Developing, Evaluating, and Comparing Multiple Parcel Delivery Networks Using Agent-Based Simulation

by

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Abstract

This dissertation focuses on assessing and developing multi-tier hub-and-spoke parcel delivery networks. The multi-tier concept has been developed to enhance network performance by reducing delivery time and operational cost while increasing client satisfaction under the pressure of e-commerce growth. In this dissertation, we examine different multi-tier parcel delivery networks: the two- and four-tier, and hybrid networks. The two-tier network simulates one of the traditional hub-and-spoke parcel delivery networks. The four-tier was proposed to substitute traditional delivery networks by introducing new concepts, techniques, and changing the network layout and structure. The hybrid network is proposed in this dissertation to combine the two- and four-tier networks to improve the network performance. Our objective is to develop, evaluate, enhance, and compare multi-tier parcel delivery networks. Due to the current massive demand, maintaining high service levels is difficult. Challenges such as providing fast, reliable, and low-rate services force logistics service providers to change their mindset about the fundamental concepts of parcel delivery service to escalate their success. In doing so, we leverage concepts of the Physical Internet to develop the four-tier network and implement the containerization technique. This work has four studies and was shaped by a multi-year, multi-university research project for one of the largest international parcel delivery carriers.

The first study investigates the evaluation and comparison between two- and four-tier networks under traditional operations such as bagging of small parcels. Findings show that the two-tier network is superior to the four-tier network except for average driving time per leg. Operational cost analysis shows that four-tier networks have an average 25% increase in cost compared to two-tier netwroks due to the increased number of scans. Additionally, average driving time per leg was reduced from about eight hours for the two-tier to about four hours for the four-tier. Implementation of the containerization technique and comparing the performance of the two- and four-tier networks when using containers instead of bags is our second study. Results indicate that containerization is one of the crucial techniques to be implemented to enhance parcel delivery network performance. Moreover, the percentage of late parcels is affected by using containers and is lowered by around 55%. The operational cost analysis shows that using containers reduces the operational cost when increasing the maximum container fill level. Another study proposed and assessed a new hybrid parcel delivery network. The proposed hybrid network, which combines two- and four-tier networks, has better results compared to the four-tier network when managers' priorities are lateness, operational cost, or driving time per leg. Results show that the multi-tier parcel delivery network has a huge potential for improvement. The last study investigates the effect of changing container capacities and types. Findings indicate that the selection decision of capacities and types has a major effect on operational cost. Besides, increasing the number of container types to a certain threshold enhances network performance. Exceeding that threshold does not affect the performance, but it could increase loading time of containers into trucks due to the need to stack them in a way that increases trailer utilization.

Acknowledgment

قال تعالى: "قُلْ بِفَضْلِ اللَّهِ وَبِرَحْمَتِهِ فَبِذَٰلِكَ فَلْيَفْرَحُوا هُوَ خَيْرٌ مِّمَّا يَجْمَعُونَ" يونس، 58.
"وَيَسْأَلُونَكَ عَنِ الرُّوحِ ۖ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا" الإسراء، 85.

Allah (SWT) Almighty says in the Quran:

"*Say: "In the bounty of Allah. And in His Mercy,- in that let them rejoice": that is better than the (wealth) they hoard.*" Yunus 10:58.

"*And they ask you, [O Muhammad], about the soul. Say, "The soul is of the affair of my Lord. And mankind have not been given of knowledge except a little."*" Al-Isra 17:85.

First of all, all praise and thanks are due to Allah for helping and guiding me through my life, and peace and blessings are upon our beloved prophet Muhammad. Here, I would like to extend my deepest appreciation and gratitude to my advisor, Prof. Jeffrey Smith, who has supported me throughout my research journey and has an essential role in completing this work through his guidance. Saying thank you just doesn't seem to be enough now that you've helped me complete this journey. You were an integral part of me being able to make it to the end. Also, I would like to thank Prof. Benoit Montreuil for involving me in the project that shaped my dissertation. I would also like to thank my committee members, Prof. Daniel Silva, Prof. Konstantinos Mykoniatis, Prof. Jia (Peter) Liu.

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Chapter 1 Introduction

1.1 Overview

This research focuses on the design and operation of parcel delivery networks. Enhancing the performance of such networks is strongly dependent on their configuration. Current networks are designed based on hub-and-spoke topology, which maintains a good efficiency in delivering parcels on time. The term “hub” primarily denotes a central sorting center, which is an intermediate facility located at a focal point to reduce delivery cost. Moreover, “spoke” refers to the travel lanes between hubs and delivery locations. Due to the current massive demand, keeping service levels high is hard to achieve. Challenges such as providing fast, reliable, and low-rate services force logistics service providers to change their mindset about the fundamental concepts of parcel delivery service to escalate their success.

Specifically, we consider assessing and ameliorating multiple parcel delivery configurations. These tests include adding new facilities and using several shipping protocols. Such changes improve delivery service efficiency and help reduce average and maximum driving time. Also, a new concept of transporting packages in modular containers, where items are loaded into multiple containers that fit in a trailer instead of packing the trailer with individual parcels is evaluated. Results consistent with improved package handling are expected. This work has made significant contributions to parcel delivery by providing solutions that will maintain satisfied clients while keeping delivery service providers highly competitive.

1.1.1 Parcel delivery service

With proliferation of the Internet, the parcel ordering process has been simplified, and companies have gained several opportunities to reach consumers in territories where they were previously unable to market their goods. Consequently, there has been a massive increase in the number of transactions dealing with such a vast demand. Nowadays, customers are willing to browse for what they need on various websites, allowing them to purchase better quality products at cheaper costs. However, it forces firms to concentrate on offering extra services that attract people to buy their merchandise, such as fast delivery and post-sale services. The rapid growth of e-commerce has significantly influenced parcel delivery couriers. They were compelled to increase their workforces, acquire more necessary equipment such as vehicles, and construct new facilities, which presented them with a challenge of soaring shipping rates. According to Pitney Bowes Inc., the number of parcels delivered in 2018 exceeded 87 billion (Spadafora, 2019). Moreover, this expansion in the pace of e-commerce is also evident as the number of delivery vehicles on the streets is higher. Parcel distribution companies are committed to delivering parcels swifter than ever before because the desires of clients are changing. For instance, consumers now expect their product to be shipped within *X*-hours and with small or no additional delivery costs. Carriers must manage their equipment, trucks and truck schedules, loading and unloading processes, scanning, sorting, and several operations to process this tremendous volume of packages. They concentrate on developing their networks to improve productivity, attract additional buyers, and boost competitiveness. Researchers and developers in this field have recently begun to create new concepts and innovations such as automation and drones to enhance their performance.

A parcel delivery courier that uses vehicles to distribute packages operates as follows (see Figure 1.1). First, a client drops a parcel at a pickup location. The shipments are then transported by truck to a hub or terminal at various times throughout the day and based on specific criteria, such as a specific parcel service level (promised delivery time). Hubs sort parcels depending on their destinations. After loading shipments to trucks, they depart to another hub or destination. When a parcel arrives at an intermediary hub, it is processed in the same manner as at the previous hub. After that, parcels are transported until they arrive at a destination hub or terminal, then they are processed and sent to clients.

As stated earlier, the enlargement of the e-commerce market is pushing carriers to build additional hubs. Such buildings are spread around the geographic regions they serve; this has reduced delivery time and promoted customer loyalty. However, delivery rates escalated as the frequency of vehicles traveling through these sites rose. Transportation costs rose higher than other logistics costs; they now account for more than 60% of total costs (Cooke, 2006). Any improvement in the transportation system has a significant impact on the overall network.

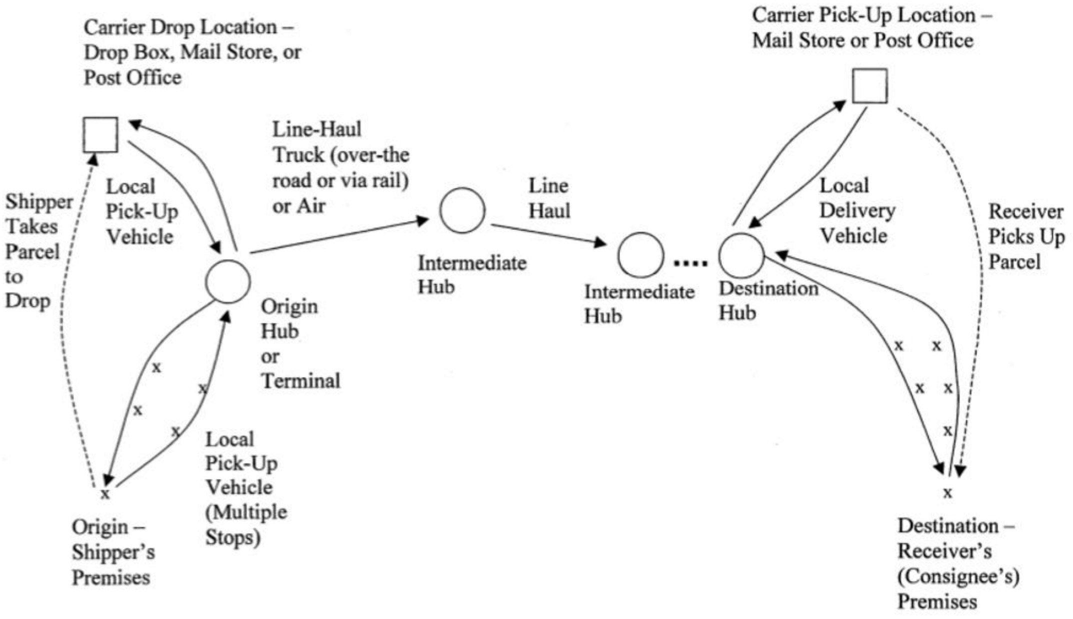


Figure 1.1: Typical steps in parcel movement from origin to destination (Dennis, 2011).

Consolidation of shipments is one of the key aspects that researchers are investigating to minimize shipping costs. This helps by reducing the number of moving vehicles, which lowers total transportation costs, as well. Next, consolidation is briefly introduced.

1.1.2 Shipment consolidation

Shipment consolidation is one of the essential strategies used to lower transportation costs. This is described as the process of aggregating small shipments, where their destination is the same or within the same region, for common transportation. It has a significant effect on lowering the total number of vehicles used, which decreases transportation costs. Bowersox (1978) discussed the value of shipments consolidation as follows:

> "*A significant opportunity existing in all logistical operations is the potential for reducing transportation expenditures as a result of shipment consolidation. Quantity discounts are provided in the published rate structures of common carriers. Generally speaking, the larger the shipments, the lower the freight rate per hundredweight*."

According to the literature, Jackson's (1985) published research explored the benefits and the importance of shipment consolidation. A survey was completed by experts from various companies to assess the value of shipment consolidation. Of those who participated, 77% indicated that shipment consolidation influences the entire network costs by reducing total logistics costs. Additionally, as the number of moving vehicles on the road grows, the probability of accidents increases. Using shipment consolidation reduces the number of trucks required, and the risk of shipment damage decreases, as well.

Implementing consolidation strategy is accomplished in several ways (Hall, 1987). First is "over stops" consolidation, which is the process of loading parcels in a truck that visits multiple locations. The destination of each parcel is one of that vehicle's stops, and a single truck is used to deliver all these small shipments. The transportation cost per unit decreases compared to sending individual vehicles as it enhances the utilization of trucks. One of the critical issues here is that it requires a good truck routing algorithm to maximize the benefits of consolidation. The second method is "over time" consolidation, where shipments tend to wait for a period before a vehicle is dispatched. The main consideration with this method is truck schedules, in addition to the duration of each truck dispatching cycle, which impacts promised delivery time. A check on the number of items ready to be shipped is considered. Otherwise, releasing a truck with a few parcels is not the right decision to be made. The third method is "over space" consolidation; this strategy is superior for sending parcels to relatively distant locations. It assumes that a firm has center hubs, where small shipments are handled at the nearest hub. Small orders are combined into a large batch, which is routed to another hub that is closer to their destination. Then it is delivered to the destination. The judgment on the location of hubs and network configuration is still a concern for this technique.

The following subsection briefly describes one of the newest ideas to improve the entire logistics system. The Physical Internet, which was recently invented, is addressed.

1.1.3 The Physical Internet (PI)

Logistics enables our planet's survival. Because of this, scholars and developers are actively working to create innovative approaches and techniques to promote logistical productivity and maintain company competitiveness. One of the most significant theories in logistics is the Physical Internet (PI). The PI was derived from the digital Internet concept. It was proposed by Professor

Benoit Montreuil, a professor of Material Handling and Distribution at the Georgia Institute of Technology (at the time of this writing). Rod Franklin (2016) defined the PI as:

> "*The Physical Internet is a vision of how physical objects might be moved via a set of processes, procedures, systems and mechanisms from an origin point to a desired destination in a manner analogous to how the Internet moves packets of information from a host computer to another host computer.*"

The following illustration shows the definition of the PI. When someone in the United States decides to send an email to a friend in Germany, the Internet is used to send the email. The sender does not care about who the Internet vendors for him or his friend are, or what path the email follows. The only thing that matters is sending that email and making sure that it was delivered quickly. Here, an e-mail message is divided into well-defined and generic packets before being delivered. Each packet has three components, which are header, payload, and trailer. They are sent by the best available path, where all packets may take the same route or not, based on what maximizes the network efficiency. Also, if a path has an issue while transferring an email, packets that are taking it are rerouted to ensure the delivery of the entire message. PI aims to ship physical objects using the same concept. Likewise, customers are not concerned about which carrier ships their packages, such as UPS, FedEx, or USPS, they are just worried about delivering and receiving them on time.

The PI strives to transport physical objects with high efficiency, in the same as the streaming of data across modern technology. System optimization is the primary move to achieve this goal. This theory design reflects on existing network issues, i.e., the number of vacant vehicles on the highway and the less-than-truckload (LTL) problem. Such troubles are causing an overall increase in cost as trucks are not 100% utilized. There are fundamental actions to be made to apply PI in real life; these are standardization, globalization, smart mobility, and constant innovation. Standardization ensures that, rather than shipping individual items, standard containers are provided to move parcels. All identical parcels that share the same origin, service level, and destination are consolidated and shipped together. Accordingly, this allows for efficient loading and unloading, and it enhances truck utilization as well. Globalization applies to interacting with hubs as a digital cloud. Here, a single courier does not control any of the network hubs that packages could pass through. Therefore, fewer trucks are required to transport shipments between such places. These vehicles would often be highly utilized as the number of shipments dispatched is aggregated from multiple carriers. Smart mobility, which is the presence of automated or autonomous vehicles, is presumed. All truck routes should be generated based on existing shipments and traffic. Even if there are drivers, this could be achieved by optimizing hub locations, which would reduce transit times and driving hours. Like any lean system, the last phase is to keep on searching for continual improvement, so businesses can have an environment to develop and expand this method usage (Sáenz, 2016).

There are pros and cons to each novel idea. The PI is expected to revolutionize the entire logistics system, and it demands much effort to persuade the world that it ought to implement it. The advantages of introducing PI are the prompt distribution of parcels, improved truck driver employment, shorter transportation distances, better competitiveness for small businesses, and reduced CO_2 emissions. On the other hand, various obstacles are challenging its implementation, such as the exchange of locations and transport systems between carriers, and the establishment of a standard to control it worldwide. Additionally, regulations around the world are inconsistent and need to be updated, and couriers globally must cooperate and approve implementation of the PI (Montreuil, 2011).

This section has introduced the major topics are covered in this proposal. A broad definition of parcel delivery service has been discussed. Then, a focus was placed on how the cost of logistics is climbing, which it should not as it is a non-value-added process. An outline of the explanation behind this surplus of logistics cost that is linked to transit was discussed. However, among all the factors that raise transportation expenses, a concentration should be on decreasing the number of vehicles traveling by enhancing the consolidation process. The following section describes the problem we are attempting to solve.

1.2 Problem statement

Parcel delivery services face further barriers due to the enormous expansion in e-commerce purchases. These obstacles influence the efficiency of delivering objects on time with high reliability. Individual carriers should focus on improving their firm systems, facilities, and processes, and applying all lean six sigma tools. However, these alone do not help in maximizing the entire system's success. Efforts have been made to improve the logistics system, which helps achieve the goal of delivering products with high-quality service as fast as possible. The carriers' problem that forces them to enhance their networks is the amount they have invested in it. Furthermore, logistics is not considered as one of the added-value processes. The other major hurdle they encounter is sustaining satisfied and loyal customers. Consider the following scenario for a consumer where two stores sell him/her an item, with identical features and price. One store provides one-week delivery, and the other offers one-day delivery. The shopper chooses the one that most suits and satisfies them, which is generally the one-day delivery. Likewise, if anyone wants to send a gift to a relative, the carrier that offers swift and efficient package delivery at the lowest price is selected. Nowadays, consumers are ordering goods that are shipped in X-hours, which forces companies to raise their prices to offer such services to their clients. At the same time, this restricts the expansion of buying these products, as customers cannot afford to pay a high shipping cost on products that cost less than that service. There are also rivalries between carriers to offer these services at cheaper rates.

With empty trucks moving on the street, the transportation system is considered a crucial problem in parcel delivery. For example, a vehicle moves between a warehouse which is located close to a manufacturing plant and a wholesaler. Here, there are two movements, the first when the truck carried the shipment to the wholesaler, and the second when it went back vacant. All expenses such as fuel, vehicle depreciation, and the driver’s wage associated with the second move are labeled as waste. When the number of these empty trucks on the road increases, service rates remain high to cover these losses. Besides, as the number of vehicles soars and total traveled miles does, as well, the problem of global warming is directly impacted due to the increase in CO_2 emissions. Driving for long periods is one of the difficulties that the logistics system struggles with. In the US, if there is a full truckload between Miami and Seattle, the lowest cost of delivery is to send a direct truck between these cities. However, that requires having two drivers or even switching drivers at particular points.

Several studies have been undertaken to overcome all such issues. Scholars have worked on optimizing hub locations in a hub-and-spoke network as all current parcel delivery networks were built based on it (O'Kelly, 1986a, 1986b, 1987; Campbell, 1994, 1996). The parcel delivery network cannot be designed in the same manner as the conventional supply chain hub-and-spoke networks. In general, there is no need to place supply chain network facilities at specific locations. On the other hand, pickup and distribution centers of a parcel delivery network must be situated in towns and cities where clients have access to them. The second step in facilitating the implementation of the hub-and-spoke network is to concentrate on consolidation. The value of shipment consolidation has been evaluated and validated, and it has been shown to have a significant effect on network performance (Jackson, 1981; Popken, 1994; Chen et al., 2005). Another group of researchers studied improving truck routes that help minimize transport costs and distribution times (Costa et al., 2008; Vidyarthi et al., 2013). Some of these approaches have been developed to enhance the current parcel delivery hub-and-spoke network, but there is still a lot of room for innovation.

The PI is one of the most modern ideas aimed at improving the logistics system. As stated in the previous section, there are several important benefits that the planet would gain by applying this theory. Scholars began designing algorithms and methods to render PI into practice quickly, while at the same time optimizing how PI would be employed. One of these approaches related to PI is the Multi-Plane Urban Parcel Logistics Web (see Figure 1.2). This technique is designed to ameliorate the delivery process in urban areas. It decomposes the territory into planes or tiers, where plane 0 links delivery and pickup locations within a block such as a suburban neighborhood or an industrial park. Each of these blocks is referred to as a zone. Plane 1 has access hubs that link between plane 0 contiguous zones. Plane 2 has local hubs that connect contiguous cells, where each cell is a cluster of adjoining zones. Plane 3 classifies each group of contiguous cells into areas, and has gateway hubs to link adjoining areas. A network could be expanded to include extra tiers depending on the size of the network. This logistics model was published in 2018, which indicates that up to this time, no projects have been carried out focusing on its implementation (Montreuil et al., 2018).

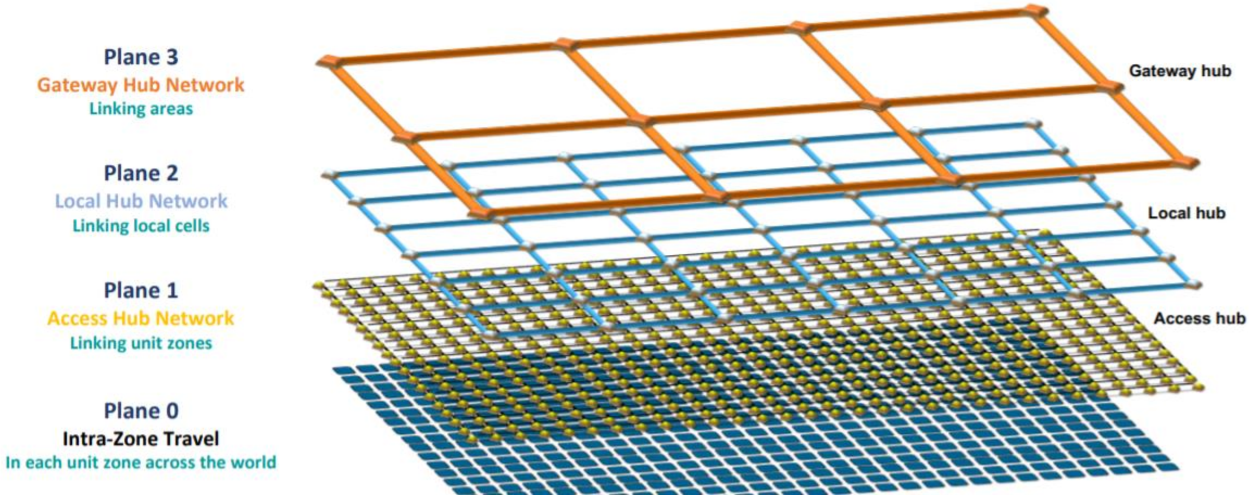


Figure 1.2: Proposed multi-plane urban parcel logistics web (Montreuil et al., 2018).

In this work, a multi-plane configuration is used to create one of the proposed hub-and-spoke networks. A network architecture extracted from the multi-plane model is designed by implementing multi-plane protocols to a traditional hub-and-spoke network. A focus on comparing and testing various network structures is discussed later. Several scientists compared different network structures in the literature. Still, our contribution is to evaluate the multi-plane concept and compare it with a traditional hub-and-spoke network, in addition to applying and testing the containerization technique for consolidation in hub-and-spoke networks.

Next, a summary of our research objectives is presented. Such studies contribute to enhance the performance of parcel delivery networks.

1.3 Research objectives and expected contributions

The goal of this research is to build an agent-based simulation model to compare and improve the performance of various hub-and-spoke network structures. Several individual studies will be done to achieve this, which are as follows:

1. Evaluate and compare the performance of both two- and four-tier hub-and-spoke networks under traditional operations such as bagging of small parcels. Findings from this study are used to investigate the circumstances that make one of them is preferable to the other.
2. Evaluate and compare the performance of both two- and four-tier hub-and-spoke networks using the containerization technique from PI, where a set of containers instead of bags will be used for shipping.
3. Develop a hybrid network that combines two- and four-tier networks to reduce the drawbacks of each of them, and to optimize performance by reducing delivery time and cost.
4. Develop an algorithm to select the best container capacities and types to achieve the goal of improving the network. Here, an optimization method and technique are used to reduce total costs and increase vehicle utilization. Then, evaluate the performance of the four-tier network with both this study and standard container capacities.

The expected contributions of this research are:

1. Design and implement a flexible, data-driven simulation model for parcel delivery networks that implement both the traditional processes and new concepts of delivery such as modular containerization.
2. Demonstrate an evaluation of different parcel delivery networks that help in selecting between different structures based on demand variation and network parameters.
3. Apply a recently invented theoretical parcel delivery concept to traditional hub-and-spoke networks; this is used to prove its feasibility and usefulness.
4. Implement and enhance a new shipment consolidation principle, including showing how it could be applied in practice.
5. Reveal a new delivery network by combining multiple parcel delivery networks, which overcomes individual network limitations.
6. Develop a code to generate several demand data sets for a parcel delivery network.

1.4 Dissertation Organization

The dissertation is composed of eight chapters. The first chapter contains a general introduction about parcel delivery service, consolidation, and also includes the problem statement and research objectives. Chapter two provides an in-depth literature review about parcel delivery service, consolidation, and simulation, including its three types: Discrete Event Simulation, System Dynamics, and Agent-Based Modeling (ABM). Chapter three contains the methodology that we will follow to achieve research objectives. The evaluation and comparison between two- and four-tier networks under traditional operations such as bagging of small parcels are discussed in Chapter four. Chapter five introduces the containerization technique and compares the performance of both two- and four-tier networks. The new proposed hybrid parcel delivery network is introduced and assessed in Chapter six. The last study investigates the effect of changing container capacities and types and is discussed in Chapter seven. Finally, Chapter eight contains the conclusion and future works.

Chapter 2 Literature Review

The ultimate goal of this work is to study network design and operational characteristics that boost the performance of parcel delivery hub-and-spoke networks. Multiple configurations and consolidation strategies are used to reach this target. The central issues of this type of network are related to transportation, loading and unloading, shipment consolidation, facility capacities, and customer satisfaction. Researchers have attempted to provide businesses with advanced methods and algorithms, helping them to achieve their visions and goals. In this chapter, Section 2.1 covers an introduction to parcel delivery and the hub-and-spoke network. Section 2.2 summarizes consolidation strategies. In Section 2.3, the literature on Agent-Based Modeling (ABM) and simulation applications in parcel delivery and logistics is reviewed. In Section 2.4, the theory of the Physical Internet is discussed. Lastly, a summary is given in Section 2.5.

2.1 Parcel delivery and hub-and-spoke network

In the literature, there is no unique definition of parcel delivery service, and experts have come up with various definitions. Dennis (2011) defined parcel delivery as:

> *"The delivery of shipping containers, parcels, or high value mail as single shipments. The service is provided by most postal systems, express mail, private courier companies, and less than truckload shipping carriers".*

The history of parcel delivery dates back to the 1850s. Wells Fargo was formed to provide services such as banking and express services. In 1918, a parcel delivery service that looked more like the one that is known these days was developed by Railroad Express Agency (REA). It was offering ground and air express services. REA Express took the lead of this sector until the United States Postal Service (USPS) and other carriers launched their businesses. These new carriers surpassed REA because of REA's poor management, which led to the closure of its operations in 1975. In the 1960s, Purolator Courier started their work by providing ground and air courier services prior to joining the Canada Post. Nowadays, the leading parcel delivery couriers in the United States are United Parcel Service (UPS), FedEx, and USPS. UPS was established as the American Messenger Company in 1907. UPS is superior in terms of both volume and revenue. FedEx and USPS both were established in the 1970s (Dennis, 2011).

A courier's primary function is to deliver parcels such as letters, spare parts, and furniture. Once these items depart from their origins, most likely, their route does not change. A parcel route may consist of intermediate hubs and facilities until it is shipped. This service is considered the first costly way to deliver products and parcels (McKinnon, 2001). It originated in cities where simple transport modes such as bicycles were used for delivery. Later, this service was shown to have a global impact because of its value.

There are many reasons for the importance of parcel delivery services. A sample of these services includes relatively cheap delivery rates, fast delivery speed, and package tracking. They encouraged companies and customers to request that carriers ship their orders rather than using their resources. Also, due to the need for mass customization, advanced technology, inventory reduction, and core competencies, clients rely on those parcel delivery couriers.

Most online orders are received over the weekend when people have time to shop for what they need (Heikamp, 2013). Thus, the amount of work on Mondays is considerably more than on other days, and couriers need to employ their full capacity to fulfill the massive number of transactions. All shipments should be delivered on schedule, which requires trucks to be on the road, thus amplifying traffic, fuel consumption, and emissions. The number of return packages is a continuing challenge as often clients are not at home at the time of delivery.

During the last ten years, this industry developed rapidly, and carriers now provide services such as same-day delivery and *X*-hours delivery. Additionally, customer needs and a vast demand for buying almost everything on the Internet are the drivers for this significant improvement. Options for buying fresh meat or vegetables are available online, but consumers are asked to pay extra for shipping it within *X*-hours. Saving time and effort is considered to be the cause of this, which pushed customers to spend more than $300 billion on annual e-commerce sales in 2014 (Braunstein, 2015). Lasisi et al. (2015) investigated same-day delivery challenges. Based on their findings, carriers' infrastructures affect the ability to compete in offering such a service. They found that large delivery carriers could reach customers' expectations, while the chances for small or medium carriers are low unless they decide to partner with one of the large carriers.

The first delivery attempt is a challenge for these service providers as it causes an increase in shipping expenses. Xing et al. (2011) suggested two factors that may enhance the success of first delivery attempts. First, carriers should use emails or texts to schedule a delivery date and time with customers. Additionally, they should offer their clients different delivery options when they are not at home, such as locations to pick up their parcels. Second, carriers should request that businesses improve their packaging process of small parcels such as books and gifts. Good packaging helps fit these items in the letterbox, which reduces the need for a customer to be at home. Delivery efficiency was studied using multiple linear regressions by Van Duin et al. (2016). Population density, house value, monthly income, and distance to the supermarket are a sample of their 13 model variables. Several relationships are defined between variables. Additionally, interactions between variables and delivery efficiency were found, such as if the population density increases, the delivery rate should decrease. Their results show that there is a problem with first-time delivery to a new zip code; hence, having a pre-delivery contract with customers shrinks that service waste. Negotiations with clients about flexibility in choosing service time, drop-off location, and delivery route should enhance customer satisfaction.

Ulmer & Streng (2019) proposed a consolidation technique to improve last-mile same-day delivery speed. Their contribution was focusing on having pickup stations, where trucks ship parcels to these stations, then packages are picked up by customers. It has been found that the average delivery time is less than two hours, and the number of fulfilled orders increased to 100 orders per truck, while in the literature, it was between 20-30 orders (Ulmer, 2017).

All major parcel delivery carriers such as UPS and FedEx use the hub-and-spoke network. The architecture of this network makes the parcel distribution process between origin and destination easier. However, to achieve the goal of lower delivery rates, movement between each hub and spoke should be minimized. For example, FedEx chose Memphis, Tennessee as a center to their hub-and-spoke network, and UPS uses Louisville, Kentucky as their worldwide shipping center.

Many scholars explored the hub-and-spoke network; O'Kelly (1986a, 1986b, 1987) developed the first mathematical models for discrete Hub Location Problems (HLP). Models for both single-HLP (each spoke is allocated to one hub) and p-HLP (each spoke could be allocated to one or more hubs) were developed. A quadratic integer programming optimization plus two enumeration-based solution heuristics were proposed, as well. The quadratic model provides an exact solution, while the heuristic method is used for large-scale networks. The heuristic method works in two ways; first, each location is allocated to the nearest hub. Second, each location can be allocated to the first nearest hubs or the second nearest one, but not both. One of the factors that affect the feasibility of using the heuristics approach is the number of facilities.

Campbell (1996) developed a linear model based on p-HLP. This model is analogous to the formulation of p-median named as the p-Hub median location problem. The p-median formulation goal is to minimize the distance between locations. This model minimizes both cost and distance between an origin-destination pair by shipping packages through several hubs. The work was updated by the scholar in 1994 to add a fixed link cost variable to the objective function. The fixed cost is related to processing a package at a hub after shipping it from a spoke or another hub. Besides, a threshold value was considered for the minimum amount of flow between any two locations. If the total number of parcels is higher than or equal to that threshold, parcels are transported to the next facility on their paths. Hub capacities were inserted into the model. Packages are not sent to a hub when it is fully utilized (Campbell, 1994). A study was done by Costa et al. (2008) focusing on developing a multi-objective p-HLP. This model has two objective functions, which minimize total transportation costs, and minimize the maximum processing time at each hub.

Vidyarthi et al. (2013) proposed a model that minimizes cost, delivery service level, and facility capacities. The goal was to simultaneously select the best route to ship a package with the minimum cost. It takes into consideration the next destination's capacities, plus shipping is done based on that parcel service level. In this model, they assumed that hubs are a single server queue system, and there are two types of service levels, where one has priority over the other. Overall, their results indicate that shipping costs get higher with these constraints. The aim of enhancing customer satisfaction was achieved.

