip generation, Cost model

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Statement: During the writing of this report, the authors used ChatGPT and DeepL to embellish language and aid in data collection and analysis. After using these tools, the authors reviewed and modified the content based on need, and take full responsibility for the content of this report.

Lingxuan Meng, Yihui Fan, Gothenburg, May 2025

List of Acronyms

Below is an alphabetically arranged list of the acronyms used throughout this report:

B2B	Business to Business
FTG	Freight Trip Generation
FTL	Full Truck Load
GHG	Green House Gas
HDV	Heave Duty Vehicle
LDV	Light Duty Vehicle
LEZ	Low Emission Zone
LSP	Logistics Service Provider
LTL	Less than Truck Load
MDV	Medium Duty Vehicle
RLC	Receiver-Led Consolidation
UCC	Urban Consolidation Center
3PL	Third-Party Logistics

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1

Introduction

This study is part of the REDIG project, led by Research Institutes of Sweden AB (RISE), under the Gothenburg Green City Zone programme. The project sets out to develop a shared approach for a fossil-free, sustainable, digital, and open freight system that supports the future development of the event area in Gothenburg. By fostering collaboration among stakeholders, the initiative seeks to reduce traffic congestion, lower emissions, and enhance overall transport efficiency, while ensuring economic sustainability, thus lay a foundation for the future logistics solution. (RI.SE., 2023)

This study focuses on the freight logistics situation in the event area of Gothenburg – Liseberg and Svenska Mässan, where B2B transportation can have a significant impact on the surrounding urban freight environment due to the business and event-related freight activities. It analyzes current freight operations of the event area, including delivery patterns, traffic outcomes and consideration factors of different stakeholders. Models are developed to explore the generation of freight vehicle trips and cost changing when implementing consolidation strategies. Thereby provides valuable insights and practical recommendations to businesses, logistics service providers and public authorities, supporting the adoption and long-term viability of a scalable urban freight consolidation model in both Gothenburg and beyond.

1.1 Background

Urban freight represents the final stage of the supply chain and mainly consists of last-mile deliveries to end consumers, thus playing an important role of modern cities, facilitating the operation of commercial, industrial, and service activities, as well as supporting the city's economic development (Ros-McDonnell et al., 2018). As economies continue to grow, urban areas and cities are experiencing increasing demand for products, services, and the distribution of goods (Baker et al., 2023). To meet this demand, there is a growing need for urban logistics, which puts more pressure on sustainability, as urban freight transport is one of the major contributors to traffic congestion, air pollution and noise emissions (Akyol and De Koster, 2018;

Russo and Comi, 2017). Studies indicate that urban freight transport accounts for up to 20–30% of total urban traffic, 25% of CO_2 emissions and 30–50% of other transport-related pollutants (Kijewska and Iwan, 2019; Muñoz-Villamizar et al., 2020; Russo and Comi, 2016).

The causes of these challenges stem from increasing freight demand, fragmented deliveries, and inefficient vehicle use that lead to high empty rates and redundant trips, while congestion and regulations like delivery time windows, in turn, makes goods transport more difficult. (Kin et al., 2018). Especially in B2B contexts, a lack of coordination between multiple suppliers and customers leads to more less-than-truck loads (LTL) that deliver to the same destination, worsening congestion and increasing pollution (van Heeswijk, 2017).

Cities are exploring various urban freight management strategies to solve the problem, while some of them are policies like dedicated loading / unloading parking bays, access and time restrictions, freight consolidation is becoming a popular approach for cities to alter the logistics of the existing urban freight transport (Marcucci and Danielis, 2008).It allows long-distance inbound freight to be handled separately from local city deliveries, which can improve load factors in urban areas and reduce the number of delivery trips. (Gillström and Björklund, 2024). Based on this, receiver-led consolidation (RLC) puts the focus actor on the receivers, allowing businesses to coordinate shipments and minimize delivery frequency based on the demand from the end (Holguín-Veras and Sánchez-Díaz, 2016).

However, despite the many benefits of freight consolidation and that many city initiatives and attempts to consolidate, it turns out that the operation of urban consolidation centers (UCCs) still faces many operational failures. Many UCCs struggle with financial viability due to the added costs of consolidation and the reluctance of shippers and carriers to participate without incentives (Isa et al., 2021; Nylander et al., 2023). Studies show that regulatory and institutional issues are identified as barriers in implementing freight consolidation, and without sufficient commitment from carriers and other stakeholders, UCCs struggle to achieve the necessary scale for long-term success (Nordtømme et al., 2015; van Heeswijk et al., 2019).

A study of the urban freight in Gothenburg gets to the conclusion that the decentralization of logistics facilities to peripheral areas has increased delivery distances and vehicle trips to city centers, and the spatial spread of logistics hubs away from urban centers has resulted in increased congestion in central areas and higher environmental impacts (Heitz et al., 2020). And for the freight management of the event area, Liseberg amusement park and the Svenska Mässan exhibition center, which are characterized by event-based freight demand, there are several factors that make this type of freight extremely complex and challenging to manage. For example, the dynamic urban goods flows that contain multiple time spans (season, week, day and hour), complex interactions among stakeholders that take place in business transactions, diverse commodities and the associated diverse levels of service, and the stochastic nature of freight demand arising out of the events happening in the area with unpredictable tourists and exhibitions activities (Friesz and Holguín-Veras, 2005). Based on the above background, sustainable urban freight management in this case requires an integrated consideration that balances economic efficiency with environmental and social aspects among different stakeholders.

1.2 Purpose

Due to the high volatility of demand, large variety of goods, the strict time and space constraints of logistics, and the involvement of multiple stakeholders, the freight transport of the event area in Gothenburg presents considerable challenges, including traffic congestion, increased emissions, and inefficient resource utilization with high logistics cost. The early data indicate that freight activity in this area fluctuates significantly, especially during peak event periods, leading to traffic pressure and environmental impact. At the same time, lack of coordination among stakeholders results in limited consolidation opportunities.

This thesis aims to investigate the potential for freight consolidation in the event area of Gothenburg, focusing on the opportunities and its feasibility to be long-term sustainable. To achieve this, the study will first analyze the current freight logistics situation in the event area, examine delivery patterns, existing inefficiencies and the specific logistical challenges to different stakeholders. Next, the study will explore the economic feasibility of freight consolidation from a cost perspective and comparatively assess the feasibility under different consolidation modes. Based on the modeling results and analysis, the study will provide recommendations to different stakeholders within the consolidation system, including suppliers, logistics service providers, receivers and public authorities, on how to facilitate the adoption of freight consolidation.

1.3 Research questions

Based on the above background and purpose, three questions are formulated:

1. What is the current freight logistics situation in the event area of Gothenburg?
2. What measures can be taken to improve the economic sustainability of the consolidation in the event area?
3. What suggestions can be given to different stakeholders to effectively adopt and implement freight consolidation?

2

Methodology

In this chapter we will describe the methodology we adopted for the study, the research process, and the considerations of the study. This chapter is divided into three sections, the first section will be a broad description of the overall research design and discuss the applicability of the research methodology in relation to the research objectives. The second section will specify the data collection and analysis process, ensuring scientific processes that drive valuable insights. The third section will discuss the validity and reliability of the study to ensure that unbiased and credible results are obtained.

2.1 Research design

Creswell (2018) suggests that philosophical assumptions can influence research practice, and that researchers need to make their own claims on the assumptions in ontology, epistemology, and so on. In terms of ontology, this study is a combination of objectivism and constructivism. For objectivism, we assume that both the current freight logistics model and the potential for consolidation of this event area can be understood through quantitative analysis. In this part, we worked with the secondary data, conducted freight trip generation (FTG) modeling, and estimated cost to identify patterns and assess outcomes in a measurable way. However, our constructivism is reflected in the interpretation of the modeling results, especially regarding to the willingness and feasibility of consolidation. In this perspective, we hypothesize that the potential for consolidation is also influenced by several underlying factors such as people's different perceptions, preferences, and policy contexts. These subjective factors are explored through the coding and analysis of interview materials, which helps to contextualize and enrich the quantitative findings. In addition, the epistemological conclusions are similar to those of ontology. Our study combines positivism and interpretivism, ensuring that the study is both theoretically informed and practically relevant.

Based on the above philosophical assumptions, a mixed approach combining qualitative and quantitative research methods will be employed. As noted by Östlund et al. (2011), a mixed approach can offer a broader perspective to study complex phenomena. This fits the aim of exploring both operational and contextual aspects of urban freight consolidation. More specifically, it will focus on the key establishments within the event area: Liseberg amusement park and Swedish Exhibition & Congress Centre (Svenska Mässan) to understand the current freight logistics model and the consolidation potential of the event area.

2.2 Data collection & analysis methods

To place our study in the context of established theory and to utilize the subsequent series of tools more scientifically, we conducted academic literature research in the following areas: urban freight management, freight consolidation, FTG, and cost structure of the consolidation system. The primary sources for gathering academic literature are Google Scholar, Chalmers Library, and materials from courses.

The data sources for this study include secondary numerical data and interview transcripts related to the event area, provided by RISE and the course TEK465 "Sustainable Transportation". To figure out the objective pattern in the event area of Gothenburg, we obtained a series of quantitative data on vehicle flows and ordering, which are shown in Table 2.1.

Table 2.1. Data sources for vehicle flow and ordering in the Gothenburg event area

Source	Area	Time Period	Data Type
RISE	Liseberg	July 22 to July 28, 2024	Vehicle in & out record
RISE	Liseberg	Orders arrived in 2024	Order record from Stella
RISE	Liseberg	Orders placed from 2022 to 2024	Order record from Proceedo
RISE	Svenska Mässan	September 17 to September 24, 2024	Vehicle in & out record
RISE	Svenska Mässan	14 days in 2023 & 2024	Vehicle data
RISE	Svenska Mässan	Orders in 2023	Exhibition flow
TEK465	Heden area	Sep 25th, 2024	Vehicle in & out record

Based on the theoretical background of the datasets, we will structure our approach for data analysis accordingly.

Firstly, by analyzing all vehicle flow and order data, we will understand the type of truck and cargo in the current event area, the time of delivery, and the delivery routes. Based on the above data categories, we will derive some patterns of the delivery situation in the current event area, one example is the seasonal pattern of goods deliveries, which will be specifically developed in the subsequent sections. By comparing the traffic information with the orders and the external ordering data, we can not only validate the data, but also identify the delivery frequency and methods of different suppliers.

Secondly, to gain a deeper understanding of the current state of logistics in Gothenburg's event area and capture the potential for consolidation, we obtained the transcripts of interviews from RISE with logistics stakeholders in the current event area. Interviewees include , receivers, LSPs and Gothenburg City. Table 2.2 lists specific interviewees.

Table 2.2. Interviewed stakeholders and their roles

Stakeholder	Role in Shipment	Date of interview
Svenska Mässan	Receiver	2024-03-12
Liseberg	Receiver	2024-03-12
Gothenburg City	Public authority	2024-03-15
GotEvent	Receiver	2024-03-21
24/7 Logistics	LSP	2024-03-22
DB Schenker	LSP	2024-03-25
GLC	LSP	2024-03-26

For these qualitative interview data, we will conduct a thematic study of the transcript introduced by Norrman (2024). It includes four steps: description, coding, display, and sensemaking. First, the description will summarize the main background and outline to get a holistic picture of each interview. Moreover, open coding will be used to identify themes in the interview statements. These themes will be compared and refined between interviews to identify key patterns. Axial coding will be used to establish the relationship between these themes. After coding, the structure of the data and analysis will be visualized to explain the abstract and complex coding logic. Finally, sensemaking and theorizing aim to build the theoretical framework or theoretical frameworks by identifying patterns and causal relationships.

Thirdly, the freight trip generation model will be used to predict the annual number of orders for Liseberg. This process involves identifying the drivers that influence the number of freight trips in this event area(Holguín-Veras et al., 2014) by using the "*Vehicle in & out record*" dataset. Then, based on the identified drivers, a prediction model will be developed based on the "*Order record from Stella*" dataset. All these analyses and modeling will be conducted using the statistical software JMP, specifically utilizing its regression analysis to identify drivers, and applying time series modeling to forecast the annual order number.

Lastly, to assess the cost variation in the aspect with the use of UCC, we will develop a cost model grounded in the theory and model proposed by Janjevic and Ndiaye (2017) and Figliozzi (2009) to compare the cost in scenarios with and without the implementation of the UCC by utilizing the data from the "*Vehicle in & out record*". Furthermore, a set of assumptions and premises will be established and aligned with the type and completeness of the available data in our study. Based on these, the cost will be simulated using MATLAB, where simulation variables will be generated to reflect the distribution observed in the real dataset. The simulated result will demonstrate the cost distribution under different scenarios to facilitate a detailed comparison.

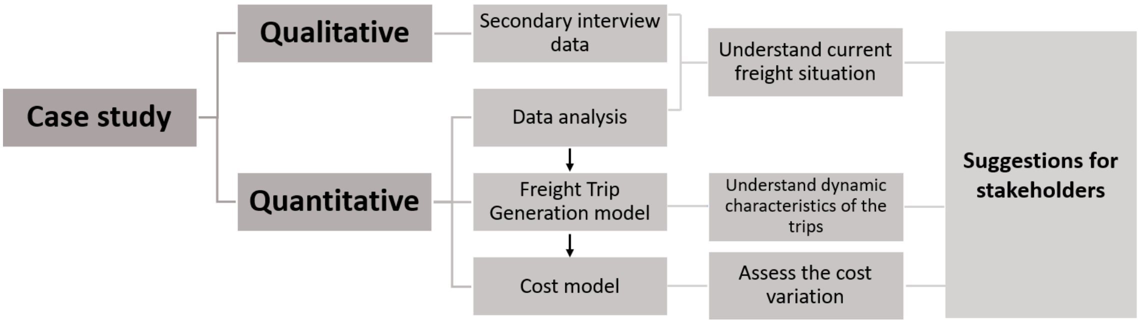


Figure 2.1. Overall research framework

2.3 Reliability and validity

1. Credibility Before proceeding with the design of FTG and cost modeling, we obtain some conclusions from three data sources: document analysis, freight flow data, and stakeholders' interviews. To ensure the credibility of the conclusions, we triangulate the conclusions from the different data sources and come up with a more comprehensive and credible conclusion. The triangulation also ensures that the data can reflect the pattern and avoid the bias caused by a single source. After understanding the current situation accurately, the factors the FTG and cost model can be considered comprehensively.
2. Transferability With the aim of ensuring the transferability of our final findings in similar contexts, we provide a detailed introduction to the background and methodology of our study in the early part of the thesis, and in the fourth chapter we provide a detailed description of the urban freight consolidation environment in Gothenburg and the current state of logistics in the event area, based on the three data sources mentioned above.
3. Dependability Our data analysis is carried out with a standardized process. For quantitative data obtained from RISE, we first perform data cleaning. The purpose of data cleaning is to remove some outliers, as well as to deal with some missing values and duplicates, ensuring the reliability and validity of the subsequent analysis(Wickham, 2014).

3

Literature Review

In order to lay a solid theoretical foundation for this study, this chapter reviews the relevant research on urban freight management, freight consolidation, and the cost structure of the consolidation system. This literature review serves as a basis for understanding the urban freight management strategies, evaluating the current freight situation, formulating cost model to explore financial feasibility, and forming practical recommendations for stakeholders.

3.1 Urban freight management

Urban freight transport represents the activity that consists of transporting freight from a departure point to an arrival within urban or metropolitan areas (El Yadari et al., 2024). It involves the movement of goods from manufacturing facilities, warehouses, distribution centers to businesses and consumers in urban areas (Moufad and Jawab, 2017a). The primary objective of urban freight management is to meet demand under optimal conditions of quality, timeliness, costs, energy efficiency and environmental protection (Karim and Fouad, 2018).

3.1.1 Overview

The urban freight transport industry has a crucial role in contributing to maintain the flow of goods and meet daily demand in cities (Moufad and Jawab, 2017b). Efficient urban freight transport consists of ensuring the availability of goods, supporting businesses, and meeting the needs of urban populations (Moufad and Jawab, 2019), and contributes to economic development by increasing logistics flows, optimizing transport costs, business competitiveness, employment opportunities, facilitating trade, business operations, and leading to the development of accessibility, and supports overall urban development and contributes to environmental sustainability (El Yadari et al., 2024).

Urban freight management faces a number of difficulties and challenges. Given the commercial stakes, urban freight services are inherently under great pressure to operate at low costs and high service levels, and they need to serve customers with tight delivery schedules and strict time-window constraints (Tanco and Escuder, 2021). In addition, carriers face difficulties operating their vehicles in complex urban road conditions with frequent traffic congestion. These factors result in inefficient use of freight vehicles, which are often not fully loaded and have long waiting times for deliveries (Taniguchi, 2008). Besides, urban freight transport has various negative externalities, contributing to traffic congestion and accidents, GHG emissions, air and sound pollutions due to large-size and poorly maneuverable trucks (Awasthi and Proth, 2006).

Due to the scale and nature of urban freight operations, they often create tension between economic needs and the social and environmental priorities of local communities (Cui et al., 2015). Optimizing freight transport helps to minimize GHG emissions, contributes to increasing service quality, optimizing traffic flows and minimizing traffic jams, accidents and social nuisances (El Yadari et al., 2024). The management and optimization of urban freight transportation can be divided into the following categories.

1. Business-led strategies focus primarily on improving logistics efficiency, reducing operating costs and minimizing environmental impacts. The first strategies were retailer-supplier collaborations to optimize delivery schedules and implement consolidation to reduce vehicle trips and increase efficiency of last-mile deliveries. Such collaborations evolved into freight consolidation through UCCs (Janjevic and Ndiaye, 2017). In addition, public-private partnerships (PPPs) facilitate the sharing of infrastructure by fostering collaboration between firms and government agencies and ensuring that firms comply with regulatory frameworks aimed at improving the sustainability of urban logistics (Taniguchi, 2014).
2. Government intervention also plays a crucial role in regulating and incentivizing sustainable urban freight practices. A common regulatory measure is the imposition of traffic and access restrictions, including Low Emission Zones (LEZs), vehicle weight limits, on-street parking reservation systems, time-restricted access, and Off-Peak Hour Delivery (OPHD). These restrictions aim to control the number of freight vehicles in downtowns, encourage cleaner modes of transportation, and help businesses avoid peak hour congestion (Holguín-Veras et al., 2016; Sánchez-Díaz et al., 2017; Russo and Comi, 2017). Financial incentives and tax policies have also been used to encourage compliance with sustainable logistics practices. Strategic land use planning, subsidies for electric vehicles, congestion pricing, and tax breaks for companies implementing green logistics solutions have been effective in reducing urban freight emissions (Holguín-Veras et al., 2016).
3. The rapid evolution of technology and its integration with transportation sys-

tem management further supports urban freight management by optimizing logistics operations and reducing emissions (Mokaddem and Jawab, 2019). The adoption of fossil-free vehicles plays a crucial role in reducing urban freight emissions to create a more environmentally friendly freight transportation system (Taniguchi, 2014). The development of automated and autonomous delivery systems including drones and automated delivery robots offers a promising solution to minimize urban congestion (Taniguchi, 2014). Logistics 4.0, based on communication technologies, autonomous systems, data technologies, integration and architecture, is also emerging as a key driver to efficient urban freight management (El Yadari et al., 2024).

3.1.2 Stakeholders in the urban freight management

Urban freight management faces several key challenges due to the complex structure of transport networks and hubs, along with the varied interests of the many involved stakeholders (Stathopoulos et al., 2012). Thus, freight transport in cities has long been regarded as an interaction between carriers and their customers, and viewed largely as a private-sector concern to address on its own (Rosales and Haarstad, 2023). Receivers, carriers, and shippers were the main players in freight systems traditionally, within a relatively narrow group of different actors. Currently, urban and transport policy-makers are becoming an important part in the urban freight system since they define the context where the freight transport is operated (Cui et al., 2015).

All the stakeholders in an urban freight system with their main interest are summarized in Table 3.1. In different freight operational scenarios, these stakeholders may play cross-cutting or overlapping roles, for example, a supplier that owned trucks may also act as a carrier, while a landowner of a logistics center may also be an LSP.

Table 3.1. Stakeholders in urban freight system

Category of stakeholders	Stakeholders	Main interest
Supply chain stakeholders	Shippers (suppliers)	Deliver goods at minimal cost while fulfilling customer demands
	Transport operators (3PLs or own account)	Efficient but affordable transport services that satisfy both shippers and receivers
	Receivers	Timely deliveries with minimal lead times
Resource supply stakeholders	Infrastructure providers	Cover costs and maintain infrastructure efficiency
	Infrastructure operators	Ensure access and effective use of the facilities
	Landowners	Economic value and returns from their properties
Public authorities	Local government	Reduce freight-related disturbances, with ensuring smooth and efficient logistics
	National government	Limit the negative impacts of freight transport with maintaining economic efficiency and performance
Other stakeholders	Residents	Face little disruption caused by urban freight
	Visitors/tourists	Face little disruption caused by urban freight activities with access to a broad range of products in shops

Source: Ros-McDonnell et al. (2018); Transmodal (2012)

Studies have shown that several stakeholders in the urban freight system have deeper inputs and influence, and that these stakeholders not only determine the operational viability of freight solutions but also influence the regulatory and economic frameworks that guide urban logistics.

Suppliers (shippers) are critical in urban freight management because they determine delivery schedules and logistics strategies that affect the viability of consolidation programs (Ciardiello et al., 2023). Suppliers and receivers influence urban freight efficiency through their operational choice and delivery preferences (van Heeswijk et al., 2019; Savchenko et al., 2022). LSPs play a pivotal role in optimizing last-mile distribution and reducing environmental impacts (Björklund and Johansson, 2018). Governments regulate urban freight transportation through policy, but face governance challenges in balancing stakeholder interests and ensuring the long-term viability of freight transportation initiatives (Rosales and Haarstad, 2023; Cui et al., 2015).

3.1.3 Event-based freight management

Event freight can be defined as the flow of goods, planning and challenges under an event setting, such as fairs or concerts (Haugen, 2011). Cities attract people and businesses with their varied economic activities and events, of which events are the main attraction for the population, driving tourist surges and giving a strong boost to the local economy. Events has complexity driven by shorter turnaround times, varying demand for goods, and unforeseen events that require flexibility (Uruchima et al., 2025). Also, event venues always prioritize efficiency, sustainability, and visitors' satisfaction to help guarantee successful outcomes (Uruchima et al., 2025). Consequently, event-based logistics are also complicated to manage due to the wide variety of goods being transported and the many additional requirements (Haugen, 2011). Despite the social and economic benefits that events bring to host cities, freight management teams also encounter numerous difficulties in handling logistics and goods transport. With events taking place in city centers, logistics for event venues must be seamless while minimizing disruption to city residents. Traffic congestion, loss of control, and freight flows due to increased emissions further disrupt the city (Uruchima et al., 2025).

As events are organized on a large scale, services and products create huge demands on operations executed simultaneously to ensure success. It is rare for a single company to be able to meet all of these requirements or specifications but they need to rely on outside resources. Thus companies tend to rely on the relationship between suppliers and the company itself to maintain operations (Snow et al., 1992). The complexity of a production setup is often seen in the large number of suppliers connected to its network, so that the source of activity shipments usually involves multiple suppliers, resulting in a large supplier network (Uruchima et al., 2025).

In order to meet the requirements of the activity and provide customized products and services at short notice, the organization of supplier network-oriented demand is crucial for the timely delivery of event-based products and services. Transportation and handling of material flows is important because supply flows have a very limited time window in which they can create value, especially during events or temporary projects (Modig, 2007). Events often face the high risk of customer disappointment, and delivery delays can also lead to higher costs or delays in the project or event, for example, failure to deliver the equipment of the exhibition facilities to the concert venue in time will have serious consequences for both the organizer and the visitors (Uruchima et al., 2025). With more outsourcing to service providers, effective planning and execution across the supplier network becomes even more crucial. Events benefit from having all deliveries sent to a single location, despite variations in goods type and volume (Modig, 2007).

Successful delivery of large projects and events depends heavily on coordination. The solution might be able to streamline material handling and reduce the number of suppliers through consolidation, easier adoption and reconfiguration of logistics systems to better meet certain requirements of the activity, and thus take advantage of economies of scale. However, there is also a view that standardized systems are usually less efficient and flexible, and that the integration of services relies on providers being able to handle large quantities of differently shaped materials (Modig, 2007). In addition, due to irregular and varied deliveries, event delivery often requires optimized material flow handling and seamless coordination, as traffic in and out of the organization's location tends to increase as the date of the event draws nearer. A study from Uruchima et al. (2025) uses Svenska Mässan as a case study to explore the use of consolidation centers to create more exhibition space for rent, thereby generating additional revenue streams. It is proposed that other companies associated with the event could also generate additional revenue by offering the use or services of the consolidation center.

3.2 Urban freight consolidation

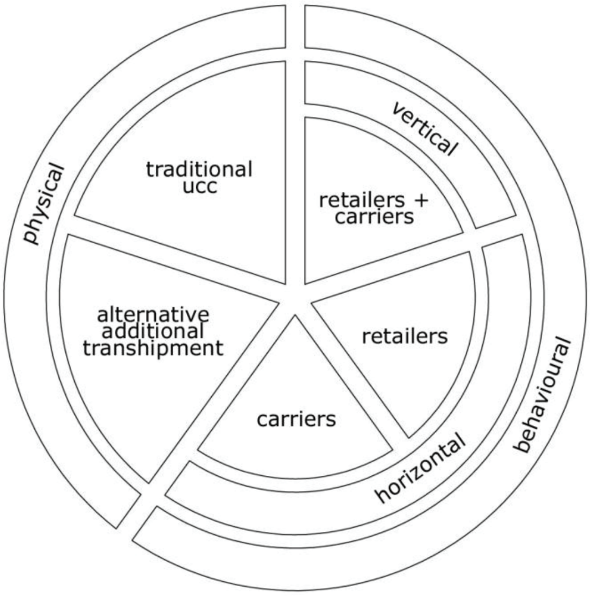
Freight consolidation has emerged as a viable strategy to improve urban logistics efficiency by reducing the number of individual deliveries and optimizing vehicle capacity utilization. However, the success of consolidation depends on various influencing factors, including stakeholder collaboration, cost structures, and operational feasibility. This section explores the fundamental concepts of freight consolidation, existing models, together with some cases in achieving freight consolidation, providing a basis for evaluating its application in the event area of Gothenburg.

3.2.1 Overview

Current studies and research on city logistics rarely view urban freight consolidation as an independent concept. This is largely because its main goal—improving vehicle load utilization to limit the number of freight vehicles in cities—can be achieved through various methods. Since only a few consolidation models are seen as truly effective, these strategies often do not fall neatly into one classification type (Verlinde et al., 2012).

From the origin side, suppliers, carriers, and major retailers often try to consolidate shipments to save costs. Yet, this kind of cost-focused consolidation doesn't always work well in the context of urban freight, as trucks will continue their journey half-empty after the first delivery, while the customers are often located spreading across multiple cities, so that most of the trucks entering the urban area are not operating at full capacity (Verlinde et al., 2012). To avoid this inefficient mode of operation causing unnecessary nuisance to cities' traffic environment, there is a need to explore more efficient and cost-saving consolidation approaches, particularly by focusing on grouping goods based from the destination side (van Rooijen and Quak, 2010).

A study carried out by Verlinde et al. (2012) examines existing urban and other consolidation practices, and put forward a framework to classify different types of consolidation-focused measures and initiatives, as shown in Figure 3.1, contains two main categories, physical and behavioral concepts.



Source: Verlinde et al. (2012)

Figure 3.1. Classification for freight consolidation-focused measures

According to Verlinde et al. (2012), the physical category refers to approaches based on infrastructures, and involves the use of physical transshipment points to consolidate goods prior to final delivery. Among them, the traditional urban consolidation center (UCC) has been one of the most popular and widely researched initiative (Orhan et al., 2024), and is reviewed in more detail in section 3.2.2 and 3.2.4. Other alternative transshipment points are improved versions of UCCs that connect to existing logistics networks or focus on specific delivery areas (Verlinde et al., 2012). For example, a concept called ‘Nearby Delivery Areas’ has been tested in France, using the privately operated underground car parks converted into local distribution hubs, where cargo is transferred to smaller, eco-friendly vehicles and serves a particular small scale area (Forkert and Eichhorn, 2007; ICLEI, 2020).

The behavioral approaches focus more on modifying the logistics and operational behaviors of supply chain stakeholders without requiring additional physical infrastructure. The two types of behavioral approaches are horizontal strategies, which encourage peer collaboration within a stakeholder sector, and vertical strategies that focus on coordinating multiple supply chain players, aligning deliveries to maximize efficiency (Verlinde et al., 2012). An example for horizontal strategies is receiver-led consolidation (RLC), and there is currently some research around it, seen in section 3.2.3. Vertical approaches, on the other hand, require cooperation between multiple players, often through technologies such as information platforms to synchronize orders, delivery schedules and transport modes to improve coordination, ensure more efficient delivery scheduling (Verlinde et al., 2012).

3.2.2 Urban consolidation center

UCCs are logistics facilities located near urban centers, designed to reduce the number of freight vehicles entering congested areas by consolidating deliveries (Savchenko et al., 2022). They always serve as strategic hubs for consolidating and distributing goods, reducing delivery trips and emissions (Marcucci and Danielis, 2008).