The hub-and-spoke optimization methods reviewed here are designed for supply chain networks and it is hard to apply them to parcel delivery networks. The pickup and distribution facilities in parcel delivery are designed to serve the people around it. Although minimizing the distance between these locations is a need, they must be built at accessible points for everyone, which forces the network designer to manually decide where to locate each facility. As consolidation is one of the critical parcel delivery topics, a literature review on it is introduced in the next section.

2.2 Shipment consolidation models

Hall (1987) defined shipment consolidation as the aggregation of different products, parcels, or items into one batch to be transported by a single vehicle. This has attracted the attention of both investors and academia due to its direct effect on cost reduction. Various consolidation models and approaches were developed during the last decades. Early studies employed simulation models to evaluate the design of such methods; in addition, the primary focus was on cost reduction and on-time delivery. One of the first studies in this area was done by Jackson (1981). Multiple consolidation strategies were studied. Additionally, a simulation approach was built to assess the impact of different attributes, such as holding time, the number of pool points, and shipment release strategies. One of the findings was that using a hybrid time-and-quantity policy guarantees faster shipping compared to a time-based policy, although associated expenses are relatively high. Results showed that long holding time when there are a high number of items to be shipped, decreased transportation costs. Evaluating the need for consolidation was done by Jackson (1985). Fifty surveys from different firms were analyzed. The study found that the leading rationale for shipment consolidation is cost reduction. Nevertheless, decisions should be made carefully to achieve the goal of decreasing total expenses, like determining the number of hubs where items are consolidated, dispatching rules, transportation modes, and vehicle routes that complicate the planning process. Hence, a drawback of parcel aggregating is the complexity of operations scheduling when adding consolidation to the network.

Popken (1994) contributed to the consolidation process by extending the scope of multi-commodity flow models. Three factors are considered for each commodity, which are volume, weight, and holding cost. The purpose was to decrease the overall cost of transportation and inventory holdings. A non-linear model was proposed to achieve the goal and satisfy the demand requirement, as well. Due to the behavior of the cost function profile, it was not capable of finding a global optimum, but a heuristic algorithm was developed to get local improvements. The assessment of this model went through two validation stages. It was tested against results that were taken from a mathematical software specialized in finding local optimums. Also, it was assessed using generated data. Overall results showed model benefits at both stages, although it has obstacles, such as the influence of the commodity’s average weight; if that rises, the efficiency of this model decreases.

The consolidation process is highly dependent on when to combine items to the next pool point (hub). There is a similarity between this and ordering in an inventory control system. The first approach is a quantity-based policy, which depends on the number of items, volume, or weight to be delivered to determine when a shipment is released to the next destination (Gupta & Bagchi, 1987). The second method is a time-based policy; a shipment is dispatched every cycle (Mutlu & Çetinkaya, 2010; Marklund, 2011). The third is a hybrid time-and-quantity policy, and a decision is made to transport items or not based on the previous two strategies. Thus, this decision is made once the quantity matches the volume threshold, or at the end of that cycle (Mutlu et al., 2010).

Vehicle dispatching decisions in freight consolidation were studied by Bookbinder & Higginson (2002). Their approach investigates the hybrid policy using stochastic clearing theory. Here, a gamma distribution was used for the order’s weight and a Poisson process for the order’s arrival. Three parameters were used to determine the expected costs, which are time, weight or volume, and probability. The results were illustrated using a nomograph. It defined the relationships between the optimal consolidation quantity, probability, cost, and consolidation cycle time. One of the limitations is that it is not a real-time controlling tool for distribution centers. For instance, if the total volume exceeds a truck capacity, the optimal decision is not to send two trucks with the whole volume or waiting to receive extra orders, then shipping them. However, if that location has different vehicle types, a small truck should be used to send the remaining parcels.

Chen et al. (2005) argued how to enhance customer order fulfillment. A comparison between time-based and quantity-based replenishment policies was made. They studied shipment consolidation of the Vendor Managed Inventory (VMI). A model was built to minimize four types of costs, which are replenishing inventory, transportation, holding cost, and customer dissatisfaction. Generated data were used to evaluate these models only. It was found that the quantity-based model is preferable in terms of reducing total costs. The quantity-based policy was not used previously due to lack of equipment, as it requires a continuous check on the current inventory levels. Nowadays, this trouble is solved by tracking everything in stock using modern technologies. They found that customer dissatisfaction increased under a time-based policy as it causes extra waiting. Other scholars worked on consolidation in VMI, such as Mutlu & Çetinkaya (2010); their proposed models' goals are finding the optimal dispatch scheduling (time or quantity-based policies) and optimal inventory.

A new freight consolidation strategy was proposed by several scholars that involve loading items into containers, then sending them to intermediate facilities or the final destination. A model was proposed by Qin et al. (2014) to consolidate items into different container sizes, where each size has three characteristics: container capacity, price, and a unique route. It attempted to optimize each container route to minimize total delivery and container costs. As third-party carriers handle some of the shipping processes, companies do not deal with truck schedules and routes. One of the assumptions here is that filling containers should be based on one-dimensional bin-packing as this was applied to a textile manufacturing planet. Containerization was studied by other researchers such as Melo & Ribeiro (2015), Nasiri et al., (2017), and Montreuil et al. (2018). Simulation is the primary tool to evaluate all previous models because of the reasons discussed in the next section. An introduction to simulation and its uses in parcel delivery service and logistics is provided.

2.3 ABM and simulation in parcel delivery and logistics

The primary evaluation processes of parcel delivery, logistics, and supply chain networks are done using simulation. The main reason behind using simulation is the limitation of optimizing the overall network by traditional methods. Such methods suggest performing an actual experiment to change truck schedules, which cost time and money without any guarantee of success. Likewise, integer programming or heuristics optimization methods were used to find the best routes that minimize the total cost. However, when trying to cover the vehicle dispatch problem, when to consolidate, holding time at each location, loading and unloading, and processing time, a simulation model is the best way to assess a network. By setting network parameters and programming the required optimization methods, the new proposed network could be evaluated (Shapiro, 2001). Briefly, simulation helps us understand how systems work, as well as testing and comparing the performance of systems under a variety of conditions.

There are three basic types of simulations: Discrete Event Simulation (DES), System Dynamics (SD), and Agent-based modeling (ABM). DES is used to emulate systems on the operational level. Events occur at discrete points in simulated time and the occurrence of these events changes the system state. In addition, there is a representation of entities, and each has specific characteristics. All actions done by or to an entity are tracked. In DES, statistical distributions are used to simulate processes and arrival times. SD is different to DES as it is mainly used to emulate strategies. The main difference between SD and other simulation methods is that SD models are based on differential/difference equations. Also, there is no representation of individual entities. The overall number of entities is used, such as the total number of items in an inventory. Another feature of SD is that averages are widely used to represent variables. SD models are considered as deterministic models when compared to DES models, which are stochastic. Here, the transition between states is done continuously. Lastly, ABM focuses on the behavior of individual agents and the interaction between agents during the simulation. Details about ABM are provided later.

Tako & Robinson's (2012) published a review paper that summarizes the uses of DES and SD in logistics and Supply Chain Management (SCM). They reviewed 127 articles in the period between 1996 and 2006. Part of their findings indicate that most scholars used DES with a percentage of around 68% of the research articles, while 30% used SD, and 2% used a combination between both DES and SD. There is broad use of DES in supply chain networks and logistics. Starting with the process of evaluating a new network configuration, when it comes to assessing a network, DES is a useful tool to simulate the flow between network activities (Alfieri & Brandimarte, 1997; Ding et al., 2005). Assessing replenishment control policies is one of the benefits of DES, such as evaluating the role of a time-based policy in improving network operations (Van Der Vorst et al., 2000; Zhao et al., 2001). The goal of each organization is to refine its Key Performance Indicators (KPI); for that reason, DES is used to test a network with new parameters attempting to optimize its KPIs (Vamanan et al., 2004; Ying & De Souza, 1998).

SD has been employed in supply chain and logistics to emulate new strategies and to solve issues related to the overall inventory level. The bullwhip effect is one of these major problems correlated with customers. This issue is connected to the lack of information sharing about proper inventory levels between network partners. Hence, SD is considered a perfect tool for such network assessments as it deals with the total number of items in the inventory (Venkateswaran & Son, 2005; Naim, 2006). Besides, it is common to use SD rather than DES for information sharing, even though both were used to overcome it in the literature (Marquez et al., 2004).

Two decades ago, scholars were not studying individual entities' behaviors in systems due to the deficiency of technology. Modeling entities requires defining a set of rules, which are performed while the model is running (North & MacAl, 2014). Decision-makers always ask for reliable measures and tools that enhance the decision-making process. However, this could be achieved by getting accurate data about their systems. Implementation of ABM approaches floated on the surface is one of these competitive tools, as the amount of data that is collected out of the model is comprehensive.

There are several definitions of ABM in the literature. Miller & Page (2009) defined it as:

> *"Computer programs in which artificial agents interact based on a set of rules and within an environment specified by the researcher."*

While the North & Macal (2014) definition is:

> *"A modeling and computational framework for simulation dynamic processes that involve autonomous agents."*

Further, a definition on Wikipedia is:

> *"An agent-based model (ABM) is a class of computational models for simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole."*

Since the definition of ABM varies among researchers, it could be defined as a modeling technique that specifies and creates system agents, where each one of them has certain parameters that describe it. The primary purpose behind this is to investigate agents' behaviors, interactions between them, and interactions with their system or environment. The following is an illustration of ABM. Consider an emergency where a large group of customers is watching a movie in a theater. The fire alarm goes off, and people begin leaving their seats and trying to escape. To save as many lives as possible, customers' escape behaviors should be taken into consideration. How will they behave if there is only one exit door? Two doors on the same wall? Two opposite doors? Answers to all questions are acquired by developing an ABM to test customer behaviors. (Bonabeau, 2002).

During the simulation, these autonomous agents are modeled at different scales, which are the macro and micro scales. An instance of a macro scale agent is a warehouse, while workers in a manufacturing plant, vehicles, and patients are micro agents. The second type of agent is utilized to supply users with information about their systems, as agents make decisions that depend on the predefined protocols. Today, smart agents are created that do not work based on rules only, but they use machine learning techniques to improve their behavior, which contributes to an increase in the volume of data collected. In addition, they are capable of handling more complex systems (Bonabeau, 2002).

The applications of ABM are not reserved for a specific field. Through the literature, the first area that counted on ABM for research purposes was social science because agents were first treated to be humans. The concept of understanding a group of people's behaviors in their work environment, community, or even a whole country is required to test and develop new control protocols and policies trying to enhance that environment (Gilbert & Troitzsch, 2005). Using ABM in industrial applications has been part of its vast scope. Since the beginning of using it as a decision-making tool, it covers material handling, process control, supply chain management, and transportation systems. ABM has also appeared in commercial applications, such as information systems and business process management. Additionally, the medical industry has employed it, where it was used to improve patient monitoring and rescue team management. To sum up, ABM is capable of handling many other applications as agents exist in all systems, which supports the feasibility of modeling such systems (Bonabeau, 2002).

2.3.1 Why ABM?

Emulating a parcel delivery network, generally, has been studied and developed by scholars before (Tako & Robinson, 2012). Furthermore, all types of simulations have been used to evaluate network performance, and to improve the decision-making processes, as well. Nevertheless, a critical question that should be answered is: why do we need to use ABM for parcel delivery instead of other simulation types? Researchers went through this, and they have concluded several reasons behind choosing ABM as the best fit simulation tool for parcel delivery and logistics networks. It depends on what was stated before about what an agent is, and what its characteristics are. The development of these systems during the last two decades has provided answers for these questions and following are some of them (Labarthe et al., 2007; Giannakis & Louis, 2011; Chen et al., 2013):

1. Agent-based models handle complex systems and deal with the non-linearity of supply chain networks. It overcomes the use of sophisticated mathematical models to study complex networks, including parcel delivery.
2. These models are capable of considering environmental changes, such as deleting or adding agents. ABM is adaptable and deals with these modifications.
3. Agents make complicated decisions while the simulation is running, and based on the sociability characteristic of agents, their behavior and performance are evaluated.
4. The supply chain's decentralized approach is more efficient when it comes to agility performance. As shown in Figure 2.1, the differences are apparent, which forces managers and scholars to invest more in ABM.
5. Agent-based models provide accurate analysis for multiple KPIs. Thus, choosing between solutions and alternatives for improving a network is comprehensive.

On the other hand, ABM has some cons, which usually make it an inferior modeling technique to others. Some of these are listed below:

1. Optimality: Dealing with agents and not monitoring overall system performance is a hard task to guarantee optimality, and that is why several studies coupled model outputs with optimization algorithms such as a genetic algorithm (Moyaux et al., 2006).
2. Simulating human behavior is a process with no guarantee of how a person will behave in a given situation. However, when it comes to humans, a group of expected behaviors is to be tested (Bonabeau, 2002).

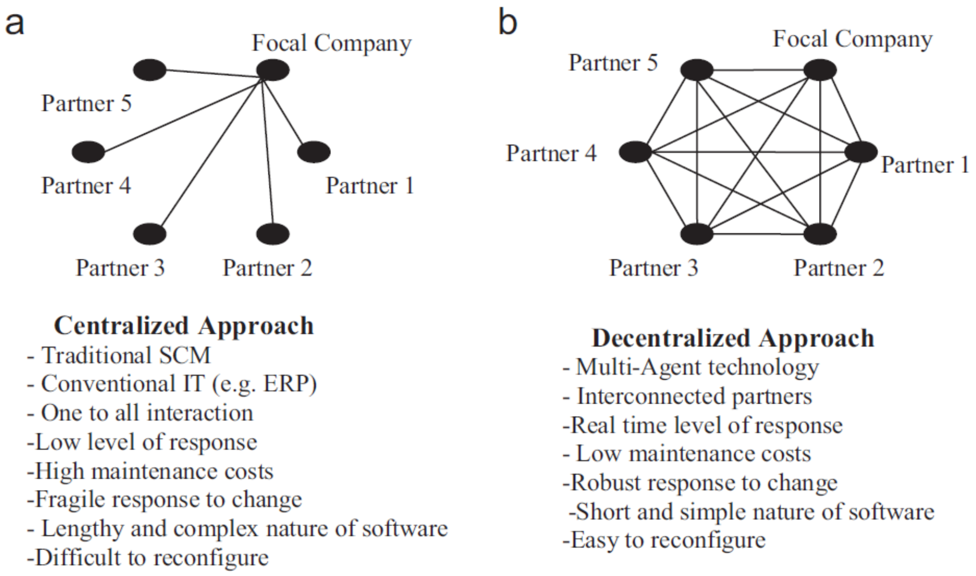


Figure 2.1: Multi-agent architecture for SCM (Giannakis & Louis, 2011).

2.3.2 ABM and simulation applications in parcel delivery and logistics

The vital role of simulation appears when studying a company's expansion or trying to modify and perfect an existing system. Usually, investors do not spend their money without assurance that a modification in the system is profitable relative to the current situation. The assessment of an expansion should be done using an excellent developed model. These models are representative and accurate in terms of performance measures, such as inventory level, shipping time, and customer satisfaction. Also, obtaining metrics provides managers with enough information to make the right decisions. One of the agents uses in parcel delivery and supply chain networks is a process monitor, which observes data that sends warnings and alerts in case of an expected failure (Reese, 2007).

Studies have discussed the benefits of using ABM in parcel delivery and logistics in general. One of the earliest models used intelligent agents to organize a supply chain network (Swaminathan et al., 1998). A framework was developed for building a precise and reliable supply chain simulation model, which represents reality by minimizing required modeling time and efforts. They studied and analyzed several supply chain networks, then extracted the agent's information, constituent control elements, and interaction rules. Results showed that the process of reengineering a supply chain is accessible and testable, and performance measures could be analyzed.

Chen et al. (2005) investigated the use of multi-agent models in logistics negotiation. They analyzed the negotiation process between suppliers and companies. A model was developed based on a pair-wise negotiation protocol. Here, a supplier agent and several agents equal to the number of partners in the network was used. The supplier sent a call for proposals to companies to schedule and control future production. After receiving their responses, the supplier agent constructed a decision tree to accept all proposals from companies, accept some and reject others, or reject all proposals. Later, it went through a pair-wise negotiation process to choose which proposal to be accepted. Likewise, Saberi & Makatsoris (2008) discussed the negotiation process. A multi-agent model was designed to emulate negotiation between customers and retailers. In this model, agents found solutions for resource allocation and matching supply and demand by analyzing the shared data. Customers sent proposals to a retailer with prices and quantities, and based on current inventory, the retailer agent decided to start the negotiation process by executing a knapsack programming. Next, the retailer decided which customer order maximized the outcomes. They found that this approach is capable of increasing customer satisfaction while reducing both the bullwhip effect and total cost. Many scholars, such as Mansour & Kowalczyk (2015) and Yang et al. (2018), have investigated this portion as the advantage of agents' interactions is noticeable.

Giannakis & Louis (2011) studied the benefits of using a multi-agent model in risk management. Their proposed framework focused on demand-driven supply chains. They used five agents (Coordination, Monitoring, Wrapper, Communication, and Disruption manager) to develop their framework, where all of them were interacting within each supplier enterprise. The communication agent was responsible for interacting with enterprises. ABM was employed to provide detailed information about the environment, which enhanced the decision-making process and sped up the response to changes in the organization. Harper (2012) contributed by proposing an ABM framework to improve the risk in Air Force logistics systems. The added value of this research compared to previous works is the handling of repairable items while others were studying consumable items.

One of the studies that combined ABM and PI was done by Sarraj et al. (2014). They developed a multi-agent model to better the sustainability and the efficiency of logistics transportation under

PI protocols. The model has three agents, which are: routing, good containerization, and consolidation on transportation means. It was implemented in a fast-moving consumer goods industry, and it has been found that PI leveraged the performance of the logistics transportation system. Similarly, Chargui et al. (2019) focused on truck scheduling and container grouping problems. A multi-agent model was designed with three parallel scheduling agents. Additionally, there were three embedded hybrid meta-heuristics in these agents to guarantee model quality and efficiency. A mixed-integer linear programming model (MILP) was developed to assess model output. Results show that in case of disruptions, this model is capable of rescheduling trucks to enhance network sustainability.

Nowadays, there is a high availability of tools capable of collecting and storing massive amounts of data, so it can be analyzed to maximize system outcomes. Giannakis & Louis (2016) developed a multi-agent model using big data analytics. Such incorporation supported a way to process real-time and offline web application data using a big data agent. Based on agent analytics, potential actions would be taken by other agents. This work attempted to enhance agility (responsiveness, flexibility, and speed) and to deal with complex networks. An improvement in agility performance was obtained; as a result, firms are capable of increasing customer satisfaction by providing precise delivery dates.

ABM was recently used as a perfect tool to be applied in Industry 4.0. Ghadimi et al. (2019) enhanced their previous supplier selection multi-agent model (Ghadimi et al., 2018) to fit Industry 4.0 design principles. These principles are interoperability, transparency in information, decentralization of decisions, and technical assistance. Interoperability is related to agents' interactions, where firms should be connected to the Internet and share information, as well. Furthermore, as agents share real-time information, it validates the transparency in information principles. Decentralization of decisions is achieved as agents are autonomous and are making real-time decisions. One of the expected outputs of this model was that it does not require human interaction. Consequently, agents could handle the technical assistance principle as they are automating the supplier selection process.

This section has reviewed ABM and simulations. The essential role of ABM in developing supply chain network design and enhancing their success was discussed, as well. ABM has a place in many research fields because agents' characteristics make it capable of representing reality. As addressed before, ABM applications in parcel delivery, logistics, and supply chains vary. We started with redesigning networks to optimize their KPIs, in addition to exploring the negotiation process. Also, there are many studies to improve the decision-making process and trying to automate it. All of these efforts show a portion of the overall picture of the benefits of ABM. Moreover, ABM proves to be capable of collecting an enormous amount of data about a system, plus it is useful for data analysis and validation (Giannakis & Louis, 2016). Finally, many previous studies show that ABM is a perfect tool to simulate and improve supply chains, including parcel delivery networks.

2.4 The Physical Internet

Since the day PI was invented, efforts have been made to try to apply it in real life. Several articles were published to clarify the vision and concepts of the PI. These works went through major problems with the current logistics system, such as having empty vehicles or containers, an increase in the number of trucks on the road that requires hiring more drivers and the need for inventories because the current logistics system is not capable of covering all countries or regions. In addition, boosting the delivery service and dealing with big cities demand, which requires driving in traffic that causes more pollution and noise, are also problems to be addressed. The PI provides several solutions for these issues, such as shipping packages and parcels in standard container capacities, which increase vehicle utilization and parcel handling. Also, having universal interconnectivity enhances the shipment of items at lower prices with faster delivery (Montreuil et al., 2010). The foundations of PI were published by Montreuil et al. (2012). These foundations are means for logistics efficiency and sustainability, universal interconnectivity, encapsulation, standard smart interfaces, standard coordination protocols, logistics web enablers, open global logistics systems, and they are driven by innovation.

According to Treiblmaier et al. (2019), about 50% of the publications related to the PI are focused on concepts, while 35% of them are quantitative models, 8% on simulation experiments, and the remaining are related to literature reviews and case studies. One of the conceptual articles by Montreuil et al. (2010) illustrated how PI would affect the whole logistics system around the world. They discussed the design of containers, how containers will move through facilities, and how they will be loaded and unloaded. Additionally, facility and hub design concepts that fit PI implementation were discussed. Depending on this, PI motivates experts from various fields to contribute to implementing it. Ballot et al. (2012) investigated the design of PI facilities that would improve the transfer of containers from a truck to a train, a train to another train, or a train to a truck. The proposed design performance could be tested using a discrete-event simulation model.

As mentioned previously, parcels are supposed to be shipped in containers where these container sizes may vary according to the PI. Sarraj et al. (2014) listed a set of container sizes such as 2.4m × 2.4m × {1.2, 2.4, 3.6, 4.8, 6, 12(m)} which fits with pallets and different transportation modes. Figure 2.2 shows the concept and the benefit of using containers. These benefits consist of simplifying material handling and increasing the utilization of trucks (through standardization). Additionally, the activeness of PI containers was discussed by Sallez et al. (2015). These containers are considered as active products as their status is available at any time, which helps in improving operations within the entire network.

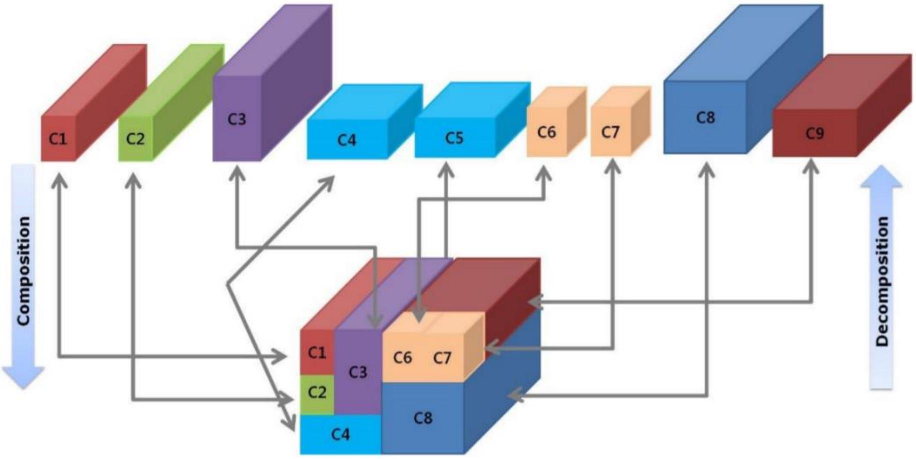


Figure 2.2: Illustrating PI-container modularization for consolidation and deconsolidation (Montreuil et al., 2010).

Maslarić et al. (2016) discussed the matches between industry 4.0 and the PI as both require advanced technology. Zhong et al. (2017) proposed a framework to process and analyze the massive amount of data that the PI requires to operate a network. This work would help managers to improve their decision-making process by converting the data analysis into managerial guidance. Betti et al. (2019) proposed an agent-based model to track agents' information throughout the network under the PI umbrella. In this model, a blockchain system stores model databases, and all processes on shipments at hubs were neglected. Hence, this model focuses on pickups and shipments in the delivery process. Moreover, each agent had an account in the blockchain to store its data, which contains the agent's actions. These data consist of date and time of occurrence, action type, agent account that performs the action, agent location, and shipment identification. One of the recent studies that uses blockchain was conducted by Meyer et al. (2019). A four-layered framework was proposed, where these layers are PI-organization, PI-nodes, PI-movers (shippers/receivers), and PI-containers. An interrelation graph (see Figure 2.3) was developed that shows how blockchains are capable of solving PI barriers. Results indicate that an additional cost, under $1, would be added to an average delivery by implementing this framework. These are additional references related to PI, such as Furtado et al. (2013), Venkatadri et al. (2016), and Sallez et al. (2016).

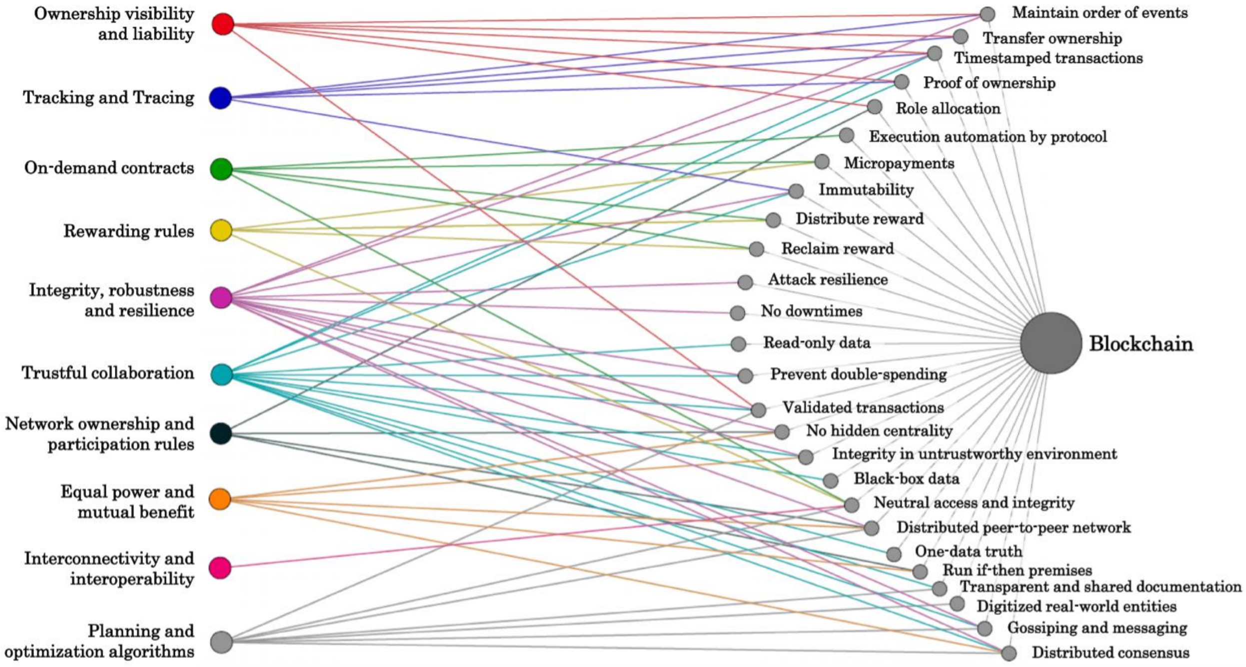


Figure 2.3: Physical Internet and Blockchain: Interrelationship diagram (Meyer et al., 2019).

2.5 Summary

In this chapter, different topics, which are the basis of our research, were summarized and reviewed. We started with a general introduction to the parcel delivery service definition and history and hub-and-spoke networks. Section 2.2 focused on shipment consolidation, the major consolidation models, and how scholars have worked on improving and optimizing them by developing new methods and algorithms. The third section explored the uses of simulation in the field of parcel delivery and logistics, then a review related to ABM and its applications in this area was delivered. The last section covered the PI and recently proposed methods to improve it.

Many problems in parcel delivery and logistics were solved in the literature. All these efforts are related to the traditional logistics system. Consequently, it is apparent that traditional networks almost achieved their maximum performance. However, the immense growth in demand, change in customer expectations, and many other factors were behind limiting its capability to overcome these issues. The PI was one of the newly developed concepts to enhance how parcels are being transported in an efficient and fast way.

In conclusion, the multi-plane urban parcel logistics web proposed a new concept of delivering parcels faster than before, such as offering *X*-minute delivery across urban agglomerations. Also, it ensures that parcels are delivered within the promised time window, which enhances shipping precision across the world’s megacities. However, this concept has some inefficiencies, such as building a high number of access hubs as they are assumed to be accessible to each neighborhood, campus, or highrise building. Consequently, these facilities require hiring more employees, which increases total expenses. Also, there is nothing in the literature that is related to this concept except one published article, which shows the proposed logic of the method. Hence, our work has a significant contribution to future implementations of this network.

Chapter 3 Methodology

A framework for the accomplishment of our research objectives is proposed in this chapter. The purpose of this work is to use agent-based simulation to promote and assess the performance of multiple hub-and-spoke network structures. First, an introduction to multi-plane urban parcel logistics web is delivered because the construction of the four-tier network relies on it. Second, this chapter addresses framework design and action plan in-depth, including domain and conceptual models, and the research schedule.

3.1 Multi-Plane Urban Parcel Logistics Web

As explained in Chapter One, this structure separates the served geographical area into multi-planes, as in Figure 3.1. Planes are divided into rectangles, and the smallest rectangles are shown in Figure 3.2 and Figure 3.3, which are the zones that create plane 0. Zone geographic sizes vary such as suburban neighborhood, an urban community, or a campus. Likewise, all yellow nodes in Figure 3.3, which are at the intersection between zones, are the access hubs that constitute plane 1. The gray spots are local hubs that make up plane 2, while the orange nodes in each region are gateway hubs that create plane 3. The geographical sizes of cells and areas are not fixed, and are based on system design. Here, all urban areas are classified as areas even though their population sizes vary. For example, the size of Los Angeles, California is three times bigger than Tampa, Florida; however, when implementing this network, both are categorized as areas. Consequently, a suburban neighborhood in Los Angeles is a zone, contiguous suburban neighborhoods or small size cities with a population around 50K is a cell, and the entire city is an area. This indicates that there is one area, while the number of zones and cells will vary based on previous definitions and design team decisions. Roughly, the number of cells and zones in Los Angeles will be higher than in Tampa because area size and population are bigger.

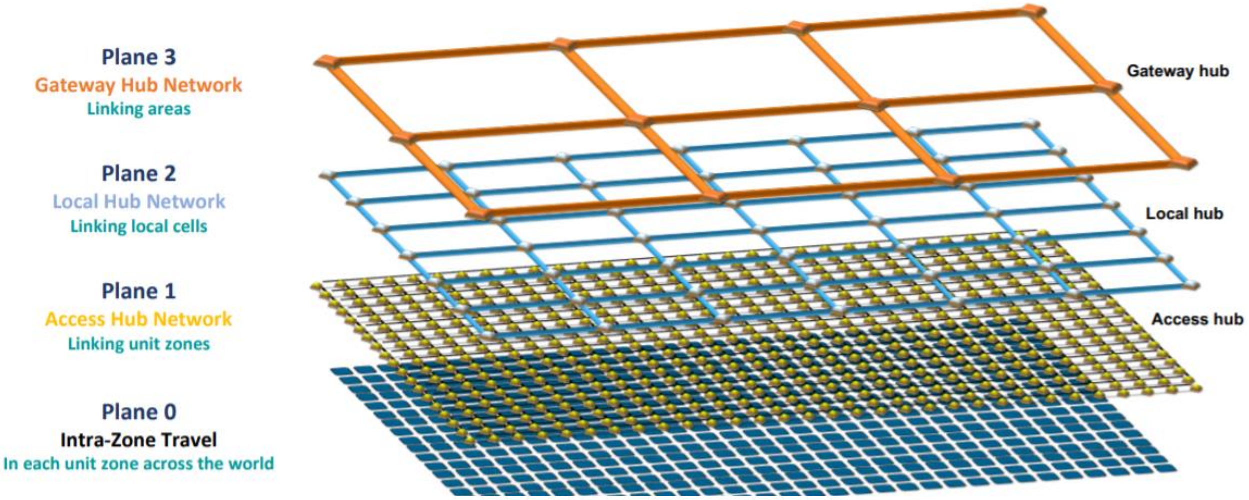


Figure 3.1: Proposed multi-plane urban parcel logistics web (Montreuil et al., 2018).

This web-based structure assumes that parcels are shipped through the entire network by different transportation methods such as trucks/cars, airplanes, and trains. The delivery process consists of different steps based on parcels' origins and destinations. Packages are picked up at a pickup location. Then, shipping paths are determined, which are generated depending on the location of both origin and destination. The parcel path generation is as follows:

1. If both the origin and destination facilities are in the same zone (plane 0), a parcel is delivered directly to its destination without passing through any other locations.
2. When a parcel's origin and destination are located in the same local cell but are not in the same zone, it is shipped to a nearby access hub. Then, it is moved along plane 1 hubs until it arrives at the zone of its destination. The parcel goes to an access hub connected to that zone. Lastly, it is shipped to its destination.

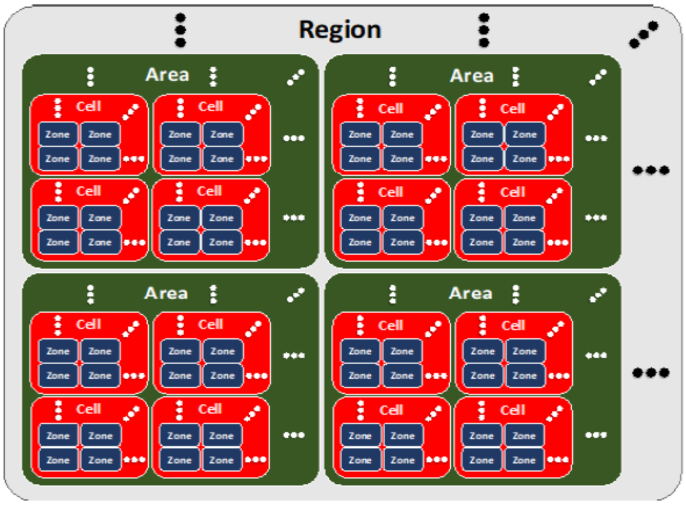


Figure 3.2: Proposed urban pixelization (Montreuil et al., 2018).

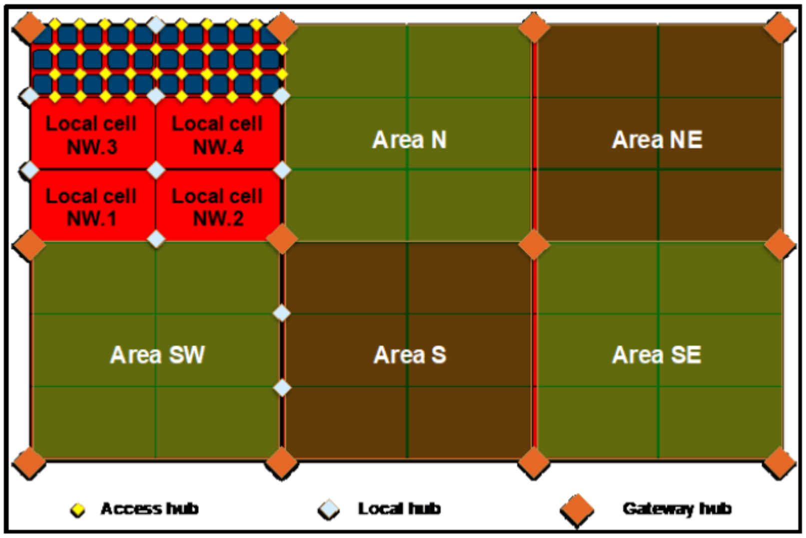


Figure 3.3: Parcel logistic web mapped on pixelized megacity (Montreuil et al., 2018).

3. If both the origin and destination are in the same area but are not in the same cell, it follows the logic in point 2. The Item is sent from a pickup location to a nearby access hub, then again to a nearby local hub. Then, it is transported along plane 2 locations

until it reaches the cell that has its destination. Finally, it is lowered gradually from plane 2 to plane 0, where the destination is located.

4. If a region has the origin and destination of a parcel, but they are not in the same area, the package is shipped progressively from plane 0 to plane 3, where it is processed at a gateway hub. Then, it is moved along plane 3 hubs until it arrives at the area of its destination. After that, the parcel is lowered as in point 3.

In moving from source to destination, all parcels follow one of the previously described patterns.

Now, as parcels are flowing through the entire network, this structure describes how shipment consolidation is executed as well. The proposed consolidation process is performed based on three principles:

1. Hub-based sorting and consolidation: Parcels are consolidated between hubs. For instance, one of the scenarios is to consolidate parcels between their first visited hub and their last visited hub. As such, there is no consolidation at intermediate locations and hubs. It is usually prompt, safe, and cheap.
2. Relay-based consolidation: Parcels are aggregated and sent to the farthest hub that all share in their path. To illustrate this principle, consider a group of items at a location in plane 0 (zone), and all should visit the same gateway hub (plane 3). Subsequently, these parcels should be separated into different routes to reach their destinations. Items are consolidated and moved as a single parcel until they arrive at that gateway hub only.
3. Smart consolidation: Depending on the former two principles, a smart system decides when to consolidate and what the destination of the consolidated parcels is before separating them. This includes collecting data about the expected demand, which helps in making these decisions based on a data-driven system.

The next section shows a description of how the proposed research objectives are developed and performed.

3.2 Research framework

This research consists of four related studies. Their accomplishment is achieved by following listed detailed procedures. In this section, the domain and conceptual models are described to specify network scope and operations, which simplify implementation of developed models. Our contributions are summarized as follows:

1. Evaluate and compare performance of two- and four-tier hub-and-spoke networks using traditional bagging strategy for small parcels. Findings are used to investigate the circumstances that make one of them preferable to the other.
2. Evaluate and compare the performance of both two- and four-tier hub-and-spoke networks using the containerization technique from PI, where a set of containers will be used for shipping instead of bags.
3. Develop a hybrid network that combines two- and four-tier networks to reduce the drawbacks of each, and to optimize performance by reducing delivery time and cost.
4. Develop an algorithm to select the best container capacities and types to achieve the goal of improving the network. Here, an optimization method and technique are used

to reduce total costs and increase vehicle utilization. Then, evaluate performance of the four-tier network with both this study and standard container capacities.

3.2.1 Domain Model

The purpose of the domain model is to understand and state the operations of interest, which help in determining the scope of the study. Besides, it is used to describe the designed network and processes. A virtual parcel delivery courier is created as a sandbox to simulate all structures that are evaluated. This company has 310 facilities located in the US in northeastern and southern states. It is capable of delivering a variety of parcels with different volumes, weights, and within specific service levels. Based on a previous multi-year project that was done for a large international parcel delivery corporation, the number of facilities in this research is sufficient to represent the concept of the multi-plane network. Furthermore, creating a parcel delivery network requires a manual searching process to find accessible spots on the map to build its facilities there, such as highway intersections. Note that some of the terminology used in this proposal came from the project mentioned above.

The parcel delivery process is described in Figure 3.4 (repeated from Figure 1.1). Parcels are received from customers at the demand location. After that, every package is shipped to a designated destination within a particular time based on the requested service level. Parcels are classified as regular, small, or irregular based on their size. At each location, small parcels can be consolidated into bags before moving, where the bags move as a single parcel. All bags and parcels are sorted and loaded into trailers at facilities, and then sent to other locations based on their routes. Parcels or bags are loaded to or unloaded from the received trailer before continuing to their destinations. All trailers are opened at the arrival location, where all items are physically scanned. Vehicles are called upon request for each separate leg (a Leg or a Transit link is a directed edge between two consecutive nodes in a route). The last-mile delivery is not in the scope of our work except in the last study where parcel lockers are used.

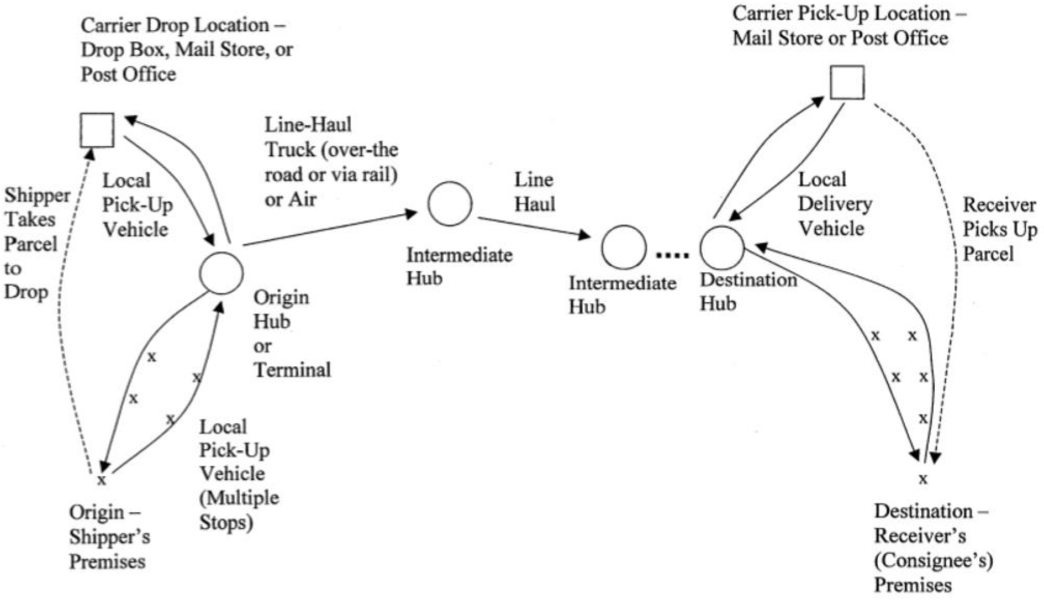


Figure 3.4: Typical steps in parcel movement from origin to destination (Dennis, 2011).

The relationship diagram in Figure 3.5 describes transportation operations over the network. Each element is color-coded by type: Green is for physical objects; Orange is for movements over a network; Blue is for attributes. Facilities are represented as well; here, two distinct types of locations are used, and together, they form the carrier network. Each parcel and bag is assigned a unique tracking number. When shipped, all shipments are loaded into trailers. Moreover, at each transit link, items are scanned. A parcel route in a two-tier hub-and-spoke network is assigned as follows:

1. Origin – Destination: If the destination is closer to the origin compared to the closest hub, then send a direct shipment to that destination.
2. Origin – Hub – Destination: If the closest hub is closer than the destination, send it to that hub first, then to the destination.
3. Origin – Hub – Hub – Destination: If the destination is far from the origin, send it to the closest hub, then to the closest hub to the destination. Afterward, ship it to the destination.

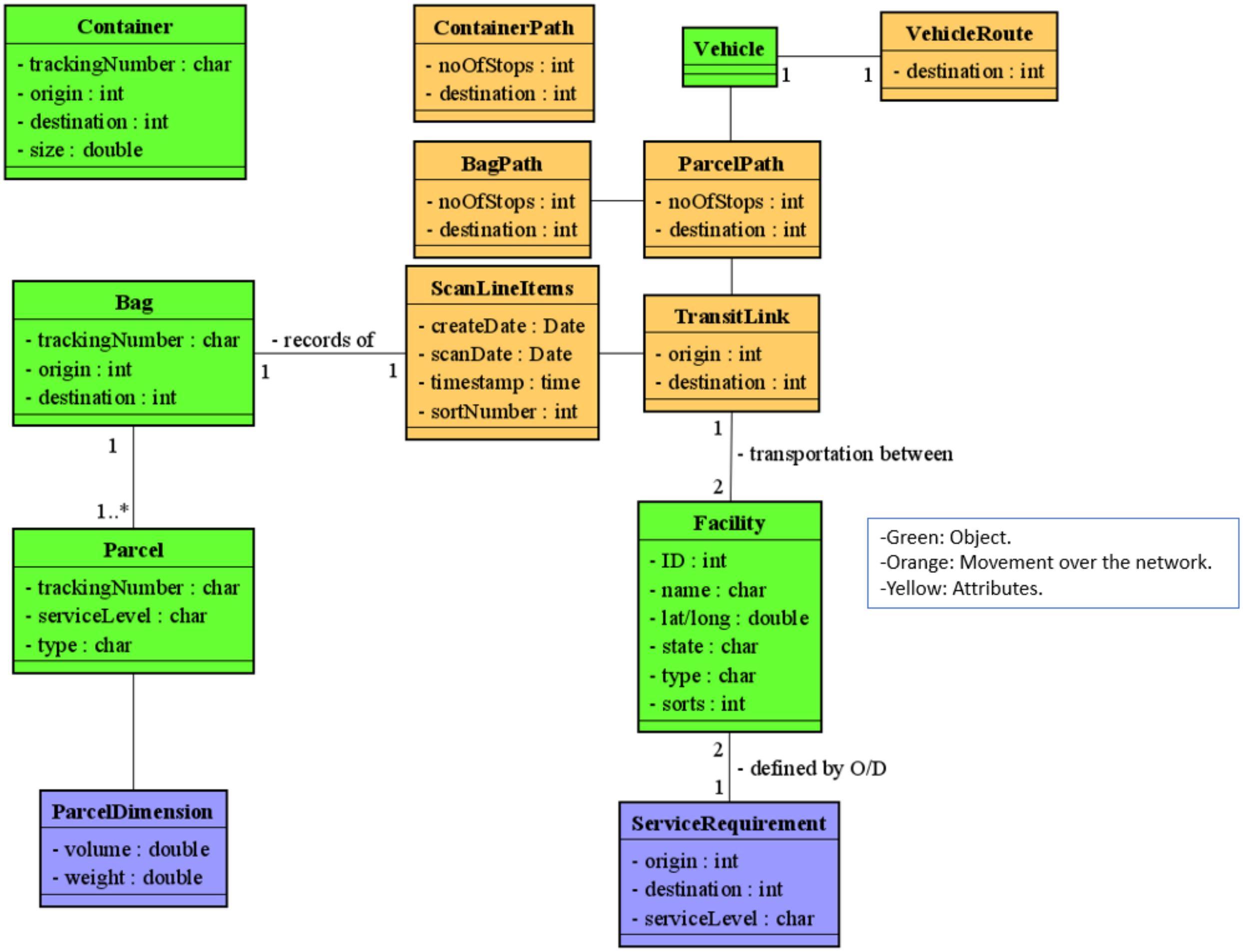


Figure 3.5: Domain model represented in an entity-relationship (ER) diagram.

In Figure 3.5, entities without connections are used for modular containers. In a fully containerized transportation network, modular containers substitute all bags, and all parcels are put in at least one container when being moved. Later, containerization is to be included in the conceptual model.

The domain model covers the geographic distribution of network locations in the US, operations within facilities, and the distribution process. The following are details about these parts:

A. Types of facilities: Two types of facilities are used in these models. First, pickup and delivery (PK/DLY) locations are where items are received from and delivered to customers. This type of facility is either an origin or a destination for parcel delivery. In general, the system receives parcels from hubs, other PK/DLY sites, or clients and dispatches them to customers.

   Hubs are primarily used for internal operations where no customer pickups or deliveries are made. Parcels could be reconsolidated at multiple hubs. Parcels are received and sent to both hubs and PK/DLY locations. Figure 3.6 shows the geographic distribution of two-tier network locations on the left side, while the right side shows the geographic distribution of hubs only.

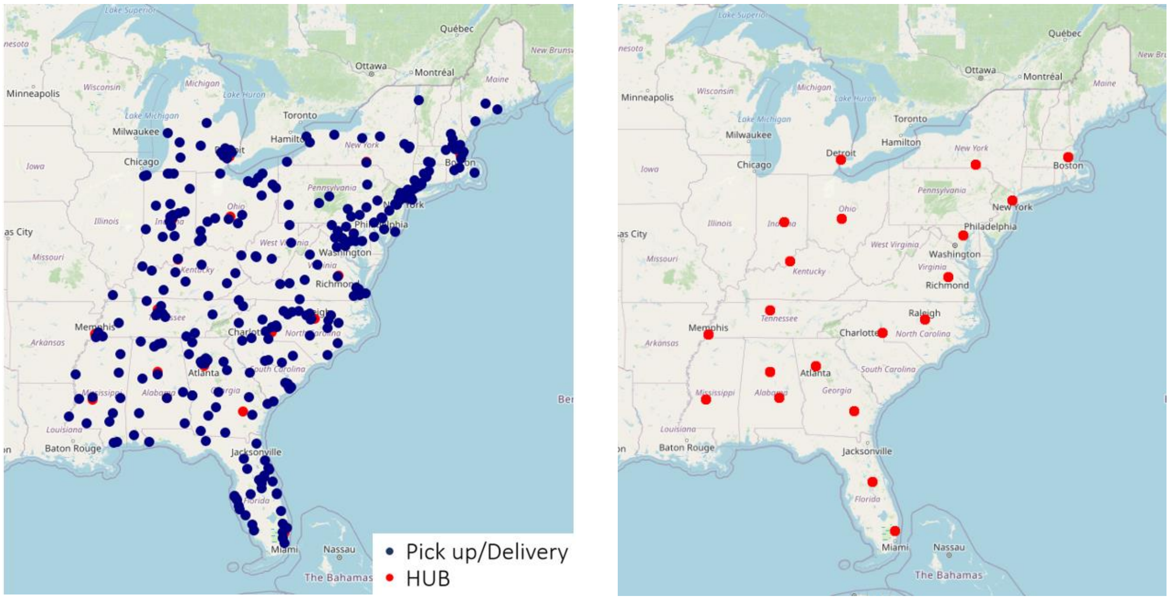


Figure 3.6: Geographic distribution of the 2-tier network locations.

B. Operations within network locations: In facilities, parcels are scanned, sorted, moved, unloaded, loaded, and consolidated. The following is a description of these operations.
   - Sorting: This is performed at hubs to separate parcels based on their destinations. There are six equal sorts at hubs, where each sort duration is 4 hours. In this model, sorting duration is not one of the model parameters as the maximum number of sorted parcels in an hour (throughput) is not limited by the capacity of a hub. Although adding a throughput constraint to the network is doable, it has been found, from the formerly mentioned project with a parcel delivery provider, that it only slightly affects network performance when there are no hub shutdowns.
   - Scanning: This is done to track parcels and bags throughout the network. Scans are taken at the origin and at all transit facilities, where each record contains the following information:
     - Scan type: Parcel or bag.
     - Tracking number: unique ID for each parcel/bag.

  - Origin.
  - Destination.
  - Transit facilities.
  - Sort number.
  - Creation date: At what date and time that parcel and bag entered the network.
  - Scanning date and time.

C. Distribution process: In this portion, parcel attributes are described in detail.

- Parcels dimension and tracking number: Parcels vary significantly in dimensions such as volume or weight. Parcels are classified into three categories, which are small, regular, and irregular. Small parcels such as letters are classified as small, and parcels with excessive volume, weight, or irregular shapes that cannot be moved via standard conveyor belts are classified as irregulars. A unique tracking number is assigned to each parcel or bag when it enters the system. It is common to differentiate parcels based on their weight and volume. Hence, Table 3.1 shows the general criteria to categorize parcels in the literature in addition to what is listed prior.

  Table 3.1: Parcel types (Dennis, 2011).

Parcel Type	Weight (lb.)	Volume (in^3)
Small (S)	< 10	< 450
Regular (R)	< 75	< 10,000
Irregular (IR)	> 75	-

  Furthermore, small parcels are not easily handled, hence, these parcels are transported in bags to improve the handling process and efficiency. Multiple smalls fit into the same bag that while the individual smalls are “small”, the consolidated bag is not. It is essential to distinguish smalls from regular parcels as their aggregated size is not negligible.

- Tracking number: A parcel’s unique tracking number consists of origin, destination, service level, type, and a unique sequence number such as 125GND23S25, where 125 is its origin, GND is the service level, 23 is the destination, S is for smalls, and 25 indicates that this is parcel number 25 that was created at facility 125. For bags, the same method will be used to generate tracking numbers except that the type is B, such as 125GND23B20. Here, the bag service level is determined based on the service levels of parcels that are in it, and the fastest service level is used to represent that bag service level. For example, if it has at least one parcel with a service level of 1-day, that bag’s service level is 1-day.
- Parcel service level: This is the promised time window for delivery. Therefore, parcels are prioritized by these service levels. Clients are charged based on the selected service level. It categorizes parcels into four major classes, which are 1-day, 2-day, 3-day, ground (GND), where it takes around 5 days to deliver a GND parcel. According to the previously mentioned project, 1-day represents less than

10% of the total delivered parcels, and 2-day and 3-day both represent less than 10% as well. In comparison, 80% of the delivered parcels are GND.

- Parcel shipping path: Route determines the sequence of facilities that are visited by a parcel before it arrives at its destination. The parcel path in a two-tier network depends on the shortest path algorithm, as shown in Figure 3.7.

```
Shortest path
If(origin is connected with destination)
    Send to destination
Else
    Find the closest hub to the origin
    Send to the closest hub to the origin
    Find the closest hub to destination
    Send to the closest hub to destination
    Send parcel to destination
```

Figure 3.7: Generating parcel paths using the shortest path algorithm.

Network Key Performance Indicators (KPIs) are covered in the domain model. They measure the performance of an organization or of a particular process in which it is engaged. KPIs are classified into three main categories according to the form of impacts they assess: Efficiency, environmental impacts, service capability, and social impacts.

A. Efficiency measures: Efficiency KPIs are essential for businesses as they are directly tied to the cost. Consequently, the quality of activities is known as efficiency measures. Such KPIs that assess efficiency are:
    1. Total induced cost: This consists of labor (handling, driver), fuel, and equipment/facility costs.
    2. Total traveled miles: The total number of miles traveled by all trucks within a period.
    3. Fillrate (Trailer Utilization): This is the fraction of truck or trailer capacity that is utilized.
    4. Total asset population: This includes the number of bags, containers, trailers, and trucks in the network.

    Travel miles measure the efficiency of routes. It also affects drivers' rates and fuel costs. Capacity utilization could be measured in terms of volume and weight. Flow imbalance, bad routing, and inaccurate product mix (e.g., products cannot be stacked) lower the fillrate. Finally, the total number of assets, which is related to the number of bags, containers, trailers, and trucks in the network, is assessed. Total population is measured as the maximum number of assets employed at the same time. Besides, these numbers indicate the demanded investment in each asset.

B. Environmental measures: KPIs are capable of assessing the environmental impact of the network. It may not be directly reflected in cost or performance, but it has an implicit influence on social responsibility. Also, these could be efficiency or economic measure. Such metrics are:
    1. Greenhouse gas (GHG) and toxic gas emission: $CO_2, NO_2,$ and SO_2.
    2. Fuel consumption.

C. Service capability and social impact measures: Service level calculates the ability to meet the current service requirements or the ability to offer better services. The list of KPIs that describe it are:
    1. Delivery delay: This measures the ability to meet current service requirements.
    2. Delivery time: This is a time window that spans from shipment to delivery.
    3. Average time of driver routes.

    Shortened shipping time and lower frequency of misloading decrease the number of incidences of overdue deliveries. However, delivery time could be further lessened, and even swift shipping could be available with modular containers. This opens doors to providing services such as *X*-hour delivery. Social impact is measured as the impact of quality of life on drivers. Average time of driver routes should be reduced, which enables them to work regularly instead of driving for several days in a long haul. When two drivers are assigned to a long haul, one of them is still being paid while he is not operating. Hence, when long-haul routes are substituted with multiple short paths, labor costs are decreased significantly.

Here, described model elements are classified into input variables, control variables, and output variables to link the domain model to the simulation. Input variables are fixed variables to be commonly used in all scenarios. Control variables are variables that define scenarios. Output variables are dependent variables, which make up the simulation’s output and are used to calculate KPIs.

A. Input variables: Input variables are the fixed variables throughout all networks. They support comparing the impact of control variables on output variables. We start with containerization, which affects overall network performance, but the manner of parcel flow is changed. Likewise, demand represents the set of items to be delivered. The number of created parcels to be shipped is the same under each scenario’s conditions. The list of input variables is as follows:
    1. Network structure: Each structure has a different number of locations. Also, their types vary except pickup and delivery locations.
    2. Demand: Different demand scenarios are used to run the model. For instance, one of the demand scenarios is created to simulate the Black Friday season (i.e., the Friday after Thanksgiving).

B. Control variables: These values vary by structure to observe their effect. This model’s control variables are:
    1. Containerization: This indicates the parcel clustering technique that uses different container capacities instead of bags.
    2. The number of containers in use.

C. Output variables: This describes simulation outputs. Also, results are strictly linked to one or multiple KPIs. These variables are as follows:
    1. Track of individual parcel:
        - Delivery time.
        - Traveled time.
        - Time/amount of handling at all visited locations.
        - Delivery delay.

2. Track of trucks and trailers:
    - Travel miles.
    - Fill-rate.
    - Fuel consumption.
    - Total driving hours.
3. Track of operations at an individual facility:
    - Throughput: Number of parcels sorted per hour.
4. Track of individual equipment (bag, container):
    - Time in use: When it is ready to be used again.
    - Total number in use.

3.2.2 Conceptual model

The conceptual model illustrates and defines the scope of the targeted simulation models. It includes comprehensive information required to build a simulation model. The overall configuration of the simulation is illustrated in Figure 3.8 in the form of an agent diagram. Emulating a parcel delivery network includes operations at locations. Hence, a discrete-event agent-based simulation is built. An agent diagram is an effective way to describe the simulation structure. There are active and passive agents, and objects along with physical or information flow between them. Active agents are the agents that make decisions based on a rule-based policy, heuristics, or optimization algorithm embedded dynamically during the simulation run. The agent is considered as a manager or a department in a company in a real-world operation. For instance, the scheduling department could be modeled as an active agent. On the other hand, passive agents perform operations based on instructions sent to them by active agents or by simulation input. Objects are used to model physical items that are moved or passively used by agents in the simulation. Parcels, locations, bags, trailers, and vehicles are modeled as objects. All agents and objects are linked and interact with each other dynamically in the simulation environment.

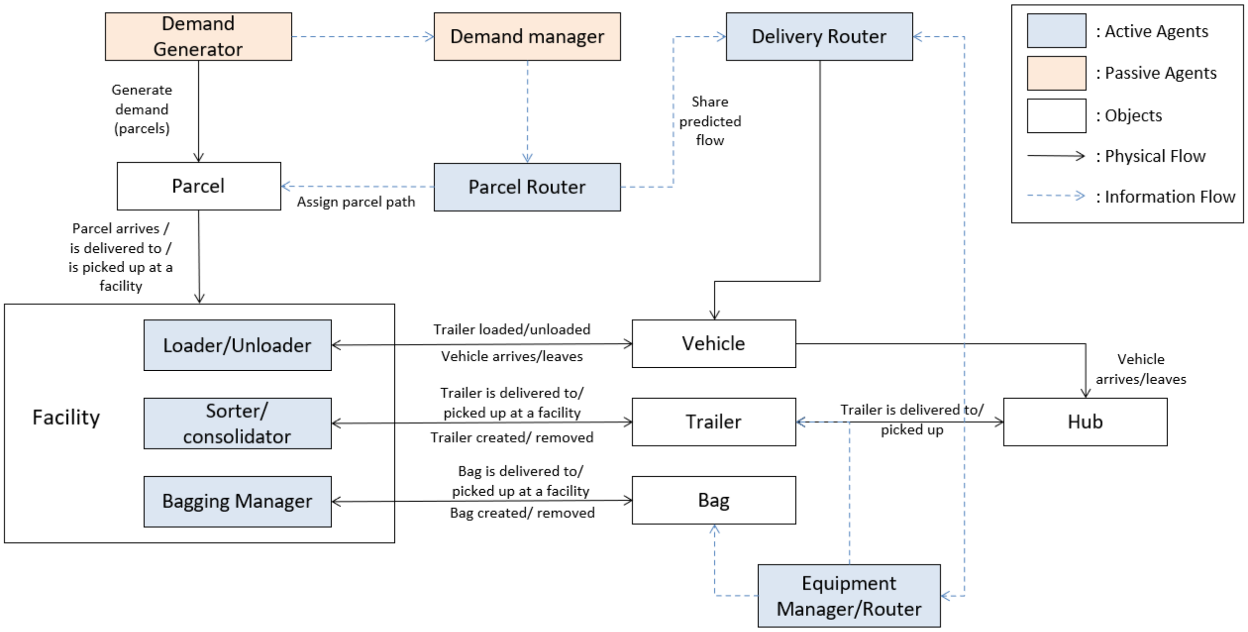


Figure 3.8: Agent diagram for the network.

This model has six active agents, two passive agents, and five objects. Customer arrival is programmed with a demand generator, which generates parcels with specific attributes such as origin, destination, and service level. The demand manager observes the historical pattern of demand and forecasts. It sends the demand prediction to a parcel router that builds paths for upcoming parcels. At arrival, the parcel router assigns a path to each package. Within a facility, parcels may be bagged or unbagged based on the decision made by a bagging manager. All parcels and bags in a facility are sorted by sorter/consolidator. Then, they are loaded into trailers to be transported to another facility or delivered to customers. A loader/unloader then loads or unloads the trailers on or off the vehicles. According to the data from the U.S Department of Energy, the average driving speed of a truck is between 50-60 mph. The assumed truck speed in this model is 55 mph. At a facility, trailers are called upon request, and then items are picked up. Trailers, as well as truck tractors, are dropped off at the next sites. Lastly, all equipment, such as bags and trailers, are managed by the equipment manager/router.

The agent diagram with containerization is shown in Figure 3.9. The only difference is that there are no bagging managers or bags. Instead, there is a container object. The equipment manager/router makes routes for containers and manages their availability at each location. Figure 3.10 shows all model elements.

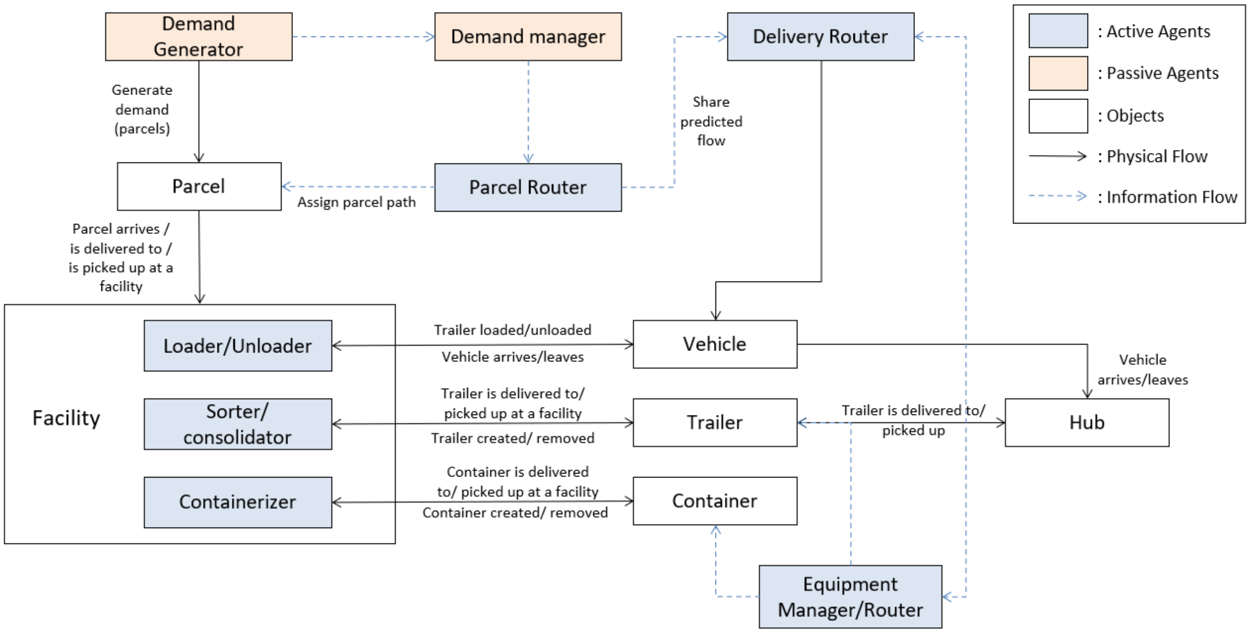


Figure 3.9: Agent diagram for the network containerization simulation (with containerization).