Some categories of products benefit from the consolidation services provided by UCCs more because of their characteristics in shipment, thus it is easier to simplify urban distribution and reduce environmental impacts. UCCs typically consolidate small e-commerce parcels (Savchenko et al., 2022), retail goods (Mepparambath et al., 2023), construction materials (Akgün et al., 2024), waste and recycling materials (Akgün et al., 2024), and sometimes specialized goods such as temperature sensitive products (Isa et al., 2021).

According to studies by Paddeu et al. (2018) and Uruchima et al. (2025), the three main challenges in implementing UCCs include cost, management changing and various stakeholders, in addition to the increased complexity that may come with scale-up. Several studies by Nordtømme et al. (2015); van Heeswijk et al. (2019); Isa et al. (2021) show that high operational costs are usually the main reason for the long-term failure of consolidation centers, as many UCCs struggle with financial viability due to increased integration costs and the reluctance of shippers and carriers to participate without incentives. In real-world cases, a large number of UCCs rely on public subsidies, and private stakeholders are often unwilling to bear the additional costs of transloading and consolidation (Isa et al., 2021; Nylander et al., 2023).

Overcoming these barriers often requires financial support from the public sector, especially in the early stages of UCC implementation (Nordtømme et al., 2015; Paddeu et al., 2018). However, after support from the regulator has removed cost concerns, regulatory and institutional issues have also been identified as important influencing factors, as uncertainty in the program can create stakeholder resistance to change across the industry (Uruchima et al., 2025). Supporting UCC initiatives requires strong political will and regulatory frameworks for communication between stakeholders, and without sufficient commitment from operators and other stakeholders, it will be difficult for UCC to reach the scale required for long-term success (Nylander et al., 2023; Uruchima et al., 2025).

3.2.3 Receiver-led consolidation and influencing factors

RLC is a consolidation strategy where receivers influence delivery patterns to reduce the frequency and number of trips through consolidating deliveries in an intermediate location (Aljohani and Thompson, 2021). According to Holguín-Veras and Sánchez-Díaz (2016) RLC focuses on receivers who can coordinate shipments, empowering businesses to coordinate their deliveries, thereby optimizing the freight resource use.

Holguín-Veras and Sánchez-Díaz (2016) states that the receiver is the primary customer in the supply chain, and they have a significant decision-making power over operational requirements. To meet their needs, carriers have to be proactive and constantly make adjustments. However, policies directed at carriers or shippers alone are ineffective to motivate receivers to make changes. Therefore, adopting a receiver-centered approach and convincing them to change their demand patterns can have an upstream impact throughout the supply chain and further drive overall efficiency improvements (Holguín-Veras and Sánchez-Díaz, 2016).

As the receiver is at the core of the supply chain, a set of decisions or characteristics of the receiver also play a decisive role for consolidation. Firstly, cost and quality of service may be a concern for receivers, and if consolidated transportation does not achieve the desired cost savings or quality of service it will cause receivers to refuse to participate in the consolidation (Holguín-Veras and Sánchez-Díaz, 2016). The receiver's demand for quality of service is mainly reflected in the certainty of delivery times (Balm et al., 2014). In addition, Marcucci and Danielis (2008) suggests that UCC's service is only advantageous if traditional delivery costs are higher than UCC's delivery service fees. More specifically, the factors determining costs can depend on the characteristics of the receiver (i.e., storage capacity, delivery frequency, etc.), the carrier (i.e., delivery model, number of vehicles and drivers, number of consignments, etc.), the UCC (i.e., storage capacity, type of vehicles, etc.) and the urban area (Marcucci and Danielis, 2008).

Moreover, businesses in specific sectors (e.g., food services, wholesale and retail) show a higher willingness to participate in RLC if it aligns with their operational routines (Holguín-Veras and Sánchez-Díaz, 2016). Browne et al. (2005) also concludes that areas that are experiencing a retail renaissance are more likely to be successful in the UCC, emphasizing the suitability of retailing for consolidation.

In terms of the value-added service of UCC, Aljohani and Thompson (2021) indicates that value-added services such as unpacking and waste removal, can enhance the attractiveness of UCC. This requires UCC to provide customized services to different receivers to enhance the benefits of using UCC.

In addition, receivers are also reluctant to change the current delivery model due to business inertia, which requires the government to encourage the receiver to join the integration model through some subsidies or pricing strategies (Holguín-Veras and Sánchez-Díaz, 2016).

3.2.4 Case study of UCC operation

In order to summarize more urban freight consolidation practices and related influencing factors, this section selects relevant studies and real-life cases about UCC operations to draw lessons from the them.

1. UCC in Belo Horizonte, Brazil

   de Assis Correia et al. (2012) studies the economic feasibility as well as the environmental benefits of UCC in Belo Horizonte, Brazil. Specifically, the city of Belo Horizonte, Brazil, has rapid urbanization and high commercial density. The study is mainly based on the adoption probability of the retailers. This emphasizes the key role of retailers in consolidation, in line with RLC research (Holguín-Veras and Sánchez-Díaz, 2016).

   de Assis Correia et al. (2012) states that in the absence of cost factors, choosing other attributes such as service, reliability, and exposure space, the probability of UCC adoption by retailers is higher at 82%. Therefore, they emphasize the need for government incentives to reduce the cost of UCC to ensure the high retailer acceptance. Apart from attracting retailers by reducing costs, a range of mandatory measures can significantly increase adoption. In addition, the study proposes a two-tier distribution model, which means that the UCC collects the goods at the periphery of the city and distributes them to the support terminals located in the urban area. The input of support terminals helps to optimize the use of vehicle types. Due to shorter delivery distances and fewer goods, more environmentally friendly vehicles can be used to further enhance the segment benefits generated by UCCs. (de Assis Correia et al., 2012)

2. UCC in Copenhagen, Denmark

   Similar to the case in Brazil, van Heeswijk et al. (2019) conducts an agent-based simulation study to find sustainable business models for UCC based on the actual situation in Copenhagen. In their conclusion, they note that UCCs can significantly improve the environment, but need to find financially sustainable solutions. Without quantifying the environmental costs, a theoretical solution would be to convince carriers to outsource UCC's stops and generate revenue through a range of value-added services. In addition, a range of policies or financial support could improve the chances of stabilizing UCC operations before they reach a certain scale. (van Heeswijk et al., 2019)

3. UCC in Bristol-Bath, UK

   Unlike the case in Brazil and Denmark which are based on the simulation to assess the feasibility of UCC, the Bristol-Bath freight consolidation center is one of the most successful consolidation centers. The consolidation center was initially involved in some EU-funded projects, and later received funding from Bristol City Council, which provided a solid foundation for the initial phase, and has continued to rely on government grants to sustain its operations. In order to attract retailers, the consolidation center offers a range of value-added services (including storage, pre-retail, crisis stock management and packaging recycling) at a reduced cost compared to normal commercial rates. According to the results of the survey, retailers show a high level of satisfaction with the current UCC services. However, many retailers do not realize that they are using UCC services, and there are still some retailers who rely on established logistics channels and are reluctant to change their habits. (Paddeu, 2017)

4. UCC in Oslo, Norway

   The implementation of UCC in downtown Oslo was not successful. Based on Nordtømme et al. (2015)'s research, there are several major barriers that led to the failure of the project. First of all, Oslo does not have a plan for financing UCC, and the government and other private actors are not willing to subsidize the operating costs. Secondly, the willingness and participation of stakeholders are low, and the uncertainty associated with UCC keeps people pessimistic. For example, carriers believe that the implementation of UCC will have a negative impact on predictability and the economy. In addition, Oslo's complex system has problems related to coordination, and redundant processes make it difficult to recommend projects. Lastly, a number of legal issues make UCC implementation particularly difficult. (Nordtømme et al., 2015)

To sum up, all four cases emphasize the importance of the cost factor in the implementation of UCC, and that the success of UCC requires finding an economically sustainable solution. de Assis Correia et al. (2012) and Paddeu (2017) emphasize the decisive role of the retailers (receivers) and the adoption of a range of value-added services to attract retailers is viewed as a solution. In addition, government support is mentioned in all cases, with upfront government funding and policy support seen as an important factor for success.

3.3 Freight trip generation

3.3.1 Overview

Freight trip generation (FTG) refers to the process by which freight-related establishments generate vehicle trips as part of their operational activities (Holguín-Veras et al., 2011). The research on FTG started from the growing concern about the externalities of the urban freight system (Holguín-Veras et al., 2014). Since freight transport does not have clear origin and destination pairs like passenger transport, and involves multiple stakeholders (e.g., shippers, carriers, consignees), its behavioral mechanism is more complicated, so the establishment of FTG model is crucial to reveal the scale, frequency and distribution pattern of urban freight transport activities (Holguín-Veras et al., 2014; Sánchez-Díaz and Castrellon, 2023).

In the calculation and models, FTG is defined as the number of freight vehicle trips per unit of time at a location (e.g., a business, an organization, a commercial site) resulting from the distribution of goods (Holguín-Veras et al., 2014). FTG is related to Freight Generation (FG), whereas FG typically measures the “quantity” of goods movement in terms of volume or weight, while FTG is more concerned with the “form” of goods delivery, that is, FG usually measures the “volume” of goods movement in terms of volume or weight, whereas FTG is more concerned with the “form” of goods distribution, that is, how many vehicle trips are required to accomplish the task of distributing these goods (Holguín-Veras et al., 2014; Sánchez-Díaz and Castrellon, 2023).

FTG can be subdivided into freight trip production (FTP) and freight trip attraction (FTA), which represent the number of freight trips generated by a given location as a source of shipment or a destination of receipt, respectively (Venkadavarahan and Marisamynathan, 2023; Middela and Ramadurai, 2024). This categorization draws on the trip production/attraction theory in the passenger transportation research, which facilitates the model to more accurately describe the functional roles of business in the freight transport network at the micro level, and also enables to identify the center of gravity of freight transport activities in the urban area (Holguín-Veras et al., 2016).

3.3.2 Uses of FTG

FTG is a fundamental data source and a forecasting tool for urban freight transportation, with a core purpose to assess the factors affecting urban freight transportation activities and to improve the controllability and transparency of urban logistics systems (Holguín-Veras et al., 2011, 2016).

Firstly, it can be used to predict the distribution pattern of distribution demand, provide quantitative support for traffic impact assessment (TIA), and enable urban planners to predict the freight impact of a certain type of activity, so as to accordingly allocate appropriate resources such as parking, loading and unloading, and access rights (Holguín-Veras et al., 2014; Brettmo and Sanchez-Diaz, 2022). Secondly, the FTG model provides inputs for the precise regulation of urban freight policies (e.g., traffic restrictions, low-emission zones, setting delivery windows), identifying delivery hotspots so as to impose targeted transportation and environmental policies (Holguín-Veras et al., 2016). For example, in New York City's OHD program, FTG was used to identify commercial parcels that are major "freight contributors" to morning congestion and prioritize these businesses for participation in the OHD pilot (Holguín-Veras and Sánchez-Díaz, 2016).

Since the reduction of FTG values is often aligned with green logistics tools such as vehicle idling reduction and route optimization, FTG is always used in analyzing logistics consolidation strategies (Holguín-Veras and Sánchez-Díaz, 2016). Studies show that the FTG model can reveal the relationship between delivery frequency, concentration and spatial agglomeration, providing a quantitative analytical framework for assessing the effectiveness and attractiveness of urban UCC implementation. As one of the key indicators for measuring the efficiency and environmental impact of urban freight transport, FTG helps to identify "high-frequency, low-volume" decentralized distribution behaviors, which tend to be the least carbon-efficient part of the urban distribution system, and also the most potential for integration in UCCs (Brettmo and Sanchez-Diaz, 2022; Holguín-Veras and Sánchez-Díaz, 2016).

In the RLC program, the identification of companies or regions with high FTG values is the core basis for selecting pilot projects and estimating the potential for emission reductions (Holguín-Veras and Sánchez-Díaz, 2016). For example, Sánchez-Díaz (2018) identify that food services and retail sectors are among the highest freight generators, often requiring frequent restocking due to limited storage capacity.

3.3.3 FTG modeling and calculation

The objective of the FTG model is to predict the number of freight trips within a given urban area and identify their drivers, thereby supporting the implementation of urban freight strategies such as traffic management, land use planning, logistics infrastructure layout, etc. (Holguín-Veras et al., 2014).

The basic starting point for constructing an FTG model is to set up an explanatory equation in the general form of:

$$FTG = f\left(X\right) + \varepsilon \tag{3.1}$$

Where X is a set of explanatory variables representing firm characteristics, location attributes, or supply chain behaviors; f is a function that may be linear, nonlinear, or categorical model; and ε is an error term (Holguín-Veras et al., 2014; Sánchez-Díaz and Castrellon, 2023; Brettmo and Sanchez-Diaz, 2022).

In practice, the model usually takes one distribution cycle of a business as the unit of analysis, and the output variable of the model is the number of freight trips generated by the business in a certain period of time (e.g., day, week), while the input variables are selected based on the granularity of the available data, the purpose of the modeling and the spatial scale (Venkadavarahan and Marisamynathan, 2023; Middela and Ramadurai, 2024).

After summarizing the literature, the possible variables in FTG model are shown in Figure 3.2. These factors are generally studied in FTG models, and it comes out that the most common explanatory variables are the freight sector (e.g., trade, industry, service) and size (e.g., number of employees, space area) (Mafla-Hernández et al., 2025).

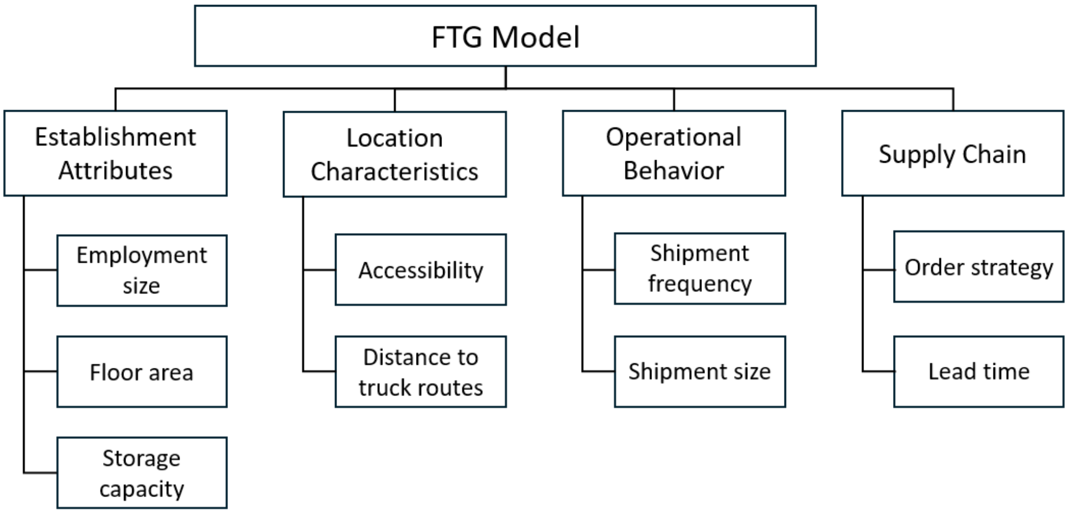


Figure 3.2. Possible variables in FTG model

In order to enhance the model's reflection of actual operational behavior, some studies incorporate the firm's role in the supply chain with logistics behavior variables into the FTG model. For example, Alho and de Abreu e Silva (2015) constructs a joint model that considers both impact of observable variables (e.g., supply frequency, number of suppliers) and unobservable variables (e.g., storage capacity, ordering policy) on FTG. Other studies also point out that many high FTG firms have high-frequency distribution because they cannot store large quantities of goods due to their space constraints, resulting in small unit order quantities but high order frequencies, especially in the retail and restaurant sectors in city center (Holguín-Veras and Sánchez-Díaz, 2016; Brettmo and Sanchez-Diaz, 2022; Oliveira et al., 2022).

Traditional FTG models are mostly based on the static assumption, that is, the distribution behavior of enterprises is uniform and stable during the modeling period. However, with the refinement of time granularity, researchers find that there is a strong time-dependence in freight transportation activities, such as peak concentration, seasonal fluctuations, and the impact of holidays. Oliveira et al. (2022) conduct a study based on express delivery data from Barcelona, Spain, and found that FTGs in different industries show regular variations within the day and within the week. This suggests that when constructing the FTG model, the introduction of time variables, such as hourly timestamps, holiday dummies, special events, or periodical terms, should be considered to more accurately portray the actual variation of distribution intensity (Brettmo and Sanchez-Diaz, 2022; Sánchez-Díaz and Castrellon, 2023; Middela and Ramadurai, 2024).

When actual collected data are used as input variables for FTG modeling, the most common of the modeling methods is ordinary least squares regression (OLS). This method is suitable for estimating the linear relationship between FTG and explanatory variables, and in most cases serves as a baseline model or preliminary modeling tool (Holguín-Veras et al., 2014; Venkadavarahan and Marisamynathan, 2023). However, OLS models have major limitations, so many studies have attempted to use other modeling techniques to optimize accuracy: nonlinear models that transform dependent or independent variables or both to linearize one or the other as appropriate (Mafla-Hernández et al., 2025); cross-classification based on statistical grouping, which performs well in policy analysis at the regional scale (Holguín-Veras et al., 2014); spatial regression, which corrects for autocorrelation due to geographic clustering and makes the model more sensitive to locational characteristics (Sanchez-Diaz et al., 2013).

3.3.4 Forecasting using time series

In practice, there are always historical or observed data missing or limited, so projections or modeling techniques might be used for future freight patterns or delivery counts (Oliveira et al., 2022).

Box et al. (2015) points out that a time series is a series of data observed in chronological order and with a strong dependence on neighboring observations. Depending on the characteristics of the time series, various models can be built in various fields. Hyndman and Athanasopoulos (2018) mainly introduces decomposition models, exponential smoothing models and Autoregressive Integrated Moving Average (ARIMA) models for forecasting using time series. For decomposition models, one classic and widely used model is the moving average model, it utilizes previous forecasting errors in the regression analysis (Hyndman and Athanasopoulos, 2018); Exponential smoothing models and ARIMA model are two dominant methods in time series forecasting, compare to Autoregressive–Moving Average (ARMA), ARIMA applies differencing to the non-stationary ARMA model (Hyndman and Athanasopoulos, 2018).

Similar to (Hyndman and Athanasopoulos, 2018), Box et al. (2015) divides stochastic models used for prediction and control into stationary and non-stationary categories. For stationary models, the assumption is that the statistical properties of the time series remain constant in time, and include models like autoregressive models, moving average models and ARMA; by combining autoregressive model and moving average model, ARMA can enhance the flexibility of fitting time series in real-time series. Compared with stationary models, Box et al. (2015) believes that non-stationary models can be more widely used in various industrial and commercial fields due to the instability of time series in real scenarios. Among them, ARIMA is introduced as a key method to cope with the non-stationary behavior of time series in real scenarios. (Box et al., 2015)

However, ARIMA is suitable for time series without seasonal patterns (Hyndman and Athanasopoulos, 2018). To fit the seasonal pattern, the seasonal ARIMA (SARIMA) adds the seasonal components in the ARIMA model (Box et al., 2015). Compare to ARIMA, SARIMA can get more accurate and reliable forecasting results due to the ability to capture seasonal patterns. By incorporating both non-seasonal and seasonal components, SARIMA improves its adaptability and robustness to various types of time series (Majka, 2024).

3.4 Cost of freight consolidation system with UCC

Browne et al. (2005) states that an additional stage in the supply chain by using UCC will increase the operational cost, and financial problems need to be solved for UCC to succeed. Allen et al. (2012) also suggests that opponents of UCC believe that the double handling of UCC results in increased transportation costs, in 114 cases of UCC, additional transportation costs were viewed as the main reason for the failure of UCC. Thus, it is generally recognized that UCC must be financially viable in the long term (Allen et al., 2012).

3.4.1 Stakeholder cost and benefit from UCC implementation

In different cases of UCCs, multiple stakeholders are involved, mainly including suppliers, LSPs, receivers, and public authorities (Ros-McDonnell et al., 2018; Transmodal, 2012). They have different roles in the operation of UCCs, they contribute to costs and benefits in different ways.

For suppliers and LSPs, the implementation of UCC can reduce transportation costs by consolidating delivery routes and providing more efficient delivery methods (de Assis Correia et al., 2012). However, it can also require suppliers, other LSPs and receivers to pay a fee to cover the operating costs of UCC due to an additional stage in the supply chain (Isa et al., 2021; Browne et al., 2005). At the same time, LSPs will also have concerns about the distribution process, due to the loss of control over final distribution after the consolidation (Browne et al., 2005).

Delivery through UCC can significantly reduce the number of trips (Browne et al., 2005), and van Heeswijk et al. (2019) research suggests that UCC can reduce the number of miles traveled by about 65 percent. Binh and Huong (2024) states that a critical challenge is the investment on logistics infactucture. To compensate this cost disadvantage, the incentives from public authorities and the receivers' acceptance play important roles (de Assis Correia et al., 2012). In addition to the cost factor, the promotion of UCC will require consensus on multiple fronts so that the stakeholders can take a holistic view of the overall potential benefits of UCC can bring (Browne et al., 2005).

For receivers, consolidated distribution through UCC can reduce the time on receiving goods (van Heeswijk et al., 2019), lower inspection costs (Isa et al., 2021), and provide a more reliable transportation mode (Browne et al., 2005). However, in some scenarios, it appears that the recipient pays a fee for UCC's services(Browne et al., 2005). More specifically, UCC can provide receivers with a range of value-added services such as just-in-time deliveries, package recycling and temporary storage (Paddeu, 2017). Receivers are often required to pay an additional fee based on the service they choose (Paddeu, 2017). In addition, compared with the previous traditional model, the use of UCC consolidation and distribution may increase the risk of delays (Paddeu, 2017).

For public authorities, supporting UCC can reduce air pollution by reducing vehicle use and mileage (Browne et al., 2005), which in turn reduces the spends on the public health system due to local pollutant emission (Isa et al., 2021); easing road congestion, and improving traffic safety by reducing traffic flow (Binh and Huong, 2024). However, public authorities also need to provide the infrastructure, funding for research work, and a pilot study of UCC to ensure its efficient implementation (Browne et al., 2005; Nordtømme et al., 2015). In addition, local authorities in the project must be aware of the concept of UCC sufficiently to take UCCs into account as part of sustainable transportation planning; in this case, the government may need to play an important role, possibly by providing advice(Browne et al., 2005).

3.4.2 Cost for the overall system

Marcucci and Danielis (2008) states that UCCs can only be economically justified if the service charge for the enterprise's own delivery is higher than that of UCC. Based on this idea, Janjevic and Ndiaye (2017) analyzed the existing cost structure of urban distribution and points out that distribution costs can be divided into time-related costs and distance-related costs. More specifically, they subdivided time-based costs into driving time costs, service time costs and labor costs; and distance-based costs into vehicle operating costs, fuel costs, tire and maintenance costs. Time-related costs are considered to be the main distribution costs, and in the Belgian case, labor costs are the main time cost, accounting for 90% of the total time cost. In order to compare the distribution costs of using UCC with the costs of not using UCC, Janjevic and Ndiaye (2017) also visualized the route diagram, which breaks down the transportation from the delivery of the goods to UCC and UCC delivery within the city. (Janjevic and Ndiaye, 2017)

To determine the route distance with multiple stops, Figliozzi (2009) summarized a series of model results in calculating the distance. Among these, Beardwood et al. (1959) proposed a simple model that can estimate total travel distance to solve the traveling salesman problems(TSP). This model contains the number of customers to be served (v), the size of the area to be served (A), and the k is the distance metric, b is the correction parameter by regression. With his assumption, a large number of points are uniformly distributed over an area, the distance traveled within this area can be calculated based on the formula below.

$$L \approx b + k\sqrt{vA} \tag{3.2}$$

Based on this model, Chien (1992) further considered the size of the distribution area and suggested that the use of a minimum rectangle can improve the accuracy of the estimated model.

4

Case Study

This chapter describes the empirical context of the study, the freight logistics situation in the event area of Gothenburg (particularly Liseberg and Svenska Mässan) and different stakeholders. The area is characterized by a high density of tourists, seasonal logistics peaks and decentralized B2B freight activities, making it an ideal pilot area for consolidation practices. The case study provides a basis for the application and validation of the FTG model, the estimation of consolidation costs and further analysis of the stakeholders in consolidation.

4.1 Overview of the event area and freight logistics

Gothenburg is an events city with many venues such as Liseberg, Svenska Mässan (the Swedish Exhibition and Congress Centre), Scandinavium, Ullevi, Universeum, etc., attracting over six million visitors annually (Jidah and El-Rifai, 2024). To address environmental concerns, Gothenburg has initiated the Green City Zone, aiming for the goal of achieving fossil-free transportation solutions by 2030 (GöteborgsStad, 2023). The event area of Gothenburg is located in this Green City Zone, and Liseberg and Svenska Mässan are situated near transportation hubs including Gothenburg's Central Station, public transport stops and highway connections (Uruchima et al., 2025). This urban event area has been expanding in recent years with new developments such as hotels, water parks, and exhibition halls. The expansion will likely increase logistics demands and traffic flows and bring more challenges related to sustainability, congestion, and environmental impacts (Eriksson et al., 2023).

4.1.1 Location and activities

Liseberg, as a central attraction in Gothenburg, is one of the leading amusement parks in Northern Europe, receiving millions of visitors each year. In addition to the park's different rides, restaurants, and park foods bars, Liseberg has many venues like stages, dance halls and theater for hosting music festivals, drama performances and other activities. Besides, the hotel Liseberg Grand Curiosa opened in April 2023, hosts travelers visiting Gothenburg city and playing in Liseberg.

There are approximately 170 different internal delivery points around the park, with high complexity and diversity of goods required by the different facilities including restaurants, fast food outlets, gaming areas, retail outlets, visitor services and offices, which are characterized large volume and variety of deliveries (Eriksson et al., 2023). Day-to-day business activities and event-based scenarios combine to form the freight demand of Liseberg with significant seasonal variations, mainly related to food, souvenirs, ride maintenance equipment, seasonal supplies, etc (Lindberg, 2025).

Svenska Mässan is one of the largest exhibition and conference centers in Northern Europe, hosting major exhibitions, conferences and business events every year and playing a vital role in attracting events, visitors and business. The facility combines exhibition halls, conference rooms, hotel rooms, restaurants and amenities to offer visitors comprehensive experience (Uruchima et al., 2025).

The freight demand of Svenska Mässan involves exhibition equipment, promotional materials, exhibit transportation, and catering supplies with two primary inflows: the event-driven “fairs and exhibitions” inflow and the “always-on” regular operational inflow, which together constitute the approximately 35 thousand deliveries it handles annually (Höjer, 2025). During peak event periods, the complexity of logistics increases sharply, often resulting in congestion and delivery delays, hence the need for freight management. (Uruchima et al., 2025)

4.1.2 Freight strategies

Freight transport in the Gothenburg event area is determined by the operational characteristics, purchasing patterns and delivery infrastructure of its main stakeholders - Liseberg and Svenska Mässan. Both companies need to handle a wide range of freight needs associated with their daily operations and large numbers of visitors, including food supplies, laundry, equipment, and seasonal or event-specific goods. However, challenges such as fragmented deliveries, peak hour congestion and fossil fuel dependency remain. In response, the REDIG project initiated a consolidation pilot utilizing the UCC, with the goal of optimizing the delivery process and coordinating off-peak scheduling in the event area. The freight transportation strategies of Liseberg and Svenska Mässan are described in more detail below, followed by a description of the consolidation pilot project and its expected impact.

(1) Liseberg

Liseberg uses a unified approach for purchasing and receiving goods, centralizing freight management through digital tools and coordinated processes to meet the demands of different sectors such as catering, hotels, amusement rides and offices.

This management model is also made possible by the fact that all businesses and departments are owned by Liseberg, avoiding conflicting costs resulting from freight management decisions. They have a central warehouse where some orders are unpacked and picked, and where they keep some daily goods in stock.

Liseberg employs a hybrid purchasing strategy that combines both formal purchasing process and the purchase of amusement park-specific items (Eriksson et al., 2023). Depending on the type of purchasing goods and the supplier involved, the ordering process can be carried out through two integrated digital platforms, Stella and Visma Business (Proceedo). Stella is responsible for all orders to direct suppliers, i.e. formal purchases, while Proceedo is responsible for orders from non-direct suppliers (suppliers to Gothenburg City) for amusement park-specific items. More than 90% of the orders from Liseberg's departments are placed through the Stella platform, with selection of items, quantities and required delivery dates. Depending on the size of the order, the availability of the goods and the location of the stock, Stella categorizes orders into three types: items where goods are ordered directly from suppliers, items that are processed and consolidated by Liseberg's central warehouse and ordered centrally, and mixed orders that are partly routed through the warehouse and partly sent directly from suppliers.

Liseberg's delivery process is supported by the digital system Bitlog Warehouse Management System (WMS) for real-time inventory management and increasing delivery transparency. Deliveries are mainly made through four designated addresses, central warehouse, Grand Curiosa Hotel and machine workshop supplies, according to product type and storage requirements related to refrigerated goods.

Depending on the size of delivery, there are two ways for suppliers to deliver goods. Large suppliers such as Martin & Servera and Carlsberg that are able to deliver by truckload do not need to be processed through the warehouse, thus they are often delivered directly to the final points within the park. Smaller deliveries, on the other hand, often require intermediate handling such as pallet removal or unpacking, using central warehouses as micro-terminals and handling internal distribution. In addition, seasonal products (e.g. Halloween or Christmas decorations) are stored externally due to limitations on the size and storage capacity of the central warehouse (Eriksson et al., 2023).