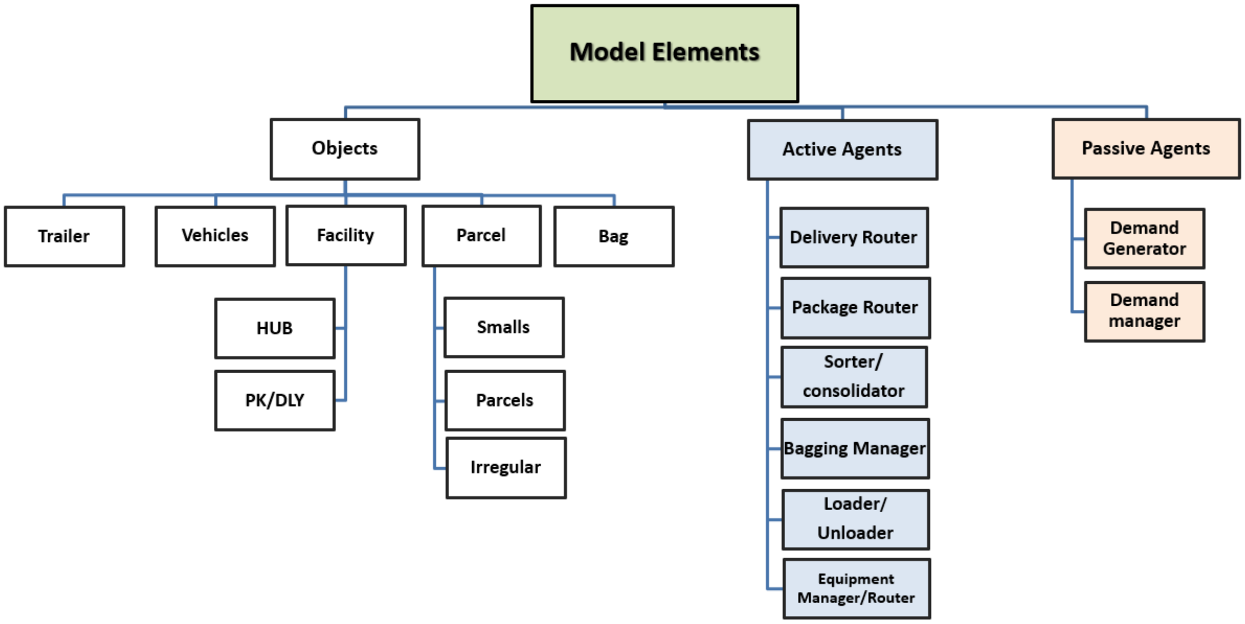


Figure 3.10: Model elements.

One section of the conceptual model defines and describes each agent and object in detail. It shows their role and functionality, attributes, any embedded algorithms, and interactions between different agents or objects.

A. Objects: Objects are entities that have no authority (i.e., they do not make decisions or move on their own) and must be moved by an agent. For example, parcels can be modeled as objects. Each parcel has attributes such as service level and origin/destination, but to move it to another facility, it must be transported by vehicles. The following are each object description:
   - Parcel: An individual parcel is a unique instance of the object type parcel. It has the following attributes:
     1) Tracking number.
     2) Origin.
     3) Destination.
     4) Creation time: At what time and date it was created.
     5) Service level.
     6) Volume.
     7) Weight.
     8) Type: Regular, irregular, or small.
     9) Parcel path: A set of locations that will be visited by a parcel, including its destination.
     10) Tracking information: location, current bag, current trailer, current container.
     11) Individual parcel IDs.
     12) Individual parcel volumes.

13) Individual parcel weights.

Attributes 1–8 are generic attributes that are assigned to packages when received from customers. Attribute 9 is assigned to each parcel by a parcel router based on its origin and destination. Attribute 10 includes the current location of the parcel and consolidation information such as the bag, trailer and/or container it is currently in. In the case of aggregated items, where multiple parcels are modeled as one instance, information about individual parcels is kept in attributes 11–13. Due to consolidation, single parcel details such as attributes 2-5 and 8–10 are not retained because they are shared. Parcels could be aggregated in a parcel pack if both the origin and destination are the same. Parcels are received from clients through the demand generator at the origin. Then, they are transported to the destination following the path assigned by a parcel router. Packages are moved between facilities by drivers as a single batch, and they are handled by a loader/unloader, a sorter/consolidator, and a bagging manager in a facility.

- Bag: This is one type of model equipment. Bags are tracked and managed by an equipment manager/router. It has the following attributes:
  1) Tracking number.
  2) Origin.
  3) Destination.
  4) Creation time.
  5) Service level.
  6) Volume.
  7) Weight.
  8) Bag path.
  9) Tracking information: location, current bag, current trailer, current container, parcels.

  Only attribute 1 is a generic attribute of a bag. Unlike parcels, attributes 2–7 are not generic. Instead, attributes 2– 8 are updated when a bag is used to consolidate a particular set of parcels. The service level of a bag is defined as the quickest service level of any of the parcels contained in the bag. Attribute 9 includes current location, consolidation information such as the bag, trailer, and/or container it is currently held in, and parcels in the bag.
- Trailer: Parcels are loaded into trailers that are tracked and managed by an equipment manager/router. A trailer has the following attributes:
  1) Tracking number.
  2) Shipping route.
  3) Volume: Both its maximum capacity and the utilized space.
  4) Weight: Both the maximum weight allowed and the utilized weight.
  5) Tracking information: location, vehicle, parcels/bags, and destination.

  Trailers also have their own tracking number. Attributes 3 and 4 have two elements: maximum capacity and amount used. Each trailer has its volume and weight capacity, but utilized volume and weight vary by case. Attribute 5 includes the current location, vehicle, destination, and parcels and bags contained in it.

- Container: This is managed by an equipment manager/router as well. It has the following attributes:
  1) Tracking number.
  2) Dimension.
  3) Origin.
  4) Destination.
  5) Creation time.
  6) Service level.
  7) Volume: Both its maximum capacity and the utilized space.
  8) Weight.
  9) Tracking information: location, vehicle, parcels.

  Each container is assigned to a unique tracking number, and they vary in dimensions. A different set of standard dimensions of containers is used to determine requirements for container types. Like bags and trailers, attributes 3–8 are updated whenever a container is used. The service level of a container is defined as the tightest service level of any of the parcels contained in the container. Attribute 9 includes the current location, vehicle, and parcels contained in it.
- Vehicle: These objects are used to transport trailers. In this work, trucks are called upon request, and they are used only once (one leg). Also, these vehicles have the same type and features, and it is assumed that each truck could carry up to three trailers. As these vehicles are not used for multiple legs, there is no need to simulate drivers. Trucks have the following attributes:
  1) Attached trailers.
  2) Current location.

  Based on the lateness of parcels, trucks are called by the loader agent to ship parcels to the next location immediately. Lateness is calculated by slack time. Slack time indicates how late the parcel is with respect to its service requirement. Suppose a parcel is not loaded and shipped to the next location after being scanned at a sorting facility. In other words, if the slack time is positive, a parcel is expected to be delivered on time. However, if the slack time is negative, the parcel needs to be transported immediately. Equation 3.1 illustrates how to calculate slack time.

$$\text{Slack time} = \text{Delivery deadline} - E[\text{remaining travel time}] - E[\text{remaining time at facilities}] \tag{3.1}$$

The delivery deadline (preload time) is the time of the day when the parcel is scanned at the destination to be out for delivery. The promised delivery time of the 1-day parcel is the time of preload on the next day, which is usually around 8:00 AM. The expected remaining travel time is the expected time to travel the remaining legs. It is calculated considering the transportation mode of that link. Similarly, the expected remaining time at facilities is the total time at each intermediate location when the parcel is not shipped immediately. In addition, for every remaining facility, the assumption is that it spends four hours on average before being sent to the next site. Since the shipment is sent at the end of the next sort, current sort remaining time is added to expected time at facilities. Vehicle routes are limited to a single leg (location A to B only).

- Facility: This is a broader type of object that has different functionality based on its type. A location has several attributes, such as:
  1) Facility ID.
  2) Location (Latitude/Longitude).
  3) Type: PK/DLY, or HUB.
  4) Current usage: Parcels, bags, trailers, and vehicles.
  5) Loader/unloader.
  6) Sorter/consolidator.
  7) Bagging manager.

  Attributes 1–3 are generic. Each facility capacity is defined as the maximum throughput by sort. Attribute 4 enables the simulator to track which parcels, bags, trailers, and vehicles are currently at the facility. A location has active agents dedicated to it, which are a loader/unloader, a sorter/consolidator, and a bagging manager, and they are considered employees.

B. Passive agents: Passive agents are agents that make no dynamic decisions during the simulation, but only serve a passive functionality. Based on simulation objectives, they are transformed into active agents by adding decision-making functions.

- Demand generator: A demand generator generates parcels during the simulation. It is a client arriving process module, and it regenerates historical demand as well. For sensitivity analysis, the demand generator generates orders from a specific probability distribution or from scaled historical demands. For example, to evaluate the benefit of containerization under twice the number of demands, the demand generator doubles historical demands. There is a single demand generator in the simulator. The demand generator goes through the following processes:
  1. Demand generation (customer arrival):
     - Historical demand: The generator creates new parcels at origin PK/DLY locations at their historical arrival time through the simulation.
     - Demand distribution: The generator creates new parcels at the origin PK/DLY locations at a given arrival rate following the demand distribution.

     Here, the demand generation process follows historical demand, where demand is created and used as historical data.
  2. Demand manager: The demand manager observes historical demand patterns and predicts future demand for routers to build routes and schedules for the future in advance. There is only one demand manager in the simulator. Since a short period is considered in this work, the demand manager is modeled to deliver a fixed demand prediction to the parcel router.
- Traffic module: A traffic module controls driving speed. It determines driving speed randomly during the simulation based on a particular probability distribution or based on historical data.

C. Active agents: Active agents serve the role of dynamic decision-makers in the simulation. Heuristics, rule-based policies, or even optimization algorithms are embedded in these agents. The six active agents in the model are:

- Parcel router: The parcel router makes planned routes for parcels based on the shortest distance for the two-tier network. For the four-tier network, it follows the same protocol as the multi-plane logistics web. There is only one parcel router in the simulator.
- Loader/unloader: There is a single dedicated loader/unloader at each facility. The job of a loader/unloader is to load/unload trailers on or off the vehicles. The loading/unloading time is negligible as all parcels are ready to be transported after each sort. The trailer is unloaded, and all parcels in it are sent to a sorter/consolidator. Loading is activated when there is a trailer waiting at the outbound dock at the time of truck arrival, or when a sort is finished. Parcels are loaded at the end of every sort.
- Sorter/consolidator: A single sorter/consolidator is stationed at each location. Their job is to sort and consolidate bags and parcels to be transported in a batch in a trailer. When they sort parcels or bags, some of them could be missorted. Sorting operation follows a continuous sort plan, which is when the sorting operation goes on without stopping, potentially with varying sort capacity by time. Figure 3.11 illustrates the sorting logic when receiving a parcel at a location, which is as follows:

  1. When a parcel arrives at facility A and its next destination is facility B, it goes through sorting immediately, except if that sort is the preload sort.
  2. If that facility is the package destination, it is sorted immediately. Later, it is sorted at the next preload sort.
  3. After the completion of the current sort, trailers wait at the dock, and they are loaded with the flow from the upcoming sorts until they are picked up by a vehicle going to facility B.
  4. The preloaded trailer picks up all out-for-delivery parcels that are sent to customers.

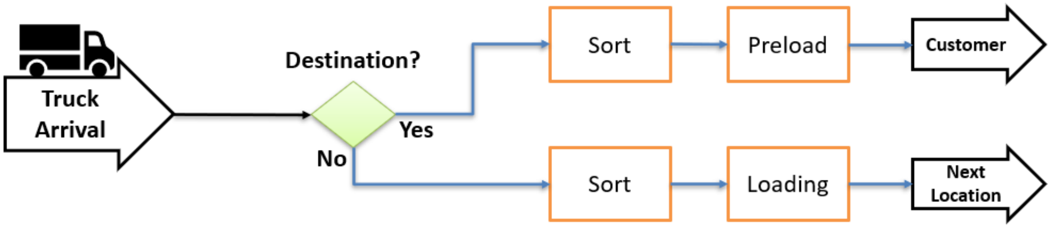


Figure 3.11: Sorting logic.

- Bagging manager: There is a single bagging manager at each facility. They make aggregation decisions and do both bagging and unbagging when needed. The bagging decisions include bag routing since the items in the bag naturally determine the bag path. The bagging manager has the information on all parcels and bags in the facility.

Consolidation through bagging is done on two levels. All smalls are consolidated into bags at their origin, depending on their destinations. The bag is maintained throughout the entire route and is only opened at the last location.

- Containerizer: Same as the bagging manager, they make containerization decisions. They have information on all parcels, bags, and containers in the facility. The containerization process is the same as the bagging process. However, unlike bagging, which is exclusive to smalls, all types of parcels can be put into containers together. At containerization, the smallest size of the container is chosen. Here, there is no limit on the number of containers that can be used to run the network. A container can be requested at any time if there are parcels to be shipped.
- Equipment manager/router: The equipment manager/router manages bags, trailers, vehicles, and containers throughout the entire network. There is a single equipment manager/router in the simulator.

Returning to the objectives of this proposal, studies are designed to assess and improve parcel delivery networks. The first three studies require multiple simulation models as follows: first, two models to simulate two different configurations when bags are used to consolidate small parcels; second, modifications of the previous two models to employ containers; and third, a model to emulate the new proposed structure. We will now consider these studies in depth.

3.2.3 Study 1

This study is designed to test and compare the performance of two different hub-and-spoke network structures. These two architectures are the two- and four-tier hub-and-spoke networks. Next, the construction of both configurations is described.

A. The two-tier hub-and-spoke: In this network, tier 1 consists of PK/DLY locations, while tier 2 contains hubs. Based on the eight protocols of the hub-and-spoke network investigated by O’Kelly & Miller (1994), we decided to choose protocol A to build this network, where there are connections between all tier 2 locations, as shown in Figure 3.12. PK/DLY facilities are in cities and towns, while hubs are mainly located in big cities. The two-tier network is described in Figure 3.13.

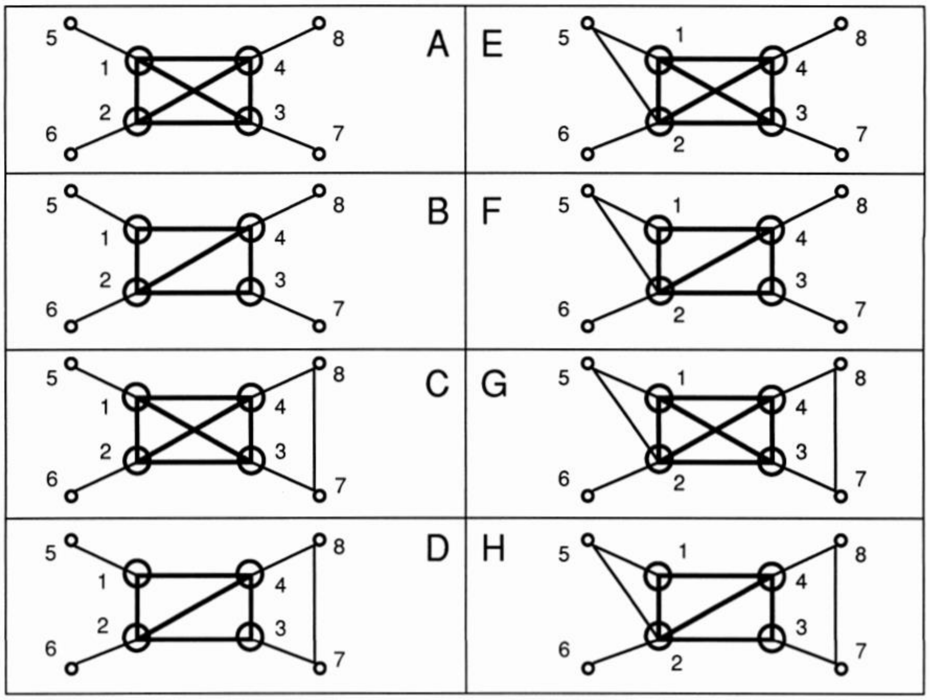


Figure 3.12: Hub-and-spoke network protocols (O'Kelly & Miller, 1994).

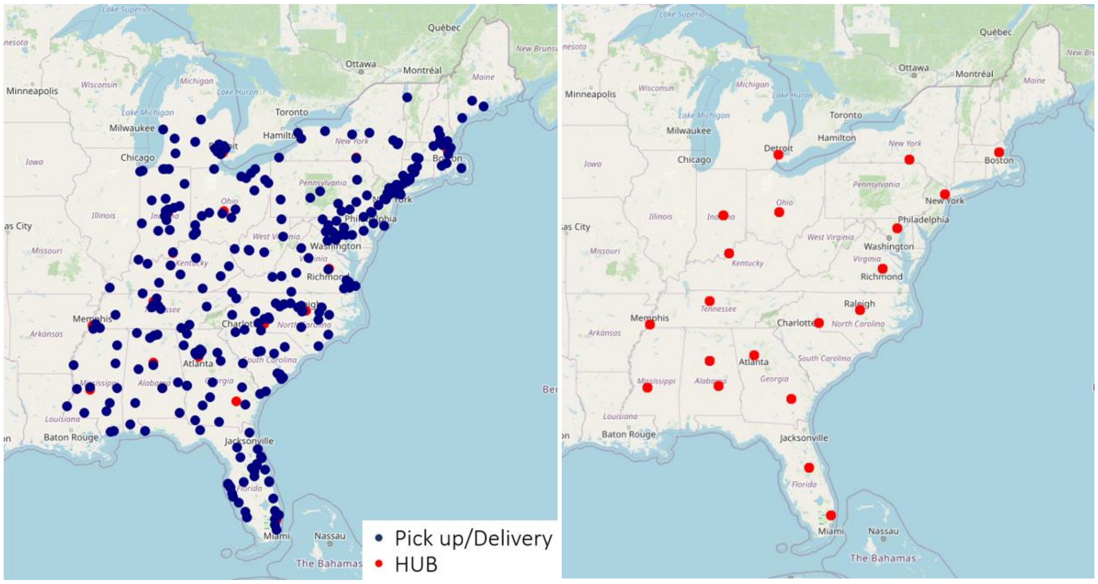


Figure 3.13: The 2-tier hub-and-spoke network.

B. The four-tier hub-and-spoke: This configuration is built based on the multi-plane logistics web, and consists of four tiers. Movements between tiers and within the same tier are restricted to network rules. These movements are shown in Figure 3.14. According to the proposed structure, there is one region, two areas, six cells, and 22 zones. Additional locations are created in the network, which are the hubs that split each plane into zones, cells, and areas. These hubs include five regional hubs and nine gateway hubs. Also, the hubs from the two-tier network are used as local hubs. Figure 3.15 shows the geographical distribution of the four-tier network hubs.

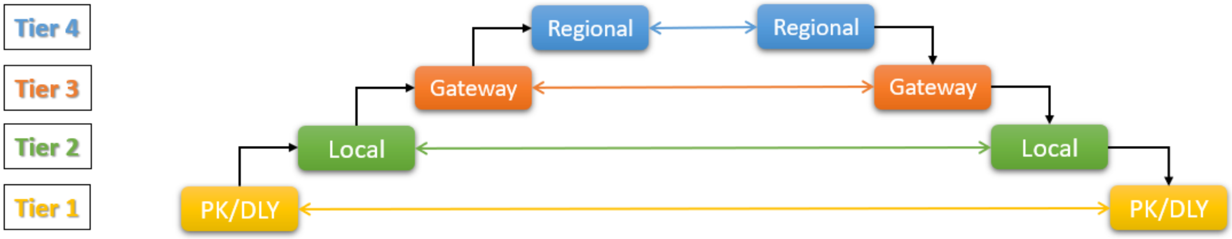


Figure 3.14: The 4-tier network movement structure.

It is essential to define the criteria that is followed to decide what the circumstances are that make one of these structures preferable to the other. Thus, the KPIs that are obtained after each run are:

1. Delivery time: The configuration that has a shorter delivery time is viewed to be a preferred architecture. This includes different delivery time statistics, such as finding the mean, quantiles, and variance for each different service level in each network.
2. Total traveled miles: The network with a shorter traveled distance is considered a better network, as it saves money and reduces CO_2 emissions.
3. The number of vehicles used: The preferred network is the one that uses fewer vehicles throughout the entire run.
4. Driving time statistics: This includes the maximum driving time per leg, the average driving time, and the percentiles.

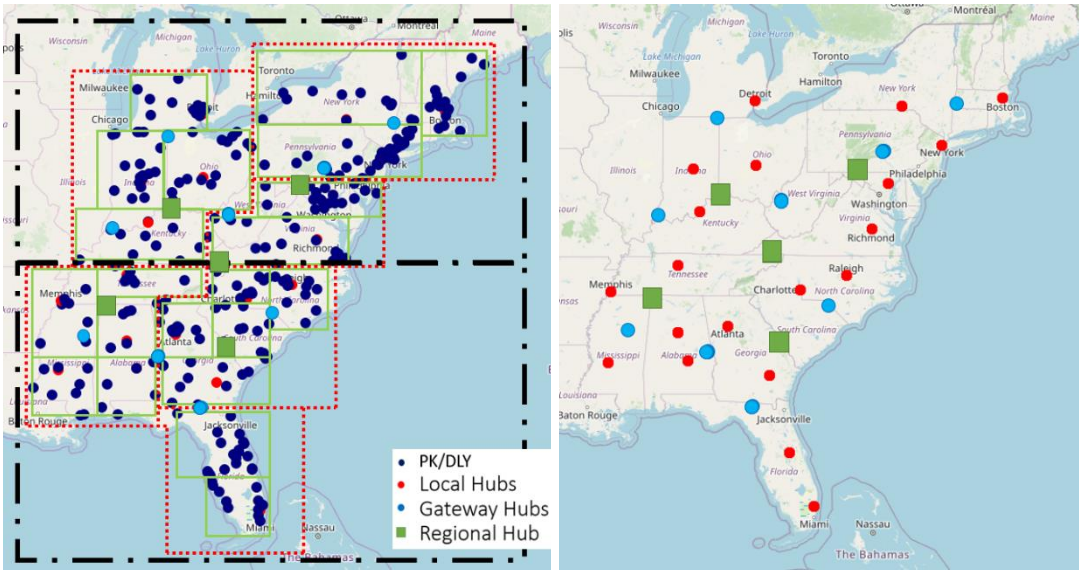


Figure 3.15: The 4-tier hub-and-spoke network.

The goal of evaluating these structures is done using simulation. The data collection process is, therefore, carried out before beginning to work on these models. Such data are used to construct facilities by looking for accessible locations on the map. In addition, simulating a virtual parcel delivery network requires data to generate realistic demands. The procedure to achieve this study has five steps, which are:

1. Data generation: Locations and various demand data sets are generated. Demand files are created based on each city's population.
2. Model development: This step is done using AnyLogic® software (AnyLogic 2020).
3. Model verification and validation: Models are put through this stage by comparing the outcomes with the project that was completed for a large international parcel delivery corporation. Also, various demands are used to verify each model.
4. Run both models (the two- and four-tier).
5. Analyze each run's output files to get the KPIs.
6. Compare both network structures to find the circumstances that make one of them preferable to the other.

3.2.4 Study 2

This study acts like the previous one, but the difference is that containers are used instead of bags. Here, a set of five standard containers are used, and they vary in sizes (in^3): 1*1*2, 2*2*2, 2*2*4, 4*4*4, and 4*4*8. As previously stated, all parcels are shipped in containers, not only smalls. The mechanism to perform this study is the same as study 1.

3.2.5 Study 3

In this study, the goal is to develop a new structure to minimize total delivery costs and time of both previous networks, including all constraints that the delivery process has. It is considered as an integration between the two- and four-tier networks, plus direct shipping between every location pair. This improvement helps in delivering parcels faster and cheaper compared to both studies 1 and 2. Here, a parcel or a consolidated shipment moves within plane 0 if both the origin and destination are in the same zone. Otherwise, it moves to a higher plane, then to another higher plane based on its path. Later, it is progressively lowered through planes until it reaches its destination. If a location has enough parcels to fill a truckload, and all share the same destination, but that destination is in a different cell or area, then parcels are transported depending on the proposed method logic, or a direct truck is sent to that location. Although the PI attempts to decrease driving time, direct shipments between two locations may require long trips. However, some reasons make it more reliable than following the PI transportation rules, such as:

1. The cooperation between carriers will take time before it is able to be applied to the PI. Hence, having direct shipments between any two locations by the same carrier is not a complicated process.
2. A direct shipment has a lower cost than any other method in case of a truckload.
3. A direct shipment has a faster delivery time compared to different approaches in case of a truckload.

Figure 3.16 describes the newly proposed method. Moreover, to keep the overall theme of the original multi-plane method, the following points and assumptions restrict the proposed direct shipments process:

1. Traveling time between the current location and the destination should not exceed eight hours, which keeps the driving time during the day less than the regulation limit.
2. The number of parcels that share the same destination should fill one of the available vehicles at that location.

3. In case there is no vehicle at that location, available vehicles that are at a nearby location are requested, and a decision is made to ship them directly or to move them to the next hub based on four-tier movement protocols.

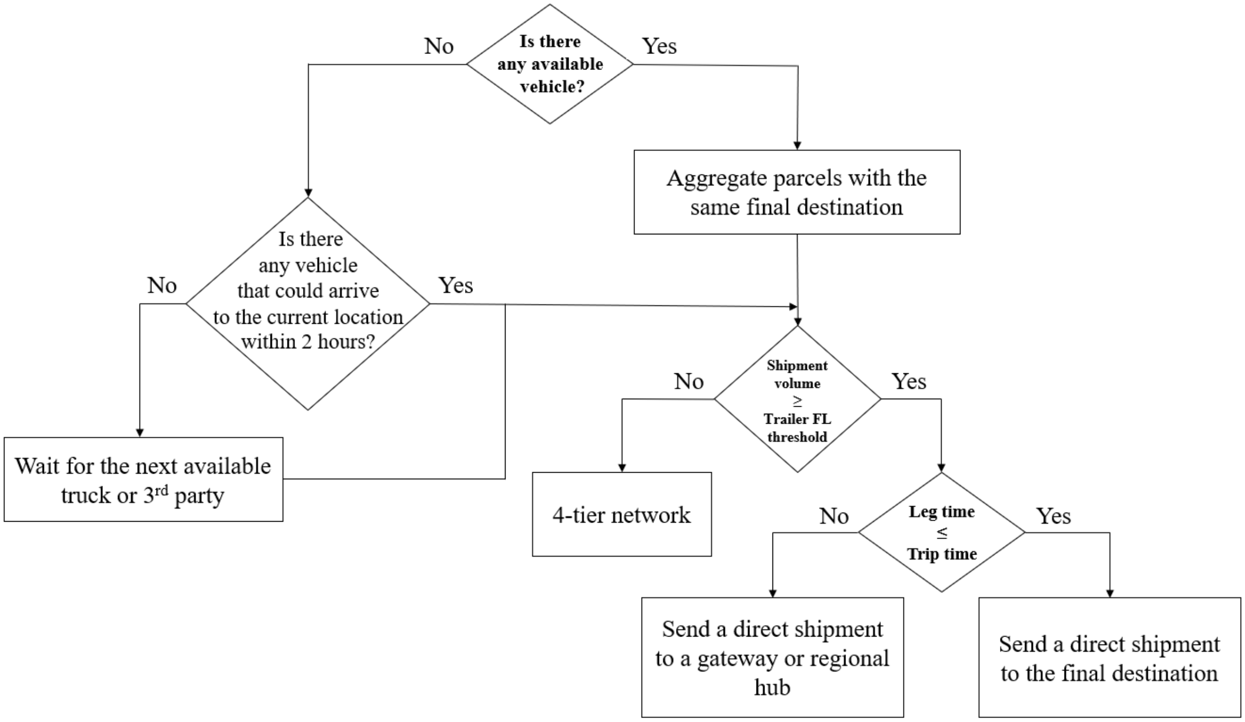


Figure 3.16: The proposed hybrid structure decision-making process.

3.2.6 Study 4

Developing an algorithm to select the best container capacities and types to achieve the goal of maximizing the overall performance of the network. It reduces total costs and enhances vehicle utilization. Standard PI container types may not fit each carrier’s operations. Thus, if a courier decides to apply these methods, selection of the optimal container capacities and types is requested. This study proposes an algorithm that uses an optimization method and technique to obtain these container characteristics. Then, the performance of the four-tier networks is assessed based on this study's results. This study procedure is as follows:

1. A container is created with a service level that is defined as the quickest service level of any of the parcels contained in it. Parcels are put in that container, and it is not opened until it reaches its destination. Data is collected at each location containing the number and total volume of parcels at any facility. Information about parcels that share the same destination after each sort is gathered. Next, these data are analyzed to find the top *X* container types, which enhance network performance.
2. Parcel data that share the same path except the destination are evaluated.
3. Data between each location pair is analyzed.
4. Classify the previous results, then get the best *X* container capacities and types for that particular structure.
5. Run the four-tier network using the best *X* container capacities and sizes found in study 4.

6. Analyze these output files to get each run KPIs.

3.3 Summary

In this chapter, the multi-plane urban parcel logistics web is illustrated, where all needed details are listed as it is one of the first study foundations. Both domain and conceptual models are discussed, which are used to describe the designed network and processes and illustrate and define the scope of the targeted simulation models. The remainder of the chapter illustrates the framework that is followed to achieve this work’s goals. All study procedures and all required steps are described. These studies are designed to evaluate and boost the outcomes of multiple parcel delivery networks and implement and develop new shipping concepts. Expected contributions from this research to the logistics service system include demonstrating an assessment of multiple parcel delivery networks, which help in deciding the best network configuration based on demand variation and network parameters. Applying the multi-plane parcel logistics web to traditional hub-and-spoke networks is one of the main contributions; this is used to prove its feasibility and usefulness. Additionally, we describe implementation and enhancement of the containerization principle, including showing how it could be applied in practice. Finally, we combine several parcel delivery networks to reveal a new configuration that overcomes the challenges of individual networks.

Chapter 4 Evaluating Performance of Two- and Four-tier Networks Using Traditional Bagging System

A parcel delivery network's performance is extremely sensitive to different factors such as hub location, the availability of trucks, route scheduling, and hub operations. Investigating the effects of these factors requires developing a parcel delivery network model, then simulating that model to determine their significance. The purpose of this study is to evaluate and compare the performance of two- and four-tier hub-and-spoke networks using traditional bagging strategy for small parcels. In this evaluation, the effect on network performance of the number of tiers, slack time, and maximum trailer fill level is studied. Results show that these factors significantly impact performance with a high contribution from the number of tiers. Moreover, the best combinations of these factors were found to enhance parcel delivery network performance under each demand pattern running condition.

A parcel delivery network performance indicator can be parcel lateness, operational cost, or vehicle utilization. Here, six KPIs are used to evaluate network performance: percentage of late parcels, operational cost, trailer average fill rates, total traveled miles, number of vehicles used, and the average driving time per leg. KPI behaviors under different factor levels were investigated. Findings show that the two-tier network is superior compared to the four-tier network except when it comes to driving time per leg.

In this chapter, Section 4.1 describes the demand generation process and model development. Section 4.2 summarizes all results, starting from the ANOVA analysis, bags and trailers analysis, KPI measurements, and subsequent sensitivity analysis. A summary is given in Section 4.3.

4.1 Demand Generation and Model Development

The demand generation process was discussed in detail in the domain model (Section 3.2). Information and data required to create different demand files to run the simulation models were collected, as well. Six demand patterns were generated, which are: low; low with warehouses; moderate; moderate with warehouses; high; and high with warehouses. The goal of using varying demand patterns is to simulate the networks under different scenarios. For example, a high demand pattern is used to simulate Christmas week demand. Difference between a pattern with or without warehouses is that warehouses simulate the case when parcels are stored and ready to be shipped, such as Amazon warehouses. The locations of these warehouses were selected using actual locations of Amazon warehouses. The goal of these warehouses is to increase the number of parcels in the network and simulate locations where a high volume is being shipped to customers.