(2) Svenska Mässan

Freight deliveries to Svenska Mässan are mainly divided into two categories: daily demands from businesses such as restaurants and hotel, and event cargo during the preparation and hosting of large events such as exhibitions. The daily business demands are relatively small, and the management strategies are similar to those of Liseberg, while exhibition cargo is the focus of their freight management.

Svenska Mässan uses the logistics of its own organization and third-party LSPs for the delivery of goods. To simplify the smaller shipments delivery, they are currently implementing small-scale consolidation node 10-15 minuts from Gothenburg city center (Uruchima et al., 2025). During peak periods, most less than truck load logistics for fresh food, laundry, equipment and exhibitions pass through this node first, and then multiple carriers handle the deliveries. At Svenska Mässan, consolidated shipments are received at a rate of up to six trucks per hour before being moved into the exhibition hall (Jidah and El-Rifai, 2024). Still, decisions on how to use the consolidation point often rely on practical experience, existing knowledge, and trial-and-error, rather than following an optimal or well-structured approach (Uruchima et al., 2025).

Also, not all goods can be transported through the consolidation node. Oversized or complex cargo such as heavy machinery bypasses this node directly delivered to the event area to minimize the risk of damage and logistical inefficiencies (Uruchima et al., 2025). In the management system of Svenska Mässan, complex cargo is defined as cargo over 4 tons, 10 cubic meters, or 3 flat meters, which due to their size and complexity of loading and unloading, are transported directly to the venue's designated location (Jidah and El-Rifai, 2024; Uruchima et al., 2025).

(3) UCC pilot for the event area

The UCC pilot within the REDIG project aims to improve sustainability and logistics efficiency for Liseberg and Svenska Mässan in the event area. The pilot was initiated by the receivers and LSPs with large delivery volumes, using GLC's terminal as the consolidation center. The current focus is on consolidating fragmented deliveries to reduce overall vehicle movements, switching to fossil fuel-free vehicles and optimizing delivery schedules during off-peak periods.

The pilot project addresses the problem of excessive deliveries that exacerbate traffic congestion during peak hours by centralizing consolidation at GLC's terminal, reducing the number of weekly deliveries to event area. In addition, all deliveries in the pilot project will be made with green vehicles, i.e., electric, biogas, or high-purity liquefied petroleum gas trucks, to assist the Green City Zone in transitioning deliveries to fossil fuel-free. At the same time, deliveries will be shifted to off-peak hours, primarily the evening hours, to alleviate congestion during the day and improve operational efficiencies for receiving deliveries.

The goal of the consolidation pilot is to reduce the total number of freight vehicles serving Liseberg and Svenska Mässan by approximately 30% with full fossil-fuel-free transportation. The initiative also includes adapting the existing procurement and ordering system to systematically deliver goods to consolidation centers. Through these interventions, the pilot project would achieve consolidated loading relatively efficiently, minimize disruptions to existing logistics processes, improve the reliability and efficiency of the freight logistics system in the event area, improve logistical efficiency, and reduce transportation costs; while at the same time, reduce urban traffic congestion, reduce emissions, and significantly improve sustainability performance. These expected results make the pilot project more than just a temporary improvement, but a scalable model for sustainable urban logistics in Gothenburg and beyond.

4.2 Freight activity patterns

Understanding freight activity patterns within the event area of Gothenburg can help to provide insights about the current logistical flows and the potential opportunies for consolidation. Using various datasets provided by the two main receivers Liseberg and Svenska Mässan of the event area (see 2.1), we analyze the freight activity patterns related with their delivery arrangement, vehicle characteristics, cargo types, and route structures. A detailed description and visualization of the data set analysis can be found in *Appendix A*.

From the freight demand side, the orders for two and half years from Liseberg are analyzed and shows significant seasonal fluctuations, with orders starting to rise in the spring and peaking in the summer. With the daily peak of vehicle arrivals from 7:30 a.m. to 9:00 a.m., Liseberg is facing greater traffic pressure and resources bottlenecks during these periods. Svenska Mässan has the same problem of concentrated delivery in the morning, but the overall delivery time is more scattered, and some extends to the afternoon and even the evening, showing a more flexibile mechanism during the exhibition.

Based on the data received by the two receivers during a representative week of peak operations, both Liseberg and Svenska Mässan receive perishable goods as the biggest proportion, resulting in frequent and time-sensitive deliveries. At the same time, the overall loading rate is quite low, with a large number of vehicles delivering only a small amount of goods, and parcel-type deliveries in particular show a high degree of fragmentation. This shows the potential for consolidation, especially in food and daily supplies, where UCC can reduce delivery frequency and improve vehicle utilization by consolidating the small orders.

In terms of vehicle types, Liseberg receives a relatively even mix of delivery vehicle sizes, but with a high proportion of fossil fuel vehicles and fewer green vehicles. Svenska Mässan, on the other hand, receives mostly medium-sized trucks, and more than half of its energy mix is fossil-free, demonstrating that it has made efforts in consolidation and green delivery.

The routes of the vehicles delivering to Liseberg are analyzed. The depots of suppliers are generally close to Liseberg within 5-12 kilometers, and a large part of them are within the Gothenburg City. Most of the distribution routes are short and have few stops, with 83% of the vehicles completing their tasks within 20 stops, and nearly 30% of the vehicles stopping only within the event area. This “short-haul, low-density” distribution pattern provides a good basis for local consolidation, which is particularly suitable for centralized processing through local UCCs, thus reducing the number of vehicles and the burden of traffic in urban areas.

To sum up, Liseberg and Svenska Mässan differ in their distribution structures and operating models, but both show needs and opportunities for different types of consolidation. Liseberg’s distribution model is more fragmented, with a large number of small deliveries, especially parcel and food orders, resulting in generally low vehicle utilization. Its distribution demand is highly affected by seasonal fluctuations and concentrated during peak hours, which directly increases the traffic pressure on the park and the surrounding road network. Against this backdrop, receiver-led UCC consolidation can be effective by pooling fragmented orders from multiple suppliers, splitting and reorganizing the flow of freight activities as needed. Svenska Mässan’s deliveries already show some concentration in terms of vehicle types and clean energy drives. Their main challenge comes from the concentration of bulk flows during trade shows, and they need to strengthen their interface with exhibitors and carriers during this period to improve their temporary consolidation capabilities.

4.3 Perspectives from different stakeholders

Urban freight transportation systems are inherently complex and involve different stakeholder groups whose interests and actions determine the operational and strategic outcomes of the logistics network. This section identifies the key factors influencing the willingness to participate in urban freight consolidation through systematic analysis of multi-stakeholder interviews. A discussion is then initiated based on the analysis results to reveal the concerns of different types of stakeholders, including suppliers, receivers, LSPs and the public authority.

4.3.1 Overall influencing factors

RISE conducted a series of interviews with organizations that are involved in the logistics of the event area in Gothenburg (as shown in Table 2.1 and 2.2) before implementing consolidation. The purpose of the interviews is to gain a deeper understanding of their current operations and challenges to assess the willingness and feasibility of their participation in the REDIG project.

To analyze the interviews, a structured case study analysis approach was adopted, consisting of four steps: description, coding, display, and sense making. First, key case characteristics from each stakeholder are described in a structured way, summarizing their logistics models, delivery contexts and key challenges. This step provided a comparative overview across organizations and most of the information is summarized and used in section 4.1.

Second, open coding was applied to the transcribed the secondary data and interviews to extract key topics about the influencing factors that are mentioned in different interviews. These initial key words were then grouped in the axial coding step into more general categories, including cargo type, logistics models, delivery frequency, storage capacity, data accessibility, policy awareness, and stakeholders' willingness to consolidate. Meanwhile, axial coding explores relationships between variables, for example, limited storage capacity increases delivery frequency and reduces the ability to consolidate shipments, or decentralized data systems affect lead times in their logistics model. The result of coding from interviews is shown in *Appendix B*, Table B.1.

Third, data display was used to visually compare the coded variables across all interviewed stakeholders. This included cross-case tables summarizing delivery types, model characteristics, and levels of willingness to consolidation, thus figure out patterns and gaps among different stakeholder types.

Finally, in the sensemaking and theorizing step, findings were verified and related to the existing literature on urban consolidation and freight demand management, as shown in Table 4.1. The consistency between empirical variables and theoretical constructs confirms known theoretical factors and also reveals the influence of practice-based factors (e.g., lack of standardized application programming interfaces), suggesting context-specific influences on stakeholders' consolidation willingness.

Table 4.1. Factors influencing willingness to consolidate

Influencing factors	**Low**	→	**High**
Perceived cost saving	Additional cost	Not much saving	Clear delivery cost reduction
Type of goods	Critical-timing items	General goods	Standard or non-perishables
Delivery model	Fragmented, direct-from-supplier	Hybrid with some coordination	Centralized via internal/external warehouse
Delivery frequency	High and unpredictable	Moderate and stable	Low with flexible timing
Storage capacity	Sufficient space for storage	Temporary buffer space	Very limited or no storage
Data sharing level	Manual/no system integration	Internal digital systems only	Real-time data sharing with partners
Consolidation service	Lack of quality and security assurance	Basic transfer only	Optional value-added services
Policy	No incentive or regulation	Soft recommendations	Strong incentives or regulatory restrictions

To look at the whole system, lack of coordination is a huge barrier in achieving efficient consolidation across all stakeholders in the REDIG project. Different systems, different levels of digital maturity and competing climates can make sustainable urban freight integration difficult to implement in practice.

In addition, the implementation of UCCs requires sufficient financial support to reduce the financial burden on stakeholders while demonstrated added value in terms of delivery efficiency, service quality and environmental benefits to compensate the early-stage cost disadvantage.

After the consolidation pilot began operation, RISE also had many conversations with stakeholders, and the key findings of these conversations are relayed into this study. Based on the analysis of the considerations of the different stakeholders in the interviews and conversations, it is clear that direct cost is their common and largest concern.

Receivers such as Liseberg and Svenska Mässan, LSPs such as DB Schenker and GLC, and Gothenburg City all emphasized the need for consolidation to be economically cost-effective. Some interviewees stated that even if they support sustainability or want to reduce the transportation burden on their site, they would not be able to accept the consolidation model if cost is higher in the long term. This finding is consistent with conclusions from the literature about the relationship between perceived costs and willingness to participate consolidation. Thus it is important to prioritize the quantification of the cost-benefit structure when implementing freight consolidation.

However, while some factors are consensus focus, there are still some specific concerns from different stakeholders based on their different freight operation constraints.

4.3.2 Suppliers

Suppliers (shippers) are the initial link in the flow of freight to the event area, and their delivery methods, including mode of delivery and volume of freight per trip, greatly influence the effectiveness of consolidation. The main suppliers involved in UCC schemes tend to be retail chains, local wholesalers, drinks suppliers and event-specific suppliers.

The main suppliers to Liseberg are food and retail suppliers including Martin & Servera, Fisk Idag, Dennfood, Dafgård, Carlsberg, Rekal and Johan i Hallen, which regularly deliver large quantities of perishables, beverages and other related products. In the past, these suppliers delivered directly to Liseberg's various business units or drop-off points on the campus, with little coordination of goods or vehicle loading. This fragmented model significantly increased the frequency of trips and reduced vehicle utilization. For Svenska Mässan, the shippers are more complex due to the wide variety of goods involved, from daily supplies for restaurants to large-scale shipments for exhibition booths (Eriksson et al., 2023; Höjer, 2025). In the pilot project, core suppliers with high delivery volumes are prioritized, and their delivery address when processing orders are changed from the event area to GLC's consolidation center.

Although RISE did not interview suppliers, historically, many suppliers have preferred to deliver goods directly to consignees for reasons of control and flexibility, which has often led to underutilization of vehicles and unsynchronized drop-offs. The literature emphasizes the challenge of engaging suppliers in consolidation efforts due to competitive pressures and reluctance to relinquish control (Savchenko et al., 2022; Ciardiello et al., 2023). In many cases, shipper participation is facilitated through procurement incentives or operating agreements. For example, some UCCs work directly with major suppliers to bundle shipments and reduce inbound shipments to congested areas of the city.

As highlighted in the literature and in the pilot evaluation, some suppliers are still reluctant to relinquish control of deliveries due to concerns about reliability, scheduling, and handling, so ongoing cooperation and clear communication are essential for long-term success. According to the conversations, the suppliers in the consolidation pilot do not pay for the costs for UCC usage according to their Incoterms, and are no longer responsible for the quality of the last-mile delivery from UCC. When the benefits of using UCC remain uncertain, it seems to be challenging for suppliers to engage in consolidation schemes.

4.3.3 Receivers

Liseberg and Svenska Mässan, as the receivers in the case, represent the main freight destinations of within the event area and therefore play a pivotal role in influencing the frequency of deliveries, vehicle access patterns and the feasibility of the consolidation. Under the original freight transport model, orders were delivered to the receiving address within the event area, with each supplier delivering independently, resulting in fragmented deliveries and inefficient vehicle utilization. Limited in-house storage capacity, based on the complexity of hosting events, exacerbated the difficulty of managing logistics. As the need for consolidation increased, receivers began to actively assume a proactive coordination role with introducing standardized ordering systems (e.g., Stella, Visma Business), harmonizing internal delivery windows, and allowing off-peak or nighttime deliveries. This shift reflects an emerging trend towards the increasing influence of receivers on urban freight dynamics through their preferences and digital interfaces, and furthermore, receiver-led consolidation.

In the case of Liseberg, the main challenge for Liseberg is the unpredictable and fluctuating traffic flow, which makes it difficult for them to carry out long lead times and accurate order planning. Also, the short lead times and high daily frequency of demand for perishable deliveries make them concerned about the flexibility of deliveries. At the same time, their limited unloading and warehouse space make it difficult to cope with peak periods or high-volume deliveries, leading to the need on the feasibility of storage capacity and delivery time, better during nighttime.

In contrast, Svenska Mässan's focus is more on the complexity of event logistics. Cargos like exhibition materials are often large in multiple batches, with fluctuating project schedules. So they are concerned about space and interfacing capabilities about unloading and handling during peak periods. Also, they have their own logistics to carry out the part of bulk goods deliveries, which becomes a waste of idle resource during the exhibition off-season. In addition, there is a lack of integration between their existing digital system and external systems, which leads to limited data sharing and process synergies.

4.3.4 LSPs

LSPs are important players in connecting suppliers and receivers, and can be carriers or the operator of the UCC. Different LSPs have their own main business, for example, 24/7 Logistics focuses on providing last mile services and small scale consolidation services for Svenska Mässan. GLC provides cold chain logistics services temperature-sensitive goods. Currently, each LSP entering the event area operates independently without coordination. In the consolidation pilot of this case, GLC undertakes to operate both UCCs and vehicles, and other LSPs such as DB Schenker, 24/7 Logistics and smaller carriers who ship to Liseberg previously will make deliveries to the UCC according to receivers' order, allowing shipments from multiple suppliers to be pooled and grouped with fewer, cleaner vehicle trips.

LSPs are more facing pressures from the customer side. For example, customers often require specific time windows for delivery, which limits the logistics provider's scope for route optimization and consolidation. GLC and 24/7 note that despite the integration capabilities of their technology systems, distribution efficiency is limited by the varied time window demands of their customers, and DB Schenker also cites the customer-side constraints on their distribution systems. The variability of time-sensitive delivery requirements across different customer segments also limits the possibility of consolidated delivery.

In addition, LSPs are concerned about the integration level of distribution systems and the willingness of shippers to share information. 24/7 mentioned about the lack of system integration with external partners, that although they had an in-house business system, as a key partner of Svenska Mässan, they are required to use Svenska Mässan's outdated system when handling event goods, which has an impact on the efficiency of the operation. Moreover, the lack of advance notice and information about the items makes it difficult for them to plan and allocate resources. In addition, the age of the current warehouse and the temporary lease creates uncertainty for operation and the long-term layout.

DB Schenker also mentions that some of their deliveries are carried out by outsourced carriers, which results in a lack of direct control over their day-to-day distribution scheduling. In addition, they are highly dependent on the cooperation and ability of these carriers to conduct consolidation and route coordination, which can be a barrier to implement operational change.

To sum up, the main difficulties for LSPs are fragmented customer requirements and coordination between different systems, which not only leads to a loss of efficiency but also creates obstacles to subsequent changes.

4.3.5 Public authorities

Public authorities, in this case Gothenburg City, play an important role both as regulators and enablers of the sustainable freight transport transition. Interviews and discussions with city representatives showed that there is strong political and strategic support for the consolidation pilot and the SDGs. Outside of the general infrastructure and procurement framework, Gothenburg City has taken an active role in policy design, access management (especially within the Green City Zone) and stakeholders coordination. At the same time, their important task in the pilot is to balance competing interests, create enabling conditions for effective stakeholders cooperation, and build a unified digital platform for logistics coordination as a way to minimize the disruption of freight transport to the city.

For Gothenburg City, the main challenge in the REDIG project was data limitations. More specifically, the current data sources are fragmented and limited in type, which makes it impossible to fully track vehicle flows and types. At the same time, the city's old camera infrastructure makes data collection difficult. In addition, due to the cumbersome information sharing process, many data access rights are restricted, and the cumbersome administrative process greatly increases the difficulty of data collection.

Interview shows that Gothenburg City is now improving the performance of urban distribution flows through traffic guidance, temporary traffic monitoring and digital twin modeling. However, there's no effective information synergy in the system, due to the data segregation, technical barriers and GDPR (General Data Protection Regulation) compliance restrictions from different private sectors. They are more concerned about rights and responsibilities of all actors in terms of data access, responsibilities clarification and sharing mechanisms in the consolidation at the city scale.

In summary, although all types of participants demonstrate a basic acceptance of consolidated distribution, the motivations and concerns behind their participation are highly heterogeneous. Future consolidation models must take this into consideration, provide customized incentives and synergistic tools to achieve the scaling and sustainable operation of consolidation.

5

Modeling and Results

This chapter first analyzes the current and projected 2024 freight trips in the event area of Gothenburg using historical data to construct an FTG model that identifies the temporal fluctuations and delivery patterns of different sectors that affect local logistics demand and provides a quantitative basis for evaluating freight consolidation. Next, the chapter presents a cost modeling framework for comparing two delivery strategies, dedicated delivery and multi-stop consolidation. Cost differences are compared by modeling scenarios with and without UCC. This chapter contributes to quantifying the effectiveness of consolidation in reducing delivery frequency, improving resource utilization, and supporting long-term system sustainability.

5.1 Freight situation with FTG model

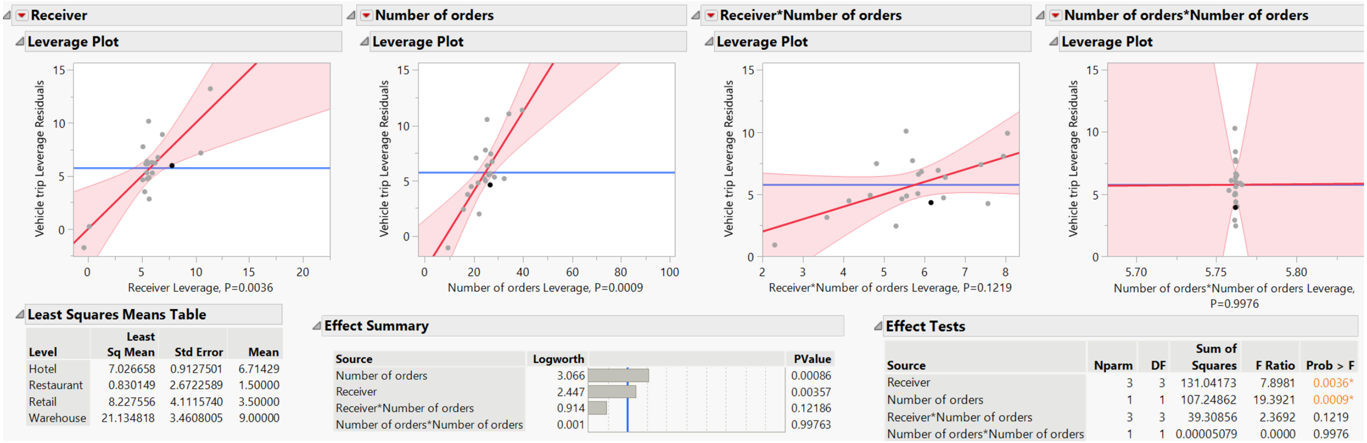
To estimate the freight vehicle activity throughout 2024, we adopted a three-step modeling framework: correlation testing to identify key influencing factors, seasonal time series forecasting of order volumes, and the application of sector-specific FTG ratios to estimate monthly freight vehicle trips. This approach enabled the estimation of total freight vehicle trips for each month of 2024, capturing seasonal peaks and supporting further analysis of consolidation feasibility and sustainability impacts.

5.1.1 Correlation of variables with vehicle trips

According to the previous literature review, the aim of FTG is to identify the factors influencing the number of freight trips in the Gothenburg event area and to forecast the number of freight trips based on the influencing factors. To construct an accurate FTG model, the first step was to determine whether a statistical relationship exists between potential variables and vehicle trips.

Among the data we obtained, the datasets directly related to trip is the *"Vehicle in & out record"* manually recorded for Liseberg's vehicle arriving data over one representative week in July 2024, where, each trip was matched with the corresponding order records by delivery date and receiver. The dataset was categorized by four main receiver sectors: restaurant, warehouse, hotel, and retail. The number of monthly orders was calculated for the month in which the expected delivery time is expected at the time the order is placed, taking the lead time into account.

In our hypothesis, order number was also considered as an important influencing factor, where more orders refers to more trips with the same receiver. To verify our hypothesis, we matched the orders in the dataset *"Order record from Stella"* with the trips based on the delivery time. After that, a least squares regression was conducted to test the influence of two factors on the number of trips: order volume and receiver sector, as shown in 5.1. Based on the effect summary, the p-value states that both the number of orders (p = 0.00086) and the receiver sector (p = 0.00357) have a statistically significant impact on freight trip generation ($p < 0.05$).



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
Hotel	7.026658	0.9127501	6.71429
Restaurant	0.830149	2.6722589	1.50000
Retail	8.227556	4.1115740	3.50000
Warehouse	21.134818	3.4608005	9.00000

Effect Summary

Source	Logworth	PValue
Number of orders	3.066	0.00086
Receiver	2.447	0.00357
Receiver*Number of orders	0.914	0.12186
Number of orders*Number of orders	0.001	0.99763

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Receiver	3	3	131.04173	7.8981	0.0036*
Number of orders	1	1	107.24862	19.3921	0.0009*
Receiver*Number of orders	3	3	39.30856	2.3692	0.1219
Number of orders*Number of orders	1	1	0.00005079	0.0000	0.9976

Figure 5.1. Effect summary of the least squares regression analysis

The result implies that the number of orders is positively correlated with trips, and different receivers have different trip patterns. Thus FTG can be modeled using historical orders data, with a differentiation by receivers' sector.

5.1.2 Order forecasting

The second step was to forecast monthly orders for 2024. The historical dataset from Liseberg contains order information for 29 months (Jan 2022 - May 2024) and shows a clear seasonal pattern both overall and by sectors. To make forecasting of trips based on receivers and orders, the number of orders from different receivers over time was integrated, resulting in a time series of orders from different receivers on a month-by-month basis.

Among several time-series forecasting methods that accommodate seasonality, such as exponential smoothing, ARMA and SARIMA discussed in the literature review, the SARIMA model was selected due to its statistical robustness and suitability for modeling purely endogenous seasonal patterns. As Liseberg's historical order data exhibits clear periodic peaks associated with public holidays and summer seasons, SARIMA provides a structured and interpretable framework to capture both non-seasonal and seasonal dynamics without the need for external regression.

Using the SARIMA model, we derived the forecasting for the next 19 months of 2024 and 2025 using 29 months of historical data (2022 and 2023 for the whole year, and 2024 for the first 5 months). Due to limited historical data, this forecast will become less accurate over time. A small difference of order number between 2022 and 2023 indicates that the forecasting value of the orders in 2025 would remain similar as the forecasting value in 2024, which might not be the actual case.

Appendix C shows the month-based order forecasting for different receivers, and the results are summarized in Table 5.1.

Table 5.1. Monthly order forecasting result by sectors

Month	**Retail**	**Restaurant**	**Warehouse**	**Hotel**	**Forecasting in total**	**Actual value**
2024-Jan	0.00	297.72	43.73	434.31	**776**	595
2024-Feb	6.31	209.06	23.87	434.31	**674**	606
2024-Mar	32.48	238.70	53.04	434.31	**759**	748
2024-Apr	27.76	554.95	61.27	434.31	**1078**	1128
2024-May	115.55	734.44	115.99	434.31	**1400**	1549
2024-Jun	165.76	1080.65	137.05	434.31	**1818**	–
2024-Jul	173.86	1263.89	130.01	434.31	**2002**	–
2024-Aug	167.42	1095.83	111.64	434.31	**1809**	–
2024-Sep	104.36	594.65	55.08	434.31	**1188**	–
2024-Oct	120.79	636.20	69.04	434.31	**1260**	–
2024-Nov	87.10	662.46	64.75	434.31	**1249**	–
2024-Dec	70.03	400.27	48.16	434.31	**953**	–
2025-Jan	60.91	43.48	0.00	434.31	**539**	–
2025-Feb	66.40	72.24	8.22	434.31	**581**	–
2025-Mar	82.66	146.22	17.31	434.31	**680**	–
2025-Apr	128.32	601.02	44.40	434.31	**1068**	–
2025-May	181.24	685.15	69.90	434.31	**1371**	–
2025-Jun	223.23	998.94	89.81	434.31	**1746**	–
2025-Jul	232.51	1189.78	76.56	434.31	**1933**	–
2025-Aug	228.58	973.28	58.28	434.31	**1694**	–
2025-Sep	171.12	428.64	5.01	434.31	**1039**	–
2025-Oct	190.85	600.82	17.68	434.31	**1244**	–
2025-Nov	163.08	546.29	13.55	434.31	**1157**	–
2025-Dec	150.67	631.04	0.00	434.31	**1216**	–

Here due to the short opening time of the hotel, the historical order data is limited and there is no reasonable pattern after time series analysis, so the monthly average is taken instead of the forecast with this sector. Comparing the forecasts with the actual data for the first five months of 2024, there is generally good agreement between the forecasts and the actual data, especially in capturing seasonal trends, demonstrating the validity of this forecasting result in capturing total orders on a seasonal or annual basis.

These forecasting values were subsequently used as inputs for the FTG model to estimate the expected number of freight vehicle trips, allowing for the analysis of seasonal logistics pressures and the evaluation of potential consolidation strategies.

5.1.3 Convert forecasting orders into trips

The results of the order forecasting and trip generation estimation for Liseberg have been empirically validated and show a good fit. To further convert the forecasting order quantities into trips, we went back to the earliest dataset *"Vehicle in & out record"* , and it was matched with the dataset *"Order record from Stella"* to end up with the average number of orders per trip for each receiver sector. As shown in Table 5.2, it indicates that hotel and retail sectors have similar order volumes per trip, both at three orders per trip, warehouse has a slightly lower rate at one order per trip, and restaurant sector has the highest rate at about 61 orders per trip, which may be due to the fact that a large portion of the orders will be delivered directly to the restaurant instead of to the uniformly accepted location, and this portion of the orders will not be included in the study of our consolidation scope.

Table 5.2. Average number of orders per trip by receiver sectors

Receiver Sectors	**Orders per Trip**
Retail	3.36
Restaurant	60.67
Warehouse	1.09
Hotel	3.53

Ultimately, the monthly forecasting of orders were transformed into trips using this average orders-per-trip ratio for each receiver sector, as shown in Table 5.3 and Figure 5.2. The vehicle trips estimation is more reliable for 2024 due to the incompleteness of the dataset and the yearly pattern of the database, especially the approximate estimation from the hotel sector, that lead to inaccurate 2025 forecasts. The monthly freight vehicle trip forecast of Liseberg shows that hotels have a consistently high volume of vehicle trips, warehouses and retail are next in line, and restaurants receive fewer vehicle trips. Overall, the number of vehicle trips into the park would peak in July 2024 at over 315 trips, dropping to approximately 150-170 trips in January and February.

Table 5.3. Monthly vehicle trips estimation by sectors

Month	Retail	Restaurant	Warehouse	Hotel	Total Estimated Trips
2024-Jan	0	5	40	123	168
2024-Feb	2	3	22	123	150
2024-Mar	10	4	49	123	185
2024-Apr	8	9	56	123	197
2024-May	34	12	106	123	276
2024-Jun	49	18	126	123	316
2024-Jul	52	21	119	123	315
2024-Aug	50	18	102	123	293
2024-Sep	31	10	51	123	214
2024-Oct	36	10	63	123	233
2024-Nov	26	11	59	123	219
2024-Dec	21	7	44	123	195
2025-Jan	18	1	0	123	142
2025-Feb	20	1	8	123	152
2025-Mar	25	2	16	123	166
2025-Apr	38	8	41	123	210
2025-May	54	11	64	123	252
2025-Jun	66	16	82	123	288
2025-Jul	69	20	70	123	282
2025-Aug	68	16	53	123	261
2025-Sep	51	7	5	123	186
2025-Oct	57	10	16	123	206
2025-Nov	49	9	12	123	193
2025-Dec	45	10	0	123	178

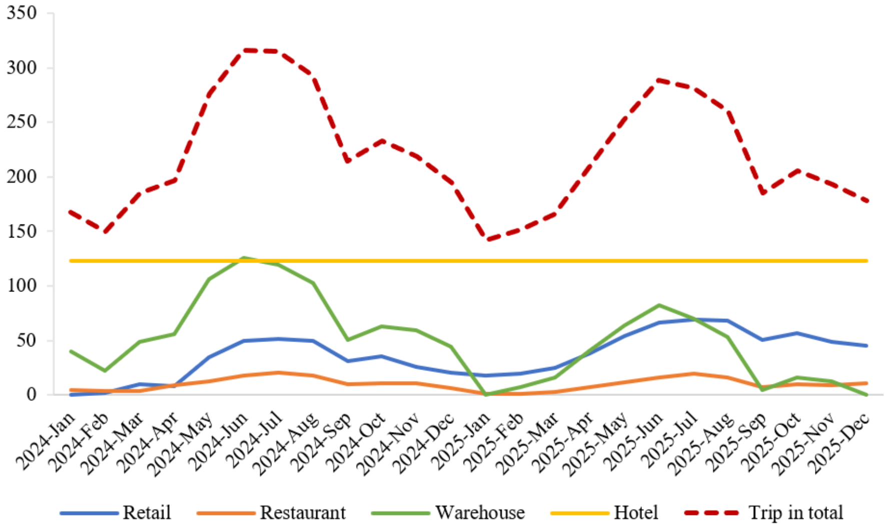


Figure 5.2. Monthly vehicle trips estimation results

The results derived from the FTG model and seasonal time series forecasts offer valuable insight into the logistical dynamics of the Liseberg event area. The monthly freight trips forecasting and the variations not only reveal the operational burden during peak periods, but also highlight opportunities for structured consolidation. By applying FTG models, the study can estimate the number of trips currently generated by establishments in the events area and evaluate how many trips can be consolidated under different scenarios. The integration of FTG and RLC models provides a comprehensive approach to quantifying benefits from consolidation and supporting data-driven urban freight planning.

Although the FTG model in this study provides monthly-level predictions of freight vehicle trips, it is important to note that more granular forecasts – at daily or even hourly levels – would offer greater value for urban logistics planning and policy implementation. For example, FTG-based delivery peaks by hour or day of the week could support strategies on the scheduling of dedicated loading zones, off-peak delivery incentives, or time-based access restrictions. However, such detailed modeling was not performed in this study due to limitations in the availability and continuity of historical trip and order data, which restrict the reliability of fine-grained time series forecasts. As a result, the current model focuses on broader seasonal trends and sectoral fluctuations, while insights into short-term peak periods rely on descriptive observations rather than predictive modeling.

5.2 Baseline consolidation cost

In this section, we construct the baseline scenario where the delivery model is that each vehicle serves only one customer (Liseberg) within the event area, whether it is a traditional delivery or a UCC-supported delivery. Using the number of vehicle trips forecast for Liseberg in 2024 in section 5.1 and the dataset *"Vehicle in & out record"* as the data base, we calculated the operating costs of the logistics service for the initial delivery and the estimated costs of the service with the use of UCC with a comparison analysis.

5.2.1 Scenario description

In this scenario, the calculation of costs focuses only on the direct operating costs incurred by the entire distribution system in accomplishing the delivery service. The main goal of the model is to create a system-wide cost comparison that is not influenced by stakeholder-specific pricing strategies or policy interventions. Cost allocation among different stakeholders and external or indirect costs such as carbon emissions, noise pollution, subsidies, or tax frameworks are not considered in the model.

Based on Janjevic and Ndiaye (2017), our cost modeling focuses on ensuring that the analysis reflects the inherent logistics efficiency and effectiveness of different distribution configurations by separating direct costs, including vehicle operating costs, labor costs, and tolls. With this approach, our focus on direct costs provides a baseline for understanding the economic performance of consolidation strategies. The results can therefore be used to directly assess whether the introduction of a UCC-based consolidation strategy can reduce the consumption of the underlying resources.

In the scenario model, firstly, we are about to demonstrate the location of stakeholders involved. As shown in Figure 5.3, the suppliers can be located inside or outside the city of Gothenburg, the UCC is located in the northern part of the city of Gothenburg, and the receiver (Liseberg) is located within the event area in the city center of Gothenburg.

In terms of the delivery process, when the UCC is not involved in the delivery process, the supplier will send a vehicle (or from LSP) to the receiver for delivery from outside the city via the highway entrance into the city of Gothenburg for last-mile delivery, or start delivery directly within the Gothenburg city. The only costs incurred by the delivery service are the vehicle costs, labor costs and the charges for the vehicle's entry into the city.

With the introduction of UCC, the receiver in the event area will set their delivery address as UCC when ordering, and UCC carries out the consolidation of goods from suppliers and handles delivery to the receiver. Thus the first part of deliveries from suppliers remain the same, with the only difference in their destination to the UCC. UCC consolidates the shipments and handles the delivery with a higher vehicle loading rate to the event area.

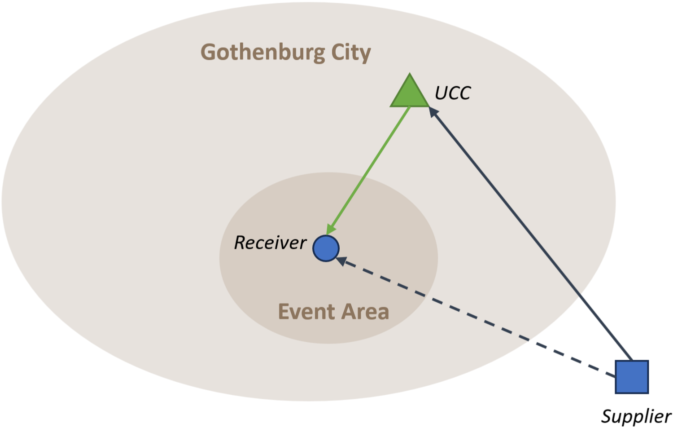


Figure 5.3. Illustration of the baseline scenario

In order to simplify the spatial part of the model, the starting point of each vehicle route for delivery by a supplier located outside the city of Gothenburg is defined as the point at which the delivery vehicle enters the city boundary of Gothenburg (highway entrance). That is, the inbound logistics of the vehicle before arriving in the city are aggregated with each highway, as shown in Figure 5.4, and the route from the supplier to the highway entrance does not change from scenario to scenario. The blue markers indicate the locations where vehicles enter the city from different directions, and the red markers indicate the event areas (Liseberg and Svenska Mässan). The section of the road from the blue markers to the red markers is the delivery route of the vehicles.

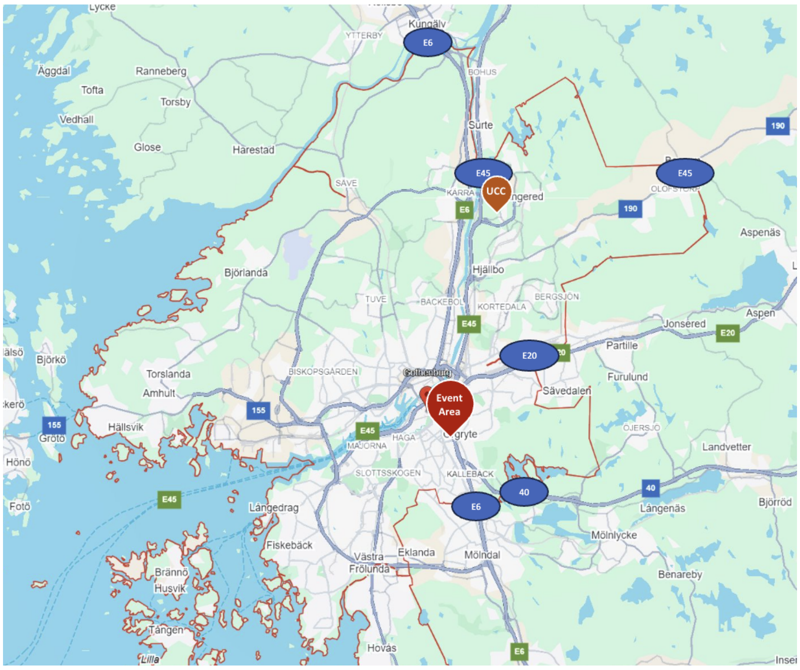


Figure 5.4. Identified highway entry points into Gothenburg

The model scenario is constructed based on the following assumptions:

1. The pre-city routing remains unchanged with or without UCC involvement.
2. The weekly delivery data is representative of average operations and can be scaled linearly to an annual basis.
3. The types of vehicles used for delivery and their usage pattern remain constant over the year, regardless of delivery frequency.
4. No return loads or backhauling are considered in either scenario.
5. UCC-based deliveries to the receiver are assumed to take place during early morning or nighttime windows.
6. Vehicle speeds are treated as average constants, without modeling traffic congestion.

7. Maintenance and depreciation costs are assumed constant per kilometer or hour across the year.
8. External costs such as emissions, noise, and congestion are not included in this cost model.

5.2.2 Model construction

According to Janjevic and Ndiaye (2017), the costs of delivery services can be categorized into distance-based costs and time-based costs. In particular, distance-based costs in transportation networks are mainly vehicle operating costs, including fuel costs, vehicle repair and maintenance, with distances varying depending on the path of the vehicle. Time-based costs, on the other hand, include the depreciation of vehicle purchases, and labor costs (driver wages and related overhead). Based on this theory, we incorporate vehicle entry tolls into the costs with the congestion tax collection rules that are being implemented in the city of Gothenburg.

The cost for a traditional distribution network (without UCC) based on the cost structure raised by Janjevic and Ndiaye (2017) is shown in Equation 5.1, where the time is calculated as the vehicle's traveling time in transit.

$$C_{OA} = \sum_{i,j} \left[n_{ij} \cdot d_j \cdot (c_{f_i} + c_{m_i}) + n_{ij} \cdot \frac{d_j}{v} \cdot (h_{d_i} + h_l) + p_t \right] \tag{5.1}$$

The variables and parameters used in Equation 5.1 are defined as follows:

i	Vehicle type
j	Vehicle route
n_{ij}	Number of vehicle type i in route j
d_j	Vehicle traveling distance in route j
v	Average speed of delivery vehicles
c_{fi}	Fuel cost for vehicle type i (kr/km)
c_{mi}	Maintenance cost for vehicle type i (kr/km)
h_{di}	Depreciation cost for vehicle type i (kr/h)
h_l	Labor cost (kr/h)
p_t	Toll prices for suppliers' vehicles entering the city

When carrying out delivery services with UCC, the cost calculation can be divided into two parts, as shown in Equation 5.2. The first part is the cost of shipment from the start of the route (city edge or intra-city supplier location) to the UCC, which is calculated in the same way as Equation 5.1, changing only the destination. The second part is the cost of delivery from the UCC to the receiver within the event area, which has a similar composition as in 5.1, but the number of different delivery vehicles used is estimated based on the total volume of goods which are delivered in relation to their loading rate within the same route. In addition, in the case of using UCCs, the goods need to be transited and reloaded at the UCCs, which will be added to the time-related costs to be calculated. Since the operating costs of UCCs are also difficult to apportion through time and customers depending on their land ownership, investment and financing model, and mode of operation, these costs are not considered in this model.

$$\begin{aligned} C_{UCC} = C_{04}^{\sigma-U} + \sum_{i} \Bigg[& \left(\frac{V_i \cdot p_i}{\bar{R}_i \cdot Lc_i} \right) d_{U-E} \cdot (c_{fi} + c_{mi}) \\ & + \left(\frac{V_i \cdot p_i}{\bar{R}_i \cdot Lc_i} \cdot \frac{d_{U-E}}{v} + t_{UCC} \right) \cdot (h_{di} + h_l) + p'_t \Bigg] \end{aligned} \tag{5.2}$$

The variables and parameters used in Equation 5.2 are defined as follows:

C_{OA}^{o-U}	Delivery cost of upstream shipment from suppliers to UCC
V_i	Rated loading capacity of vehicle i
p_i	Proportion of goods transported by vehicle i
$\bar{R}_i$	Average loading factor of vehicle i
Lc_i	Rated loading capacity of vehicle i
d_{U-E}	Route distance from UCC to the event area
t_{UCC}	Vehicle dwell time at UCC (h)
p'_t	Toll prices for UCC's vehicles entering the city (nighttime)

5.2.3 Parameter setting and calculation

The model's calculations are based on real-world data, so the parameter settings have specific reference sources. For the specific calculations, it was based the dataset *Vehicle in & out record*of Liseberg for one week under the traditional delivery model, where each vehicle is considered as a separate trip. The parameters available from this dataset are: the type of vehicle, the amount of goods loaded on the vehicle, the depot of vehicle routes (and the corresponding highway entrance to the city for suppliers outside of Gothenburg), and the length of the delivery path, the time the vehicle enters the event area for deliveries (and the corresponding toll charge for congestion tax), which form the empirical basis for the weekly operational cost modeling.

Based on the vehicle types in the dataset, we categorized vehicles into trailers, delivery trucks, light trucks, and light vans, each of which is subdivided according to fuel type to obtain a more detailed breakdown. From this, we use web-based information and other secondary data to determine vehicle fuel, maintenance and depreciation costs, and labor costs, as shown in *Appendix D*. The main sources of this data are reputable energy and automotive information sites, including GlobalPetrolPrices.com, Circle K Sweden and Volvo Trucks. According to statistics from the Glassdoor Website, the pay rate for truck drivers in Gothenburg is approximately 190kr per hour (Glassdoor, 2025). In the scenario using UCC, since there is no specific data recorded, based on the current operation and expectations of pilot, we set the main vehicles used to be the three fossil fuel-free MDVs, including HVO, Biogas, and electric, which are the same in number and frequency of use, with an average loading rate of 80%.

The lengths of the routes for the different delivery vehicles were derived from the vehicle navigation search in Google Maps, as shown in Table 5.4.

Table 5.4. Comparison of average delivery distances from different entry points with and without using the UCC

Area/Entrance	**Count**	**Distance w/o UCC (km)**	**Distance w/ UCC (km)**
Within Gothenburg City	60	10.85	$7.96 + 16.2$
40E	18	5.50	$17.7 + 16.2$
E20E	34	7.80	$18.6 + 16.2$
E6N	3	21.00	$11.7 + 16.2$
E6S	11	3.50	$16.9 + 16.2$
(blank)	4	9.30	$13.1 + 16.2$
Total/Average	**130**	**8.88**	**29.29**

Taking a trip from Vara on 22.07.2024 in the data set as an example, the transportation vehicle is a diesel distribution car, and we can determine that the maintenance cost of this vehicle is roughly 0.52 kr/km, the depreciation cost is 13.65kr/km, fuel consumption is 0.2L/km, and the fuel cost is 17.157 kr/L. In addition, the vehicles originating from Vara generally enter Gothenburg city via the E20 highway from the east, and we can determine that the distance traveled by this vehicle is roughly 7.8 km. Therefore, based on Equation 5.1 and the set of parameters mentioned above, we can calculate that the transportation cost of this trip is roughly 187 kr.

Based on the above calculation approach and combining them with vehicles entering data for Liseberg for one week, we calculated the cost of each trip individually and get a sum-up, as shown in Table 5.5.

Table 5.5. Comparison of transportation costs with and without UCC

Description	Cost
Cost without UCC in the week	28,862 kr
Cost with UCC in the week	43,596 kr
Cost without UCC in year 2024	608,305 kr
Cost with UCC in year 2024	918,844 kr

5.2.4 Results discussion

Based on the above results we can conclude that even without considering the construction and operational costs of UCC, when there is only one receiver, there is no cost advantage to consolidated delivery due to the added operational processes. In this baseline scenario when UCC serves only one receiver (Liseberg), the use of UCC brings a disadvantage in terms of distance and time related costs compared to the traditional delivery model.

The main reason for this disadvantage is the location of the UCC. In our model, the location of UCCs largely affects the overall cost. In the week's dataset, 46% of all orders originated from within Gothenburg City. In terms of distance from the origin or highway entrance to the UCC / receiving location, the shipment within the city has a certain advantage in terms of the route distance. For orders from outside Gothenburg, excluding trips coming in from the north highway, none of them have a distance advantage when using the UCC. Therefore, by optimizing the location of UCCs, it can be used to compensate for certain cost disadvantages, achieving smaller cost increasing for a later stage of consolidation.

In addition to this, while the distance and time-related costs of UCCs do not dominate in the short term, certain indirect impacts may offer potential long-term benefits. Examples include reducing urban congestion, lowering carbon emissions, and enhancing the delivery experience. In the case of improving the delivery experience, for example, the range of value-added services that UCCs provide can compensate for some of the economic disadvantages, thereby encouraging stakeholders to participate in the consolidation. These indirect effects are difficult to quantity, but they still carry real weight and shouldn't be ignored. Section 6.2 of this report will continue to discuss the impact of other factors on the indirect benefits of consolidation from different stakeholder perspectives.

In addition to this, if Liseberg is not the only destination but a stop on the delivery route, costs can be significantly reduced by realizing economies of scale and further lowering cost sharing on both the supply and the receiver side, which is also a more common operational model in real life.

5.3 Multi-stop delivery consolidation cost

To further simulate real-life delivery scenarios, this section will further refine the cost model in section 5.2 by introducing multiple customers and detour delivery routes, which are used to estimate and compare delivery costs per unit volume before and after the use of a UCC in a multi-stop delivery scenario. In this model, a supplier's goods are delivered to a UCC acting as a regional hub, which then redistributes them to a set of receivers located within its defined service area - in this case, the event area of Gothenburg.

5.3.1 Model description

In urban logistics practice, it is common for suppliers or UCC operators to use a multi-stop delivery model rather than delivering goods individually to each receiver, which would result in duplicated delivery distances and vehicle occupancy of urban space. Especially in dense event areas or central business districts, it is common to have a shared supplier base or a third-party logistics provider serving multiple receivers in close proximity. This operational logic is particularly applicable in the event area of Gothenburg, where several independent but closely located receivers (e.g. exhibition halls, hotels, restaurants, as well as Liseberg and Svenska Mässan) can be grouped together in a single delivery route. However, the implementation of this model also introduces more complex routing structures and cost allocation mechanisms that must be carefully modeled and evaluated.

Therefore, we constructed a multi-stop delivery cost model to reflect this actual configuration, as shown in Figure 5.5. The model reflects the reality that one delivery vehicle will serve multiple receivers. The delivery area is divided into two nested zones. The larger, lighter shaded area represents the entire city of Gothenburg and contains all the receivers in the system. The inner, darker area represents the UCC's delivery area, i.e. the area where the activities of the receivers are concentrated.

In the traditional distribution model, where the supplier makes the delivery directly, the supplier, located either inside or outside the city of Gothenburg, makes a round trip to all the customers in the city of Gothenburg (including the event area) and returns to the starting point. With the introduction of UCC, the scope of service of UCC is set to be all customers in the event area, so that the supplier no longer enters the event area, but delivers these orders to UCC as a centralized stop on its delivery route, and UCC acts as a consolidation and distribution node to carry out multi-stop delivery services in the event area.

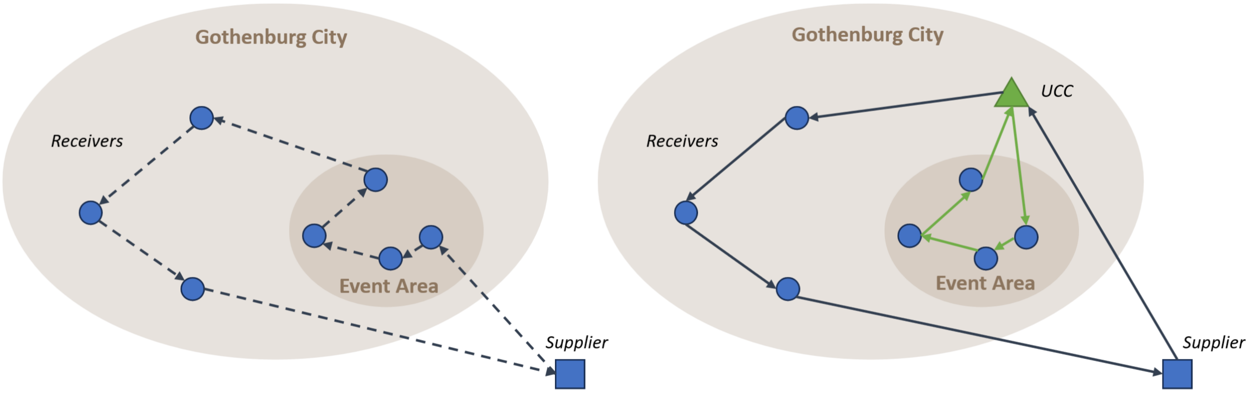


Figure 5.5. Illustration of the multi-stop delivery scenario

The model scenario is constructed based on the following assumptions:

1. The UCC vehicles operate at night or early morning, whereas supplier-side vehicles follow daytime delivery schedules as observed in operational data.
2. All per-unit cost estimates are calculated based on volume (per m^3), assuming stable vehicle capacities and loading efficiency.
3. Vehicle routes include return trips, but return trips are not included as a separate component, but are embedded in the estimated total distance traveled using the average route length including detours and return trips.
4. Each UCC-dispatched vehicle continues to serve only the original set of receivers from its corresponding supplier, without further route optimization across different suppliers' freight flows.
5. The volume of cargo loaded on a vehicle is not related to the route distance of the vehicle and the number of stops on the route.
6. The cost model excludes externalities such as emissions, noise, or congestion cost.

5.3.2 Model construction

Similar to the cost structure in the baseline calculation in section 5.2, the costs in the multi-stop delivery scenario still include three parts: distance-related, time-related and toll charge costs. The difference is that in the multi-stop delivery scenario, Liseberg is no longer the only receiver on the delivery route, thus the total delivery cost cannot be directly allocated and compared. Therefore, we use the average unit volume cost of delivered goods to provide a normalized and comparable measure. This not only allows for a fair assessment of the cost efficiency of different delivery configurations, but also leads to more generalized insights applicable to the broader real-world urban freight environment in identifying the conditions under which the use of UCCs can be economically efficient.

$$\bar{c}_{OA} = \frac{1}{k} \sum_{k} \frac{d_k \cdot (c_{fk} + c_{mk}) + \frac{d_k}{v} \cdot (h_{dk} + h_l) + p_t}{V_k} \tag{5.3}$$

The variables and parameters used in Equation 5.1 are defined as follows:

k	Number of vehicles from suppliers
d_k	Distance of the delivery route of vehicle n
V_k	Volume of goods loaded on vehicle n
v	Average speed of delivery vehicles
c_{fk}	Fuel cost for vehicle n (kr/km)
c_{mk}	Maintenance cost for vehicle n (kr/km)
h_{dk}	Depreciation cost for vehicle n (kr/h)
h_l	Labor cost (kr/h)
p_t	Toll prices for suppliers' vehicles entering the city

Equation 5.4 presents the cost formulation for the scenario with UCC. The cost is divided into two components. The first part The first component is still the cost to the supplier of making traveling deliveries, but the stops do not include customers within UCC's service area, i.e., event area of Gothenburg, but rather deliver those customers' shipments to UCC as a stop on the route. The second part covers the delivery from the UCC to the multiple receivers in the event area. Both parts follow the same cost logic as in Equation 5.3, but use different estimated distances: d_1 for the supplier-to-UCC segment, and d_2 for the UCC-to-receiver segment. The UCC delivery cost is further scaled based on volume ratios between supplier and UCC vehicles, and includes toll charges and dwell time for unloading and reloading at the UCC. Here the number of vehicles used on the supplier side is directly based on the observed number of trips n, while the number of UCC delivery vehicles is derived from the ratio V/V_{UCC}, which reflects the volume-based vehicle demand under UCC operations.

$$\begin{aligned} \bar{c}_{UCC} = \frac{1}{k} \sum_{k} \Bigg[& \frac{d_{k1} \cdot (c_{fk} + c_{mk}) + \frac{d_{k1}}{v} \cdot (h_{dk} + h_l) + p_t}{V_k} \\ & + \frac{V_k}{V_{UCC}} \cdot \frac{d_{k2} \cdot (c_{fk} + c_{mk}) + \frac{d_{k2}}{v} \cdot (h_{dk} + h_l) + p'_t}{V_{UCC}} \Bigg] \end{aligned} \tag{5.4}$$

The variables and parameters used in Equation 5.4 are defined as follows:

k	Number of vehicles from suppliers
d_{k1}	Distance of the route outside event area for supplier delivery vehicle n
d_{k2}	Distance of the route inside event area for UCC delivery vehicle
V_{UCC}	Volume of goods loaded on the vehicles
p'_t	Toll prices for UCC's vehicles entering the city (nighttime)

However, unlike the dedicated delivery model where exact trip-level data was available, the multi-stop delivery model relies on approximations of vehicle routing distance due to the lack of complete vehicle routes data. In this context, to estimate the total distance traveled in a multi-stop delivery route, we adopt the empirical approximation proposed by Figliozzi (2009), which expresses the average route length as a function of the number of delivery points and the size of the delivery area: $d = b + k \cdot \sqrt{NA}$

where d is the estimated total travel distance, N is the number of delivery stops, and A is the size of the area in which deliveries take place. The parameters b and k are calibration constants that reflect route configuration and operational conditions such as depot location, urban density, and routing constraints.

The values of b and k are scenario-specific, with many studies obtaining the values of these two parameters for different scenarios by fitting different geometric model and realistic empirical data. Thus the values of b and k are calibrated using available operational data from Gothenburg and are adjusted in different simulation experiments to reflect alternative scenarios and routing configurations.

To estimate the total route distance d for vehicles operating within the city of Gothenburg, we used a data-driven approach based on actual operational records. Specifically, we utilized a dataset provided by a local logistics service provider (GLC), which contains detailed daily delivery records including the total distance traveled and the number of delivery stops per vehicle. By fitting this dataset to the functional form proposed by Figliozzi (2009), see *Appendix E*, we derived the following empirical approximation:

$$d = 26.64 + 0.98\sqrt{NA} \tag{5.5}$$

This formula reflects the typical route length for multi-drop vehicle operations in the context of Gothenburg, incorporating local traffic conditions, customer density, and delivery practices. The variables and parameters used are defined as follows:

N	Number of stops on the delivery route
A	Size of the delivery area

Similarly, when using UCC as the regional hub, the distance traveled by vehicles from suppliers can be expressed as:

$$d_1 = 26.64 + 0.98\sqrt{[(1-a)N + 1]A} \tag{5.6}$$

where the parameter a is defined as:

a The proportion of receivers in the event area to the total number of stops in the path of the delivery vehicle

For the delivery within the event area, no detailed operational data was available. As a result, we referred to the approximation by Chien (1992), which was developed based on simulation and regression analysis of traveling salesman problems under urban constraints. The use of this formulation was justified by the structural similarity between the event area in Gothenburg and the spatial contexts in which Chien (1992)'s model was validated. This enabled us to approximate last-mile route distances in the absence of actual routing data. This formula estimates the route length as:

$$d_2 = 2.1r + 0.67\sqrt{nR} \tag{5.7}$$

The variables and parameters used in Equation 5.7 are defined as follows:

r	Average distance from supplier depots to the event area
R	Area size of the minimum bounding rectangle that covers all receiver points within the event area
n	Number of delivery stops inside the event area, $n = aN$

5.3.3 Case simulation

Given the lack of complete empirical data on actual routing paths and vehicle-level allocation decisions in a fully consolidated multi-drop delivery system, a simulation-based approach is adopted to compare the cost performance before and after the implementation of a UCC. The model estimates the delivery cost per unit volume under realistic stochastic conditions, using parameter distributions derived from observed operational patterns in Gothenburg.

Each simulation trial replicates a one-week delivery scenario involving 58 delivery vehicles. This number is based on a filtered subset of the original vehicle dataset, which recorded 131 vehicle arrivals in total. However, only 58 vehicles could be reliably assumed as conducting deliveries within the Gothenburg urban area. Vehicles whose delivery range exceeded the defined geographic scope were excluded to ensure consistency with the model's assumptions.

In each trial, 58 virtual vehicle configurations are generated. For every vehicle, the total number of stops N, the proportion of stops located within the UCC's event area scope a, and the loaded cargo volume V are drawn from pre-defined probability distributions. These distributions are derived from actual delivery data to reflect operational variability. Also, the vehicle-type-specific coefficients are replaced by their weighted average, reflecting the frequency distribution of different vehicle types in the dataset with cost parameters follow the same values and structure as defined in section 5.2. For deliveries from the UCC to the event area, MDV is assumed as the fixed vehicle type, with a constant volume capacity corresponding to 80% of its rated loading capacity, that is, V_{UCC} is treated as a constant 80 m^3. Same with the parameter setting in 5.2, the driveline for MDVs driveline consists of three types: electric, biogas and HVO, which are equally distributed.

The cost for each vehicle is calculated using the cost model, and the total weekly cost per cubic meter is obtained by dividing the total cost of all vehicles by the total deliveries. This weekly simulation is repeated 500 times to construct a distribution of total cost outcomes for both the UCC and non-UCC scenarios. The results is shown in Figure 5.6.