In these demand files, parcels are created every day within a two-week demand period between 8 AM and 8 PM except on Sundays where there are no shipments. These parcels have three types; small, regular, and irregular, with four different parcel service levels; 1D, 2D, 3D, and GND. Figure 4.1 shows the number of parcels created per day for each demand pattern.

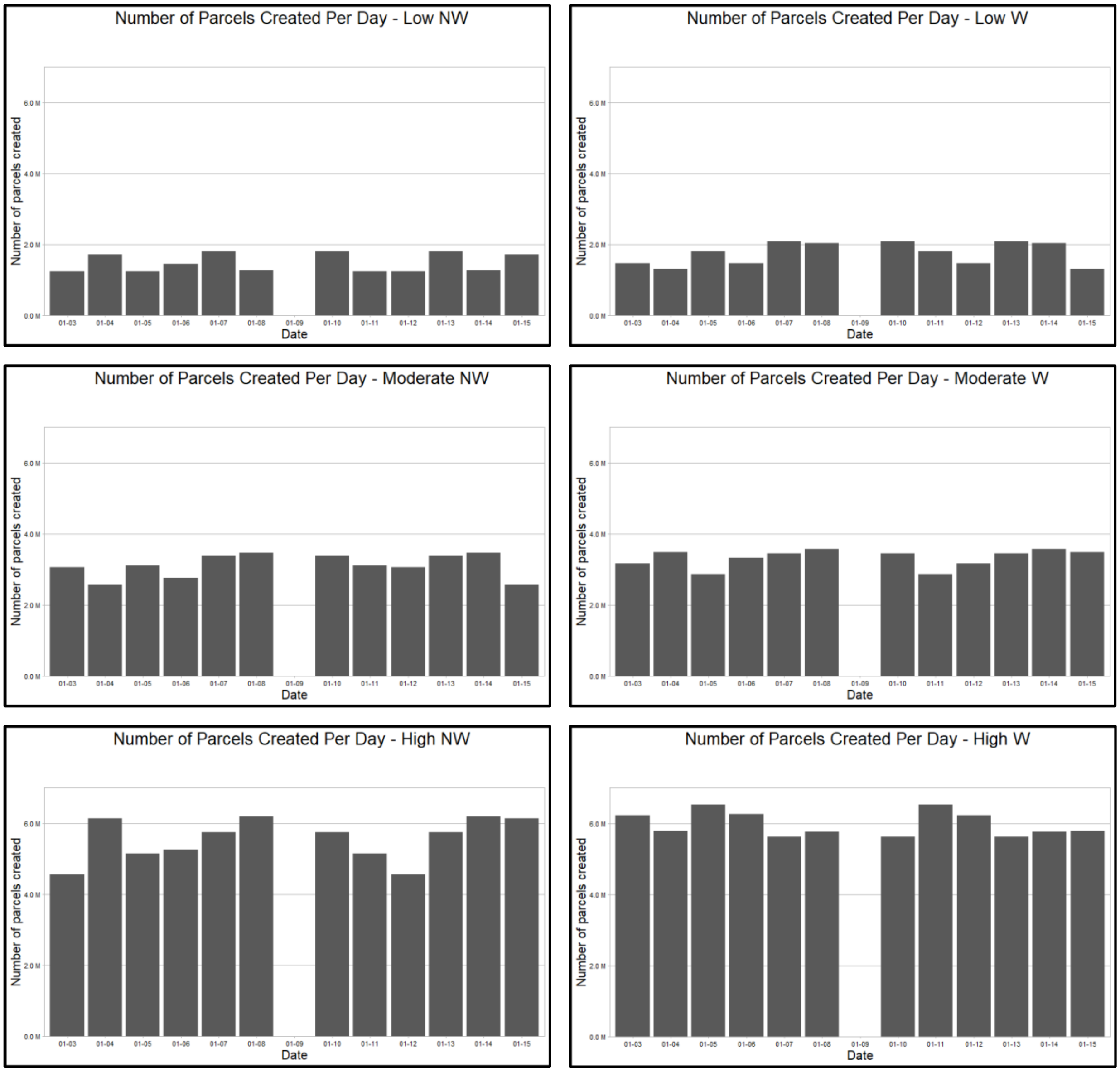


Figure 4.1: Number of parcels created per day for each demand pattern.

Also, this section illustrates the simulation model development process. AnyLogic users and scholars should be able to replicate these steps to develop similar models in the future. The model aim is to simulate two- and four-tier networks. It starts with dropping off a parcel and ends when it is delivered. In detail, a simulation run starts by declaring model agents, variables, and entities that are introduced and described in detail in the domain and conceptual models (Section 3.2). Facilities are added to the map based on their attributes such as latitude/longitude and facility type (PK/DL or hub). Parcels are created at their origins depending on drop-off time. Also, parcel expected delivery times are calculated. The delivery process begins at this point; this step is considered as a parcel drop-off. Afterward, parcels are scanned, then they are individually sorted or sent (small parcels) to a bagging process before being sorted. After the end of each sort, parcels are loaded in trucks based on slack times; the slack time is updated in the model at each parcel's event. The leg times are calculated before truck departures. A parcel will stay in transit state from a hub to another hub until it arrives at its final destination. Finally, it will be sent to a preload sort and considered as a delivered parcel. All KPIs are measured when the model is finished. The major steps to develop the model are listed below. Figure 4.2 shows the simulation model flowchart.

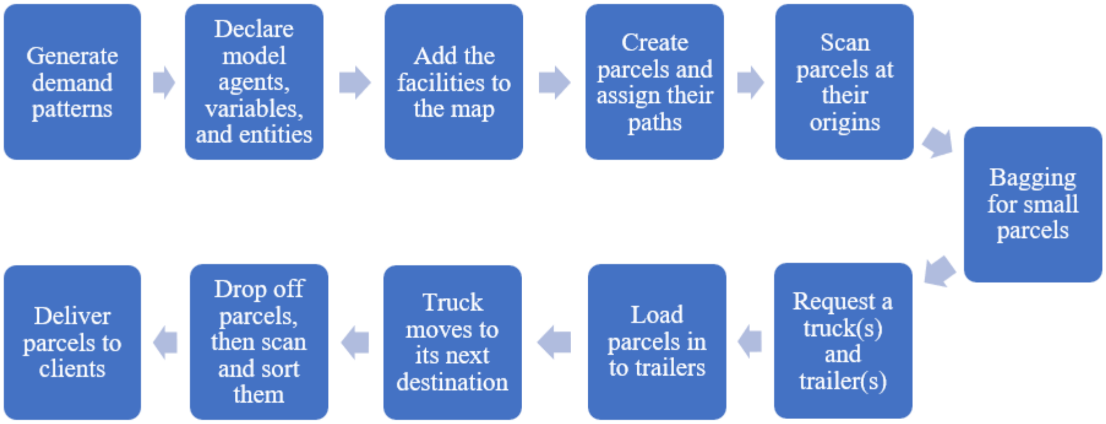


Figure 4.2: Simulation model flowchart.

1. Reading demand files. Once the demand file is generated or collected from a real data set, it could be used to run the model. Each line in the demand file simulates a parcel and contains that parcel type, service level, weight, volume, origin, and destination. First, a function is used to read locations and demand input files. The locations file is used to develop the network on the map. The demand file is used to generate parcels during the run. Figure 4.3 shows a state chart that is used to generate parcels based on their creation time. Each parcel path is assigned based on that parcel's origin and destination. Here, a parcel is created and stored at its origin before sending it to sorting.

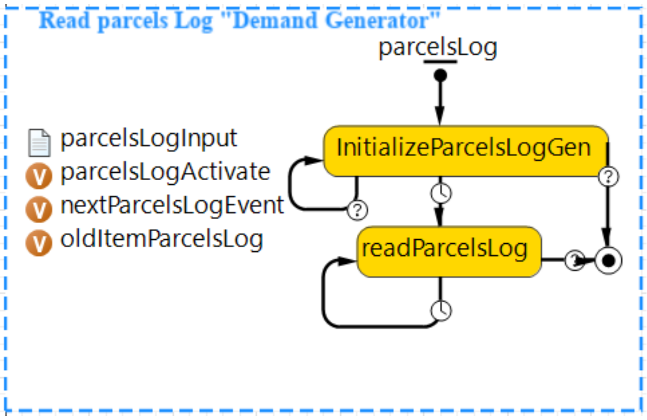


Figure 4.3: Demand generation state chart.

2. The sorting process is modeled using a state chart, where parcels are scanned individually. Parcels are sent to bagging or loading after being sorted. The bagging process is modeled through a function that runs after each sort to put all small parcels in bags based on their final destination. Figure 4.4 shows the sorting process state chart.

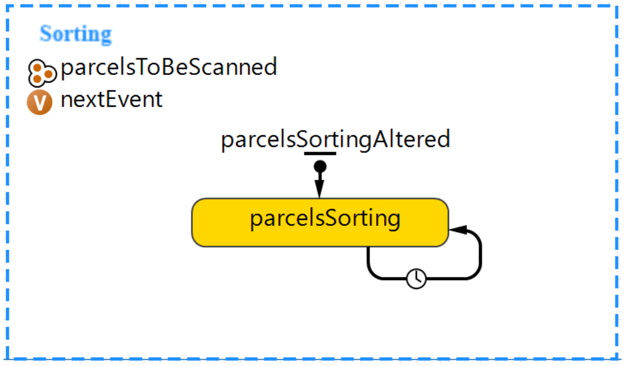


Figure 4.4: Parcel sorting state chart.

3. After each sort, a function is run to check ready parcel volumes to decide if a truck should be requested. If a truck(s) is coming to that location, the required number of trailers to be attached to each truck is determined based on the available volume that should be shipped. The loading process is modeled using a function, where parcels are loaded to the first trailer up to the maximum trailer fill level, then the second and third trailer, respectively.
4. A truck departs after trailers are loaded. The leg distance is calculated using the distanceByRoute(agent) function, which is a built-in function in AnyLogic that calculates distance from the current agent to another one by route based on the GIS map. Upon arrival at that truck's destination, parcels and bags are unloaded. Each parcel will be checked to determine if it arrived at its final destination. Parcels that arrived at their final destination are scanned and sent to a preload sort, while others are scanned, sorted, and loaded to another truck. After each leg, that leg's truck is deleted from the network. A parcel will be deleted and assumed that it was delivered after being scanned at a preload sort. Figure 4.5 shows the truck movement process chart.

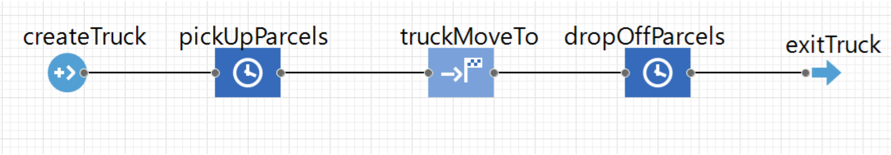


Figure 4.5: Truck movement process chart.

5. To verify and validate this model, sample demand files are generated. The parcel paths and delivery times are calculated before being run as a reference to check model output. The verification process is completed by debugging the code and printing out each function or process output. These prints are checked to test that each process or function is running properly. Moreover, run outputs are analyzed and compared to their reference. Once the model is verified, actual demand files are used to validate the model. KPIs are measured and analyzed after each run. These KPIs are compared to the KPIs obtained from the previous project that was done for one of the international carriers. During the project, several domain experts from the sponsor company evaluated the model and participated in the final validation process. Also, different scenarios were run and evaluation of these run's outputs was done based on our experience that was developed after working on the

mentioned project. After the verification and validation process, the model was ready to run.

4.2 Results and Discussion

In this section, results and related analyses are discussed. First, model factor analysis was done to determine which factors were significant, and a conclusion was made based on ANOVA analysis. Second, an analysis of the number of bags and trailers for all design points is demonstrated. Third, an investigation about the effect of model factors on the behavior of the network KPIs is performed. The last section contains a sensitivity analysis to evaluate results under different fuel prices and sorting costs.

The simulation model was run to evaluate performance of both two- and four-tier networks. Different demand patterns were used to study the effect of the number of tiers, slack times, and maximum trailer fill levels on network performance. The slack time factor is a threshold value that is used as a reference to determine if a parcel is late. For example, if the slack time factor is set to 0, then a parcel is considered as a late parcel if it's slack time, which is updates based on equation 3.1, is less than the slack threshold. The slack factor values were zero and four hours, and three different maximum trailer fill levels of 60%, 80%, and 100% were tested. A reduction in the percentage of late parcels is one of the main aims of this study; thus, slack times were selected to test the network at different levels. In the two-tier network, it was found that slack time affects the percentage of late parcels if it is increased from zero up to four hours, but showed no effect on network performance for slack greater than four hours. Changing slack time up to 24 hours did not affect the percentage of late parcels in the four-tier network, as shown in Figure 4.6.

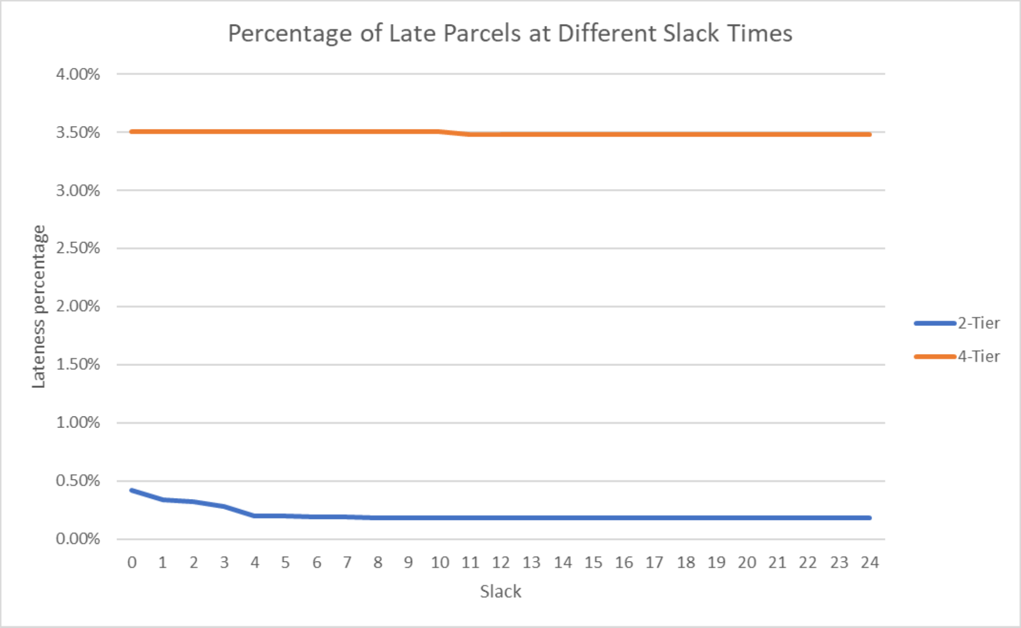


Figure 4.6: The effect of increasing slack on the percentage of late parcels for both the two- and four-tier networks.

Based on the number of factors and levels, this study has 72 design points. For each of these points, three replicates (216 runs in total) were run to improve result accuracy. Table 4.1 illustrates each design factor and its levels, while Figure 4.7 shows a tree of all factors and levels with a sample of its branches. Each branch of this tree has three replicates. The use of three replicates helps guard against sharing conclusions without sufficient evidence. Results obtained are close at the same design point.

Table 4.2 shows two KPI statistics (operational cost and driving time per leg) after three replicates when warehouse demand is high. The coefficient of variation, which is the easiest measure to be tracked in the table, indicates that dispersion is low, which means that a small number of replicates is enough to describe output variability. Furthermore, the rest of the KPIs show similar results that strengthen the decision to use three replicates. Besides, driving time measures indicate that run outputs are close to each other, and the randomness could be described using three replicates. In this work, each run time ranges between 0.3 to 10 hours depending on the demand level, and there are more than 1,250 runs. Given the relatively low variability and the long run length, the three replicates' decision is reasonable and describes the randomness.

Table 4.1: Network design factors and levels.

Design Factor	Factor Levels					
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Demand Pattern	Low	Low W	Mod	Mod W	High	High W
Number of Tiers	2	4	-	-	-	-
Slack	0	4	-	-	-	-
Maximum Trailer Fill Level	60%	80%	100%	-	-	-

Table 4.2: Operational cost statistics when the demand is high with warehouses.

Slack time	Maximum trailer fill level	Number of tiers	Average	Standard deviation	Coefficient of variation	Standard error	Confidence interval
0	60	2	166578015	5094861	3%	2941519	12656337
0	80	2	140548087	4037641	3%	2331133	10030055
0	100	2	123027855	15980560	13%	9226381	39697912
4	60	2	166126915	9483419	6%	5475254	23558118
4	80	2	149330210	7433021	5%	4291457	18464649
4	100	2	140280072	5706040	4%	3294384	14174588
0	60	4	231826134	7218407	3%	4167549	17931517
0	80	4	209847125	6442062	3%	3719326	16002969
0	100	4	196777416	5965938	3%	3444436	14820211
4	60	4	232096581	7237082	3%	4178331	17977908
4	80	4	210220414	6411565	3%	3701719	15927211
4	100	4	197176536	5951202	3%	3435928	14783606

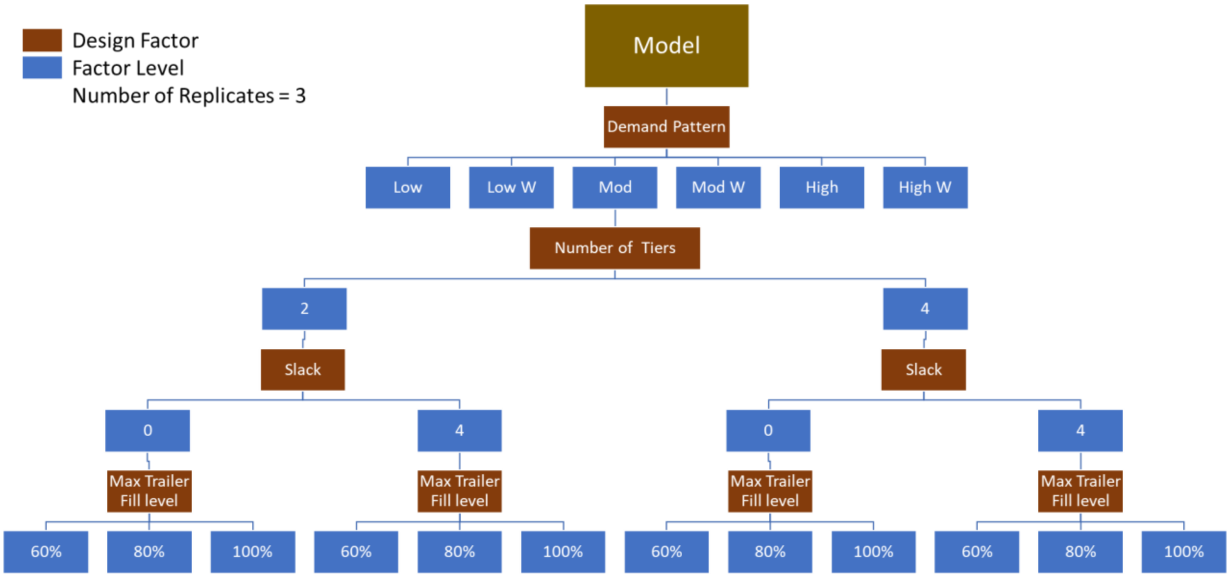


Figure 4.7: Full factorial design 3 variables under each demand pattern.

4.2.1 Model Parameters

Three different factors were used to investigate each demand pattern's parcel delivery network performance: the number of tiers, slack, and maximum trailer fill level. Testing if these factors are significant or not is the first step. Results confirm that these factors are crucial, and directly affect performance. ANOVA was performed to determine the key factors and their contributions to parcel delivery network performance. Results were obtained for each demand pattern separately as one of this study's goals is to study performance under different scenarios.

There are no specific universal criteria to judge network performance. In real life, managers' priorities vary; many KPIs focus on cost reduction, while others consider customer satisfaction as their goal. Another group tries to optimize all KPIs. To better evaluate and compare distinct scenarios, eight different priorities were tested: the percentage of late parcels, operational cost, the utilization of trucks and trailers, average driving time per leg, environmental effect, operational cost and lateness together (2 different cases), and all eight priorities were equally weighted. An equation that includes all KPIs is used to describe each priority. KPIs with high priority are given a weight coefficient of nine, moderate priority weight is five, while low priority weight is one. The fill rate KPI coefficient is negative because if the fill rate increases, the cost should decrease indicating good performance. The term cost is used to describe the following equation.

$$Y_j = \sum_{i=1}^{6} \alpha X_i \tag{4.1}$$

Where Y_j represents the cost as described in Table 4.3. X_i represents each of the KPIs (1: Traveled miles; 2: Number of vehicles used; 3: Operational cost; 4: Driving time per leg; 5: Lateness; 6: Fillrate), while α represents the weight coefficient. KPIs values are standardized before being used in this equation to ensure that all variables contribute to a scale when added together.

Table 4.3: KPI cost equations based on priorities.

Priority	Cost Equation
Equality (Y_1)	$= X_1 + X_2 + X_3 + X_4 + X_5 - X_6$
Lateness and Operational Cost I (Y_2)	$= 9 * (X_5 + X_3) + X_1 + X_2 + X_4 - X_6$
Lateness and Operational Cost II (Y_3)	$= 9 * X_5 + 5 * X_3 + X_1 + X_2 + X_4 - X_6$
Utilization (Y_4)	$= 9 * (X_2 - X_6) + X_1 + X_2 + X_3 + X_5$
Driving Time per Leg (Y_5)	$= 9 * X_4 + 5 * X_5 + X_1 + X_2 + X_3 - X_6$
Environment (Y_6)	$= 9 * (X_1 + X_2) + 5 * (X_3 + X_5) + X_4 - X_6$
Operational Cost (Y_7)	$= 9 * X_3 + 5 * X_5 + X_1 + X_2 + X_4 - X_6$
Lateness (Y_8)	$= 9 * X_5 + 5 * X_3 + X_1 + X_2 + X_4 - X_6$

ANOVA results indicate that the number of tiers, slack, and maximum trailer fill level significantly affect parcel delivery network performance. The number of tiers has a higher contribution to performance than slack and maximum trailer fill level. Also, interaction between slack and number of tiers, and maximum trailer fill level, and the number of tiers are significant. In contrast, interactions between slack and maximum trailer fill level and a three-way interaction between all factors are insignificant in most scenarios. Table 4.4 shows significant factors for each cost when the demand is low, while analyses for the remaining five demand patterns is in the appendix.

Table 4.4: Significant factors for each cost based on ANOVA analysis when the demand pattern is low.

Low - No warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level								
Slack*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers								

Based on the previous analysis, the best combination of factors and levels for each demand pattern is summarized in Table 4.5. The best combination for most scenarios is when slack is zero hours, maximum trailer fill level is 100%, and the number of tiers is two. These results are reasonable as the two-tier network uses the lowest number of trucks, lowest operational cost, and lowest traveled miles. Also, lateness percentages are always less than the four-tier network. When the maximum trailer fill level is 100%, it indicates that the model is assumed to use fewer trucks; consequently, it lowers the total traveled miles and operational cost. Each cell in Table 4.5 can be read as follows: slack, maximum trailer fill level, and the number of tiers.

Table 4.5: The best parcel delivery network configuration for each demand pattern.

Demand Pattern	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Low	0,80%,2	0,100%,2	0,100%,2	0,60%,2	0,100%,2	0,100%,2	0,100%,2	0,100%,2
Low W	0,80%,2	0,80%,2	0,100%,2	0,60%,2	0,100%,2	0,100%,2	0,100%,2	0,100%,2
Moderate	0,100%,2	0,100%,2	0,100%,2	0,60%,2	0,100%,2	0,100%,2	0,100%,2	0,100%,2
Moderate W	0,100%,2	0,100%,2	0,100%,2	0,60%,2	0,100%,2	0,100%,2	0,100%,2	0,100%,2
High	0,100%,2	0,100%,2	0,100%,2	0,80%,2	0,100%,2	0,100%,2	0,100%,2	0,100%,2
High W	0,100%,2	0,100%,2	0,100%,2	0,80%,2	0,100%,2	0,100%,2	0,100%,2	0,100%,2

4.2.2 Bags and Trailers Analysis

This study aims to evaluate and compare two- and four-tier networks when bags are used to deliver small parcels. A bag capacity is 25,000 in^3, which means that a single bag can carry a minimum of 55 small parcels when it is full. Slack times and number of tiers are the factors that affect the number of active bags in a network. Obtaining the maximum number of active bags helps managers decide how many bags a company needs to run its operations. Figure 4.8 shows the maximum number of active bags for each demand pattern at different slack times and number of tiers. Findings indicate that there is around a 30% increase in the number of active bags when slack increases in the two-tier network. In comparison, there is no difference in results in the four-tier network. Also, the four-tier network uses more bags compared to the two-tier by around 25%.

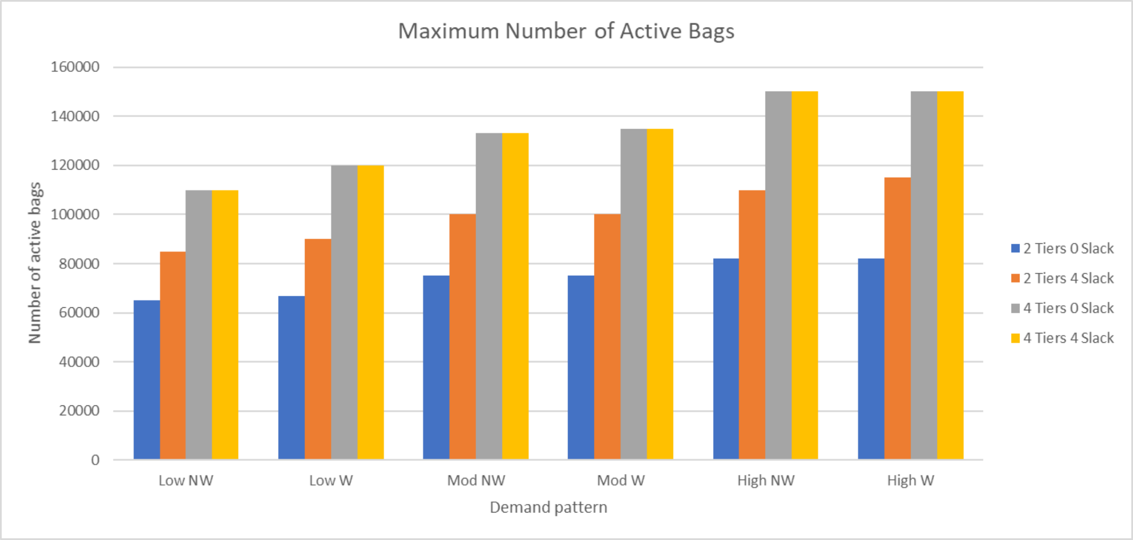


Figure 4.8: Maximum number of active bags for each demand pattern based on slack and number of tiers.

Determining the number of trailers to run a network is essential information. In this model, six different trailer types were used, each with a different capacity. The number of active trailers is affected by all factors except slack, as shown in Figure 4.9. Furthermore, trucks move from a hub to hub, hub to pickup and delivery location, vice versa, or between two pickup and delivery locations. These movements require shipping a high volume between locations. Hence, results show that the most used trailer is the highest capacity trailer, type 6 (28-foot trailer), while other types' usage was extremely low. Hence, Figure 4.10 illustrates the usage of other trailer types that are more commonly used by the four-tier network compared to the two-tier network. Results in Figure 4.9 confirm that as maximum trailer fill level increases, the required number of trailers decreases. Also, the four-tier network uses slightly more trailers compared to the two-tier network.

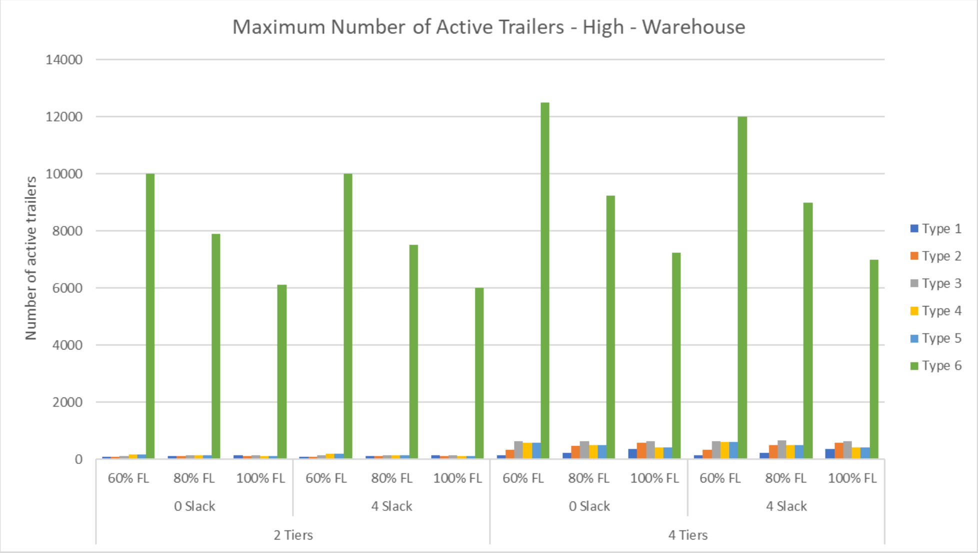


Figure 4.9: Maximum number of active trailers for each design point per trailer type when the demand pattern is high with warehouses.

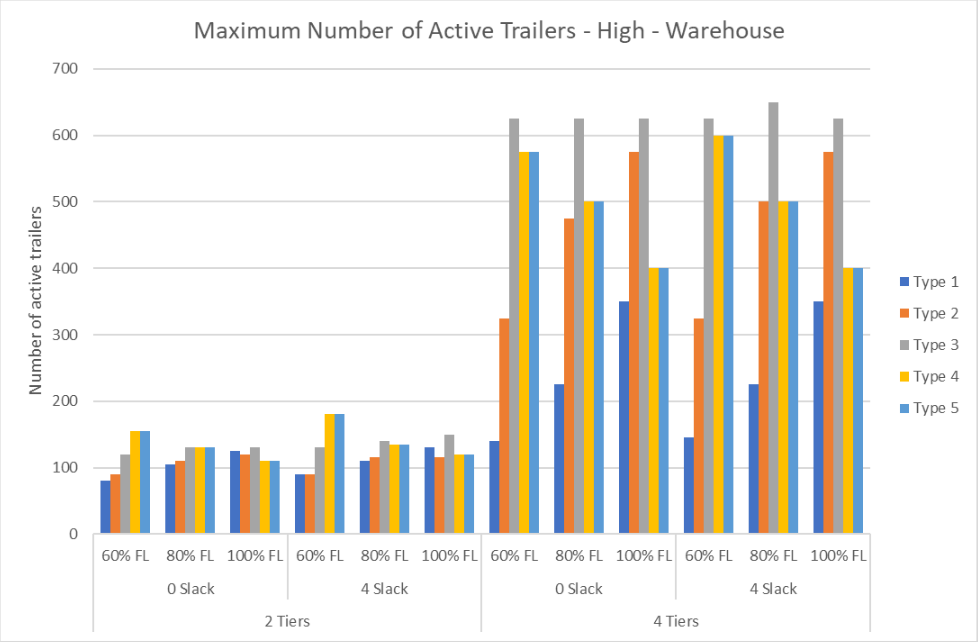


Figure 4.10: Maximum number of active trailers for each design point per trailer type (1,2,3,4, & 5) when the demand pattern is high with warehouses.

After investigating the maximum number of active trailer results, it was found that the four-tier network uses more trailers compared to the two-tier. However, figures show that there are spikes in these numbers for a short period, as in Figure 4.12. From a managerial perspective, owning a massive fleet of trailers to serve these spikes will increase overall costs. Hence, spikes are eliminated by taking the 90th percentile of the maximum number of active trailers, then comparing them between all scenarios. Figure 4.12 and Figure 4.13 show the maximum number of active trailers after excluding these spikes. New results indicate that the four-tier network uses a smaller number of active trailers than the two-tier. Also, as other trailer types are rarely used, it is recommended to use the 28-foot trailer only.

In practice, eliminating these spikes may be carried out by signing contracts with third parties to ship parcels to their next destination. These collaborations directly influence original operational cost, which is calculated using transportation and scanning costs only. However, by having partnerships to handle these spikes, a new term will be added to the cost equation that is third-party cost. Managers should have a feasibility study that analyzes the impact of having their fleet only or having partnerships with a third party. These spikes occur once to three times per day for a short period, which is less than two hours. Hence, if managers decide to reduce their fleet size, then they do not need to keep tracking and working with those partners during the entire day.

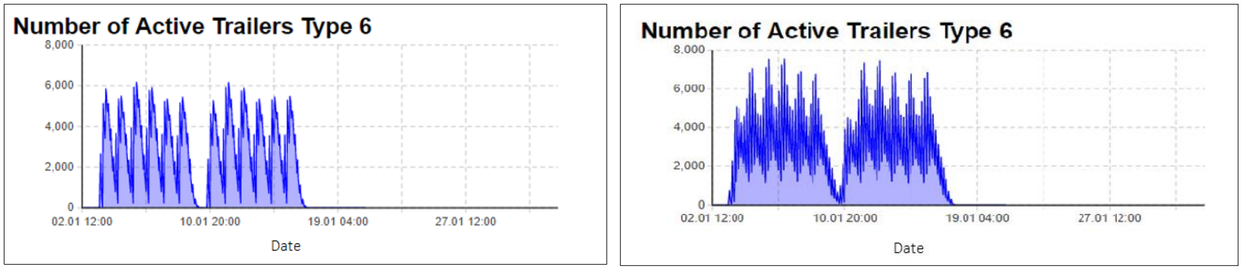


Figure 4.11: The effect of spikes on the maximum number of active trailers plot.

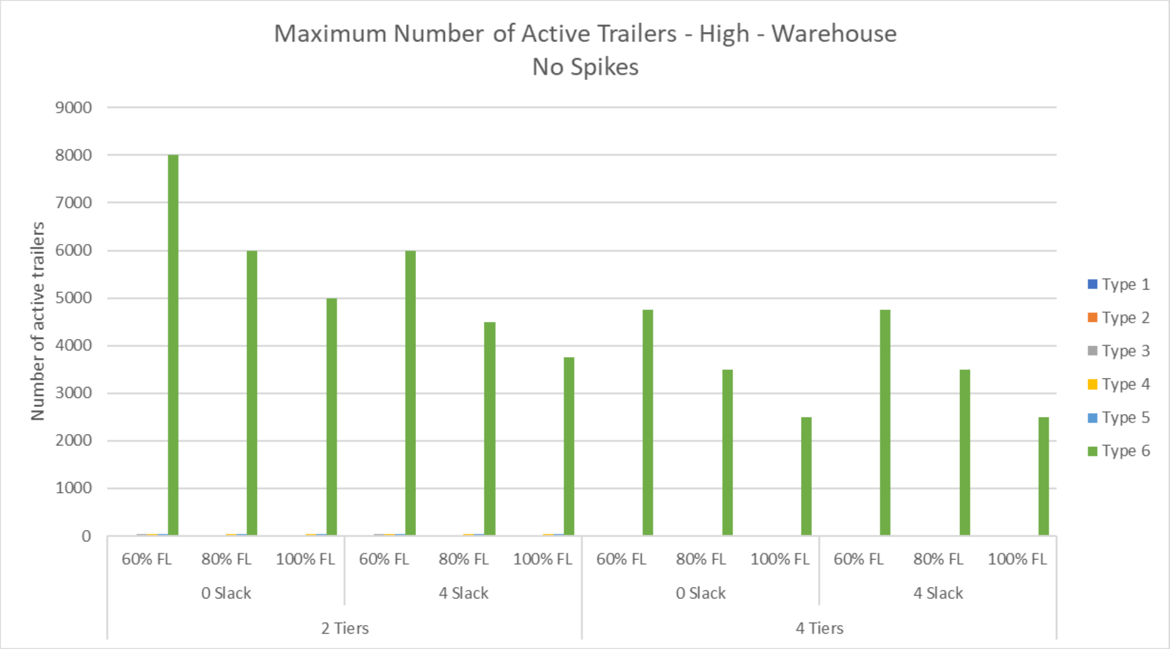


Figure 4.12: Maximum number of active trailers for each design point per trailer type when the demand pattern is high with warehouses – spikes are excluded.

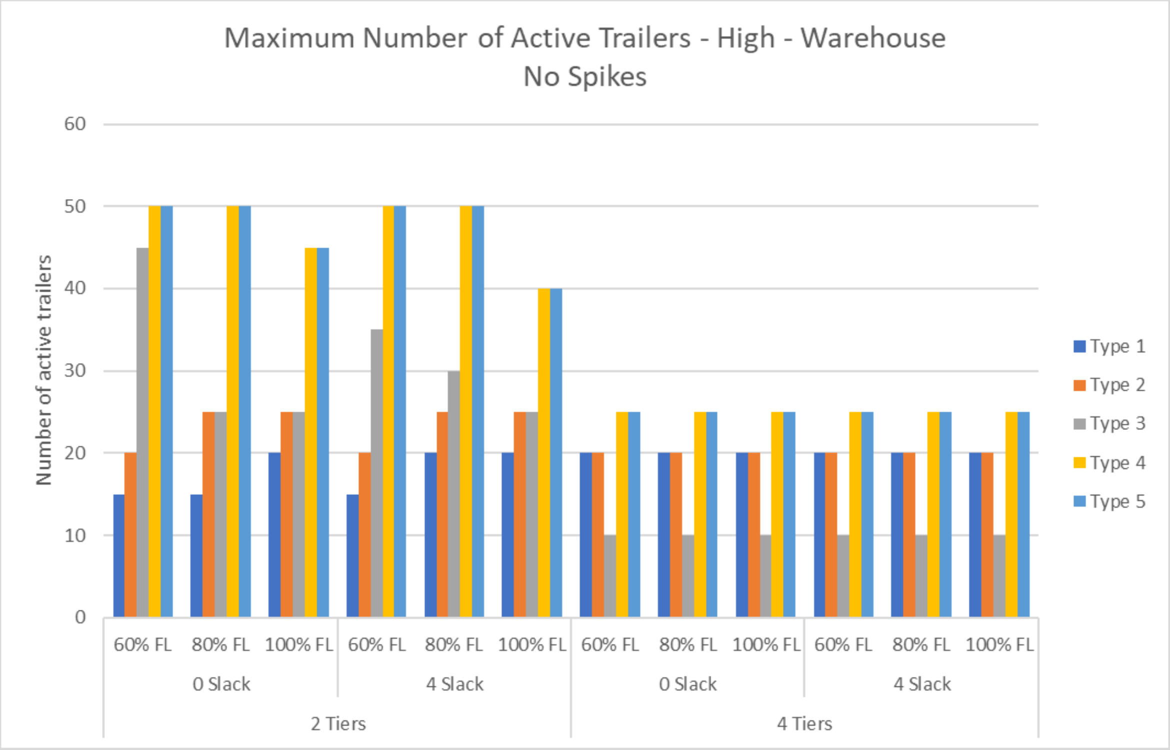


Figure 4.13: Maximum number of active trailers for each design point per trailer type (1,2,3,4, & 5) when the demand pattern is high with warehouses – spikes are excluded.

4.2.3 KPI Analysis

Performance analysis converts data into information. Practical analysis helps managers make better decisions that drive improved strategic outcomes. As discussed in Chapter 3, there are six different KPIs to be measured after each simulation run: percentage of late parcels, total traveled miles, number of vehicles used, operational cost, fill rate, and driving time per leg. Each of these KPIs are analyzed at each design point.

One of the most critical KPIs that affects both the company and clients is the percentage of late parcels. Lateness percentage is obtained using the following equation:

$$\text{Lateness\%} = \text{number of late parcels} / \text{total number of parcels} \tag{4.2}$$

The number of late parcels varies for each service level and is tracked daily; the lateness percentage is then measured. Here, a threshold is set at 4 PM to split 1D parcels with high guarantees that they will be delivered on time and those that may be delayed for another day. If a client dropped off his parcel at any time before 4 PM at a pickup and delivery location, his/her parcel is considered 1D and is counted as a late parcel if it was not delivered before the end of the next day's working hours. However, parcels that are dropped off after 4 PM are considered 2D. If a parcel service level is 2D, it should be delivered within two days; otherwise, it is late. The same follows for 3D service level parcels, which should be delivered within three days. Ground parcels should be delivered within five days; otherwise, they are late. Parcels in a four-tier network visit additional locations in their path to destinations, which may cause a delay compared to a two-tier network. If this is the only KPI to select the best network configuration, then the option will be one of the two-tier alternatives when slack time is four hours. Figure 4.14 shows the percentage of late parcels for each design point.

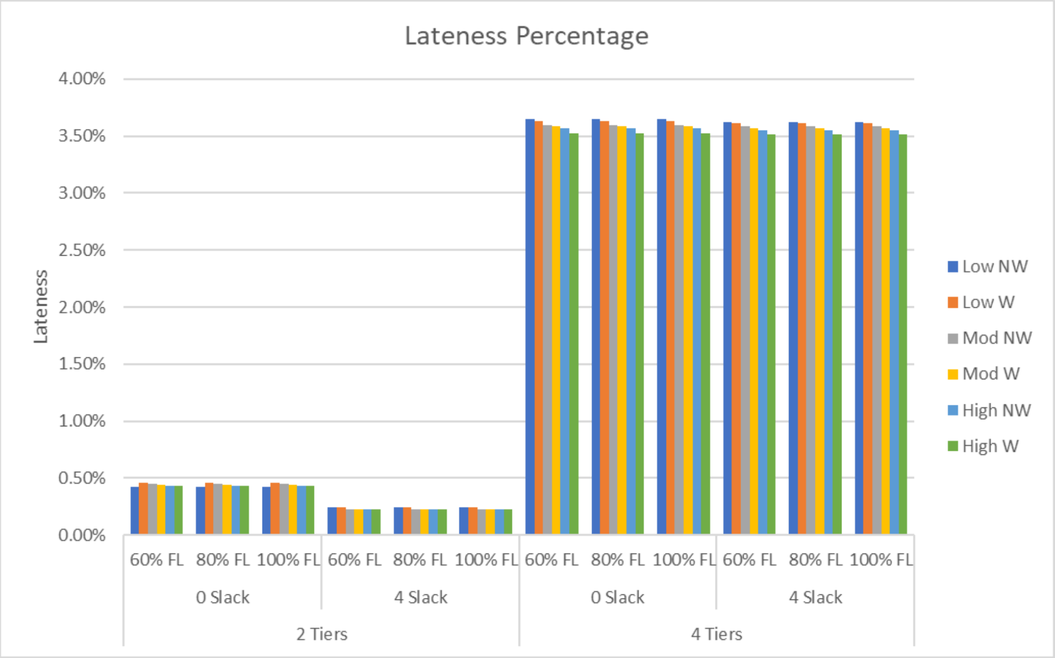


Figure 4.14: Lateness percentage for each design point.

The second most essential KPI is operational cost. Reducing this KPI is a goal for all companies in all sectors. In this study, the operational cost is calculated using the following equation:

$$\textit{Operational cost} = \textit{Transportation cost} + \textit{Small parcels cost} + \textit{Regular parcels cost} + \textit{Irregular parcels costs} + \textit{Bags cost} \qquad (4.3)$$

- *Transportation cost = 2.5 * traveled miles*
- *Small parcels cost = 2 * 0.15 * number of scans(small)*
- *Regular parcels cost = 5 * 0.15 * number of scans(regular)*
- *Irregular parcels cost = 5 * 0.55 * number of scans(irregular)*
- *Bags cost = 2 * number of bags + 3 * number of scans(bags) + 0.16 * number of bagging + 0.16 * number of unbagging*

Coefficients in the equations were specified based on previous research conducted for an international parcel delivery company. The two-tier network has a lower cost than the four-tier network; this increase in operational cost for the four-tier network is due to an increase in the number of scans. In general, using the four-tier configuration to run a parcel delivery network with bags is not a good option, since it causes an increase in operational cost. If bags are opened during runs at hubs to increase their capacities, then the cost will exponentially increase. Operational cost for each design point is shown in Figure 4.15. In all scenarios, as the maximum trailer fill level increases, the operational cost decreases because of the reduction in number of vehicles used. Slack is shown to slightly affect operational cost.

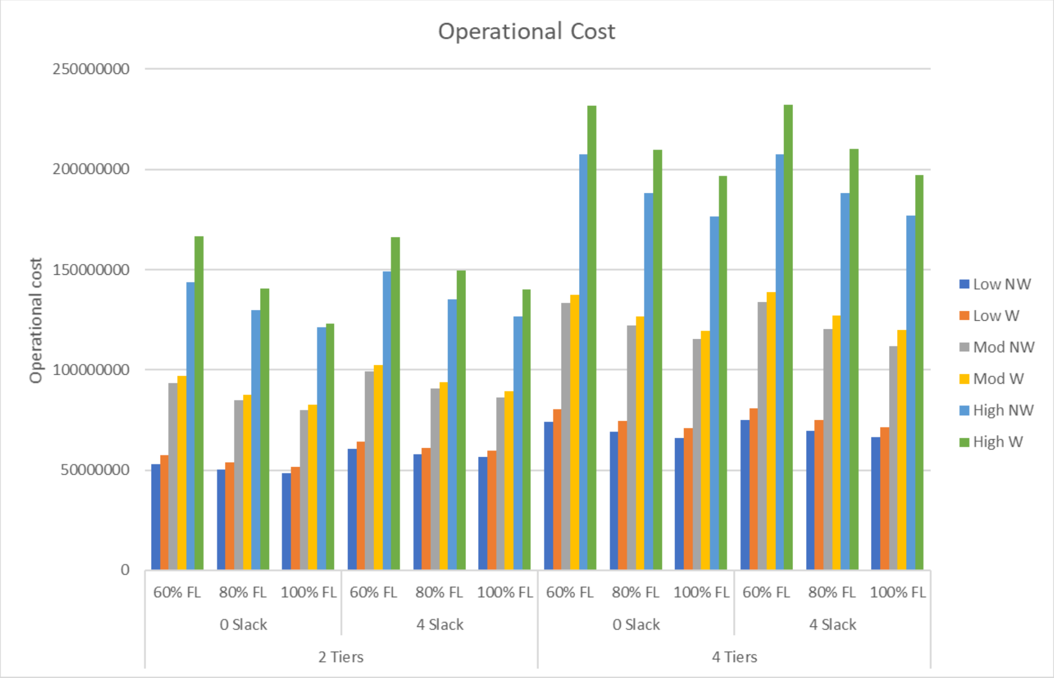


Figure 4.15: Total operational cost for each demand pattern at all design points.

The total traveled miles KPI is similar and correlated with operational cost. There is a slight difference in traveled miles between the two- and four-tier when the demand is low, while as the demand increases, the traveled miles difference increases. The four-tier network's traveled miles are also higher than the two-tier network because it has more legs between different hubs and PK/DL locations. Figure 4.16 illustrates the changes in total traveled miles at each design point.

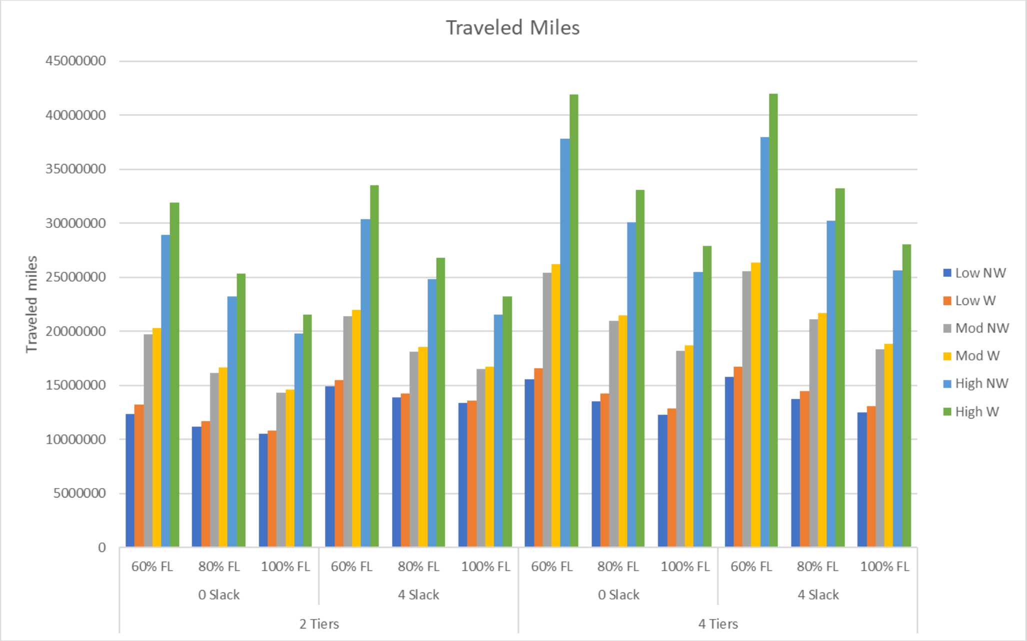


Figure 4.16: Total traveled miles for each demand pattern at all design points.

Another KPI that is measured is the number of vehicles used. Its behavior could be tracked in Figure 4.17. The main thing to notice is the increment in the number of vehicles used for the four-tier network, which is the same as total traveled miles (additional legs). Also, as maximum trailer fill level decreases, the number of vehicles increases to ship all parcels using additional trucks. Slack has little effect on the number of vehicles, which causes a slight increase in the number.

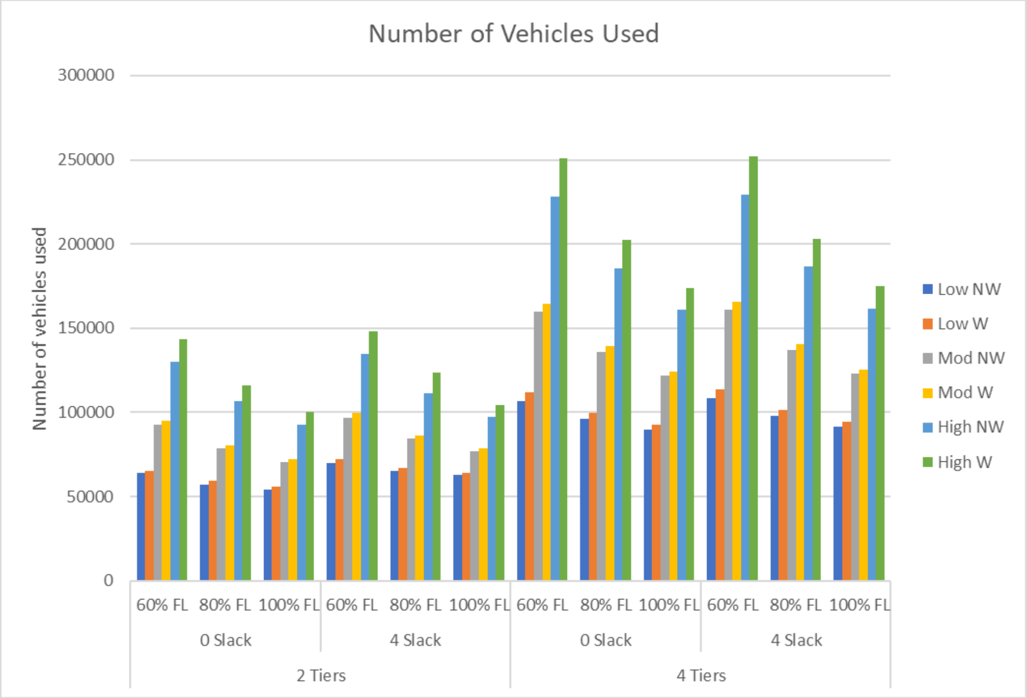


Figure 4.17: Total number of vehicles used for each demand pattern at all design points.

One of the four-tier network's main goals is to reduce average driving time per leg. A feeder team in parcel delivery refers to a truck that is driven by two drivers to a distant location to reduce driving time by having shifts. For example, two drivers will be assigned to drive a truck from New York to California. Achieving the goal of reducing average driving time per leg will help eliminate the need for feeder teams and enhance drivers' lives by reducing their driving times. This improvement in driver quality of life is one of the main tenants of the Physical Internet. Driving time per leg is calculated using the following equation:

$$\text{Driving time per leg} = (\text{Average driving time per leg} + 90^{th} \text{ driving time per leg}) / 2 \qquad (4.4)$$

There are two main findings: first, the four-tier network's goal is achieved by reducing driving time per leg by around 50%; second, demand level does not affect driving time per leg, as shown in Figure 4.18.

The last KPI to be discussed is the trailer average fillrate. In this study, fillrate is measured based on the utilized space compared to maximum available space. For example, if a trailer's maximum fill level is 80%, then the average fillrate must be a number that is less than the maximum fill level. So, comparing between a 60% and 80% maximum trailer fill level will be biased. To compare between all scenarios, the fillrate is measured using the following equation:

$$\text{Average Fillrate} = \text{Average fillrate of non-empty trailers} / \text{maximum trailer fill level} \qquad (4.5)$$

Figure 4.19 shows that average fillrate at all design points behaves the same, but it is clear that the four-tier network has a slightly higher fillrate than the two-tier network. Moreover, as slack time increases, the gap between the two-tier and the four-tier average fillrate increases.

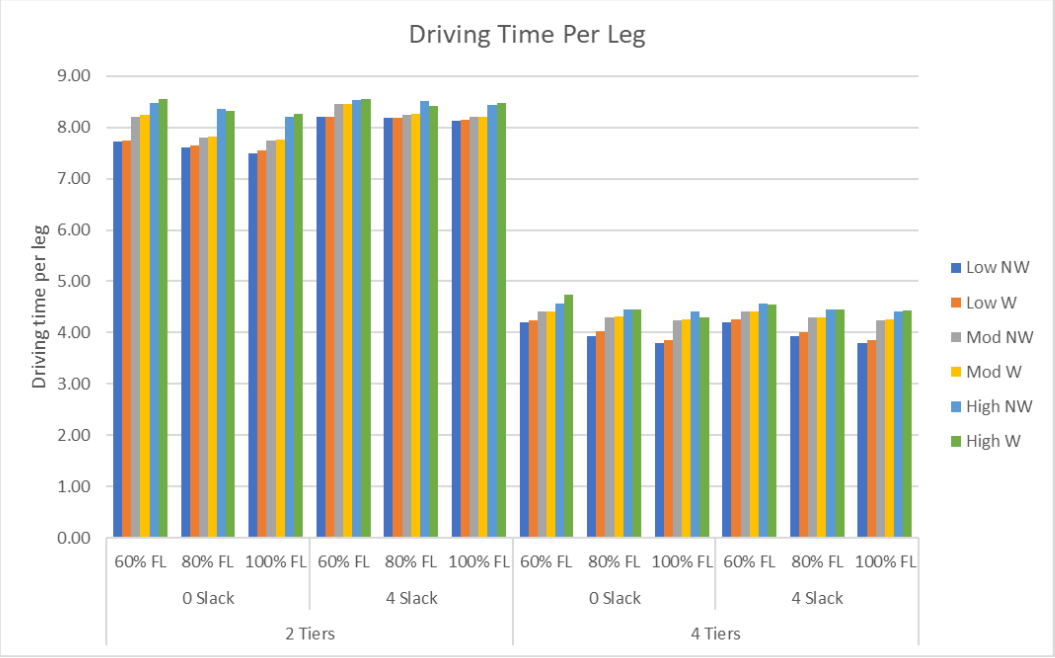


Figure 4.18: Average driving timer per leg for each demand pattern at all design points.

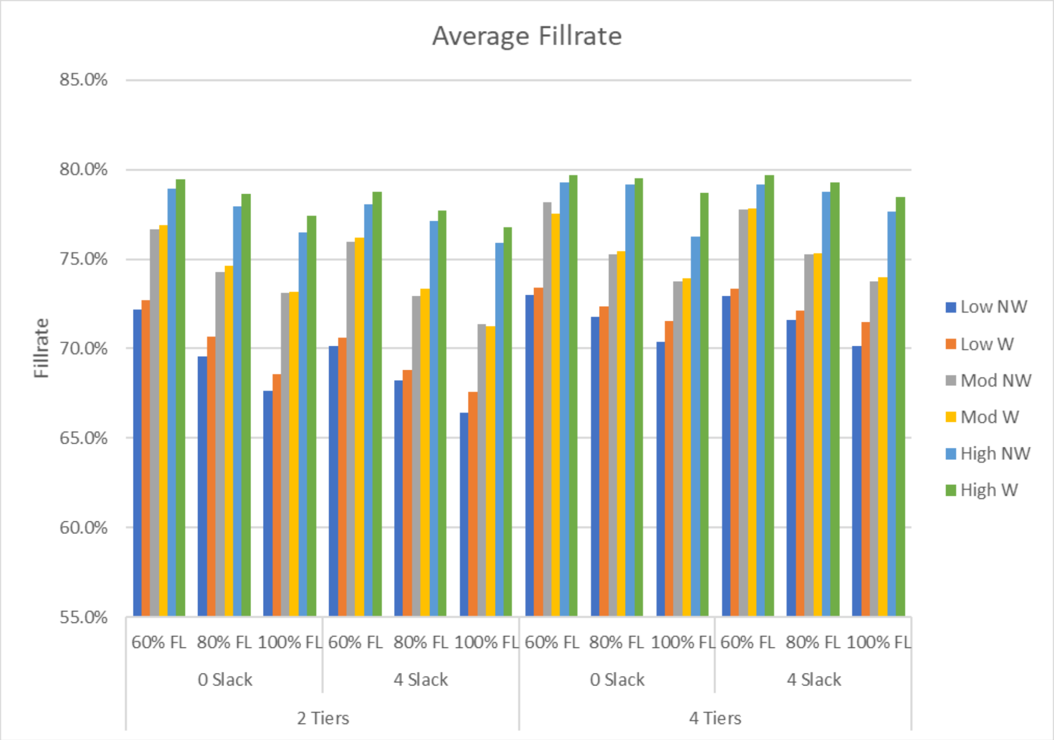


Figure 4.19: Average trailer fillrate for each demand pattern at all design points.

4.2.4 Sensitivity Analysis

Fuel prices directly affect parcel delivery carriers' overall operational costs due to the vast fleet they have. Fuel prices fluctuate depending on a variety of factors such as demand and political conflicts. Hence, this study includes investigating fuel prices' effect on a parcel delivery network's operational cost. Ten scenarios were used to study the effect of increasing or decreasing fuel prices. A range from 10% to 50% with a step of 10% for the percentage of fuel price reduction was used. The other five scenarios are ranges for the percentage of price increment from 10% to 50% with a step of 10%. Results show that the two-tier network is more sensitive to a change in fuel price than the four-tier.

Table 4.6 summarizes the obtained results. On average, any increment or reduction in operational cost is equal to 50% of the percentage of reduction or increment in fuel price. For example, if fuel price increases by 20%, it is expected to have a 10% increase in operational cost.

Table 4.6: Effect of fuel price changes on operational cost.

			Percentage of Reduction and Increment in Fuel Prices										
# Tiers	Slack	Max Trailer FL	-50%	-40%	-30%	-20%	-10%	0%	10%	20%	30%	40%	50%
2	0	60%	-26%	-21%	-15%	-10%	-5%	0%	5%	10%	15%	21%	26%
		80%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%
		100%	-28%	-22%	-17%	-11%	-6%	0%	6%	11%	17%	22%	28%
	4	60%	-26%	-21%	-16%	-10%	-5%	0%	5%	10%	16%	21%	26%
		80%	-23%	-19%	-14%	-9%	-5%	0%	5%	9%	14%	19%	23%
		100%	-21%	-17%	-13%	-8%	-4%	0%	4%	8%	13%	17%	21%
4	0	60%	-23%	-18%	-14%	-9%	-5%	0%	5%	9%	14%	18%	23%
		80%	-20%	-16%	-12%	-8%	-4%	0%	4%	8%	12%	16%	20%
		100%	-18%	-14%	-11%	-7%	-4%	0%	4%	7%	11%	14%	18%
	4	60%	-23%	-18%	-14%	-9%	-5%	0%	5%	9%	14%	18%	23%
		80%	-20%	-16%	-12%	-8%	-4%	0%	4%	8%	12%	16%	20%
		100%	-18%	-14%	-11%	-7%	-4%	0%	4%	7%	11%	14%	18%

Traditional hub operations require many sorting and scanning tools, and workers to run the network, which increases operational cost. Managers try to apply new technologies and continuous improvement principles to reduce hub operations cost. A sensitivity analysis was done to study the effect of an increase or decrease in sorting and scanning cost. A range from 10% to 50% with a step of 10% for the percentage of sorting and scanning cost reduction was used. A similar range was used for the percentage of cost increment. Results confirm that the four-tier network is more sensitive to a change in sorting and scanning cost than the two-tier as the number of scans is higher for the four-tier. Table 4.7 illustrates the effect of scanning cost change on operational cost, which seems similar to the fuel prices analysis.

Table 4.7: Effect of sorting and scanning cost changes on operational cost.

			Percentage of Reduction and Increment in Sorting Cost										
# Tiers	Slack	Max Trailer FL	-50%	-40%	-30%	-20%	-10%	0%	10%	20%	30%	40%	50%
2	0	60%	-24%	-19%	-15%	-10%	-5%	0%	5%	10%	15%	19%	24%
		80%	-25%	-20%	-15%	-10%	-5%	0%	5%	10%	15%	20%	25%
		100%	-22%	-18%	-13%	-9%	-4%	0%	4%	9%	13%	18%	22%
	4	60%	-24%	-19%	-14%	-10%	-5%	0%	5%	10%	14%	19%	24%
		80%	-27%	-21%	-16%	-11%	-5%	0%	5%	11%	16%	21%	27%
		100%	-29%	-23%	-17%	-12%	-6%	0%	6%	12%	17%	23%	29%
4	0	60%	-27%	-22%	-16%	-11%	-5%	0%	5%	11%	16%	22%	27%
		80%	-30%	-24%	-18%	-12%	-6%	0%	6%	12%	18%	24%	30%
		100%	-32%	-26%	-19%	-13%	-6%	0%	6%	13%	19%	26%	32%
	4	60%	-27%	-22%	-16%	-11%	-5%	0%	5%	11%	16%	22%	27%
		80%	-30%	-24%	-18%	-12%	-6%	0%	6%	12%	18%	24%	30%
		100%	-32%	-26%	-19%	-13%	-6%	0%	6%	13%	19%	26%	32%

4.3 Conclusions

This study investigated the performance and effect of various factors on two and four-tier parcel delivery networks. To do so, a simulation model has been developed in AnyLogic®, experimenting with six different demand patterns. Our investigation showed that the number of tiers, slack time, maximum trailer fill level, and some of the interactions significantly affect network performance. The best set of these factor levels were specified to run the network under a set of circumstances. For example, if the demand pattern is low, and the priority is the percentage of late parcels, then the best network configuration is to run the network using the two-tier layout, zero-hour slack, and 100% maximum trailer fill level.

Our analysis shows the required number of bags and trailers to run each of these networks. It was clear that the four-tier network requires additional bags, but these bags are less occupied compared to the two-tier network. On the other side, the number of trailers varies based on whether curve spikes are counted or not. When they are included, the two-tier network requires fewer trailers, while their exclusion shows the four-tier requiring fewer trailers (but with additional cost for contracting).

Later investigations of various KPIs illustrated that two-tier KPIs results are better than the four-tier, except for driving time per leg. Percentage of late parcels is affected by slack time, and results show that, on average, lateness percentage is reduced by around 50% when increasing slack to four hours in the two-tier network. In comparison, four-tier network lateness is not affected by an increase in slack. Operational cost analysis shows the four-tier has an average 25% increase in cost compared to the two-tier network due to the increase in number of scans. Total traveled miles and number of vehicles used are higher for the four-tier network as both are correlated. Also, average fillrate analysis shows similar results for both networks. One of the four-tier network's primary goals is achieved and proven in this study, which is reducing average driving time per leg. Driving time per leg was reduced from about eight hours for the two-tier to about four hours for the four-tier.