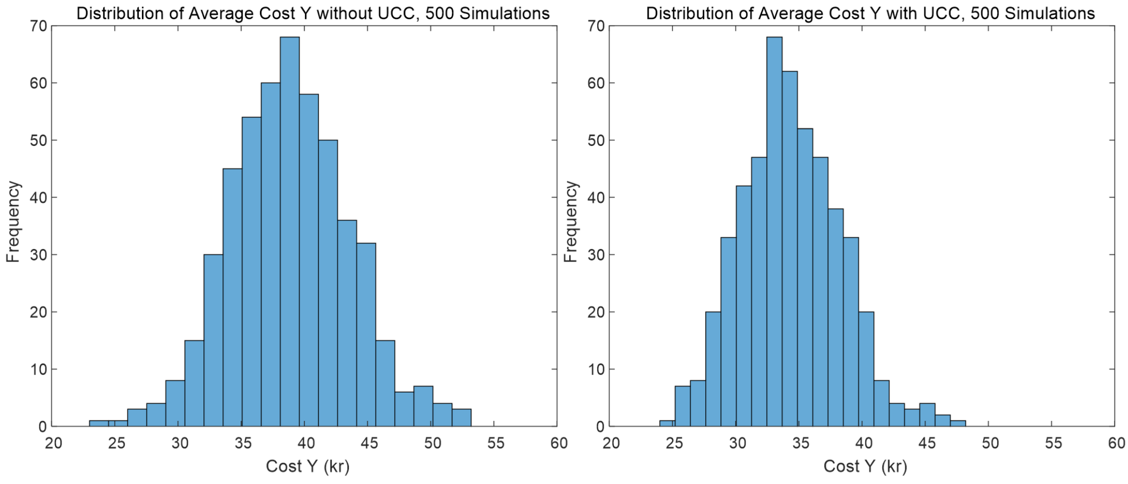


Figure 5.6. Illustration of the baseline scenario

As shown from the graph of the simulation results, there is an overall shift to the left in the cost distribution when using UCC compared to traditional delivery before consolidation. This suggests that even under conservative assumptions, the UCC strategy is able to reduce the unit delivery cost of goods within the Gothenburg event area while reducing the variability associated with route complexity. As a rough comparison, substituting the 33kr/m^3, which occurs most frequently in the average volumetric cost, into the one-year freight volumes calculated in 5.2, the cost of Liseberg's freight demand in 2024 is calculated to be 591,961kr with UCC, which is lower than the cost of considering only one-way deliveries under the baseline, dedicated delivery model (608,305kr without UCC and 918,844kr with UCC).

5.3.4 Numerical simulation

Urban logistics systems are sensitive to operational parameters. Based on the multi-stop delivery scenario and cost modeling developed in section 5.3.3, this part explores how different delivery conditions affect the cost performance of consolidation. This exploratory analysis focused on varying the three core input parameters of the model, the number of distribution stops N per vehicle, the loading volume V per vehicle, and the proportion of stops a in the UCC service area. By systematically changing the distributions and ranges of these variables, we aim to simulate a wider scope of real-world delivery configurations and analyze the cost results before and after using UCC.

Firstly, a baseline scenario is defined with the values of N, V and a following normal distributions fitted to the dataset from event area. This serves as a reference for comparison across all subsequent scenarios. Under these assumptions, a cost result comparison (as shown in Figure 5.7) confirms that the use of a UCC can reduce average delivery costs per cubic meter compared to traditional distribution, with the cost distribution under the UCC scenario (in red) clearly shifted to the left.

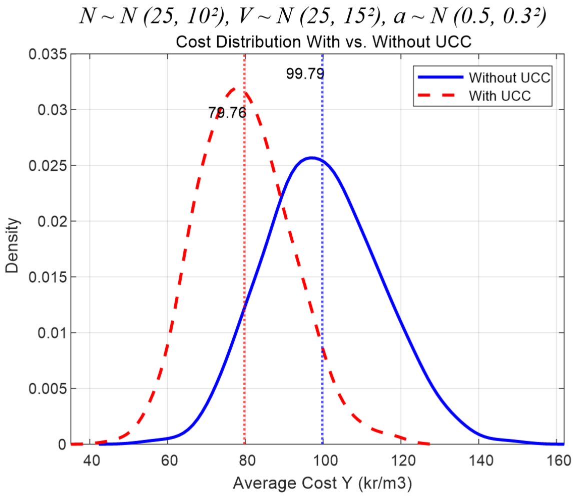
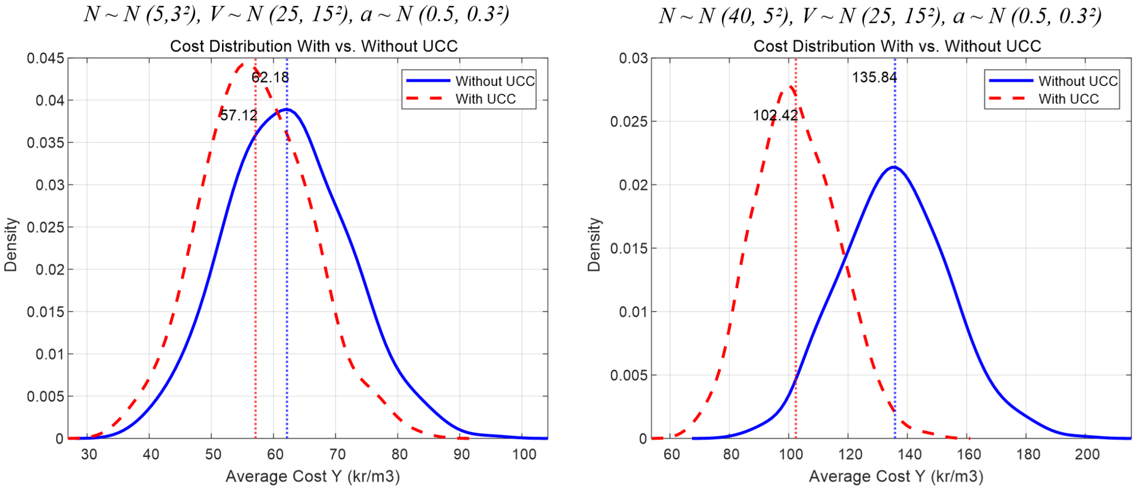


Figure 5.7. Cost distribution under baseline parameters

Next, we examine the effect of changing the distribution of delivery stop count N, while keeping the other parameters fixed, see Figure 5.8. When N is relatively small, the cost difference before and after using the UCC is limited. In contrast, when N increases, the cost-saving advantage of the UCC becomes more significant. Since the the loading volume V of vehicles remains constant in this test, the change in N reflects how the size of each individual order varies. A smaller N implies larger, more consolidated orders per customer, leading to shorter travel distances and lower delivery costs. In contrast, a larger N corresponds to more fragmented deliveries, where the consolidation effect of the UCC becomes more beneficial. This also explains why both the numerical and relative difference in cost results vary for different distributions of N.

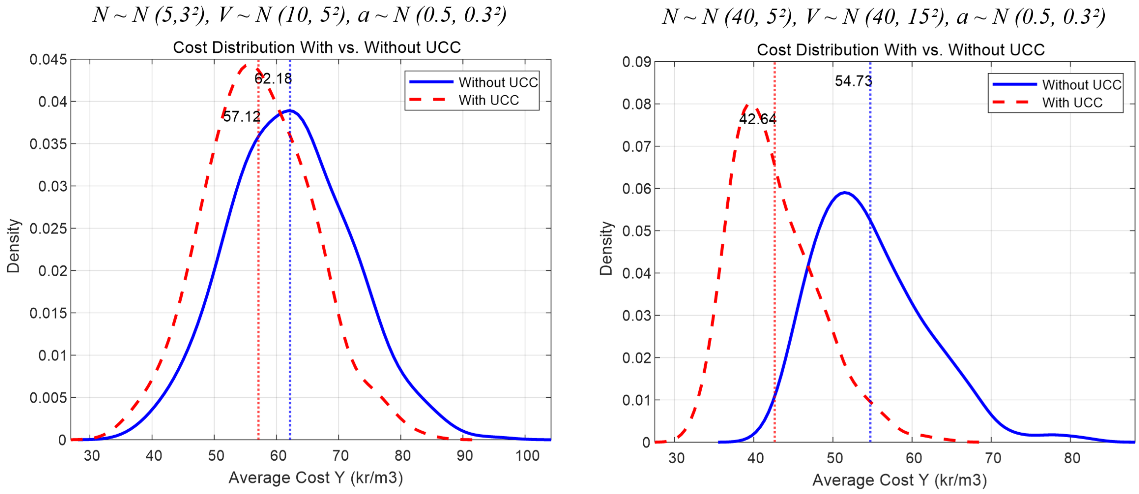


$N \sim N\ (5,3^2),\ V \sim N\ (25,\ 15^2),\ a \sim N\ (0.5,\ 0.3^2)$

$N \sim N\ (40,\ 5^2),\ V \sim N\ (25,\ 15^2),\ a \sim N\ (0.5,\ 0.3^2)$

Figure 5.8. Impact of delivery stop count N on cost performance

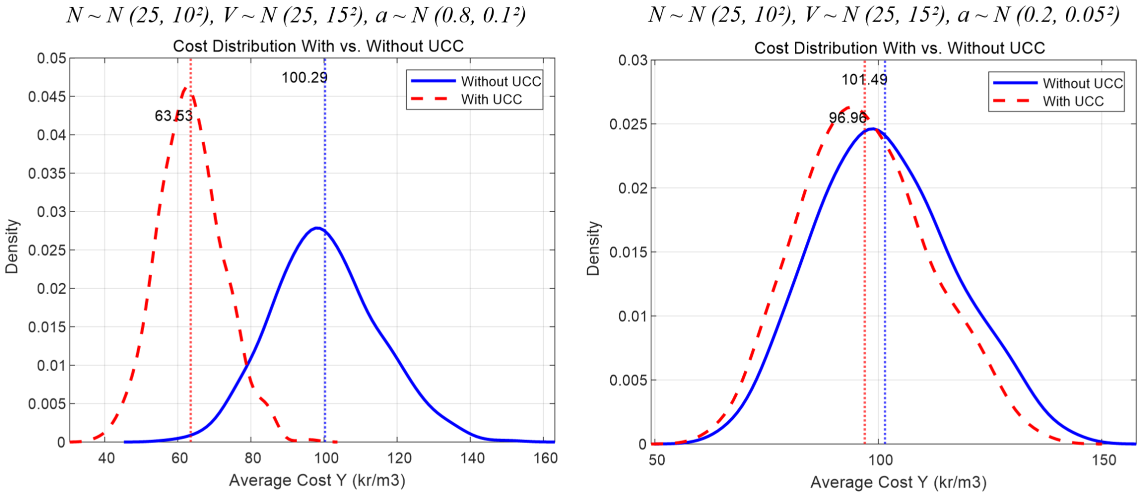
Also, there's interdependence between stop count N and vehicle loading volume V, as in real-world operations, a higher number of delivery points often corresponds to higher total cargo volume. As shown in Figure 5.9, we jointly modify the distribution of N and V. The results confirm that higher cargo volume reduces unit cost overall, as expected due to economies of scale. Moreover, the advantage of using UCC becomes more pronounced in high-N and high-V conditions, as there's greater separation between the two cost distribution peaks.


N ~ N (5,3²), V ~ N (10, 5²), a ~ N (0.5, 0.3²)

N ~ N (40, 5²), V ~ N (40, 15²), a ~ N (0.5, 0.3²)

Figure 5.9. Combined impact of N and V on cost performance

The impact of the proportion a of delivery stops within the UCC service area is also investigated, see Figure 5.10. The results show a clear trend that the greater the share of customers located in the event area (i.e., higher a), the more cost-effective the consolidation becomes. When the UCC serves a small share of total stops, the advantage diminishes or disappears due to the limited volume that benefits from the cost redistribution.


N ~ N (25, 10²), V ~ N (25, 15²), a ~ N (0.8, 0.1²)

N ~ N (25, 10²), V ~ N (25, 15²), a ~ N (0.2, 0.05²)

Figure 5.10. Impact of UCC delivery share a on cost performance

To sum up, these experiments highlight that the cost effectiveness of consolidation is particularly strong in operational settings with many delivery points and higher concentration of freight demand within the UCC service scope. The combination of route complexity and volume density can enhance the economic feasibility of using a UCC-based consolidation strategy.

6

Discussion

This chapter presents a comprehensive discussion of the study's findings, linking empirical observations, freight activity analysis, and cost simulation results to broader insights in urban freight consolidation. It aims to interpret how the logistical characteristics and stakeholder practices in the Gothenburg event area create both challenges and opportunities for consolidation. The discussion is structured around three core aspects: the contextual factors that generate demand for consolidation, the feasibility of implementing a consolidation system, and the conditions required to achieve long-term sustainability. This chapter contributes to a deeper understanding of how consolidation can serve as a strategic solution in complex urban logistics environments.

6.1 Opportunities for consolidation

The current freight dynamics in the Gothenburg event area face a number of pressures and challenges, but also create a strong demand and favorable environment for implementing consolidation strategies. These opportunities stem from spatial constraints, time fluctuations, ordering principles and stakeholder management challenges, requiring consolidation to reduce delivery frequency and improve control.

First, the physical constraints of the event area is the most obvious issue. Within Liseberg, there are historical buildings and scattered drop-off points, limit in-house vehicle movement and on-site storage, and their existing central warehouse has limited space to stack all the goods at peak times. Similarly, Svenska Mässan experiences logistical bottlenecks during large trade fairs as multiple suppliers try to enter at the same time through limited gates. By consolidating logistics, fewer vehicles can enter the event area, deliveries can be made in a more timely manner, and dock congestion can be reduced.

Second, the constraints also stem from the highly seasonal nature of freight demand within the event area, and freight trip generation models based on order histories showing monthly fluctuations with deliveries peaking during the activity season. These surges place significant strain on existing infrastructure and receiving capacity, resulting in traffic congestion, operational overlap, and a degraded visitor experience. In this case, consolidation provides a practical response by smoothing out delivery spikes through staggered timing and centralized distribution. In addition, this seasonality exposes low utilization of transportation resources during off-peak periods. It is therefore necessary to introduce a scalable, demand-responsive consolidation system that reduces delivery redundancy.

Next, the ordering patterns of Liseberg and Svenska Mässan show that small, frequent deliveries are very common, especially in the food service and hospitality industries. These orders are often placed independently by multiple departments and lack cross-departmental synchronization, resulting in many suppliers delivering LTL shipments multiple times per week. This fragmentation is inefficient and redundant, creating a clear opportunity for receiver-led consolidation and demonstrating a potential need for third-party systems such as UCC. Consolidation can significantly reduce the frequency of deliveries through internal coordination and centralized scheduling, while systems can aggregate small orders into full shipments and streamline delivery windows.

The difference in freight trips by receivers' sectors further demonstrates the underlying drivers of freight volumes. Deliveries during the peak season are dominated by the food and beverage due to the frequency requirements for perishable goods. In contrast, retail and warehouse orders show little seasonal variation, suggesting that their deliveries are easier to pre-schedule and integrate into regular distribution routes. This fluctuation or consistency over time gives them their own different applicable strategies for freight operations, such as on a fixed schedule or peak consolidation.

Through interviews and operational observations, in addition to the pressures on freight traffic directly faced by receivers in the event area, other stakeholder pain points rely on consolidation to address. For example, carriers faced frequent rescheduling of customer orders, shorter lead times, unpredictable arrival peaks, and overlapping vehicle arrival times. Liseberg's use of structured ordering platforms such as Stella and Proceedo, as well as the cooperation of Svenska Mässan with activity-specific logistics partners, demonstrate the existing willingness and attempts to engage in consolidation logistics.

Last but not least, Gothenburg is integrating sustainability into procurement and transportation policies, such as mitigating the link and social impacts of peak traffic, the replacement of fossil-fueled vehicles with fossil-free vehicles. In addition, the emission targets for green city zones also provide regulatory incentives for the adoption of consolidation solutions and facilitate the start-up and roll-out of coordinated delivery models.

6.2 Feasibility of consolidation pilot

Despite the range of consolidation opportunities in the event area based on quantitative analysis, the feasibility of piloting the project in REDIG has been impacted by a combination of factors. In terms of barriers, there are issues of incomplete data, outdated system, and lack of integration between different stakeholders. Initial financial support and suppliers' reliance on delivery control also make the implementation of the consolidation pilot difficult. However, issues such as space constraints at the receiver's provide an opportunity for the introduction of the consolidation pilot. Therefore, assessing the feasibility of the consolidation program requires a combination of current system constraints and potential drivers to identify those that can be improved and those that can be leveraged to drive the program to fruition.

6.2.1 Challenges limiting feasibility

One of the main challenges that is mentioned frequently in interviews is the data collection and sharing among key stakeholders. Firstly, the incomplete data means that the data collected does not fully cover important parameters such as the cargo type, volume, weight as well as delivery time. Systems do not cover these information will result in a lack of data to predict delivery demand in pilot projects and produce reliable delivery plans, which is important for optimizing vehicle load factors. In addition, outdated systems make real-time dynamics integration and consolidation difficult, for example, Svenska Mässan still relies heavily on manual record, which resulting in frequent lags and gaps in distribution records and logistics information. Moreover, the lack of integration of the systems among the stakeholders will affect the potential effectiveness of the consolidation project. This makes it extremely difficult to coordinate logistics planning when each organization operates its own system independently.

Another key factor affecting the feasibility of the pilot is the initial financial support, and as mentioned previously in the literature review (section 3.2.4), government financial and policy support is an important factor influencing the success of consolidation projects. The reason for this is that the UCCs put in additional infrastructure as well as an operational team, and without sufficient external funding or subsidies, these initial costs will fall on the participating stakeholders. In this case, stakeholders may not be willing to join the consolidation project from a cost perspective.

In addition, many suppliers as well as receivers are reluctant to adopt a consolidation logistics model due to concerns about reliability. Specifically, suppliers' lack of direct control over the last-mile delivery process can cause their worries about potential delays and contact with their customers, which can negatively affect their relationships. This concern may make it difficult for consolidation pilots to gather enough volume to achieve economies of scale, affecting the economic sustainability.

6.2.2 Factors enhancing feasibility

Despite the significant barriers identified, the current context also presents a number of factors that may enhance the feasibility of the consolidation pilot.

Firstly, the consolidation pilot project's commitment to use fossil-free fuel capacity in all consolidated deliveries is in line with Gothenburg and Europe's wider carbon reduction goals, making it easier to obtain policy and financial support from public authorities. The use of fossil-free fleet also demonstrates the environmental benefits of the consolidation model, increasing stakeholder confidence and acceptance.

Second, the pilot program focused on nighttime delivery. By shifting freight activity away from peak traffic periods, the UCC model can significantly reduce daytime congestion in the event area. This results in a cleaner and safer environment during opening hours, which can greatly enhance the visitor experience. In addition, off-peak deliveries optimize vehicle utilization and increase logistical efficiency. In this way, the nighttime delivery strategy helps to both better performance and less traffic disruptions caused by deliveries.

Third, consolidation centers have the potential to increase the utilization of resources by various stakeholders. By providing a range of services, such as storage management, it can address the lack of warehouse space mentioned by three receivers in the interviews. Moreover, during the meeting with RISE, it was mentioned that Svenska Mässan wanted to eliminate redundant resources they hold during the off-season, and that the UCC's intervention could reduce their input in resources by providing flexible solutions. In addition, they also mentioned that consolidation centers can also facilitate the efficient recycling of loading units such as empty pallets and roll cages during the delivery process, which are often underutilized in traditional distribution deliveries. Therefore, by optimizing inbound and outbound processes, UCC can maximize resource utilization and minimize idle assets.

6.3 Achieve a sustainable consolidation

First of all, in our cost simulation results, UCC deliveries with only one single stop generate higher costs in terms of time- and distance-based costs. However, when the model includes multiple distribution stops, which is more consistent with urban freight consolidation, in this more realistic detour assumption, the cost distribution using UCC tends to get lower, indicating lower average distribution costs per unit. In addition, the simulation results with adjusting different parameters (area size, proportion of delivery points within UCC's scope, loading volume in the vehicles) indicates that the UCC has cost advantages when there are more delivery points and more centralized delivery points within UCC's service scope. Thus, without the need for stakeholders to cover the initial investment costs, UCC's model can provide economic sustainability under ideal operating conditions and potential financial advantages for participating stakeholders.

Although the simulation results show that UCC is economically viable with efficient multi-stop delivery, implementing the model in real-world scenarios would still require significant upfront investment as well as ongoing operational commitment. Therefore, a range of operational strategies is required to offset the initial disadvantages to achieve a sustainable consolidation model.

The importance of government financial and policy support from the early stage has been discussed in the previous sections, and the financial support should be more than just a one-time subsidy. Specifically, to ensure the long-term sustainability of consolidation, the government needs to invest in the infrastructure upfront as well as in project coordination, and assist in the creation of a transitional financial model.

To enhance coordination, a centralized digital system organized by the Gothenburg City will play an important role. Given that many stakeholders are currently using fragmented or outdated systems, a government-developed harmonized system could help to increase transparency of information, streamline delivery processes and thus improve shipments efficiency through consolidation. In addition, government support can be combined with policy measures to encourage stakeholders to join the consolidation process and reinforce the environmental value proposition. For example, including carbon reductions in logistics service procurement criteria or providing tax incentives to companies that adopt low-emission delivery models.

In addition to external support, UCC also needs internal improvement to achieve a sustainable profit model. As described in section 5.2, the location determination of the UCC plays a crucial role in terms of time- and distance-based costs. Most of the trips will enter the city of Gothenburg from the west and south highway entrances, excluding the goods distributed within the city of Gothenburg. However, the GLC consolidation center we used in our calculations is located in the northern part of the city of Gothenburg, and this spatial mismatch results in longer route distance in deliveries, which increases transportation costs. Therefore, the choice of location can minimize the path of transport vehicles and supports a more economically sustainable integration model. UCC can also provide a range of value-added services that can provide more tangible benefits to their customers. For example, UCC can act as a preposition storage facility, which is a way for suppliers to ship goods in advance to the front warehouses closer to the city, thus can handling more flexible delivery arrangements.

For the receiving part, since the goods have been stored in the UCC warehouse closer to the event area, the delivery can be served with more customized requirements from receivers. Through a series of value-added services, the main objective is to improve the customer experience as well as the benefits, thus attracting more participants to join the consolidation project. In this way UCC will be able to achieve certain economies of scale and achieve long-term economic sustainability.

7

Conclusion

This chapter concludes the study by providing answers to the three core research questions of this report. Using the results and discussions from the various sections of empirical data, freight mode analysis, FTG calculations, and cost-based modeling, this chapter summarizes current logistics challenges, explores how to achieve an economically sustainable consolidation system, and provides practical recommendations for various stakeholder groups. These insights contribute to a deeper understanding of how coordinated logistics solutions can address urban freight transport inefficiencies, reduce environmental impacts, and support long-term goals for sustainable urban development.

7.1 What is the current freight logistics situation in the event area of Gothenburg?

The current state of freight logistics in the Gothenburg event area is characterized by event-based logistics and significant seasonal fluctuations, thus leading to multiple challenges in terms of space, time, operations and management. This characterizes high inefficiencies and creates a strong demand for consolidation from the receiver side.

Hosting tourist visits is the main activity in the Gothenburg event area, so the freight demand in this region are closely linked to events, with perishable goods from the food and hospitality industries being the main types of cargo. During large events, limited internal access and storage constraints at businesses often lead to transportation congestion and reduced service reliability. These problems are further exacerbated by highly decentralized ordering practices, with departments frequently placing redundant orders, generating large volumes of freight that are smaller than the truck's loading capacity.

Furthermore, peak seasons such as holidays and summers, see a surge in freight demand that is difficult for existing infrastructure to handle, while off-peak logistics resources are severely underutilized. These inefficiencies not only affect receivers but also cause disruption for LSPs, who must deal with irregular delivery peaks, limited planning horizons, and frequent scheduling conflicts.

However, the existence of structured purchasing platforms (e.g. Stella, Proceedo) adopted by receivers and the cooperation with their LSP partners have prepared the foundation for consolidation. In addition, the policy environment in Gothenburg, especially in the Green City Zone, which includes the entire event area, further enhances the basis for implementing consolidation solutions.

7.2 How to achieve an economically sustainable consolidation system in the event area?

Based on the cost model, UCC needs to stick to the strategy of multi-stop delivery, and prioritize the lower volume trips for consolidation and introduce route and UCC location optimization to improve operational efficiency. Also, the delivery time can be shifted to nighttime to reduce the delivery cost as well as alleviate the problem of urban road congestion. In addition, consolidation from suppliers is also seen as a viable strategy to improve the utilization of transportation resources. The ultimate goal is to consolidate the demand for freight delivery, attract more stakeholders, especially receivers, to participate in the project, and ultimately achieve economies of scale.

To this end, coordination plays an important role. First of all, order pooling across different stakeholders can be linked through platform interconnection and data transfer, in which government-developed platforms act as intermediaries that enable providing a platform for all stakeholders to exchange information to further integrate and efficiently consolidate the required data. Through demand consolidation, consistent cargo type, delivery points and time windows, bulk shipment formation can be identified to establish an efficient and sustainable consolidation system.

7.3 What measures can be taken to improve the economic sustainability of the consolidation in the event area?

From the suppliers' perspective, adopting and implementing efficient consolidation requires proactive approaches to achieve collaboration and data transparency. Firstly, suppliers should provide complete and comprehensive information to LSPs for further consolidation. Second, setting a regular shipment lead time can help improve the stability of distribution volume and frequency from the source, and can further make large-scale consolidation feasible. Furthermore, suppliers should participate in the UCC revenue and cost sharing models, which can help establish economic incentives across stakeholders. Lastly, loading integration with neighboring suppliers can further improve the efficiency of the delivery network to establish a profitable consolidation network across the supply chain.

For LSPs, they should first strengthen their cooperation with government systems. By integrating with government-developed platforms, LSPs can supplement the missing vehicle routing data in purchasing systems to build a foundation for consolidation. Furthermore, LSPs can use sophisticated models and algorithms to optimize vehicle routes and loading systems to improve delivery efficiency. In addition, LSPs can enhance the attractiveness of the UCC model through a range of value-added services and further increase stakeholders' engagement. Finally, the adoption of green vehicles will align with the goals of governments and environmental organizations to reduce emissions while reinforcing the UCC value proposition.

Receivers, as the primary decision makers in selecting consolidation strategies, can improve internal coordination by consolidating orders across departments and set a unified ordering approach. Receivers can increase the transparency in ordering and receiving schedules to help suppliers and UCC planning their upstream shipments. Also, nearby receivers can coordinate their needs to lead the consolidation process actively. Besides, depending on the value-added services offered by the UCC, receivers can choose the solution that best suits their needs to maximize freight service utilization based on different freight demand considerations. In addition, applying for dedicated receiving slots or unloading areas can facilitate smooth last-mile operations and reduce delivery conflicts.

Finally, the government can play an important enabling role. Policies can provide direct support through subsidies for fossil-free vehicles usage or operational incentives, as well as indirect measures such as allowing nighttime deliveries, providing parking space, and issuing special passes, to initiate and sustain a UCC-based consolidation model. Also, as mentioned above, the government can establish a centralized digital platform to support efficient delivery, communication and inter-organizational coordination across the freight processes. By publicizing the benefits of consolidation and encouraging more stakeholders to participate, the government can help achieve the necessary volume of goods to ensure long-term viability.

8

Implications and Prospects

This chapter aims to explain the significance of our study and interpret the delimitations and limitations of our study scenarios. Based on these, we will offer some suggestions related to future research directions and model improvement for this research topic.

8.1 Significance of the study

On the practical level, the significance of this study is to find some potential design ideas for the REDIG project in the direction of consolidating urban freight, and provide theoretical support and practical references for policymakers and urban planners based on actual data simulation. Moreover, this study offers insights from different stakeholders for understanding their roles and collaborative strategies in implementation of sustainable consolidation model.

On the theoretical level, the significance of this study is to apply the FTG, consolidation cost and stakeholders' coordination through real-world scenarios. Within these theories, a combination of FTG and cost simulation provides a general and replicable approach for evaluating the economical sustainability of consolidation in different areas. Through this application, this study seeks to add a deeper understanding under conditions of seasonal variability, fragmented ordering by different sectors and infrastructure limitation.

8.2 Delimitations and limitations

The scope of this study is defined as follows. Firstly, this study focuses only on the case event area of Gothenburg with current freight activity patterns (2024), while the analysis will primarily focus on the recorded data from this region. Some secondary data from other regions and historical logs are used as contextual reference only. Besides, this study only analyzes the feasibility of sustainable consolidation, and does not include the design of a pathway for commercial promotion.

There are some shortcomings in this study. In the case study part, we did not interview stakeholders involved in the consolidation, thus all interviews and data sets are provided by RISE. Also with the lack of communication with stakeholders, we only have a limited database in terms of time frame and quality, while FTG analysis often requires relatively high quality data, which may have an impact on the accuracy of modeling and analysis. In the modeling part, there is a gap between some idealized assumptions, such as simplified cost model and specific scenario for calculating delivery route distance, in the simulation and the real operational situation. Finally, a full life-cycle benefit analysis taking environmental impact into account is not conducted in this study due to time and resource constraints.

8.3 Further research suggestions

Firstly, specific operational models using UCC can be further refined and discussed to build more accurate cost models to assess the economic viability of UCC in real-world scenarios. In addition, consolidation from the supplier side is seen as a potential way to improve the effectiveness of the overall consolidation model. The impact of supplier-side consolidation into the model can be further investigated. Moreover, this study lacks discussion on sharing and incoterms of different stakeholders in real scenarios, which can be understood to give a more targeted recommendation. Finally, quantification of the environmental benefits of UCC could further enhance the feasibility of UCC and help convince a wider range of stakeholders to join the initiative.