The last part of the analysis was to perform a sensitivity analysis on the effect of changing fuel price and scanning and sorting costs. Findings show that the two-tier network is more sensitive to the change in fuel cost, while the four-tier network is more sensitive to changes in sorting and scanning cost.

Chapter 5 Evaluating the Performance of Two- and Four-tier Networks Using Containerization

In the first study, two- and four-tier hub-and-spoke network performance using traditional bagging strategy for small parcels was evaluated and compared. Results indicate that the two-tier network is preferable to deliver parcels in all scenarios except if the primary KPI is reduced leg drive time. In this study, an evaluation and comparison of both two- and four-tier hub-and-spoke network performances using the containerization technique from PI is completed, where a set of containers is used for shipping instead of bags. The effect of the number of tiers, slack time, maximum trailer fill level, and maximum container fill level factors on network performance are studied in the same context. Findings confirm that these factors affect performance notably with a high contribution to the number of tiers. Moreover, the combinations of these factor levels that enhance parcel delivery network performance under different demand pattern scenarios are selected.

The use of containers has benefits such as simplifying material handling and increasing trucks utilization (through standardization) (Sallez et al., 2015). Here, the effect of using containers instead of bags on different KPIs was analyzed. Summarized results show that lateness and operational costs are significantly decreased when using containers rather than bags. The driving time per leg is slightly affected while total traveled miles and number of vehicles used are increased due to the need for additional space to ship these containers.

In this chapter, Section 5.1 summarizes results, starting from the ANOVA analysis, containers and trailer analysis, and KPI measurement. A summary is given in Section 5.2.

5.1 Results and Discussion

Running network models with containers requires updating developed models from the first study. Model updates are related only to substituting bags with containers. At origins, scanned parcels are sent to the containerization process after each sort, where they will be filled in containers based on their destinations. Here, the process of filling a container is considered a one-dimensional bin packing problem. Five standard container capacities are used, which are:

1. 2 ft^3 (1*1*2).
2. 8 ft^3 (2*2*2).
3. 16 ft^3 (2*2*4).
4. 64 ft^3 (4*4*4).
5. 128 ft^3 (4*4*8).

Based on the shipped volume, one or more of these containers will be selected to ship parcels. A for loop is used to create containers and check if all parcels are in these containers.

Five factors are selected to run the model. These factors are first study factors (demand patterns, number of tiers, slack, maximum trailer fill level), and maximum container fill level. Filling containers with parcels is a complex process that requires time to maximize utilized space. Hence, a reduction in container filling time will reduce the risk of truck impediment. Filling time can be reduced by sacrificing a portion of container capacity, meaning if the container's maximum fill level is 80% of its capacity, then a worker will fill the container in less time without focusing on optimizing the space. In this study, three container maximum fill levels are used: 60%, 80%, and 100%. Based on the number of factors and levels, this study has 216 design points. Three replicates (648 runs total) were run to improve result accuracy. Table 5.1 illustrates design factors and their levels, while Figure 5.1 shows a tree of all factors and levels with each branch having three replicates.

This study model is developed based on the previous study model. The only difference between them is the use of containers. After each sort, parcels are sent to the containerization process instead of sending smalls for bagging. Containerization is modeled using a function that checks and splits the number of parcels to be shipped based on their final destination. A container is selected based on shipping volume, as follows. If the shipment volume is larger than the biggest container capacity, parcels are put into that container up to the maximum container fill level. Depending on the remaining volume, another container(s) is selected until all parcels are put in containers.

Table 5.1: Network design factors and levels.

Design Factor	Factor Levels					
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Demand Pattern	Low	Low W	Mod	Mod W	High	High W
Number of Tiers	2	4	-	-	-	-
Slack	0	4	-	-	-	-
Maximum Trailer Fill Level	60%	80%	100%	-	-	-
Maximum Container Fill Level	60%	80%	100%	-	-	-

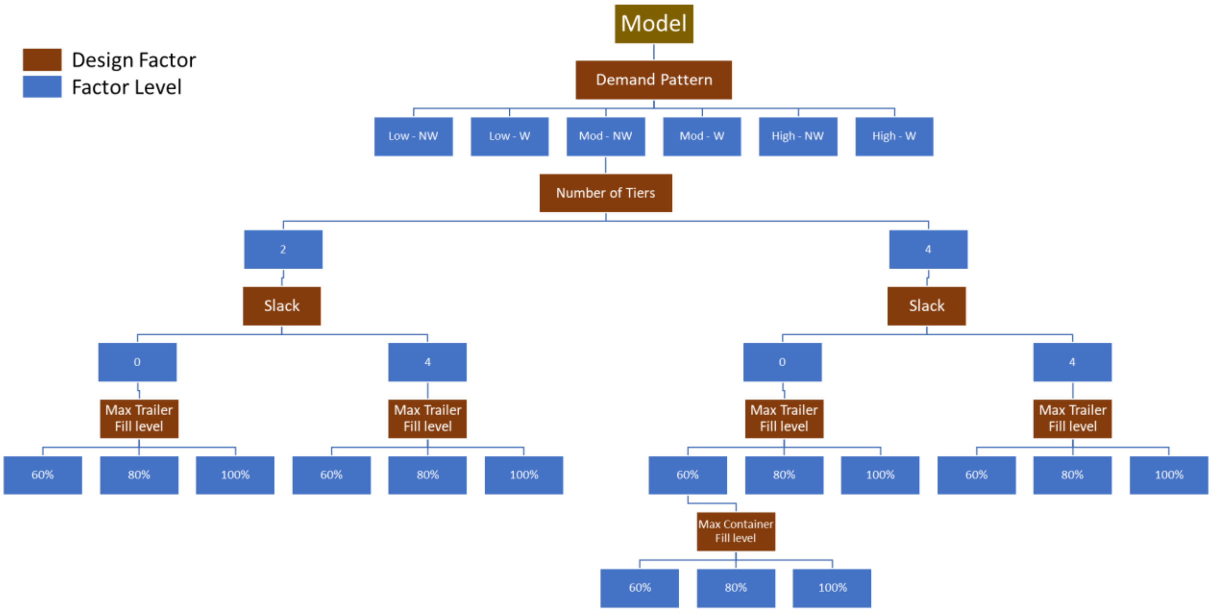


Figure 5.1: Full factorial design with four variables under each demand pattern.

5.1.1 Model Parameters

The effect of each factor on network performance was analyzed using ANOVA. Most of the factors' main effect is noteworthy except when demand is high with warehouses, where slack is insignificant. The highest contribution is from the number of tiers, which is similar to the first study. The two-way interactions between slack and maximum trailer fill level, and between slack and maximum container fill level were insignificant in all scenarios, while other two-way interactions are significant except when the demand is high with warehouses. Lastly, the three- and four-way interactions are insignificant, except in some cases when demand is moderate with and without warehouses.

The cost equation (4.1) from Chapter 4 is used to judge network performance and select the best alternatives. Here, the analysis is the same as the first study, where KPIs are standardized then added to the cost equation. Table 5.2 shows the significant factors for each priority when demand is low. Analyses for the remaining demand patterns are found in the appendix.

Table 5.2: Significant factors for each cost based on the ANOVA analysis when the demand pattern is low.

Low demand – No warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√		√	√	√
Max container fill level	√	√	√	√	√	√	√	√
Two-Way Interactions								
Slack*Max trailer fill level								
Slack*Number of tiers	√	√	√	√	√	√	√	√
Slack*Max container fill level								
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Max container fill level	√	√	√	√	√	√	√	√
Max container fill level*Number of tiers	√	√	√	√	√	√	√	√
Three-Way Interactions								
Slack*Max trailer fill level* Number of tiers								
Slack*Max container fill level* Max trailer fill level								
Slack * Max container fill level *Number of tiers								
Max container fill level*Max trailer fill level*Number of tiers								
Four-Way Interactions								
Slack*Max trailer fill level* Max container fill level*Number of Tiers								

Based on the previous analysis, the best combination of factors and levels for each demand pattern is summarized in Table 5.3. The best combination for most scenarios is when slack is zero, maximum trailer fill level is 100%, the number of tiers is two, and maximum container fill level is 100%. These results are reasonable, if the maximum container fill level is less than 100%, additional trucks are requested, which causes an increase in total traveled miles and operational cost, as well. Moreover, lateness percentages of the two-tier network are always less than the four-tier network. The four-tier is superior when driving time per leg is the priority; this result differs from the first study where all the best alternatives were from the two-tier only. Table 5.3 can be read as follows: slack, maximum trailer fill level, number of tiers, maximum container fill level.

Table 5.3: The best parcel delivery network configuration for each demand pattern.

Demand Pattern	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Low	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 4,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%
Low W	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%
Moderate	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 4,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%
Moderate W	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 4,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%
High	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 4,100%	0,100%, 2,100%	0,100%, 2,100%	4,100%, 2,100%
High W	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 2,100%	0,100%, 4,100%	0,100%, 2,100%	0,100%, 2,100%	4,100%, 2,100%

5.1.2 Containers and Trailers Analysis

Two of the primary pieces of information required to run such networks is the number of trailers and containers. These numbers can be found using the maximum number of active trailers and containers. The maximum trailer fill level does not affect the maximum number of active bags from the first study, which is the same case for containers. For each demand pattern, the maximum number of active containers is directly affected by the number of tiers and maximum container fill level. Figure 5.2 shows the maximum number of active containers when the demand pattern is high with warehouses. As expected, the 128 ft^3 container is the most used container for such demand, while the 2 ft^3 container is less utilized. When slack and maximum container fill level increase in the two-tier network, the number of 128 ft^3 containers decreases, but increases for other containers. On the other side, the number of 128 ft^3 containers in the four-tier network increases slightly when slack increases, however, other containers are not affected.

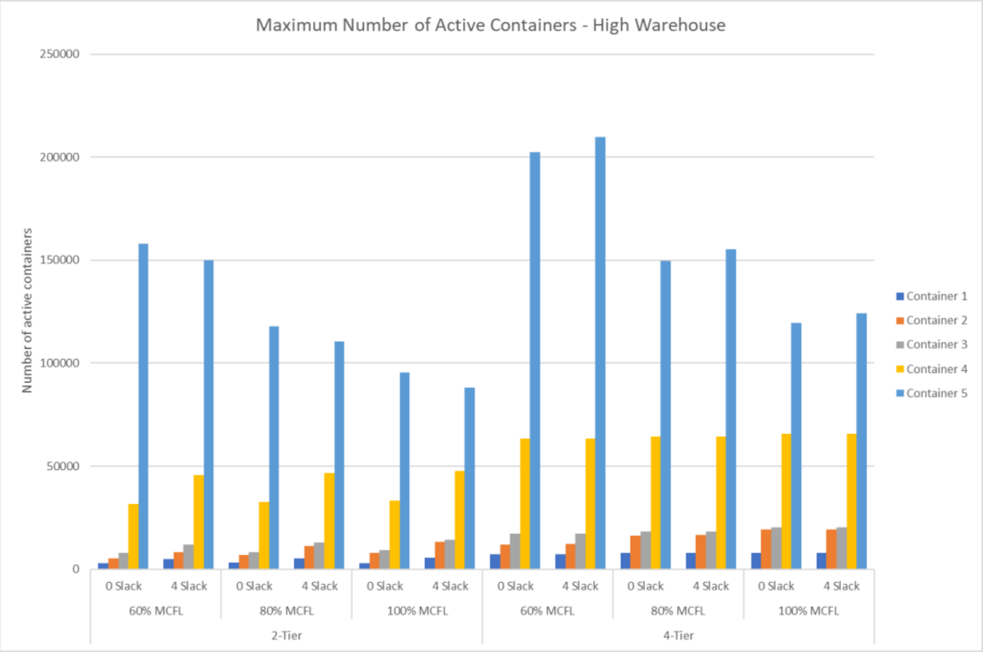


Figure 5.2: Maximum number of active containers when the demand pattern is high with warehouses.

The number of active trailers is affected by all factors. Here, results are represented by comparing current study numbers with the first study results. Table 5.4 illustrates the change in percentage of maximum number of active trailers when demand is high with warehouses. The 28-foot trailer is the most frequently used, which is the same result as the first study, while others are not recommended to be part of the company fleet. The elevated increase in percentage of other trailer types is negligible; the reason is that these trailer type numbers are, on average, less than 100 trailers. For example, if an increase in the number of type 1 trailers is 50%, but the number of trailers of this type is 20 in the first study, then the actual increase is 10 trailers. So, by focusing on the type 6 trailer column, it is proven that as maximum container fill level decreases, the maximum number of active trailers increases. However, slack and maximum trailer fill level do not affect 28-foot trailer numbers. Table 5.4 confirms that the four-tier network has a greater increase in the number of active trailers.

Following the same analysis as in the first study, spikes in the number of active trailers can be eliminated by taking the 90th percentile. Findings show that the four-tier network's trailer fleet should be doubled, on average, compared to the first study. Slack has a significant effect when these spikes are excluded in the two-tier network. In general, when slack increases, rise in percentage of the number of trailers is at least double the case when slack is zero. However, four-tier results are not affected by slack. The lowest increase, which is 3%, occurs when the number of tiers is two, the maximum container fill level is 100%, slack is zero, and maximum trailer fill level is 100%. Table 5.5 describes the change in these numbers after the spikes are removed.

Table 5.4: Percentage of increase or decrease in the maximum number of active trailers for each design point per trailer type when the demand pattern is high with warehouses.

# Tiers	MCFL	Slack	MTFL	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
2	60%	0	60%	60%	15%	52%	144%	208%	62%
			80%	60%	15%	100%	120%	184%	62%
			100%	160%	190%	100%	47%	130%	56%
		4	60%	-53%	20%	20%	42%	104%	106%
			80%	-65%	-4%	83%	18%	74%	107%
			100%	30%	4%	60%	33%	130%	100%
	80%	0	60%	120%	40%	56%	124%	204%	26%
			80%	100%	25%	116%	96%	180%	26%
			100%	210%	220%	95%	47%	143%	22%
		4	60%	-40%	35%	23%	20%	84%	61%
			80%	-55%	-4%	73%	8%	94%	62%
			100%	45%	32%	72%	48%	120%	56%
	100%	0	60%	160%	60%	60%	104%	156%	6%
			80%	160%	45%	116%	96%	180%	6%
			100%	250%	210%	55%	0%	93%	3%
		4	60%	-13%	55%	14%	10%	68%	37%
			80%	-40%	28%	93%	26%	102%	36%
			100%	70%	16%	32%	-5%	45%	34%
4	60%	0	60%	-50%	80%	880%	280%	160%	235%
			80%	-50%	80%	1160%	224%	120%	241%
			100%	130%	340%	720%	124%	168%	282%
		4	60%	-50%	85%	900%	268%	172%	235%
			80%	-50%	80%	1200%	224%	132%	241%
			100%	135%	335%	700%	120%	172%	282%
	80%	0	60%	-35%	170%	970%	212%	124%	161%
			80%	-35%	175%	1310%	188%	148%	166%
			100%	230%	370%	570%	112%	144%	198%
		4	60%	-35%	175%	940%	212%	136%	161%
			80%	-35%	180%	1290%	176%	148%	165%
			100%	230%	370%	560%	116%	124%	197%
	100%	0	60%	-15%	300%	910%	184%	132%	120%
			80%	-15%	290%	1130%	152%	152%	124%
			100%	360%	365%	500%	72%	116%	150%
		4	60%	-15%	300%	910%	172%	124%	120%
			80%	-15%	295%	1090%	148%	136%	124%
			100%	365%	345%	490%	72%	108%	151%

Table 5.5: Percentage of increase or decrease in the maximum number of active trailers for each design point per trailer type when the demand pattern is high with warehouses - spikes are excluded.

# Tiers	MCFL	Slack	MTFL	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
2	60%	0	60%	-15%	-39%	43%	130%	85%	67%
			80%	-84%	-45%	108%	181%	59%	59%
			100%	-49%	23%	114%	143%	71%	65%
		4	60%	-81%	-20%	42%	104%	76%	61%
			80%	-85%	-44%	98%	170%	73%	62%
			100%	-48%	27%	85%	135%	80%	63%
	80%	0	60%	5%	-16%	94%	122%	42%	29%
			80%	-81%	-22%	158%	146%	31%	23%
			100%	-26%	73%	124%	86%	38%	28%
		4	60%	-77%	3%	91%	97%	34%	26%
			80%	-80%	-22%	151%	144%	44%	27%
			100%	-22%	90%	105%	95%	68%	27%
	100%	0	60%	30%	8%	131%	108%	17%	9%
			80%	-76%	0%	201%	117%	14%	3%
			100%	-4%	95%	115%	46%	10%	8%
		4	60%	-71%	27%	118%	90%	8%	7%
			80%	-77%	3%	189%	117%	34%	7%
			100%	-2%	111%	94%	48%	10%	9%
4	60%	0	60%	-85%	-70%	-39%	29%	1%	89%
			80%	-91%	-79%	-1%	62%	-15%	91%
			100%	-67%	-42%	-2%	44%	-6%	95%
		4	60%	-85%	-68%	-38%	25%	1%	93%
			80%	-91%	-80%	-4%	63%	-12%	92%
			100%	-66%	-41%	-1%	47%	-5%	98%
	80%	0	60%	-81%	-50%	-11%	32%	-21%	47%
			80%	-88%	-66%	28%	48%	-36%	48%
			100%	-47%	-13%	3%	23%	-37%	51%
		4	60%	-79%	-49%	-11%	28%	-21%	50%
			80%	-86%	-67%	24%	49%	-35%	49%
			100%	-47%	-12%	3%	26%	-32%	54%
	100%	0	60%	-73%	-25%	0%	27%	-31%	23%
			80%	-83%	-49%	42%	26%	-51%	25%
			100%	-23%	-1%	5%	-2%	-53%	27%
		4	60%	-72%	-25%	0%	23%	-32%	26%
			80%	-82%	-51%	36%	27%	-47%	26%
			100%	-21%	1%	7%	1%	-47%	29%

5.1.3 KPI Analysis

This section analyzes each of the six KPIs by comparing them with first study results. The effect of using containers on these KPIs can be noticed, except for driving time per leg, which has results close to the first study. Numbers presented in the following tables are percentage of increase or decrease in these KPIs.

The use of containers reduces the percentage of late parcels. This goal is achieved because of these containers' service levels, which are the same as each container's lowest service level. For example, if a container has 20 parcels and one of these parcels is 1D, this container service level is 1D, so shipping these parcels is faster than bags. In Table 5.6, two-tier results show that, on average, the percentage of late parcels is reduced by around 25%. Also, the reduction is doubled when slack is four hours as opposed. The maximum trailer and container fill levels do not affect lateness percentage as results are the same when changing these factors while others are constant. On the other hand, the reduction in lateness percentage in the four-tier is similar for all scenarios, which is, on average, 55%.

Operational cost is reduced in more than 95% of the cases. This reduction is due to reduction in the number of scans. Although total traveled miles is increased, reduction in number of scans has a greater effect on operational cost. Also, when maximum container and trailer fill levels increase, operational cost decreases, while slack has a slight effect on its reduction. Running the model with bags is superior when both maximum container and trailer fill levels are 60%. When these two factors decrease, the reduction in the number of scans has a lower effect compared to the increase in total traveled miles. The four-tier network yields better results compared to the two-tier as it has a higher number of scans when bags are used. Table 5.7 shows the change in operational cost.

Table 5.6: Percentage of increase or decrease in the percentage of late parcels at each design point.

# Tiers	MCFL	Slack	MTFL	Low	Low W	Mod	Mod W	High	High W
2	60%	0	60%	-18%	-28%	-24%	-26%	-24%	-25%
			80%	-18%	-28%	-24%	-26%	-24%	-25%
			100%	-18%	-28%	-24%	-26%	-24%	-25%
		4	60%	-32%	-35%	-30%	-34%	-33%	-33%
			80%	-32%	-35%	-30%	-34%	-33%	-33%
			100%	-32%	-35%	-30%	-34%	-33%	-33%
	80%	0	60%	-18%	-30%	-24%	-26%	-24%	-25%
			80%	-18%	-30%	-24%	-26%	-24%	-25%
			100%	-18%	-30%	-24%	-26%	-24%	-25%
		4	60%	-32%	-37%	-30%	-32%	-33%	-34%
			80%	-32%	-37%	-30%	-32%	-33%	-34%
			100%	-32%	-37%	-30%	-32%	-33%	-34%
	100%	0	60%	-19%	-30%	-24%	-26%	-23%	-25%
			80%	-19%	-30%	-24%	-26%	-23%	-25%
			100%	-19%	-30%	-24%	-26%	-23%	-25%
		4	60%	-34%	-37%	-30%	-34%	-33%	-32%
			80%	-34%	-37%	-30%	-34%	-33%	-32%
			100%	-34%	-37%	-30%	-34%	-33%	-32%
4	60%	0	60%	-53%	-53%	-53%	-54%	-55%	-54%
			80%	-53%	-53%	-53%	-54%	-55%	-54%
			100%	-53%	-53%	-53%	-54%	-55%	-54%
		4	60%	-53%	-53%	-54%	-54%	-55%	-55%
			80%	-53%	-53%	-54%	-54%	-55%	-55%
			100%	-53%	-53%	-54%	-54%	-55%	-55%
	80%	0	60%	-53%	-54%	-54%	-54%	-55%	-55%
			80%	-53%	-54%	-54%	-54%	-55%	-55%
			100%	-53%	-54%	-54%	-54%	-55%	-55%
		4	60%	-53%	-54%	-55%	-55%	-56%	-55%
			80%	-53%	-54%	-55%	-55%	-56%	-55%
			100%	-53%	-54%	-55%	-55%	-56%	-55%
	100%	0	60%	-53%	-54%	-55%	-55%	-56%	-55%
			80%	-53%	-54%	-55%	-55%	-56%	-55%
			100%	-53%	-54%	-55%	-55%	-56%	-55%
		4	60%	-53%	-54%	-55%	-55%	-56%	-55%
			80%	-53%	-54%	-55%	-55%	-56%	-55%
			100%	-53%	-54%	-55%	-55%	-56%	-55%

Table 5.7: Percentage of increase or decrease in operational cost at each design point.

# Tiers	MCFL	Slack	MTFL	Low	Low W	Mod	Mod W	High	High W
2	60%	0	60%	12%	5%	7%	6%	4%	-1%
			80%	2%	-3%	-2%	-2%	-5%	-3%
			100%	-5%	-9%	-8%	-8%	-11%	-3%
		4	60%	12%	7%	11%	11%	7%	6%
			80%	3%	-1%	1%	1%	-2%	-3%
			100%	-4%	-7%	-5%	-6%	-8%	-9%
	80%	0	60%	-3%	-9%	-11%	-11%	-15%	-19%
			80%	-10%	-14%	-16%	-17%	-21%	-20%
			100%	-14%	-17%	-21%	-21%	-26%	-20%
		4	60%	-1%	-5%	-6%	-7%	-11%	-13%
			80%	-8%	-11%	-13%	-14%	-17%	-18%
			100%	-11%	-14%	-16%	-17%	-22%	-23%
	100%	0	60%	-11%	-17%	-21%	-21%	-25%	-29%
			80%	-16%	-21%	-24%	-25%	-30%	-29%
			100%	-19%	-23%	-28%	-28%	-33%	-28%
		4	60%	-9%	-12%	-17%	-18%	-21%	-23%
			80%	-10%	-16%	-20%	-21%	-26%	-27%
			100%	-15%	-18%	-23%	-24%	-30%	-32%
4	60%	0	60%	8%	7%	0%	1%	-5%	-6%
			80%	-2%	-4%	-10%	-11%	-15%	-16%
			100%	-9%	-10%	-18%	-18%	-22%	-24%
		4	60%	8%	6%	0%	0%	-5%	-6%
			80%	-3%	-4%	-9%	-11%	-15%	-16%
			100%	-9%	-10%	-15%	-18%	-22%	-24%
	80%	0	60%	-8%	-10%	-17%	-17%	-23%	-24%
			80%	-16%	-17%	-25%	-26%	-31%	-32%
			100%	-20%	-22%	-30%	-31%	-36%	-37%
		4	60%	-8%	-17%	-17%	-18%	-23%	-24%
			80%	-16%	-17%	-24%	-26%	-31%	-32%
			100%	-20%	-22%	-28%	-31%	-36%	-37%
	100%	0	60%	-18%	-19%	-27%	-27%	-33%	-34%
			80%	-23%	-25%	-33%	-34%	-39%	-40%
			100%	-27%	-29%	-38%	-38%	-44%	-45%
		4	60%	-18%	-19%	-27%	-28%	-33%	-34%
			80%	-23%	-25%	-32%	-34%	-39%	-40%
			100%	-27%	-28%	-35%	-38%	-44%	-45%

Total traveled miles KPI has an opposite behavior compared to the percentage of late parcels. When maximum container and trailer fill levels increase, the lower represents the increase in traveled miles. Additionally, as the demand decreases, fewer trucks are used, reducing the increase in total traveled miles. In general, when demand is low, maximum trailer fill level and maximum container fill level is 100%, and total traveled miles are almost similar to the network with bags. Table 5.8 displays changes in total traveled miles. In contrast, the number of vehicles used has the same analysis and behavior shown in Table 5.9.

Table 5.8: Percentage of increase or decrease in total traveled miles at each design point.

# Tiers	MCFL	Slack	MTFL	Low	Low W	Mod	Mod W	High	High W
2	60%	0	60%	52%	44%	60%	59%	61%	61%
			80%	37%	34%	53%	52%	56%	57%
			100%	29%	27%	46%	46%	53%	53%
		4	60%	42%	39%	61%	61%	64%	63%
			80%	29%	28%	50%	50%	57%	59%
			100%	19%	19%	41%	41%	52%	54%
	80%	0	60%	29%	23%	30%	29%	29%	28%
			80%	20%	17%	27%	26%	26%	27%
			100%	15%	13%	23%	24%	23%	24%
		4	60%	24%	22%	32%	32%	33%	31%
			80%	14%	14%	26%	25%	29%	30%
			100%	10%	9%	23%	23%	24%	25%
	100%	0	60%	17%	11%	13%	13%	12%	10%
			80%	11%	7%	13%	13%	9%	9%
			100%	8%	6%	10%	10%	9%	7%
		4	60%	13%	11%	15%	14%	16%	14%
			80%	12%	6%	15%	14%	12%	13%
			100%	5%	4%	11%	11%	10%	9%
4	60%	0	60%	70%	72%	77%	78%	77%	77%
			80%	59%	61%	69%	69%	72%	72%
			100%	51%	53%	62%	63%	68%	68%
		4	60%	69%	71%	76%	77%	77%	76%
			80%	58%	60%	68%	69%	72%	72%
			100%	50%	52%	61%	62%	67%	68%
	80%	0	60%	43%	43%	45%	45%	42%	41%
			80%	36%	37%	39%	39%	39%	38%
			100%	31%	32%	35%	35%	36%	36%
		4	60%	42%	29%	44%	44%	42%	41%
			80%	35%	36%	39%	39%	39%	38%
			100%	30%	31%	35%	35%	36%	36%
	100%	0	60%	27%	27%	26%	25%	22%	21%
			80%	22%	23%	22%	22%	21%	20%
			100%	19%	20%	20%	20%	19%	18%
		4	60%	26%	26%	26%	25%	22%	21%
			80%	22%	22%	22%	22%	20%	20%
			100%	18%	19%	20%	19%	19%	18%

Table 5.9: Percentage of increase or decrease in the number of vehicles used at each design point.

# Tiers	MCFL	Slack	MTFL	Low	Low W	Mod	Mod W	High	High W
2	60%	0	60%	43%	43%	60%	60%	64%	65%
			80%	36%	33%	51%	52%	58%	59%
			100%	29%	26%	45%	45%	53%	55%
		4	60%	44%	41%	63%	64%	67%	68%
			80%	31%	30%	52%	53%	60%	58%
			100%	23%	22%	43%	43%	55%	57%
	80%	0	60%	24%	25%	33%	33%	33%	32%
			80%	21%	19%	28%	28%	30%	30%
			100%	17%	15%	25%	25%	27%	27%
		4	60%	26%	24%	37%	37%	37%	36%
			80%	18%	17%	29%	29%	33%	31%
			100%	14%	13%	24%	24%	29%	31%
	100%	0	60%	14%	14%	18%	17%	16%	15%
			80%	13%	11%	16%	16%	14%	14%
			100%	11%	9%	13%	14%	13%	13%
		4	60%	16%	14%	21%	21%	20%	19%
			80%	16%	10%	17%	17%	18%	15%
			100%	9%	8%	13%	14%	15%	15%
4	60%	0	60%	54%	56%	67%	67%	70%	70%
			80%	42%	45%	57%	58%	64%	65%
			100%	35%	37%	49%	50%	58%	60%
		4	60%	52%	55%	66%	67%	69%	70%
			80%	41%	44%	56%	57%	63%	64%
			100%	34%	36%	48%	49%	58%	59%
	80%	0	60%	32%	33%	39%	38%	38%	37%
			80%	25%	27%	32%	32%	34%	34%
			100%	21%	22%	27%	27%	31%	31%
		4	60%	31%	22%	38%	38%	37%	37%
			80%	25%	26%	31%	31%	34%	34%
			100%	20%	22%	27%	27%	31%	31%
	100%	0	60%	20%	20%	22%	22%	20%	19%
			80%	15%	16%	18%	17%	18%	18%
			100%	13%	13%	15%	15%	16%	15%
		4	60%	19%	20%	21%	21%	20%	19%
			80%	15%	16%	17%	17%	18%	17%
			100%	12%	13%	15%	15%	15%	15%

As mentioned earlier, the driving time per leg is not affected by using containers instead of bags. Table 5.10 illustrates percentage of change in driving time per leg. However, these increments or decrements are negligible; for example, a 3% percent reduction in the average driving time per leg of a two-tier network is less than 15 minutes. Moreover, a 10% percent reduction in average driving time per leg of a four-tier network is less than 30 minutes. Two-tier scenarios show a reduction in average driving time per leg of around 3%, while four-tier scenarios show an increment in the average driving time per leg of around 5%.

Table 5.10: Percentage of increase or decrease in average driving time per leg at each design point.

# Tiers	MCFL	Slack	MTFL	Low	Low W	Mod	Mod W	High	High W
2	60%	0	60%	3%	3%	2%	1%	-1%	-2%
			80%	-1%	-1%	5%	5%	0%	0%
			100%	-1%	-2%	4%	4%	2%	1%
		4	60%	0%	0%	-1%	-1%	-2%	-2%
			80%	-1%	-1%	0%	0%	-2%	-1%
			100%	-2%	-1%	0%	0%	-1%	-1%
	80%	0	60%	-2%	-2%	0%	-1%	-2%	-2%
			80%	-2%	-3%	3%	2%	-1%	0%
			100%	-1%	-2%	0%	1%	0%	-1%
		4	60%	-1%	-1%	-2%	-2%	-2%	-2%
			80%	-2%	-2%	0%	-1%	-2%	-1%
			100%	-2%	-3%	0%	0%	-2%	-2%
	100%	0	60%	-4%	-4%	-2%	-3%	-2%	-3%
			80%	-3%	-3%	1%	0%	-2%	-1%
			100%	-2%	-3%	-4%	-4%	-2%	-3%
		4	60%	-2%	-2%	-3%	-3%	-2%	-2%
			80%	-3%	-3%	0%	-1%	-3%	-1%
			100%	-3%	-4%	-2%	-1%	-2%	-3%
4	60%	0	60%	6%	5%	8%	8%	9%	6%
			80%	11%	9%	4%	4%	8%	6%
			100%	13%	12%	5%	5%	8%	11%
		4	60%	6%	4%	8%	8%	8%	10%
			80%	10%	9%	4%	4%	9%	9%
			100%	13%	12%	5%	5%	8%	7%
	80%	0	60%	5%	4%	2%	3%	6%	2%
			80%	9%	7%	3%	3%	7%	7%
			100%	11%	10%	4%	4%	2%	4%
		4	60%	5%	2%	2%	2%	6%	6%
			80%	9%	7%	3%	3%	7%	7%
			100%	11%	10%	4%	4%	2%	1%
	100%	0	60%	3%	3%	1%	1%	4%	1%
			80%	8%	6%	3%	3%	1%	4%
			100%	8%	9%	2%	2%	1%	4%
		4	60%	3%	2%	1%	1%	4%	5%
			80%	8%	6%	3%	3%	1%	4%
			100%	8%	8%	2%	2%	1%	1%

Average trailer fillrate KPI is analyzed differently when using containers. Here, there are two different fillrates which are: the actual fillrates and the normal fillrates. The normal fillrate is measured by considering container capacities in that trailer, while actual fillrate is measured using parcel volumes in these containers. Consider the case when maximum container fill level is 60%, all containers are 60% full, and maximum trailer fill level is 100%. Then if this trailer is full, the normal fillrate is 100%, while the actual is 60%. The best way to describe this KPI is the actual fillrate, as it can be used to indicate if both trailers and containers are full. As the demand level, maximum container and trailer fill levels increase, the average fillrate difference between the network with bags and the network with containers is minimal. Table 5.11 shows percentage of change in the average fillrate compared to the first study.