References

Akgün, E. Z., Monios, J., Cowie, J., and Fonzone, A. (2024). The retailer perspective on the potential for using urban consolidation centres (uccs). *Research in Transportation Economics*, 103:101413.

Akyol, D. E. and De Koster, R. B. (2018). Determining time windows in urban freight transport: A city cooperative approach. *Transportation Research Part E: Logistics and Transportation Review*, 118:34–50.

Alho, A. R. and de Abreu e Silva, J. (2015). Modeling retail establishments' freight trip generation: a comparison of methodologies to predict total weekly deliveries. *Transportation*, pages 1–18.

Aljohani, K. and Thompson, R. G. (2021). Modelling individual preferences of goods receivers for a receiver-led delivery consolidation service. *Transportation Research Part A: Policy and Practice*, 150:74–94.

Allen, J., Browne, M., Woodburn, A., and Leonardi, J. (2012). The role of urban consolidation centres in sustainable freight transport. *Transport reviews*, 32(4):473–490.

Awasthi, A. and Proth, J.-M. (2006). A systems-based approach for city logistics decision making. *Journal of Advances in Management Research*, 3(2):7–17.

Baker, D., Briant, S., Hajirasouli, A., Yigitcanlar, T., Paz, A., Bhaskar, A., Corry, P., Whelan, K., Donehue, P., and Parsons, H. (2023). Urban freight logistics and land use planning education: Trends and gaps through the lens of literature. *Transportation Research Interdisciplinary Perspectives*, 17:100731.

Balm, S., Browne, M., Leonardi, J., and Quak, H. (2014). Developing an evaluation framework for innovative urban and interurban freight transport solutions. *Procedia-Social and Behavioral Sciences*, 125:386–397.

Beardwood, J., Halton, J. H., and Hammersley, J. M. (1959). The shortest path through many points. In *Mathematical proceedings of the Cambridge philosophical society*, volume 55, pages 299–327. Cambridge University Press.

Binh, N. T. and Huong, T. T. T. (2024). Factors affecting public support for the development of urban consolidation center: The case of hanoi city, vietnam. *Research in Transportation Business & Management*, 57:101220.

Björklund, M. and Johansson, H. (2018). Urban consolidation centre–a literature review, categorisation, and a future research agenda. *International Journal of Physical Distribution & Logistics Management*, 48(8):745–764.

Box, G. E., Jenkins, G. M., Reinsel, G. C., and Ljung, G. M. (2015). *Time series analysis: forecasting and control.* John Wiley & Sons.

Brettmo, A. and Sanchez-Diaz, I. (2022). Property owners as possible game changers for sustainable urban freight. *Research in Transportation Business & Management*, 45:100745.

Browne, M., Sweet, M., Woodburn, A., and Allen, J. (2005). Urban freight consolidation centres final report. *Transport Studies Group, University of Westminster*, 10.

Chien, T. W. (1992). Operational estimators for the length of a traveling salesman tour. *Computers & operations research*, 19(6):469–478.

Ciardiello, F., Genovese, A., Luo, S., and Sgalambro, A. (2023). A game-theoretic multi-stakeholder model for cost allocation in urban consolidation centres. *Annals of Operations Research*, pages 1–24.

Creswell, J. W. (2018). *Qualitative, quantitative, and mixed methods approaches+ a crash course in statistics.* Sage publications.

Cui, J., Dodson, J., and Hall, P. V. (2015). Planning for urban freight transport: An overview. *Transport Reviews*, 35(5):583–598.

de Assis Correia, V., de Oliveira, L. K., and Guerra, A. L. (2012). Economical and environmental analysis of an urban consolidation center for belo horizonte city (brazil). *Procedia-Social and Behavioral Sciences*, 39:770–782.

El Yadari, M., Moufad, I., Jawab, F., and Arif, J. (2024). Logistic 4.0 implementation for efficient urban freight transport: A systematic literature review. In *2024 IEEE 15th International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA)*, pages 1–8. IEEE.

Eriksson, A., von Wieding, S., Gestrelius, S., Lyrberg, M., Ranäng, S., Carlén, V., and Hansson, M. (2023). Redig-regionala godshubbar i göteborg: Förstudie–drive sweden.

Figliozzi, M. A. (2009). Planning approximations to the average length of vehicle routing problems with time window constraints. *Transportation Research Part B: Methodological*, 43(4):438–447.

Forkert, S. and Eichhorn, C. (2007). Innovative approaches in city logitics: Space management for urban delivery.

Friesz, T. L. and Holguín-Veras, J. (2005). Dynamic game-theoretic models of urban freight: formulation and solution approach. In *Methods and models in transport and telecommunications: cross Atlantic perspectives*, pages 143–161. Springer.

Gillström, H. and Björklund, M. (2024). Assessing the benefits of urban consolidation centres: an overview based on a systematic literature review. *Transport Reviews*, 44(5):972–991.

Glassdoor (2025). Truck driver salaries in gothenburg, sweden. Accessed: 2025-04-16.

GöteborgsStad (2023). Gothenburg green city zone - business region göteborg.

Haugen, K. K. (2011). *Event logistics.* Tapir Academic Press Trondheim, Norway.

Heitz, A., Dablanc, L., Olsson, J., Sanchez-Diaz, I., and Woxenius, J. (2020). Spatial patterns of logistics facilities in gothenburg, sweden. *Journal of Transport Geography*, 88:102191.

Holguín-Veras, J., Jaller, M., Destro, L., Ban, X., Lawson, C., and Levinson, H. S. (2011). Freight generation, freight trip generation, and perils of using constant trip rates. *Transportation Research Record*, 2224(1):68–81.

Holguín-Veras, J., Jaller, M., Sánchez-Díaz, I., Campbell, S., and Lawson, C. T. (2014). Freight generation and freight trip generation models. In *Modelling freight transport*, pages 43–63. Elsevier.

Holguín-Veras, J. and Sánchez-Díaz, I. (2016). Freight demand management and the potential of receiver-led consolidation programs. *Transportation Research Part A: Policy and Practice*, 84:109–130.

Holguín-Veras, J., Sánchez-Díaz, I., and Browne, M. (2016). Sustainable urban freight systems and freight demand management. *Transportation Research Procedia*, 12:40–52.

Hyndman, R. J. and Athanasopoulos, G. (2018). *Forecasting: principles and practice.* OTexts.

Höjer, N. (2025). Interview with svenska mässan. Online Interview.

ICLEI, S. M. (2020). How cities in developing countries can address urban freight – part 2.

Isa, S. S., Lima Jr, O. F., and Vieira, J. G. V. (2021). Urban consolidation centers: Impact analysis by stakeholder. *Research in Transportation Economics*, 90:101045.

Janjevic, M. and Ndiaye, A. (2017). Investigating the theoretical cost-relationships of urban consolidation centres for their users. *Transportation Research Part A: Policy and Practice*, 102:98–118.

Jidah, M. and El-Rifai, R. (2024). Integrating accessibility in the city planning process; investigating the case of frölunda, gothenburg using a systems approach. *Chalmers Student Thesis*.

Karim, Z. and Fouad, J. (2018). Measuring urban public transport performance on route level: A literature review. In *MATEC Web of Conferences*, volume 200, page 00021. EDP Sciences.

Kijewska, K. and Iwan, S. (2019). The implementation of environmental friendly city logistics in south baltic region cities. In *Data Analytics: Paving the Way to Sustainable Urban Mobility: Proceedings of 4th Conference on Sustainable Urban Mobility (CSUM2018), 24-25 May, Skiathos Island, Greece*, pages 599–606. Springer.

Kin, B., Spoor, J., Verlinde, S., Macharis, C., and Van Woensel, T. (2018). Modelling alternative distribution set-ups for fragmented last mile transport: Towards more efficient and sustainable urban freight transport. *Case Studies on Transport Policy*, 6(1):125–132.

Lindberg, W. R. (2025). Interview with lieberg. Online Interview.

Mafla-Hernández, F. J., Gonzalez-Calderon, C. A., and Posada-Henao, J. J. (2025). Freight trip generation modeling for large facilities in urban areas: An empirical investigation. *Transport Policy*, 163:102–115.

Majka, M. (2024). Seasonal time series analysis: Why sarima outshines arima.

Marcucci, E. and Danielis, R. (2008). The potential demand for a urban freight consolidation centre. *Transportation*, 35:269–284.

Mepparambath, R. M., Cheah, L., Zegras, P. C., Alho, A. R., and Sakai, T. (2023). Evaluating the impact of urban consolidation center and off-hour deliveries on freight flows to a retail district using agent-based simulation. *Transportation Research Record*, 2677(2):264–281.

Middela, M. S. and Ramadurai, G. (2024). Effect of the measurement period and spatial dependence on the accuracy of urban freight trip generation models. *Transportation Research Part A: Policy and Practice*, 179:103884.

Modig, N. (2007). *Material flows incurred by activities at project sites.* Chalmers University of Technology.

Mokaddem, Y. and Jawab, F. (2019). Researches and applications of intelligent transportations systems in urban area: Systematic literature review. *ARPN J. Eng. Appl. Sci*, 14(3):639–652.

Moufad, I. and Jawab, F. (2017a). Conception and validation of a decision support model for urban freight transport. In *2017 International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA)*, pages 94–99. Ieee.

Moufad, I. and Jawab, F. (2017b). Multi-criteria analysis of urban public transport problems: the city of fes as a case. *Int. J. Sci. Eng. Res*, 8(1):675–682.

Moufad, I. and Jawab, F. (2019). Proposal methodology of planning and location of loading/unloading spaces for urban freight vehicle: A case study. advances in science, technology and engineering systems journal, 4, pp. 273-280.

Muñoz-Villamizar, A., Santos, J., Montoya-Torres, J. R., and Velázquez-Martínez, J. C. (2020). Measuring environmental performance of urban freight transport systems: A case study. *Sustainable cities and society*, 52:101844.

Nordtømme, M. E., Bjerkan, K. Y., and Sund, A. B. (2015). Barriers to urban freight policy implementation: The case of urban consolidation center in oslo. *Transport Policy*, 44:179–186.

Norrman, A. (2024). Reflections on case study analysis. Presentation, Lund University, Engineering Logistics. Available from Chalmers course materials.

Nylander, A., Blinge, M., and Laan, L.-A. (2023). Urban consolidation centers–insights from a design thinking perspective. *Transportation Research Procedia*, 72:3979–3986.

Oliveira, L. K. d., Araújo, G. G. F. d., Bertoncini, B. V., Pedrosa, C. D., and Silva, F. G. F. d. (2022). Modelling freight trip generation based on deliveries for brazilian municipalities. *Sustainability*, 14(16):10300.

Orhan, C. C., Goez, J. C., Guajardo, M., Osicka, O., and Wallace, S. W. (2024). Assessing macro effects of freight consolidation on the livability of small cities using vehicle routing as micro models: The case of bergen, norway. *Transportation research part E: logistics and transportation review*, 185:103521.

Östlund, U., Kidd, L., Wengström, Y., and Rowa-Dewar, N. (2011). Combining qualitative and quantitative research within mixed method research designs: a methodological review. *International journal of nursing studies*, 48(3):369–383.

Paddeu, D. (2017). The bristol-bath urban freight consolidation centre from the perspective of its users. *Case Studies on Transport Policy*, 5(3):483–491.

Paddeu, D., Parkhurst, G., Fancello, G., Fadda, P., and Ricci, M. (2018). Multi-stakeholder collaboration in urban freight consolidation schemes: Drivers and barriers to implementation. *Transport*, 33(4):913–929.

RI.SE. (2023). Redig system demonstration: open logistics system in gbg event area | rise.

Ros-McDonnell, L., de-la Fuente-Aragón, M. V., Ros-McDonnell, D., and Cardós, M. (2018). Analysis of freight distribution flows in an urban functional area. *Cities*, 79:159–168.

Rosales, R. and Haarstad, H. (2023). Governance challenges for urban logistics: Lessons from three n orwegian cities. *Environmental Policy and Governance*, 33(3):221–231.

Russo, F. and Comi, A. (2016). Urban freight transport planning towards green goals: Synthetic environmental evidence from tested results. *Sustainability*, 8(4):381.

Russo, F. and Comi, A. (2017). From the analysis of european accident data to safety assessment for planning: the role of good vehicles in urban area. *European transport research review*, 9:1–12.

Sánchez-Díaz, I. (2018). Potential of implementing urban freight strategies in the accommodation and food services sector. *Transportation Research Record*, 2672(9):194–203.

Sánchez-Díaz, I. and Castrellon, J. P. (2023). Freight trip generation models: using establishment data to understand the origin of urban freight traffic. In *Handbook on City Logistics and Urban Freight*, pages 115–139. Edward Elgar Publishing.

Sánchez-Díaz, I., Georén, P., and Brolinson, M. (2017). Shifting urban freight deliveries to the off-peak hours: a review of theory and practice. *Transport reviews*, 37(4):521–543.

Sanchez-Diaz, I., Holguin-Veras, J., and Wang, C. (2013). Assessing the role of land-use, network characteristics, and spatial effects on freight trip attraction. Technical report.

Savchenko, L., Grygorak, M., Polishchuk, V., Vovk, Y., Lyashuk, O., Vovk, I., and Khudobei, R. (2022). Complex evaluation of the efficiency of urban consolidation centers at the micro level. *Zeszyty Naukowe. Transport/Politechnika Śląska*, (115):135–159.

Snow, C. C., Miles, R. E., and Coleman Jr, H. J. (1992). Managing 21st century network organizations. *Organizational dynamics*, 20(3):5–21.

Stathopoulos, A., Valeri, E., and Marcucci, E. (2012). Stakeholder reactions to urban freight policy innovation. *Journal of Transport Geography*, 22:34–45.

Tanco, M. and Escuder, M. (2021). A multi-perspective analysis for the better understanding of urban freight transport challenges and opportunities in montevideo. *Case Studies on Transport Policy*, 9(2):405–417.

Taniguchi, E. (2008). *City Logistics: Network Modelling and Intelligent Transport Systems.* Emerald, Bingley.

Taniguchi, E. (2014). Concepts of city logistics for sustainable and liveable cities. *Procedia-social and behavioral sciences*, 151:310–317.

Transmodal, M. (2012). Dg move european commission: Study on urban freight transport. *Quak, H.(2008, 03 20). Sustainability of Urban Freight Transport: Retail Distribution and Local Regulations in Cities. Retrieved*, 6(30):2016.

Uruchima, J. M., Niemann, O., and Browne, M. (2025). Investigating the feasibility of enhancing the efficiency and sustainability of event logistics in urban areas with application of actor-resource-activity and materials flow mapping. *Transportation Research Procedia*, 82:3871–3888.

van Heeswijk, W., Larsen, R., and Larsen, A. (2019). An urban consolidation center in the city of copenhagen: A simulation study. *International Journal of Sustainable Transportation*, 13(9):675–691.

van Heeswijk, W. J. A. (2017). Consolidation and coordination in urban freight transport.

van Rooijen, T. and Quak, H. (2010). Local impacts of a new urban consolidation centre–the case of binnenstadservice. nl. *Procedia-Social and Behavioral Sciences*, 2(3):5967–5979.

Venkadavarahan, M. and Marisamynathan, S. (2023). Development of freight trip generation model using observed and unobserved information of supply chain characteristics for a sustainable urban transformation. *Journal of Cleaner Production*, 421:138500.

Verlinde, S., Macharis, C., and Witlox, F. (2012). How to consolidate urban flows of goods without setting up an urban consolidation centre? *Procedia-Social and Behavioral Sciences*, 39:687–701.

Wickham, H. (2014). Tidy data. *Journal of statistical software*, 59:1–23.

A

Freight activity pattern in the event area

Understanding freight activity patterns within the Gothenburg event area provides insights into current logistical flows and informs strategies for potential consolidation. This section synthesizes the delivery activities observed at two main receivers in the event area, Liseberg and Svenska Mässan, outlining distinct patterns related to delivery scheduling, vehicle characteristics, cargo types, and route structures.

(1) Overview traffic counts in the event area - Heden

In order to better understand the overall freight pattern in the event area of Gothenburg, this section begins with an analysis based on traffic observations made in a broader area - Heden. This area is located in the northern part of the event area and occupies the majority of the entire area, including Svenska Mässan.

The relevant dataset comes from a field trip and data collection in the Heden area on September 25, 2024 (8 a.m. - 5 p.m.) carried by students in course TEK465 Sustainable Transportation, Chalmers University of Technology. The data of more than 1,000 freight vehicles (after data cleaning) entering and leaving each of the major roadway entrances in the Heden area were collected for a comprehensive understanding of freight transportation patterns, vehicle types, and traffic composition in the area.

Observations show that freight traffic is frequent and consistent throughout the day, as shown in Figure A.1. During operating hours, traffic increases gradually in the morning, decreases slightly in the middle of the day, and peaks again in the early afternoon – between 12:30 and 14:00. This reflects the typical delivery schedules of the business area, with the overall intensity of the freight traffic flow.

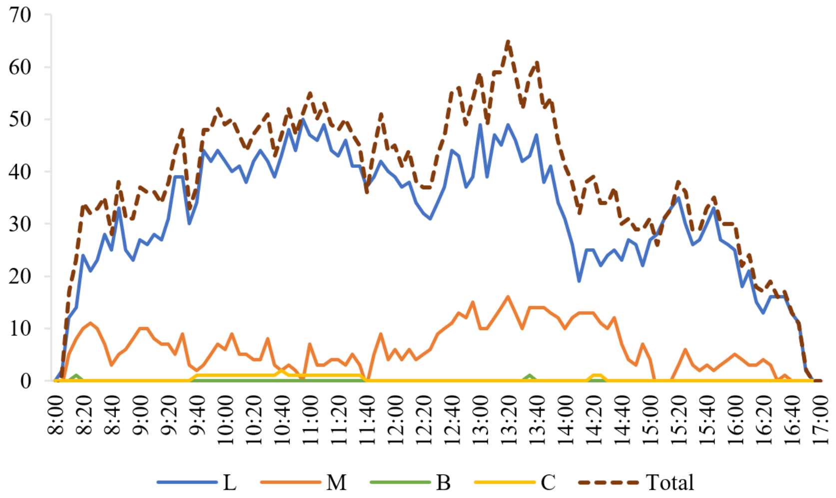


Figure A.1. Cumulated number and type of freight vehicles inside Heden by time

However, in terms of vehicle dwell time, as shown in Figure A.2, almost half of all recorded trips lasted less than five minutes, suggesting that a large proportion of these vehicles were not delivering goods but just passing through the area, highlighting the challenge of distinguishing passing traffic from local freight activity when assessing the potential for consolidation. Approximately 15% of the vehicles have a dwell time of between 5-15 minutes and a further 17% have a dwell time of more than 1 hour in the Heden area, showing that there is a mix of quick drop-off vehicles, i.e. fragmented small deliveries, as well as vehicles with long loading and unloading operations. This further reinforces the need for consolidation.

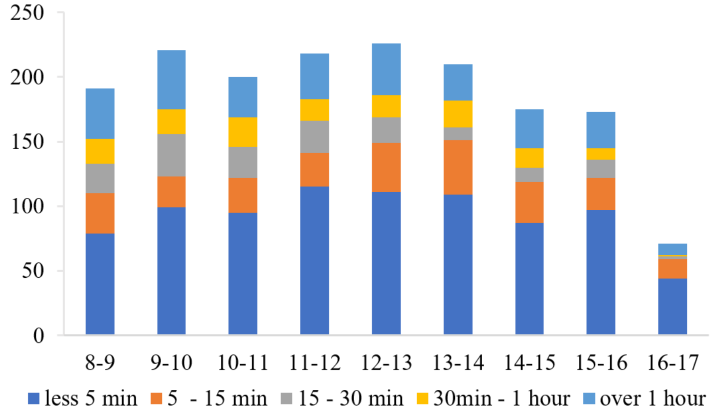


Figure A.2. Vehicle staying time in Heden during the day

In terms of vehicle type distribution, as shown in Figure A.3, light-duty vehicles (LDVs, L) accounted for more than 75% of all observed freight traffic, followed by medium-duty vehicles (MDVs, M) at 23%. Cargo bike (C) and bicycle (B) delivery services are almost negligible. The predominance of light-duty cargo vehicles confirms the prevalence of small, frequently operated delivery vehicles in the area.

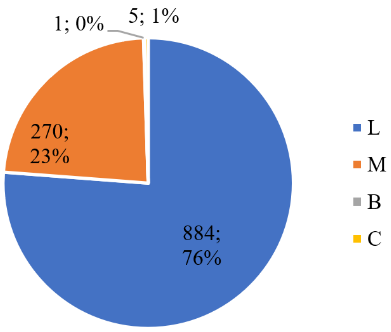


Figure A.3. Distribution of freight vehicle types in Heden

Analyzed by powertrain type, see Figure A.4, the majority of vehicles observed in Heden still use traditional power, with diesel vehicles accounting for as much as 83% of the total, while electric vehicles accounted for only 11%, and others, such as methane and hybrids, with gasoline vehicles accounting for a smaller percentage. In terms of vehicle types, MDVs are almost entirely diesel-powered, while light goods vehicles are still predominantly diesel-powered, with a slight degree of power diversity. Looking at emission standards, despite the 73% share of EURO 6 vehicles, there are still about 10% of vehicles with EURO 5 standards, reflecting the lagging update of some vehicles and the low level of emission control. This structure of reliance on fossil fuels not only puts pressure on the city's air quality, but also poses a challenge to the implementation of green urban transport policies.

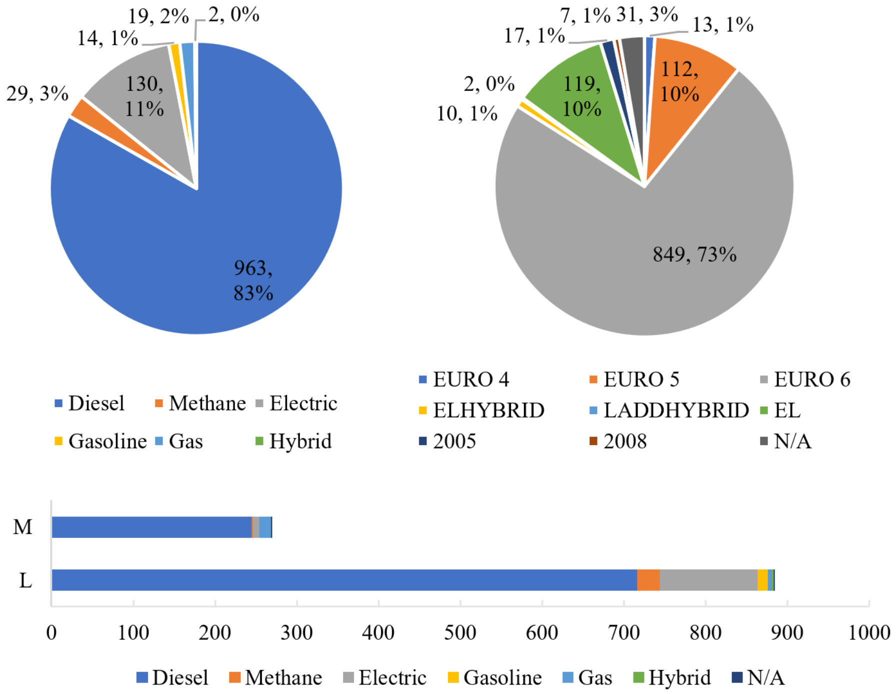


Figure A.4. Distribution of drivelines and emission classifications of the freight vehicles in Heden

An analysis of the distribution of freight vehicles by industry in the area, see Figure A.5, shows that food service, courier and package delivery, and retail (non-perishables) are the industries that use the most urban freight vehicles. The food service sector has the highest daily vehicle entries due to frequent demand and time-sensitive nature. In contrast, the public services, health care, and education sectors have fewer deliveries. This distribution highlights the need to prioritize consolidation efforts in the high-frequency business sectors.

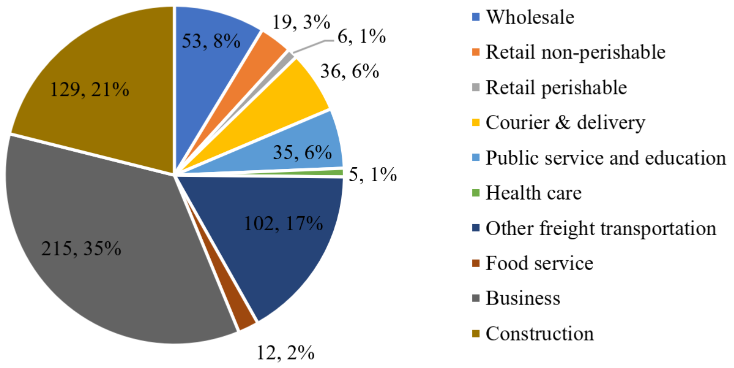


Figure A.5. Number of counts of the different freight categories in Heden

(2) Liseberg

Freight activity in Liseberg was analyzed using data of all orders placed by different departments within Liseberg from 2022 through May 2024 and the records of vehicles making distribution trips to Liseberg during a representative sampling period (July 22 to July 28, 2024). The sampling period is the peak activity period of the year in Liseberg, with a corresponding high number of distribution trips, making it easier to get a pattern of freight transportation.

Analysis of this dataset revealed pronounced seasonal fluctuations. Order volumes peak sharply from March to July, reaching their highest levels in July. Conversely, from October to December, the demand remains relatively stable, see Figure A.6.

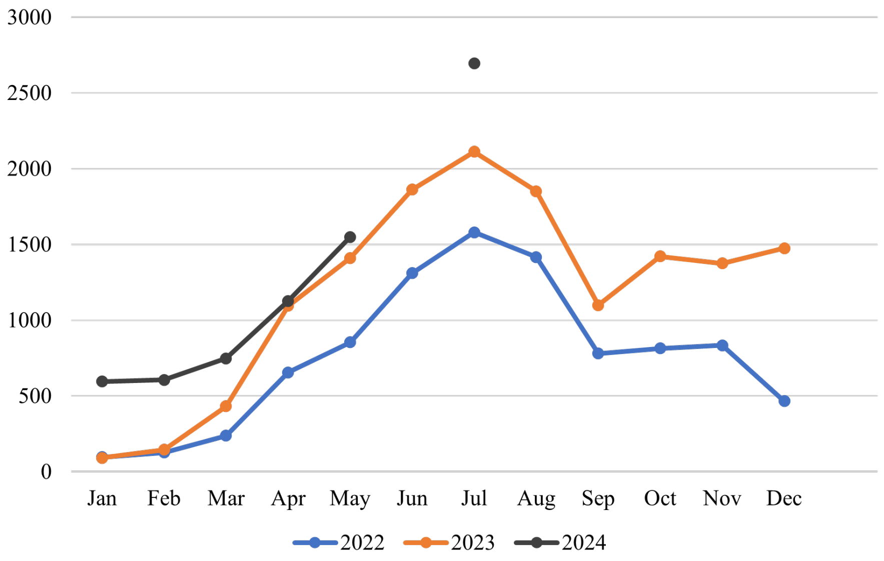


Figure A.6. Number of orders arrived at Liseberg each month

Also, the examination of department-level orders (Figure A.7) highlights distinct seasonality patterns across departments, notably within restaurants, the Grand Curiosa Hotel, park food outlets, warehouse, and shopping.

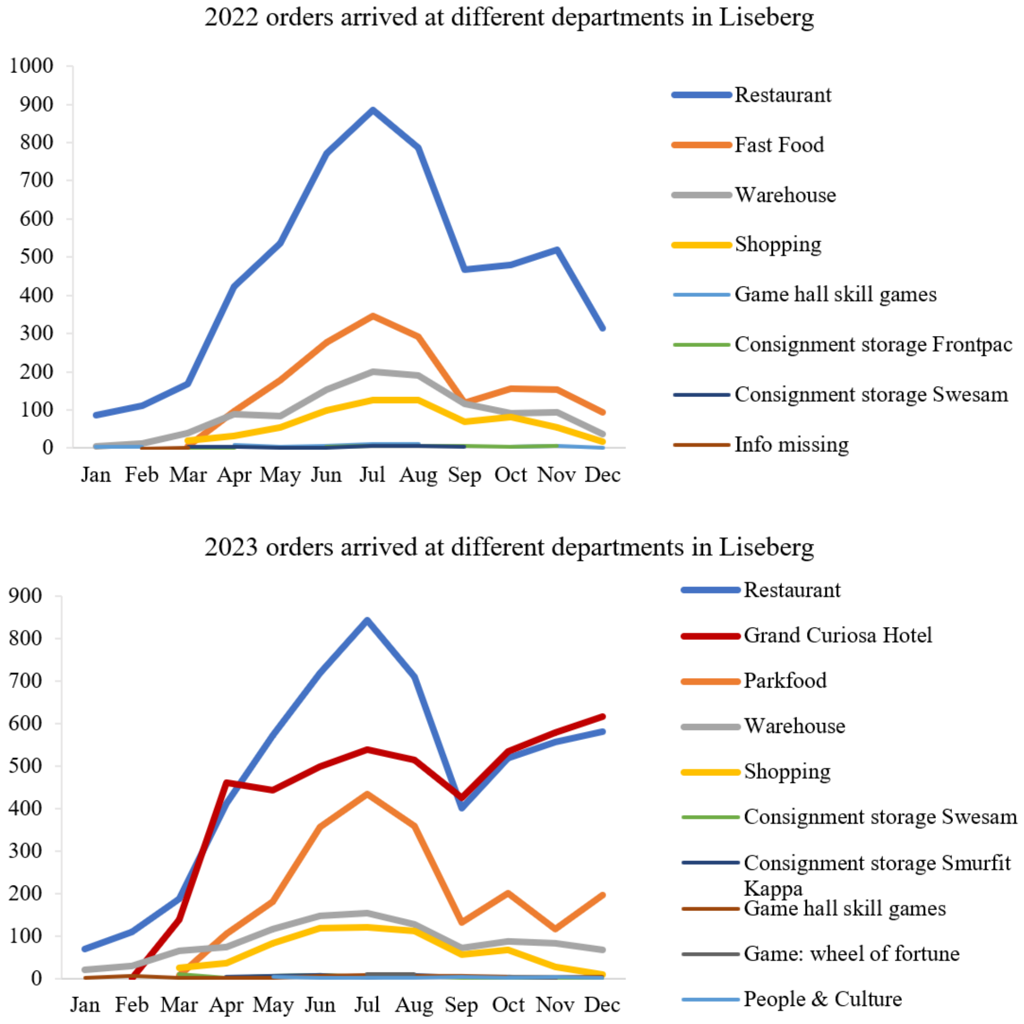


Figure A.7. Number of orders arrived at different departments of Liseberg each month

In terms of the categories of goods shipped, as shown in Figure A.8, the most predominant category of goods shipped in Liseberg are perishables, with normal temperature perishables (41%) and temperature-sensitive perishables (30%) due to the need for frequent replenishment. Other notable categories include office supplies, electronics (13%) and a variety of non-perishables (clothes, souvenirs, etc. 12%), while postal deliveries only make up a very small percentage (1%). The diversity of goods categories highlights the logistical complexities related with handling, storage and timely delivery, and also reveals significant scope for targeted consolidation efforts.

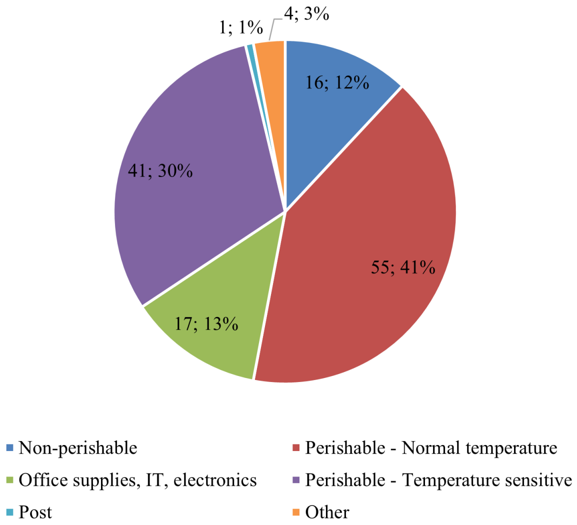


Figure A.8. Cargo type distribution of Liseberg

In terms of vehicle types, as shown in Figure A.9, MDVs (medium duty vehicles) account for the largest proportion of all delivery vehicles (54%). This suggests that smaller, more maneuverable vehicles are the preferred mode of transport for delivering goods to Liseberg. Light trucks (29%) and vans (13%) are also frequently used, considering both the capacity and flexibility of the vehicles.

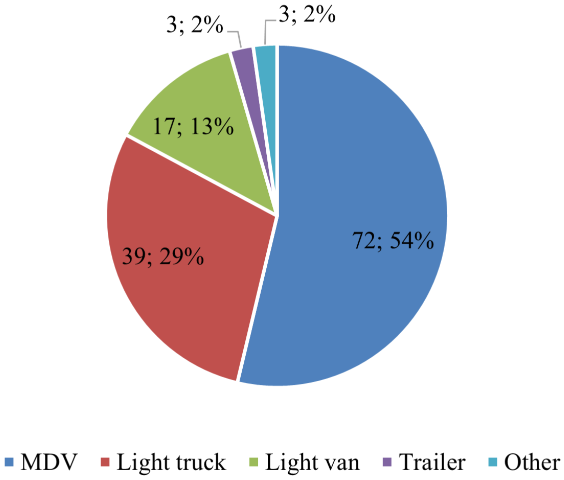


Figure A.9. Distribution of vehicle types to Liseberg

Figure A.10 illustrates the distribution of vehicle driveline. Most freight vehicles entering Liseberg are still diesel powered, accounting for 63% of the total, followed by HVO vehicles (19%), natural gas vehicles (9%), and electric vehicles (7%), reflecting the challenges in the transition to sustainable vehicles.

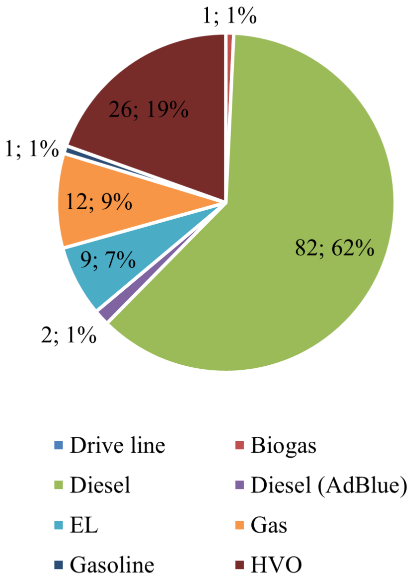


Figure A.10. Distribution of vehicle driveline to Liseberg

The total number of loading units used in the delivery of goods and the distribution of delivery vehicles used to load them are shown in Figure A.11. In terms of volume, the loading units used for deliveries are mainly pallets (44%) and roll cages (39%), which are used for transporting a variety of goods that need to be handled loosely, e.g. beverages, retail supplies, etc. Smaller parcels account for about 20% of deliveries while the volume is only 11%, suggesting that it is more poorly consolidated.

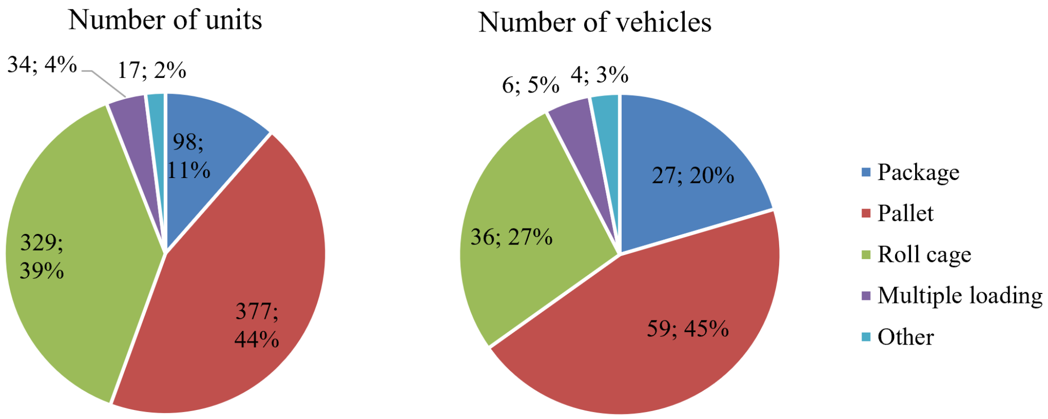


Figure A.11. Distribution of loading units number and vehicles to Liseberg

The loading of different loading units in the vehicle is shown in Figure A.12. Roll cages and pallets are preferred for larger deliveries, as shown by their high number in the >20 unit category, and goods that need to be easier to handle or shipped in large quantities can be managed effectively using these units. Parcels are more used for smaller deliveries, with a noticeable decrease in vehicles delivering more than 10 units. It is worth noting that many deliveries are loaded with less than 5 units per vehicle, suggesting that there is a clear opportunity for freight consolidation to improve efficiency.

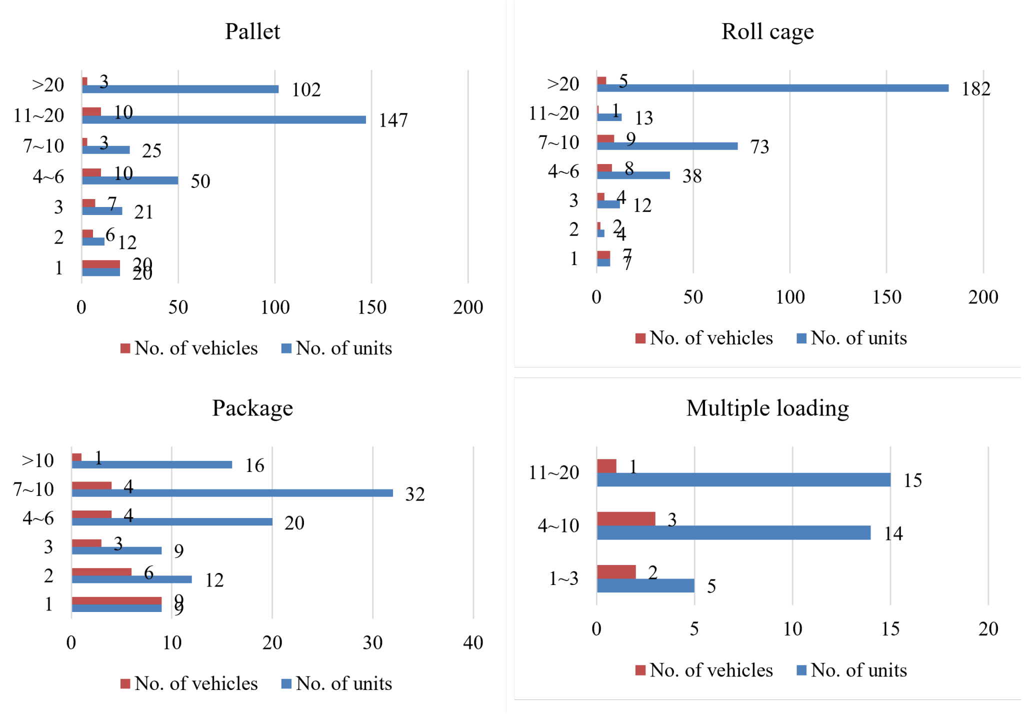


Figure A.12. Usage patterns of different loading units to Liseberg

Figures A.13 and A.14 show the location analysis of the supplier. Most of the shipments come from the Gothenburg metropolitan area and surrounding areas like Mölndal, Mölnlycke, and Hisings Backa, which are within 10 km from Liseberg. Besides, trips from Helsingborg and Vara also account for a significant proportion among the origins outside Gothenburg.

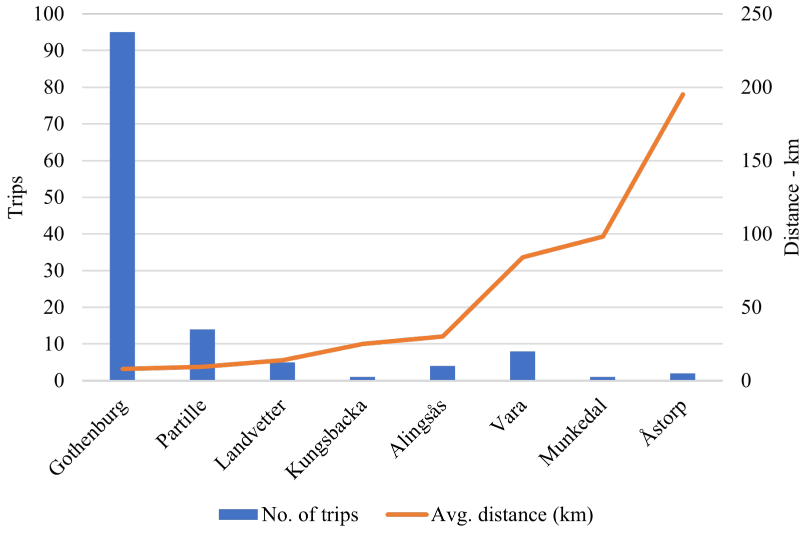


Figure A.13. Number of trips origins and average distance to Liseberg

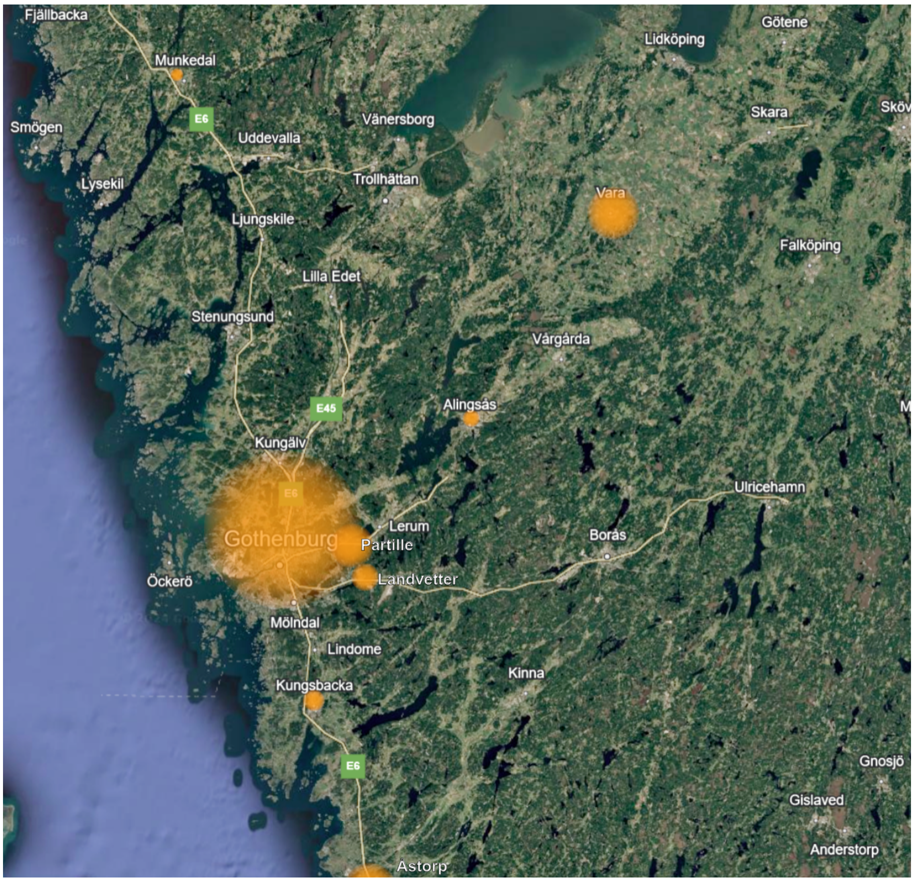


Figure A.14. Delivery route origins with corresponding shipping units scale to Liseberg

In terms of delivery routes, see Figure A.15, about 83% of the routes involve fewer than 20 stops, and these deliveries with fewer stops typically contained larger shipments, especially perishable items on pallets. Complex routes with more stops typically involve express package deliveries from carriers such as PostNord, UPS, and DHL.

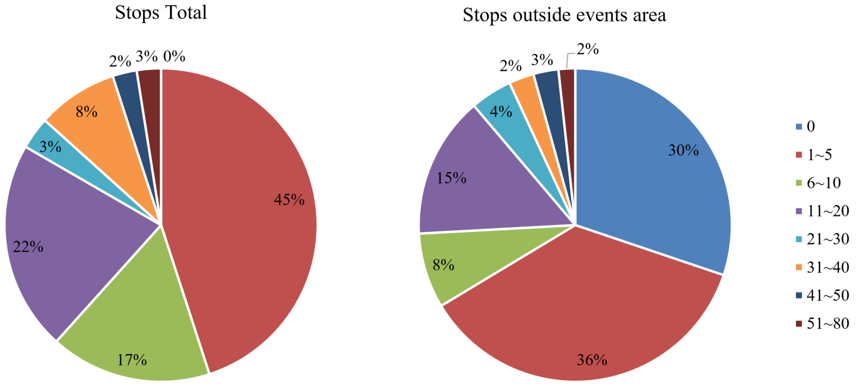


Figure A.15. Delivery route stops distribution

In terms of delivery vehicle arrivals, Liseberg's daily delivery times show a distinct peak, see Figure A.16, concentrated in the early morning hours (7:30-9:00 a.m.). Delivery activity decreases significantly in the afternoon and is also lower on weekends. However, at the same time, the number of vehicles making deliveries varies significantly from day to day, with no consistent pattern.

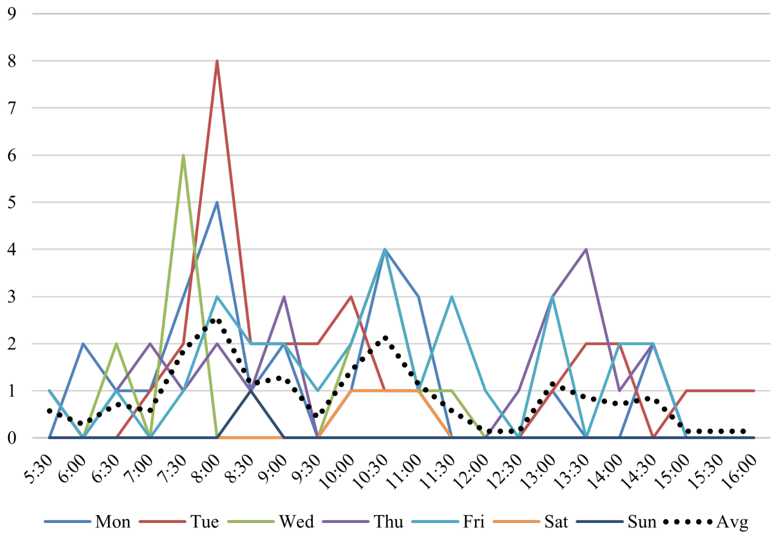


Figure A.16. Vehicle arriving time over the week at Liseberg

Deliveries to Liseberg are mainly made through four designated addresses, as shown in Figure A.17, which vary according to product type and storage requirements related to refrigerated goods, central warehouse, Grand Curiosa Hotel and machine workshop supplies.

Figure A.17. Delivery address locations of Liseberg

(3)Svenska Mässan

The analysis of Svenska Mässan's freight activity is based on two separate datasets, firstly a week of delivery vehicles records in September 2024 from ordering goods, which is the same as the dataset of Liseberg, and secondly using secondary data collected over 14 days in late 2023 and early 2024, with goods such as facility equipment delivered by exhibitors.

Exhibition-related shipments are difficult to integrate, so the analysis from the perspective of shipment type considers only the first dataset, as shown in Figure A.18. Similar to Liseberg, the predominance of perishable goods (almost 70%) emphasizes the importance of timeliness and temperature-controlled logistics in the day-to-day freight operations.

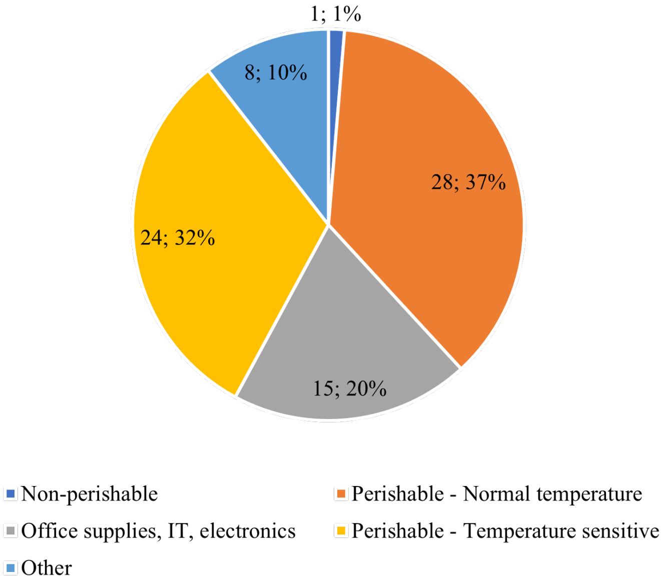


Figure A.18. Cargo type distribution of Svenska Mässan

However, the pattern of the loading units to Svenska Mässan shows a big difference compared with Liseberg. For the exhibition items, Svenska Mässan has a high percentage of heavy and bulky freight during the events, thus requires a different vehicle and loading unit strategy, with a focus on large trucks and specialized loading and unloading equipment. For the daily business goods, the distribution of loading units is shown in Figure A.19 and A.20. In terms of the number of units, roll cages are the most common loading units, accounting for 71% of all units . This reflects the venue's reliance on roll cages for the efficient handling and transportation of medium-sized loads, particularly for food, beverages, and supplies to hotels and restaurants. When assessed by number of vehicles, the situation changes slightly. Vehicles transporting roll cages are still the most common (34%), but their share has declined compared to the unit volume transported, indicating the existing consolidation with more roll cages carries by one vehicle. Pallet and parcel shipments have a smaller total unit volume, but as less-consolidated shipments, they still account for a large percentage of the frequency of vehicle trips.

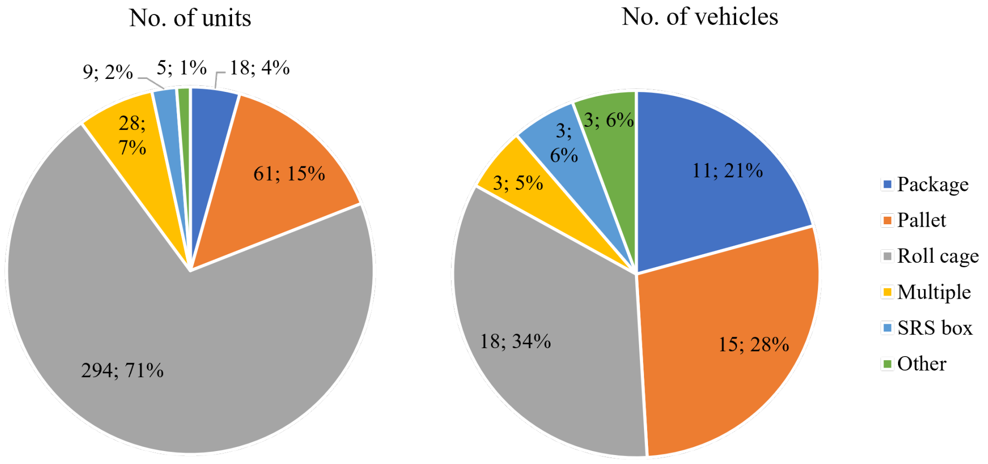


Figure A.19. Distribution of loading units number and vehicles to Svenska Mässan

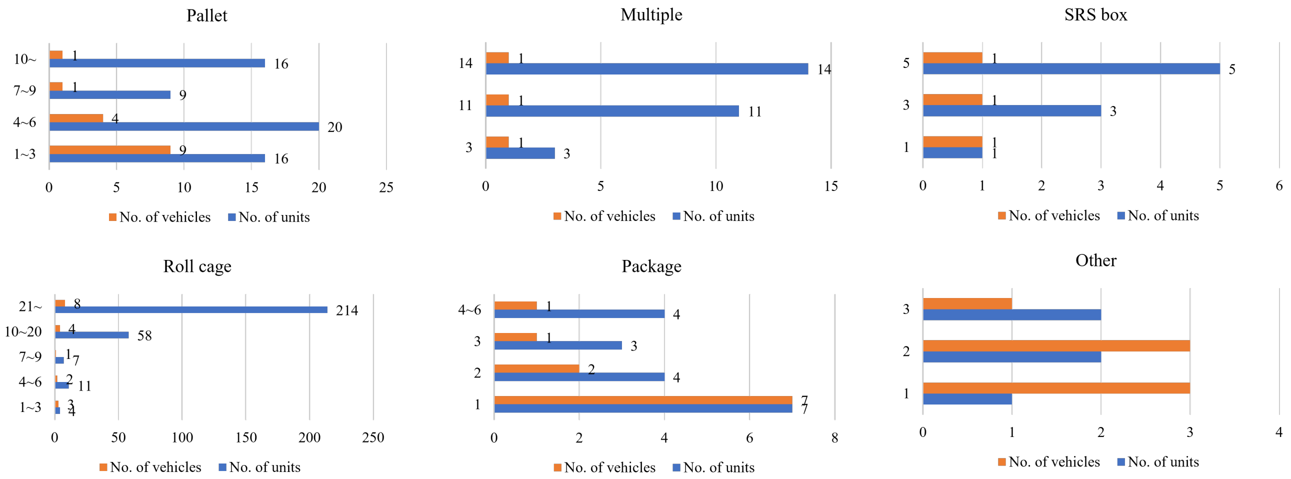
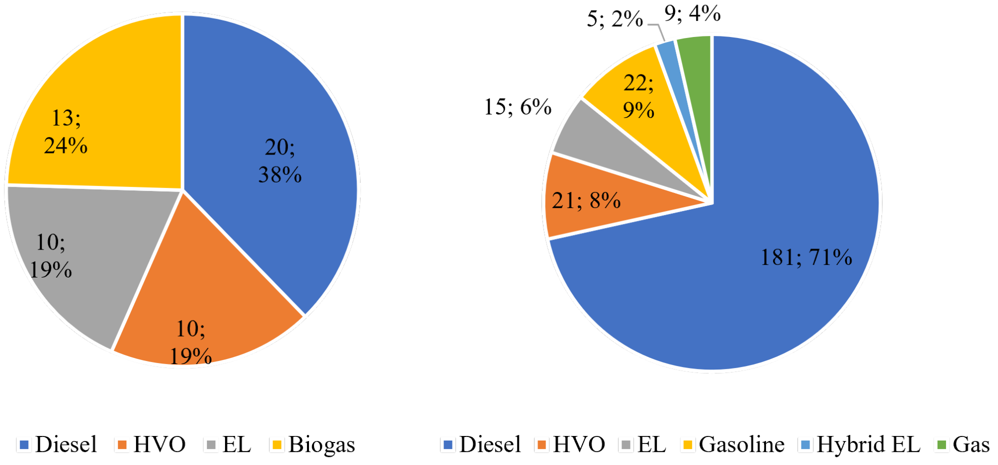


Figure A.20. Usage patterns of different loading units to Svenska Mässan

Figure A.21 compares the vehicle driveline distribution for two distinct delivery contexts at Svenska Mässan. Deliveries recorded over a one-week period were mainly related to shipments required for day-to-day operations, such as hotels, restaurants or retail supplies, and in this dataset, though diesel vehicles still dominate (38%), the distribution of alternative fuels is relatively balanced: biogas (24%), EL (19%), and HLVs (19%), suggesting that they have moderately adopted fossil-free transport solutions. In contrast, freight related to event and exhibition logistics is usually provided by external players such as exhibitors or international logistics companies, where the use of diesel vehicles is much higher at 71%, with lower use of HVO, EL, etc.



Vehicle drive line distribution 1 week

Vehicle drive line distribution 14 days

Figure A.21. Distribution of vehicle driveline to Svenska Mässan

As shown in Figure A.22, vehicle arrival time patterns show a clear peak in deliveries in the morning of each day, particularly with the peak for event-based freight vehicles concentrated at 10:00 a.m. After that, delivery activity decreases significantly after 13:00 a.m., and only very limited deliveries arrive after 16:00 a.m. This situation reflects typical commercial operating hours and receiver availability.

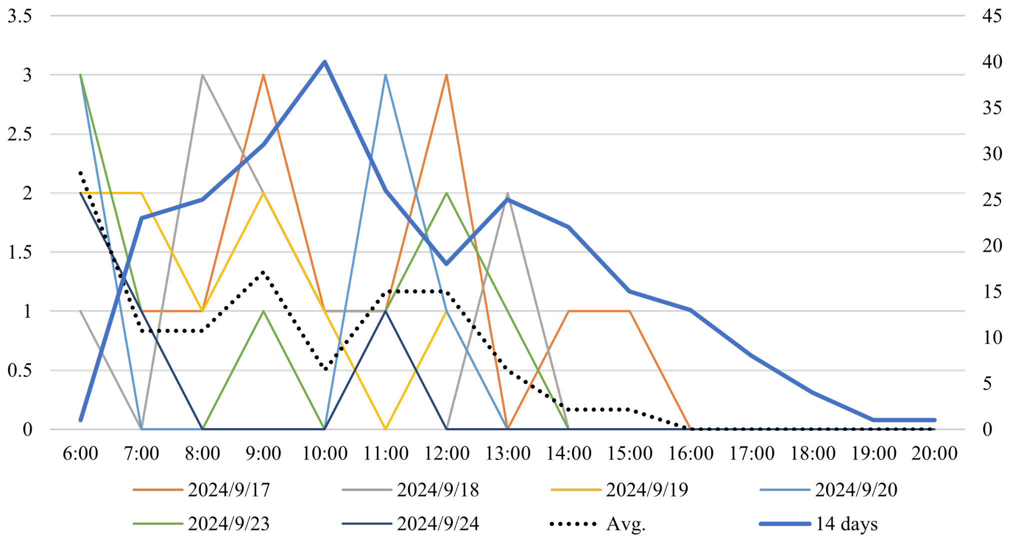


Figure A.22. Vehicle arriving time at LSvenska Mässan

B

Interview and factors identifying

The interview data in the table are derived from the interview transcripts provided by RISE. The original text is in Swedish and was translated into English by Google Translate before analyzing.

Table B.1. Open coding and factors extracted from stakeholder interviews

Company	**Interview data**	**Open coding**	**Axial coding**
Liseberg	We use Visma Business as our main system, and we have Bitlog VMS as our warehouse management system. We have also developed our own ordering system called Stella, which restaurants and other outlets use to place orders. Orders go into Visma, which then directs them either to the central warehouse or directly to the supplier. The biggest suppliers are connected via EDI.	Multiple logistics management systems, but lacks integration with external platforms	Logistics model / Integration challenge
Liseberg	In the park, we have very large limitations in storage. Some buildings are from 1923, and there is very little space. The central warehouse has better capacity, but we can handle at most 1-2 containers at a time without blocking operations.	Limited storage capacity in park area	Storage capacity
Liseberg	For food deliveries to restaurants and fast food, we have very short lead times. Most of it is delivered daily from Martin & Servera, our largest supplier. We place the order the day before for delivery the next day.	High-frequency deliveries due to fluctuating demand	Delivery frequency

Company	Interview data	Open coding	Axial coding
Liseberg	We prefer deliveries early in the morning or at night. The suppliers that come in early are happy because they avoid city traffic, and it allows us to clear out deliveries before guests arrive.	Preferred off-peak deliveries	Delivery frequency
Liseberg	Our guest numbers can vary from 2,000 to 35,000 per day. This makes it very difficult to plan deliveries far in advance.	Demand volatility impacts supply chain stability	Delivery frequency
Liseberg	We don't have complete control over supplier deliveries. Sometimes deliveries arrive on different days than planned. It's difficult to coordinate larger deliveries at specific times after the pandemic.	Uncoordinated supplier deliveries	Delivery reception
Liseberg	We can extract all data on what has been purchased, including weight and volume, but we cannot track which trucks arrive or their fuel type. The suppliers decide that, and we don't have visibility.	Moderate data accessibility but lacks detailed tracking	Data accessibility
Liseberg	We have introduced unmanned deliveries in collaboration with Martin & Servera. This allows for night-time deliveries. We are in discussions to expand this model to more restaurants.	Potential interest in delivery consolidation / Readiness for logistics integration	Willingness to consolidate
Liseberg	The dream scenario is to reduce the number of trucks delivering to us. Right now, meat, vegetable, and fish deliveries happen multiple times per day, which is difficult to coordinate. It would be better if these were consolidated into fewer deliveries.	Interest in logistics efficiency, but supplier habits remain a challenge	Willingness to consolidate
Liseberg	We follow sustainability standards, and we track some environmental data, but we don't have direct control over which trucks our suppliers use.	Sustainability concerns, but weak supplier regulations	Policy incentive
Svenska Massan	We, we do, yes and we can do manual logs too. We do a manual log at the moment and it's really based on calculating our climate impact because it can't be done with the system.	Manual logging	Logistics system
Svenska Massan	And then these systems that you are talking that you have today. This last expo talked to other systems or is it integrated into other systems?	Fragmented system integration	Logistics system
Svenska Massan	Everything is here to be used once a year. The Christmas decorations are like a hundred and forty pallets, they are also allowed to go away, so they are seasonally adjusted.	Space limitations	Storage capacity

Company	Interview data	Open coding	Axial coding
Svenska Massan	Big bunnies and eggs and yes, Halloween stuff. Such things always go away on external storage.	Space limitations	Storage capacity
Svenska Massan	We can, we do not have enough space to meet 2 projects always. I mean if one project goes out, the goods must go out and then the other project must go in	Scheduling Limitations due to space limitation	Scheduling
Svenska Massan	We take for example apart from co-loading and have to take off-peak all the time.	Off-peak deliveries to avoid congestion	Scheduling
Svenska Massan	And then these systems that you are talking that you have today. This last expo talked to other systems or is it integrated into other systems and then also ask portfolio question when you make procurement for a new system, do you have any requirements that the system should talk to other systems for example? I do not know if.	Fragmented data, Lack of integration	Data accessibility
Svenska Massan	So we do. We require that there should be open APIs for such a system.	Fragmented data, Lack of integration	Data accessibility
Svenska Massan	The project needs two types of baselines: one for ’event goods’ and one for regular deliveries. Discussions were held about how the systems at the Swedish Exhibition and Congress Centre can communicate with other systems to facilitate data collection.	Fragmented data, Lack of integration	Data accessibility
Svenska Massan	So we are logging. Now I should say that we log the event goods because the stuff that comes directly from a controlled supplier, there we get that figure from the supplier.	Reliance on supplier-reported data for event goods	Data accessibility
Svenska Massan	And we’re never allowed to use those films from a calculation perspective or anything like that in any case. So even if we were to get yes on five hundred cameras, we would still not be allowed to use it.	GDPR restrictions on data use	Data accessibility
Svenska Massan	If you are coming directly to us, then it is Tuesday at 13.30. But there you get a little bit bigger range, but it is clear that it is one you can maybe get one more.	Time slots for deliveries, limited flexibility	Delivery reception
Svenska Massan	We can, we do not have enough space to meet 2 projects always	Restrictions on delivery sizes	Delivery reception

Company	**Interview data**	**Open coding**	**Axial coding**
Svenska Massan	So the economic incentives must be quite strong. So that even though there are good philosophies and and so on, but that it.	Limited interest in sustainability efforts without financial incentives	Policy incentive
GotEvent	We trade with the City of Gothenburg's purchasing system proceedo	Municipal purchasing system / No independent logistics management system	Logistics system
GotEvent	These places to make the delivery do not exist today, but you need someone who receives and drives it in	Limited on-site storage and receiving capacity	Storage capacity
GotEvent	The purchasing page here about what is possible to get out of Proceedo is that you have direct contact with purchasing at the City of Gothenburg as well, I suppose.	Limited access to logistics data from Proceedo, dependent on municipal procurement system	Data accessibility
GotEvent	There are many different at different times and we have no specific function, so to speak, that receives this, but you have to drop what you have and run and try to chase them and they rarelt call but it shows up right as it is.	Dispersed delivery times and places, lack of centralized receiving function	Delivery reception
GotEvent	And as you said, you have a lot of different properties hypothetically there would be the possibility for any property that HM so nightlife is thus as unmanned from taking on any deliveries.	Dispersed delivery times and places, lack of centralized receiving function	Delivery reception
GotEvent	Otherwise, if you order directly to the door, it will come. It comes when it comes and it is not easy to catch and we sometimes have some inaccessible arenas we inside the fence and barriers sometimes and then events are sometimes and.	Dispersed delivery times and places, lack of centralized receiving function	Delivery reception
GotEvent	So it generally works there, we have one for small parcels we receive at the vallabadet, where we have a so to speak the opportunity to catch so that those who are not as well can receive the package or larger deliveries then themselves, you often provide the address of the vallabadet and the reception we have there and then you simply have to trudge there and pick up your stuff.	Small papackage reception point	Delivery reception

Company	Interview data	Open coding	Axial coding
GotEvent	A scheduled vehicle, coming once or twice a day, so that deliveries are in place for us to pick up.	Potential for scheduled consolidated deliveries for regular goods	Willingness to consolidate
GotEvent	So it would be perfect if deliveries could be made at night. & We have forklifts and unloading areas, so it could work at night.	Potential for off-peak deliveries	Possibility of night-time deliveries for event goods

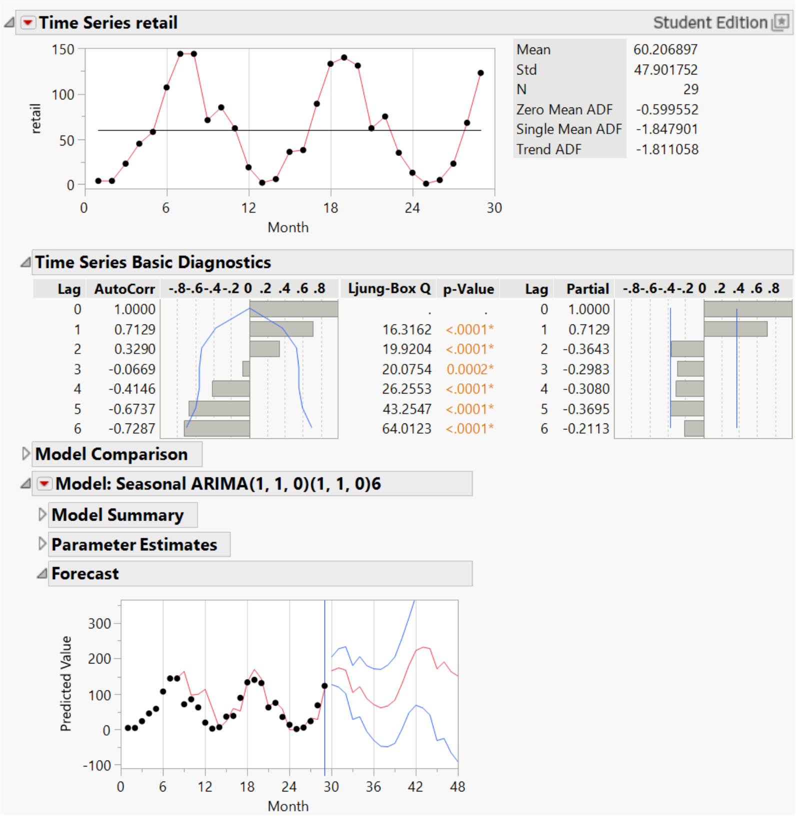
Gotevent is a company owned by Gothenburg City that is responsible for all the stadium activities. Although they are not involved in the freight consolidation pilot, they were also interviewed and asked for comments by RISE in the pilot pre-preparation phase, which are summarized together in the table. Their interview also provides valuable insights for us to understand the receiver's concerns.

C

Time series forecasting results

This appendix show the forecasting results of Liseberg's monthly orders from different sectors for 2024 and 2025. The historical dataset from Liseberg contains order information for 29 months (Jan 2022 - May 2024), and the forecasting period is 17 months until Dec 2025. Seasonal Autoregressive Integrated Moving Average (SARIMA) moel was chosen in JMP to carry out this forecasting.

The orders from retail, restaurant and warehouse sector are all predictable that SARIMA can capture the overall structure, with relatively small deviation from actual, as shown in Figure C.1. The Grand Curiosa Hotel is a newer addition to Liseberg (opened April 2023), and thus has limited historical data. Order patterns appear unstable without strong seasonality in the observed 8-month period, shown in Figure C.2. As a result, a simple average-based forecasting approach was adopted.



Time Series retail

Mean	60.206897
Std	47.901752
N	29
Zero Mean ADF	-0.599552
Single Mean ADF	-1.847901
Trend ADF	-1.811058

Time Series Basic Diagnostics

Lag	AutoCorr	-.8-.6-.4-.2 0 .2 .4 .6 .8	Ljung-Box Q	p-Value	Lag	Partial	-.8-.6-.4-.2 0 .2 .4 .6 .8
0	1.0000		.	.	0	1.0000	
1	0.7129		16.3162	<.0001*	1	0.7129	
2	0.3290		19.9204	<.0001*	2	-0.3643	
3	-0.0669		20.0754	0.0002*	3	-0.2983	
4	-0.4146		26.2553	<.0001*	4	-0.3080	
5	-0.6737		43.2547	<.0001*	5	-0.3695	
6	-0.7287		64.0123	<.0001*	6	-0.2113	

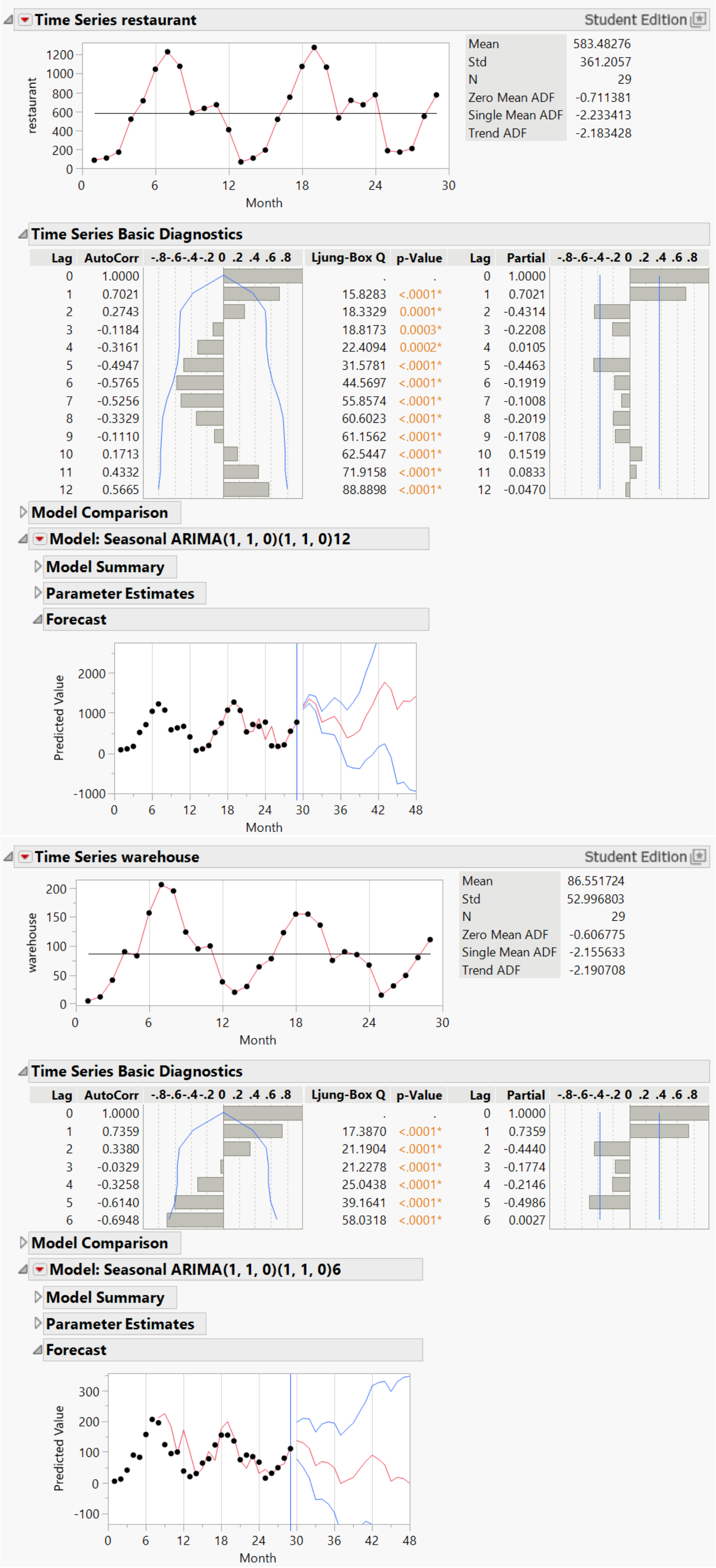
Model Comparison

Model: Seasonal ARIMA(1, 1, 0)(1, 1, 0)6

Model Summary

Parameter Estimates

Forecast



Time Series restaurant

Mean	583.48276
Std	361.2057
N	29
Zero Mean ADF	-0.711381
Single Mean ADF	-2.233413
Trend ADF	-2.183428

Time Series Basic Diagnostics

Lag	AutoCorr	Ljung-Box Q	p-Value	Lag	Partial
0	1.0000	.	.	0	1.0000
1	0.7021	15.8283	<.0001*	1	0.7021
2	0.2743	18.3329	0.0001*	2	-0.4314
3	-0.1184	18.8173	0.0003*	3	-0.2208
4	-0.3161	22.4094	0.0002*	4	0.0105
5	-0.4947	31.5781	<.0001*	5	-0.4463
6	-0.5765	44.5697	<.0001*	6	-0.1919
7	-0.5256	55.8574	<.0001*	7	-0.1008
8	-0.3329	60.6023	<.0001*	8	-0.2019
9	-0.1110	61.1562	<.0001*	9	-0.1708
10	0.1713	62.5447	<.0001*	10	0.1519
11	0.4332	71.9158	<.0001*	11	0.0833
12	0.5665	88.8898	<.0001*	12	-0.0470

Model Comparison

Model: Seasonal ARIMA(1, 1, 0)(1, 1, 0)12

Model Summary

Parameter Estimates

Forecast

Time Series warehouse

Mean	86.551724
Std	52.996803
N	29
Zero Mean ADF	-0.606775
Single Mean ADF	-2.155633
Trend ADF	-2.190708

Time Series Basic Diagnostics

Lag	AutoCorr	Ljung-Box Q	p-Value	Lag	Partial
0	1.0000	.	.	0	1.0000
1	0.7359	17.3870	<.0001*	1	0.7359
2	0.3380	21.1904	<.0001*	2	-0.4440
3	-0.0329	21.2278	<.0001*	3	-0.1774
4	-0.3258	25.0438	<.0001*	4	-0.2146
5	-0.6140	39.1641	<.0001*	5	-0.4986
6	-0.6948	58.0318	<.0001*	6	0.0027

Model Comparison

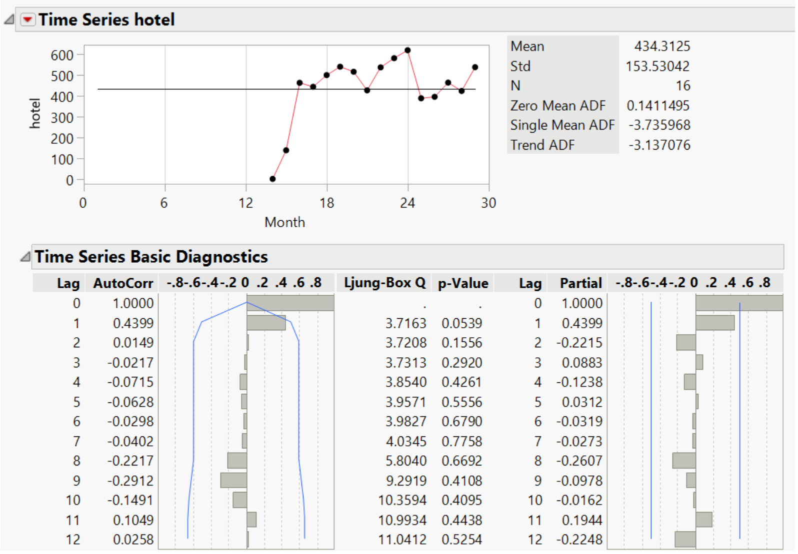
Model: Seasonal ARIMA(1, 1, 0)(1, 1, 0)6

Model Summary

Parameter Estimates

Forecast

Figure C.1. SARIMA forecasting result for retail, restaurant and warehouse orders



Time Series hotel

Mean	434.3125
Std	153.53042
N	16
Zero Mean ADF	0.1411495
Single Mean ADF	-3.735968
Trend ADF	-3.137076

Time Series Basic Diagnostics

Lag	AutoCorr	-.8-.6-.4-.2 0 .2 .4 .6 .8	Ljung-Box Q	p-Value	Lag	Partial	-.8-.6-.4-.2 0 .2 .4 .6 .8
0	1.0000		.	.	0	1.0000	
1	0.4399		3.7163	0.0539	1	0.4399	
2	0.0149		3.7208	0.1556	2	-0.2215	
3	-0.0217		3.7313	0.2920	3	0.0883	
4	-0.0715		3.8540	0.4261	4	-0.1238	
5	-0.0628		3.9571	0.5556	5	0.0312	
6	-0.0298		3.9827	0.6790	6	-0.0319	
7	-0.0402		4.0345	0.7758	7	-0.0273	
8	-0.2217		5.8040	0.6692	8	-0.2607	
9	-0.2912		9.2919	0.4108	9	-0.0978	
10	-0.1491		10.3594	0.4095	10	-0.0162	
11	0.1049		10.9934	0.4438	11	0.1944	
12	0.0258		11.0412	0.5254	12	-0.2248	

Figure C.2. Time series analysis result for hotel orders

D

Parameters setting in cost model

The data in this table are mainly used for cost calculation in the cost model; fuel cost values are derived from the sources listed under the "Link" column. Data related to the vehicle (vehicle dimensions, part of the fuel consumption) are mainly from industry reports and Volvo Trucks' official website.

Table D.1. Fuel cost and specifications for different vehicle types

Vehicle type	Length (m)	Rated loading capacity (ton)	Rated loading volume (m3)	Maintenance cost (kr/km)	Depreciation cost (kr/h)	Fuel type	Fuel consumption (L or kWh)/100km	Fuel consumption (L or kWh)/km	Fuel cost (kr/L, kg or kWh)	Cost/km	Link
Trailer	13	25	180	0.67	18.65	Diesel	30	0.3	17.157	5.1471	https://www.globalpetrolprices.com/Sweden/
Trailer	13	25	180	0.67	18.65	Gasoline		0	15.49	0	https://www.globalpetrolprices.com/Sweden/
Trailer	13	25	180	0.67	18.65	Natural Gas	25	0.25	18	4.5	https://cngeurope.com/countries/sweden/
Trailer	13	25	180	0.67	18.65	Biogas	25	0.25	28.99	7.2475	gasefuels.se
Trailer	13	25	180	0.67	18.65	HVO	30	0.3	19.3	5.79	https://www.circlek.se/foretag/drivmedel/truckdieselpriser
Trailer	13	25	180	0.67	18.65	Electric	150	1.5	4.53	6.795	https://vision-mobility.de/cn/news/milunsizairuidianwaerbeilikaishekachechongdianzhan-342318.html
Distribution car	8	7	100	0.52	13.65	Diesel	20	0.2	17.157	3.4314	https://www.globalpetrolprices.com/Sweden/
Distribution car	8	7	100	0.52	13.65	Gasoline	25	0.25	15.49	3.8725	https://www.globalpetrolprices.com/Sweden/
Distribution car	8	7	100	0.52	13.65	Natural Gas	18	0.18	18	3.24	https://cngeurope.com/countries/sweden/
Distribution car	8	7	100	0.52	13.65	Biogas	18	0.18	28.99	5.2182	gasefuels.se
Distribution car	8	7	100	0.52	13.65	HVO	20	0.2	19.3	3.86	https://www.circlek.se/foretag/drivmedel/truckdieselpriser
Distribution car	8	7	100	0.52	13.65	Electric	80	0.8	4.53	3.624	https://vision-mobility.de/cn/news/milunsizairuidianwaerbeilikaishekachechongdianzhan-342318.html
Light truck	6	3.5	30	0.37	11.2	Diesel	12	0.12	17.157	2.05884	https://www.globalpetrolprices.com/Sweden/
Light truck	6	3.5	30	0.37	11.2	Gasoline	15	0.15	15.49	2.3235	https://www.globalpetrolprices.com/Sweden/
Light truck	6	3.5	30	0.37	11.2	Natural Gas	10	0.1	18	1.8	https://cngeurope.com/countries/sweden/
Light truck	6	3.5	30	0.37	11.2	Biogas	10	0.1	28.99	2.899	gasefuels.se
Light truck	6	3.5	30	0.37	11.2	HVO	12	0.12	19.3	2.316	https://www.circlek.se/foretag/drivmedel/truckdieselpriser
Light truck	6	3.5	30	0.37	11.2	Electric	50	0.5	4.53	2.265	https://vision-mobility.de/cn/news/milunsizairuidianwaerbeilikaishekachechongdianzhan-342318.html
Light van	5	1.5	18	0.3	10.96	Diesel	8	0.08	17.157	1.37256	https://www.globalpetrolprices.com/Sweden/
Light van	5	1.5	18	0.3	10.96	Gasoline	10	0.1	15.49	1.549	https://www.globalpetrolprices.com/Sweden/
Light van	5	1.5	18	0.3	10.96	Natural Gas	6	0.06	18	1.08	https://cngeurope.com/countries/sweden/
Light van	5	1.5	18	0.3	10.96	Biogas	6	0.06	28.99	1.7394	gasefuels.se
Light van	5	1.5	18	0.3	10.96	HVO	8	0.08	19.3	1.544	https://www.circlek.se/foretag/drivmedel/truckdieselpriser
Light van	5	1.5	18	0.3	10.96	Electric	30	0.3	4.53	1.359	https://vision-mobility.de/cn/news/milunsizairuidianwaerbeilikaishekachechongdianzhan-342318.html

E

Equation fitting for route distance estimation

To apply the Figliozzi (2009) distance approximation model in the Gothenburg context, we calibrate the model parameters using real-world delivery data from GLC, a major logistics service provider operating in the city. The dataset includes daily records of total driving distance and number of stops for a large number of multi-stop delivery vehicles over a defined observation period.

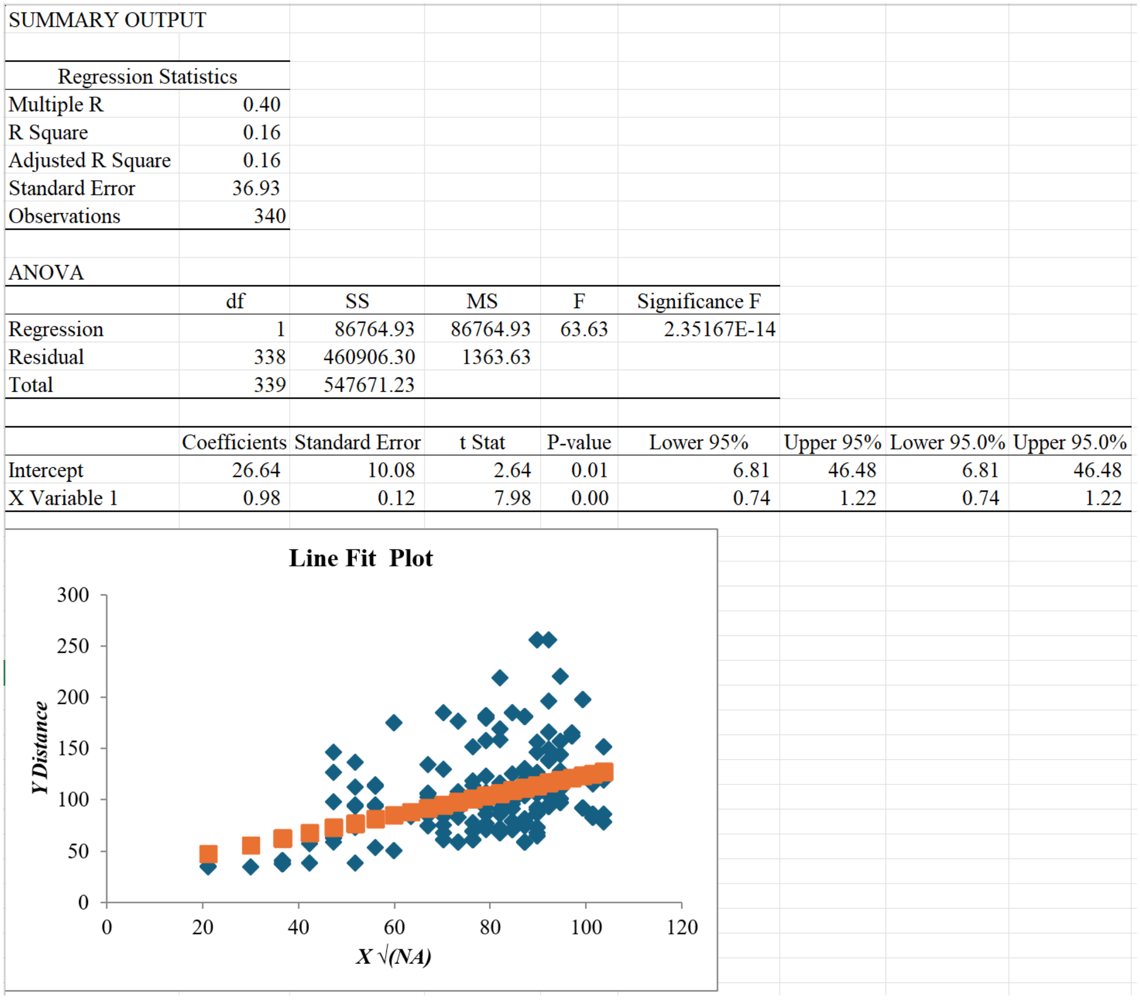
The original model takes the following functional form: $d = b + k \cdot \sqrt{NA}$

where d is the estimated total travel distance for a single vehicle trip, N is the number of stops on the delivery route, and A is the size of the area in which deliveries take place. The parameters b and k are coefficients need to be fit.

In the fitting process, A is the size of Gothenburg City, 447.9 m^3, and the variables N and d are taken directly from the dataset of GLC vehicles operation. A total of 340 vehicle-day records are used in the regression, covering the period from 01/03/2024 to 31/05/2024. The resulting regression yields the following fitted parameters:

$b = 26.64, k = 0.98, R^2 = 0.16$

These values are obtained through Excel ordinary least squares, with detailed regression results provided in Figure E.1. Although the coefficient of determination, $R^2 = 0.16$, indicates that the model can only explain about 16% of the variation in the dependent variable, this regression model was used in this study. The main reason for this is that it is the only available dataset based on actual operational records that captures the empirical relationship between the length of distribution routes and the number of stops in Gothenburg. In the absence of more complete or higher quality data, the model remains reliable for estimating delivery distances in Gothenburg, rather than other fitting results in the literature that rely only on assumptions. Nevertheless, this study should recognize the limitations of the model and treat its results with caution, and therefore will not be applied to model calculations beyond the scope of the observed dataset.



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.40
R Square	0.16
Adjusted R Square	0.16
Standard Error	36.93
Observations	340

ANOVA

	df	SS	MS	F	Significance F
Regression	1	86764.93	86764.93	63.63	2.35167E-14
Residual	338	460906.30	1363.63		
Total	339	547671.23			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	26.64	10.08	2.64	0.01	6.81	46.48	6.81	46.48
X Variable 1	0.98	0.12	7.98	0.00	0.74	1.22	0.74	1.22

Figure E.1. Illustration of the baseline scenario

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