Finally, one of the main goals for using containers is to simplify the scanning and sorting process. Findings confirm that using containers instead of bags reduces the total number of scans by around 50% in the two-tier network and 60% in the four-tier network. Consequently, operational cost decreases because of the decrease in number of scans. It was found that maximum trailer fill level does not affect the number of scans in both networks, while slack and maximum container fill level affect it slightly. Table 5.12 shows percentage of reduction in the total number of scans.

Table 5.11: Percentage of increase or decrease in average fillrate at each design point.

# Tiers	MCFL	Slack	MTFL	Low	Low W	Mod	Mod W	High	High W
2	60%	0	60%	-41%	-41%	-36%	-36%	-34%	-34%
			80%	-41%	-41%	-36%	-35%	-34%	-33%
			100%	-39%	-40%	-35%	-35%	-33%	-33%
		4	60%	-44%	-44%	-40%	-39%	-36%	-36%
			80%	-45%	-44%	-38%	-38%	-36%	-35%
			100%	-44%	-44%	-38%	-37%	-36%	-35%
	80%	0	60%	-27%	-26%	-20%	-19%	-16%	-15%
			80%	-27%	-27%	-19%	-19%	-16%	-15%
			100%	-25%	-25%	-18%	-18%	-15%	-14%
		4	60%	-31%	-30%	-24%	-24%	-19%	-18%
			80%	-32%	-31%	-24%	-23%	-19%	-18%
			100%	-30%	-30%	-23%	-22%	-19%	-18%
	100%	0	60%	-14%	-14%	-6%	-5%	0%	1%
			80%	-14%	-14%	-5%	-5%	-1%	0%
			100%	-11%	-12%	-4%	-4%	0%	1%
		4	60%	-19%	-18%	-12%	-11%	-5%	-3%
			80%	-26%	-19%	-11%	-11%	-6%	-4%
			100%	-17%	-18%	-10%	-9%	-5%	-4%
4	60%	0	60%	-44%	-43%	-40%	-39%	-36%	-35%
			80%	-44%	-43%	-38%	-38%	-37%	-36%
			100%	-42%	-42%	-37%	-37%	-34%	-35%
		4	60%	-44%	-43%	-40%	-39%	-36%	-36%
			80%	-44%	-43%	-38%	-38%	-36%	-36%
			100%	-42%	-42%	-37%	-37%	-35%	-35%
	80%	0	60%	-29%	-28%	-24%	-23%	-19%	-18%
			80%	-30%	-29%	-22%	-22%	-19%	-18%
			100%	-28%	-27%	-21%	-20%	-16%	-17%
		4	60%	-29%	-30%	-24%	-23%	-19%	-18%
			80%	-30%	-29%	-23%	-22%	-19%	-18%
			100%	-28%	-27%	-21%	-20%	-18%	-17%
	100%	0	60%	-17%	-15%	-10%	-9%	-4%	-3%
			80%	-18%	-16%	-9%	-8%	-5%	-3%
			100%	-15%	-14%	-7%	-6%	-1%	-2%
		4	60%	-17%	-15%	-10%	-9%	-4%	-3%
			80%	-18%	-16%	-14%	-8%	-5%	-3%
			100%	-14%	-14%	-7%	-6%	-3%	-2%

Table 5.12: Percentage of increase or decrease in total number of scans at each design point.

# Tiers	Slack	MCFL	Low	Low W	Mod	Mod W	High	High W
2	0	60%	-46%	-50%	-47%	-47%	-47%	-47%
		80%	-46%	-49%	-47%	-47%	-47%	-47%
		100%	-45%	-49%	-47%	-47%	-48%	-48%
	4	60%	-45%	-49%	-46%	-46%	-47%	-47%
		80%	-46%	-48%	-47%	-47%	-47%	-47%
		100%	-45%	-49%	-47%	-47%	-47%	-47%
4	0	60%	-59%	-60%	-61%	-61%	-62%	-62%
		80%	-60%	-60%	-62%	-62%	-62%	-62%
		100%	-60%	-60%	-62%	-62%	-63%	-63%
	4	60%	-59%	-60%	-61%	-61%	-61%	-62%
		80%	-60%	-60%	-62%	-62%	-62%	-62%
		100%	-60%	-60%	-62%	-62%	-62%	-63%

5.2 Conclusions

This study investigated the performance and effect of using containers and different factors on two- and four-tier parcel delivery networks. Simulation models have been developed in AnyLogic® based on the first study and experimenting with six different demand patterns. Findings indicate that the number of tiers, slack time, maximum trailer fill level, maximum container fill level, and several two-way and three-way interactions significantly affect network performance. The best set of factor levels were specified to run the network under a set of circumstances. For example, if the demand pattern is high, and priority is on average driving time per leg, then the best network configuration is to run the network using four-tier configuration, zero-hour slack, and at 100 %maximum trailer and container fill level.

The second part of the analysis was to specify the required number of containers and trailers to run each network. As expected, the four-tier network requires additional containers, but these containers are less occupied than the two-tier network. On the other hand, the number of trailers varies based on counting curve spikes. Overall, to run both networks without any shortage in trailers, the two-tier fleet should be increased by around 30% if the maximum trailer fill level is 100% and slack is four hours, while this increase is about 5% if slack is zero. In comparison, the fleet of four-tier network trailers should be increased by around 125%.

Later investigations of various KPIs illustrated that two-tier KPIs results are better than four-tier, except for driving time per leg. Percentage of late parcels is affected by using containers and is lowered by around 25% compared to running the network with bags in the two-tier network. In context, four-tier network lateness is reduced by around 55%. Operational cost analysis shows that using containers reduces operational cost as the maximum container fill level increases. However, total traveled miles and the number of vehicles used is higher than the bag model. Results of actual fillrate analysis provide two different conclusions; the first is that numbers are similar to the first study when maximum container and trailer fill level are 100%. In comparison, the second conclusion is that this KPI is reduced by around 35% when maximum container fill level is 60%. Results show that driving time per leg is similar to the network with bags.

Chapter 6 Development of a Hybrid Parcel Delivery Network

Containerization has a huge impact on parcel delivery network performance. In Chapter 5, findings illustrate the importance of implementing containerization in real life to improve overall performance and reduce parcel delivery cost. Moreover, other techniques such as reconstruction of network flow could be implemented to enhance performance. In this chapter, the goal is to develop a hybrid network that combines two- and four-tier networks to improve performance by reducing delivery time and cost. Two-tier networks have the advantage of visiting a smaller number of locations compared to four-tier networks, thereby decreasing scanning cost. On the other hand, the four-tier network reduces average driving time per leg and simplifies flow between facilities. Theoretically, the combination between these two networks results in a network with improved performance.

Parcel lockers is a widely used method that decreases delivery time and improves parcel delivery security. In this study, implementation of parcel lockers is modeled to enhance lateness results. Crossdocking scanning is another newly proposed technique to reduce scanning operational cost that was introduced as a scanning method when dealing with containers instead of bags. Implementation of parcel lockers and crossdocking scanning is discussed in Section 6.1, as well. Results of running the newly developed network and these techniques show that performance could be significantly improved. It is found that the percentage of late parcels is reduced by around 35% without an increase in operational cost.

This chapter is organized as follows: Section 6.1 summarizes the study methodology, starting with network design, then parcel delivery lockers, and crossdocking scanning. Results are analyzed and discussed in Section 6.2, while Section 6.3 contains study conclusion.

6.1 Methodology

This section clarifies the methodology implementation of the developed network. Prior to describing network logic, three new factors are used to run the four-tier network. The definition of these factors is introduced, as follows. First is destination shortcut, which is a factor used to indicate if a company has the choice to deliver parcels directly to their final destination. This decision is made based on available shipping volumes and the distance between the current location and the final destination. Furthermore, this factor can be set to hubs and final destinations, where if the final destination is distant from the current location, then parcels are sent to one of the regional or gateway hubs; more details are discussed later. Second is trailer fill level threshold, which is a factor associated with available shipment volume that should be sent to a specific hub or destination. Briefly, if loading the current volume to a 28-foot trailer fills it to a specific threshold or greater, then a decision is made regarding sending these parcels using the developed network. Third is trip time factor, which is used to check if the trip time between the current location and the destination is less than or equal to a specific value. This factor is used to keep the advantage of reducing driving time per leg from the four-tier network. Figure 6.1 and Figure 6.2 show the hybrid network logic. Starting with trucks ready to ship parcels to their next location, these parcels are aggregated in containers depending on their final destination to create a shipment that could be delivered to that location. The hybrid network requires two conditions to be met. First, total volume to be delivered to a specific final destination must be greater than the trailer fill level threshold. Second, trip time to that final destination should be less than the trip time factor. If the first condition is not met, then parcels use the four-tier network from Chapter 5. Otherwise, the second condition is checked. The second condition is checked based on the destination shortcut factor, where if it is hubs and final destination and the condition met, then a direct shipment is sent to that final destination. The shipment is otherwise sent to a regional hub if it takes less than the trip time factor to arrive. If the shipment takes longer than the trip time factor, then it is sent to a gateway hub, as in. On the other hand, if the destination factor is set to a final destination only, and the second condition is met, a direct shipment is sent to that final destination.Otherwise, parcels are shipped using the four-tier network.

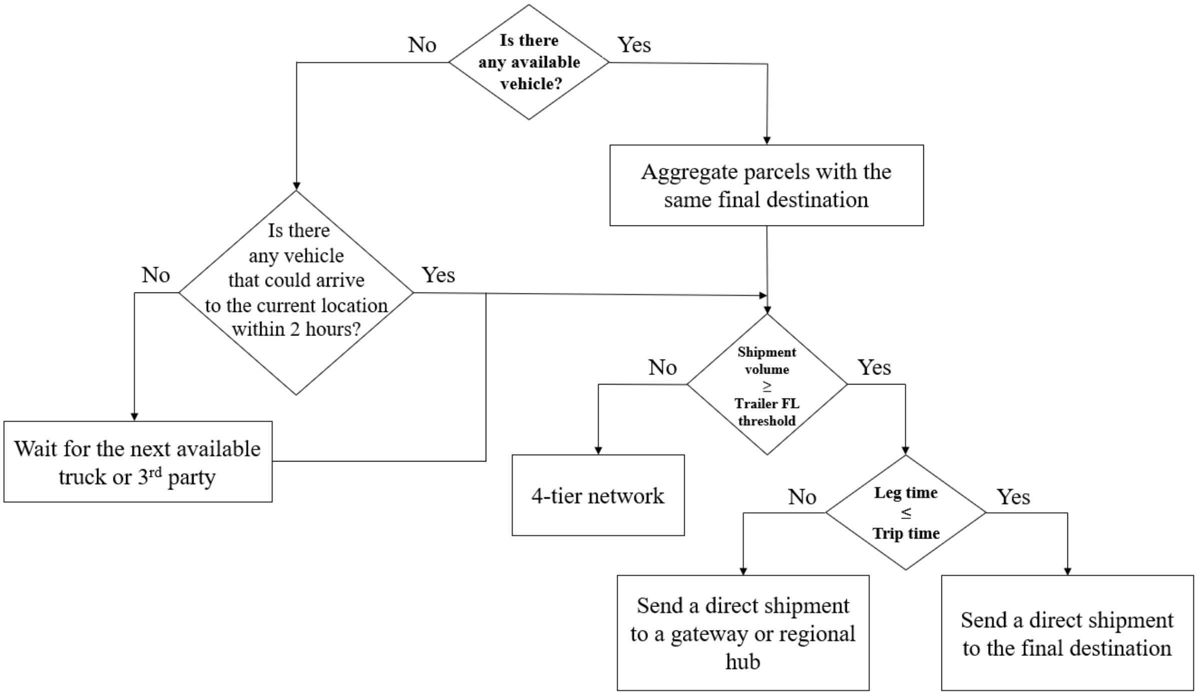


Figure 6.1: Hybrid network logic when destination shortcut factor is set to hubs and final destination.

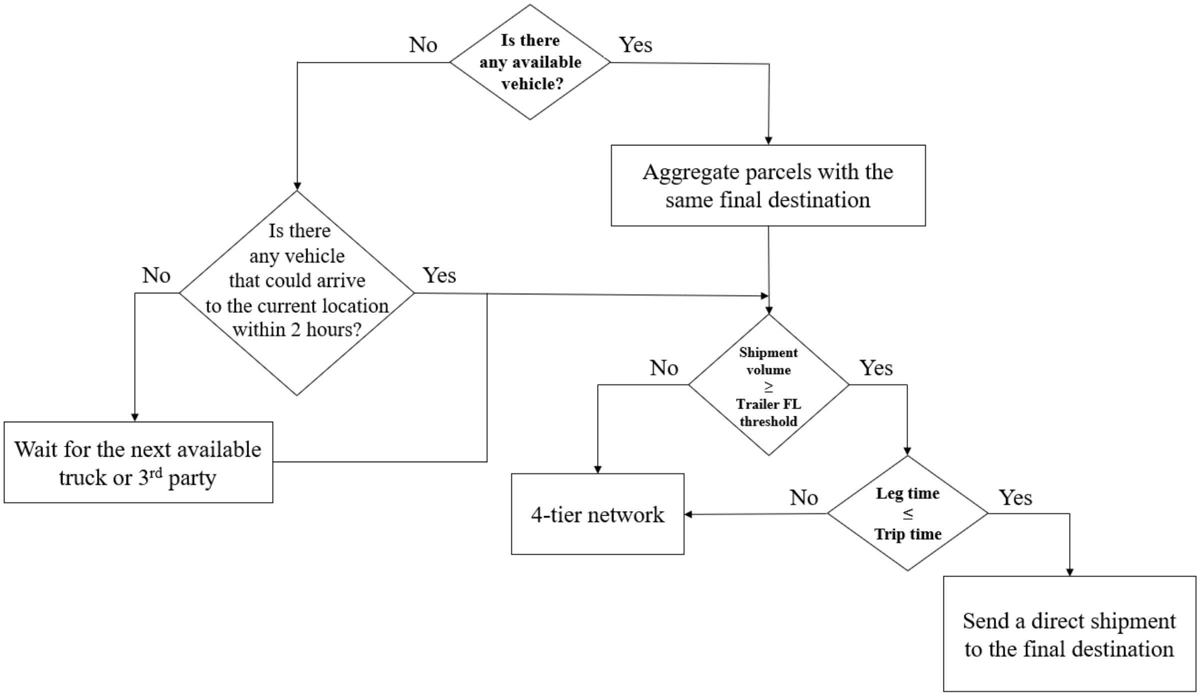


Figure 6.2: Hybrid network logic when destination shortcut factor is set to a final destination only.

6.1.1 Parcel Lockers

In real life, many companies and businesses are popularly using parcel lockers (for instance, UPS, Amazon, and DHL), which could also be used for parcel collection (Amazon, 2020). Parcel lockers are used in most companies for internal use and are not connected with other companies. Academic studies analyzed it as a solution to the Last-Mile Delivery (LMD) (Weltevreden, 2008; Mangiaracina et al.).

Many modern and traditional concepts of last-mile delivery have been introduced and discussed recently. Last-mile delivery or “final mile logistics” refers to the move or transfer of goods from the transportation hub or warehouse to final destinations or “the end-user”. Growing demand for completely involved omnichannel retailing has recently made last mail delivery an area of interest for retailers and researchers. A recent study shows that many companies and businesses now prefer the same LMD value creation, similar to what occurs in the business to customer sector (Choe et al., 2018). Based on previous studies, most of the literature focused on the following four keys of parcel locker: use, location, cost, and environment.

Iwan et al. (2016) evaluated the client perspective of using parcel lockers. Results showed that parcel locker users are comforted with service where the achieved grade ranged from 8.7 and 8.9 based on 95% probability. Compared to the Polish Post-normal service, research revealed that 89% of the population prefers parcel lockers. Jiang et al. (2019) proposed a local search model based on the heuristic approach that aims to reduce cumulative costs which include delivery, pickup, and locker opening costs. This model aims to help customers get parcels from a locker bank.

In a study by Faugère & Montreuil (2017) engineering sense was used to tackle design of the stationary parcel locker. Designs of four parcel lockers have been studied and pros and cons of each one was assessed. Optimization techniques were thereafter applied to maximize compartments of the parcel locker. Zenezini et al. (2018) published their research based on interviews. Results showed that total delivery costs could be minimized, and vehicle routing optimized. Also, these enhancements could positively affect drivers, where they will work more efficiently, which allows drivers to not suffer from issues related to missed deliveries or mistakes in delivery addresses.

Furthermore, Deutsch and Golany (2018) introduced their study to find the optimal parcel locker location to optimize delivery profit and significantly reduce delivery time. Recently, Giuffrida et al. (2016) showed an environmental perspective concerning use of parcel lockers proving that they can save up to 75% of deliveries. In Zhao et al.'s (2018) study, a routing network of two-echelon capacitates for a parcel locker was designed and optimized in a civilian place with a heterogeneous fleet. Zhao et al. were interested especially in finding the optimal configuration of Intermediate Depots (IDs) involving number of IDs and location of each one.

In this study, parcel lockers are considered a supplementary component in the network. They are not mentioned explicitly in the developed model. Figure 6.3 shows an Amazon parcel locker. Here, the implementation of parcel lockers is simplified, as follows. If 1D and 2D parcels arrived at their final destination within delivery and pickup location working hours and after the preload sort, then they are sent to these lockers and considered as delivered. Amazon offers the usage of parcel lockers for prime members with no additional cost when the parcel service level is two-day shipping (www.Amazon.com), thereby reducing the number of late parcels. Figure 6.4 shows the benefit of lockers on the percentage of late parcels. Implementation of these lockers has a significant effect on performance in terms of reducing lateness and increasing customer satisfaction by allowing clients to receive their parcels even if they are not at home.

Figure 6.3: Amazon parcel locker (Abraham, 2014).

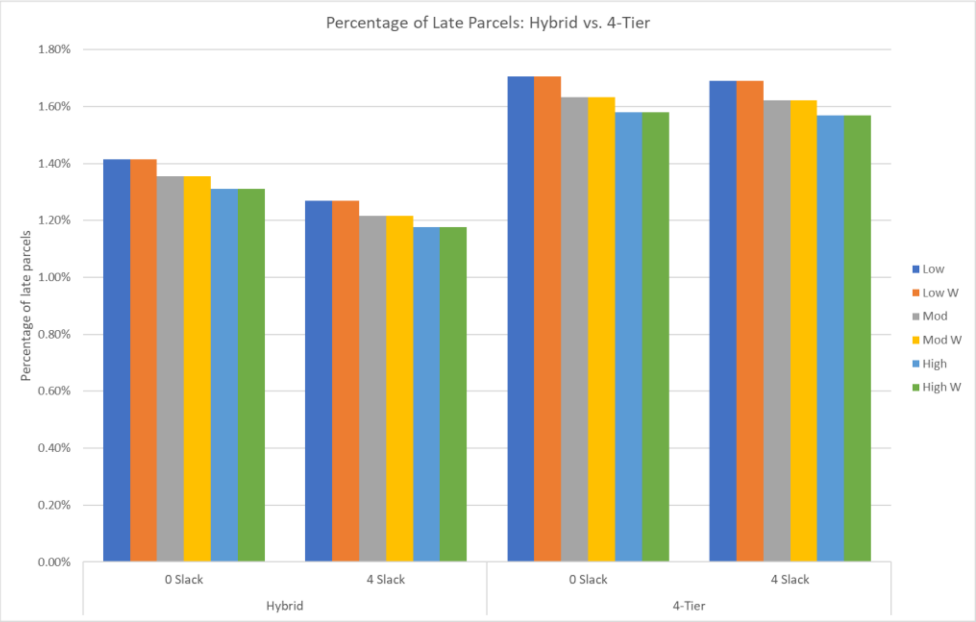


Figure 6.4: Effect of using parcel lockers on percentage of late parcels.

6.1.2 Crossdocking Scanning

One of the newly proposed methods to improve the sorting and scanning process is crossdocking sorting and scanning. This new concept suggested to work in parallel with PI containers focuses on reducing number of scans and sorting time. When a truck arrives at the crossdocking area of a hub that supports this type of scanning, PI-containers are unloaded and scanned, then loaded directly to their new truck at the crossdocking area without the need to pass through the entire facility. This proposed method requires redesigning hubs to handle such new operations. The novel design includes new aisles, buffer areas, docks, gates, maneuvering, and service areas. Figure 6.5 illustrates the proposed crossdocking concept. Incoming containers needing to be sent to their next destination pass through crossdocking sorting aisles to their new trucks, then to their next destination, and so on (Montreuil et al. (2012); Montreuil et al. (2018)).

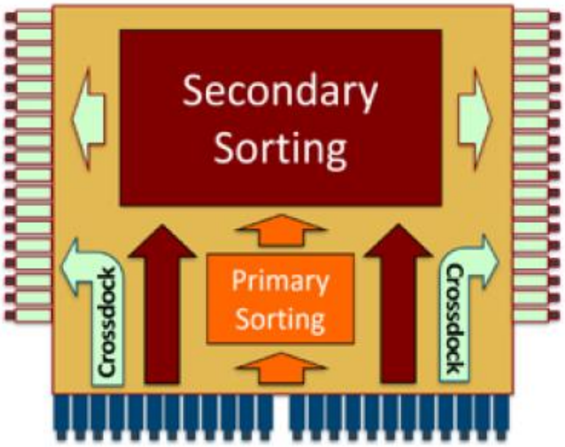


Figure 6.5: Crossdocking scanning concept at hubs that support it.

In this model, the effect of using crossdocking scanning over normal scanning in the four-tier network is illustrated in Table 6.1. Results indicate that such a technique has the advantage of lowering the number of scans by around 5%. The number of scans is slightly affected by implementing the new hybrid network and crossdocking scanning. This reduction substitutes the increment in traveled miles, which keeps operational cost close to the four-tier network, this part is discussed later.

Table 6.1: Percentage of increase or decrease in total number of scans for each demand pattern.

Demand Pattern	Percentage of number of scans
Low	-7%
Low W	-7%
Moderate	-6%
Moderate W	-5%
High	-4%
High W	-3%

A hybrid network model is developed based on the Chapter 5 model. The main differences are determination of a truck destination, parcel lockers, and crossdocking scanning. In the truck movement process chart, the default setting is to move a truck using the four-tier network. However, when one of the two conditions (shipment volume or trip time) or both are met, a new destination is assigned to that truck. Implementation of crossdocking scanning is modeled in the 'dropOffParcels' block in the truck movement process chart. A container is considered to be scanned one time instead of two (arrival and departure), then it will be sent to another truck that will ship it to its next destination. If a container arrives at its final destination, it is scanned then sent to a preload sort. Parcel lockers are modeled in the sorting state chart, where if a 1D or 2D parcel arrives at its final destination after the preload sort and before that day's working hours, it is delivered to these lockers and considered as a delivered parcel.

6.2 Results and Discussion

The developed hybrid network requires updating the four-tier network model from Chapter 5. New updates include network logic, parcel lockers, and crossdocking scanning. Five standard container capacities from Chapter 5 are also used, similar to the previous four-tier network.

The five factors selected to run the model are demand patterns, slack, destination shortcut, trailer fill level threshold, and trip time. Demand patterns and slack are identical to the previous studies. The destination shortcut has two levels discussed earlier, which are final destination only or hubs and final destination. Trailer fill level consists of three levels, which are 60%, 75%, and 90%. At each run, one of these levels is used in the first condition. For example, if trailer fill level is set to 75%, then if there are parcels that share the same final destination and can fill at least 75% of a 28-foot trailer, the first condition is met. Otherwise, the four-tier network is used. The last factor is trip time, which is set to eight or ten hours, to achieve the goal of reducing average driving time per leg. Also, maximum trailer and container fill levels factors are set to 100%, to enhance network performance. Based on the number of factors and levels, this study has 144 design points, and three replicates (432 runs in total) were executed to improve accuracy of results.

Table 6.2 illustrates design factors and their levels, while Figure 6.6 shows a tree of all factors and levels with a sample of its branches. Each branch of this tree has three replicates.

Table 6.2: Network design factors and levels.

Design Factor	Factor Levels					
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Demand Pattern	Low	Low W	Mod	Mod W	High	High W
Slack	0	4	-	-	-	-
Destination shortcut	FD	HFD	-	-	-	-
Trailer Fill Level Threshold	60%	75%	90%	-	-	-
Trip Time	8	10	-	-	-	-

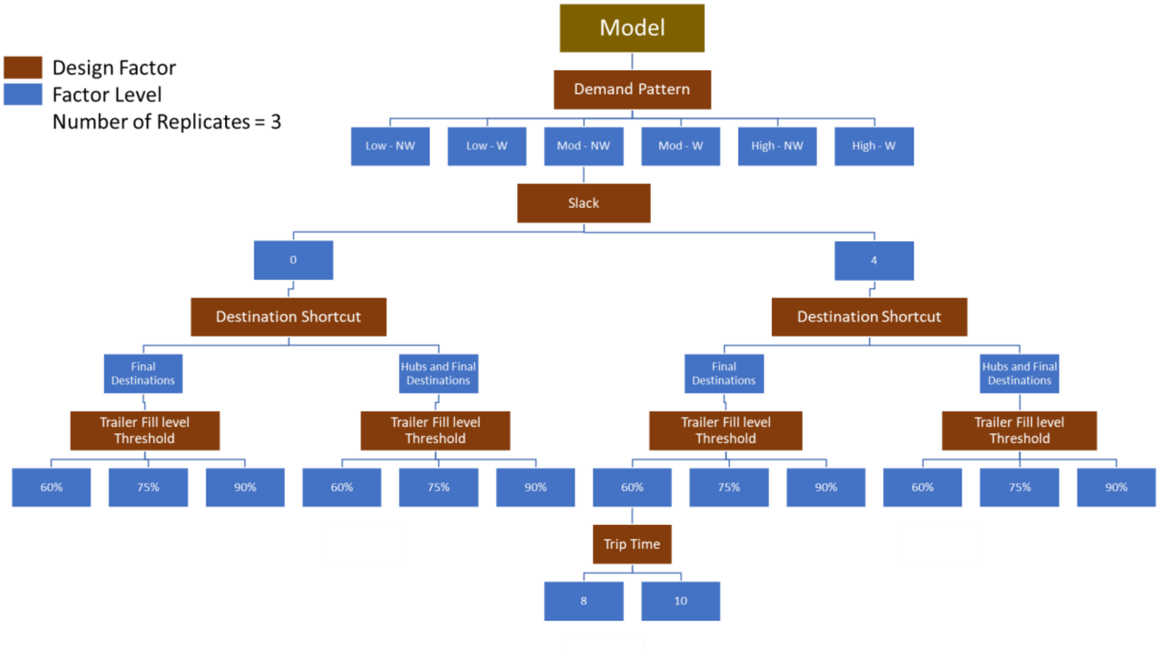


Figure 6.6: Full factorial design with four factors under each demand pattern.

6.2.1 Model Parameters

The effect of each factor on network performance was analyzed using ANOVA. Most of the factors' main effect is significant except when demand is low; trip time is insignificant in most cases. The highest contribution in most scenarios is from the destination shortcut and trailer fill level threshold. The two-way interactions are negligible when demand is low but are significant when demand is moderate or high. Lastly, the three- and four-way interactions are insignificant, except in some cases of interaction between slack, destination shortcut, and trip time.

The cost equation (4.1) from Chapter 4 is used to judge network performance and select the best alternatives. Here, the analysis is the same as the first study, where the KPIs are standardized then added to the cost equation. Table 6.3 shows significant factors for each priority when demand is low, while the analysis for the remaining demand patterns is in the appendix.

Table 6.3: Significant factors for each cost based on ANOVA analysis when demand pattern is low.

Low – No warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	
Trailer Fill Level Threshold	√	√	√	√	√	√	√	√
Destination shortcut	√	√	√	√	√	√	√	√
Trip Time			√			√		
Two-Way Interactions								
Slack*Trailer fill level threshold								
Slack*Destination shortcut	√	√	√	√	√	√	√	
Slack*Trip time								
Trailer fill level threshold *Destination shortcut								
Trailer fill level threshold*Trip time								
Destination shortcut*Trip time	√	√	√	√	√	√	√	
Three-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut								
Slack*Trailer fill level threshold *Trip time								
Slack*Destination shortcut*Trip time			√					√
Trailer fill level threshold *Destination shortcut*Trip time								
Four-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut*Trip time								

Based on previous analysis, the best combination of factors and levels for each demand pattern is summarized in Table 6.4. One major expectation is that the hybrid network will not be the best option for all scenarios. Hence, it was found that the hybrid network is better than the four-tier when the priority is lateness, operational cost, driving time per leg, or operational cost and lateness II. The best combination for most scenarios using the hybrid network is when slack is zero or four hours, the destination shortcut is a final destination only. However, in case of high demand and when the priority is lateness, the destination shortcut should be set to hubs and final destination. Trailer fill level threshold in the hybrid network is 90%, and trip time is ten hours. On the other hand, the four-tier is superior when priority is the environment, utilization, operational cost and lateness I, or when all are equal. The best combination for most scenarios of the four-tier network is when slack is zero and the maximum container and trailer fill levels are 100%. These results are reasonable as if the maximum container fill level is less than 100%, then additional trucks are requested, which causes an increase in total traveled miles and operational cost, as well. Table 6.4 can be read as follows: the four-tier network is written as slack, maximum trailer fill level, number of tiers, and maximum container fill level, while the hybrid network is written as destination shortcut, slack, trailer fill level threshold, and trip time.

Table 6.4: Best parcel delivery network configuration for each demand pattern.

Demand Pattern	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Low	4-tier 0,100%, 4,100%	4-tier 0,100%, 4,100%	FD 0,90%, 10	4-tier 0,100%, 4,100%	FD 0,90%, 10	4-tier 0,100%, 4,100%	FD 0,90%, 10	FD 0,90%, 10
Low W	4-tier 0,100%, 4,100%	4-tier 0,100%, 4,100%	FD 0,90%, 10	4-tier 0,100%, 4,100%	FD 0,90%, 10	4-tier 0,100%, 4,100%	FD 0,90%, 10	FD 0,90%, 10
Moderate	4-tier 0,100%, 4,100%	4-tier 0,100%, 4,100%	FD 0,90%, 10	4-tier 0,100%, 4,100%	FD 0,90%, 10	4-tier 0,100%, 4,100%	FD 0,90%, 10	FD 4,90%, 10
Moderate W	4-tier 0,100%, 4,100%	4-tier 0,100%, 4,100%	FD 4,90%, 10	4-tier 0,100%, 4,100%	FD 0,90%, 10	4-tier 0,100%, 4,100%	FD 0,90%, 10	FD 4,90%, 10
High	4-tier 0,100%, 4,100%	4-tier 0,100%, 4,100%	FD 4,90%, 10	4-tier 0,100%, 4,100%	FD 0,90%, 10	4-tier 0,100%, 4,100%	FD 4,90%, 10	HFD 0,90%, 10
High W	4-tier 0,100%, 4,100%	4-tier 0,100%, 4,100%	FD 4,90%, 10	4-tier 0,100%, 4,100%	FD 4,90%, 10	4-tier 0,100%, 4,100%	FD 4,90%, 10	HFD 0,90%, 10

6.2.2 Trailers Analysis

As discussed in previous chapters, running a parcel delivery network requires knowing two main pieces of information, the number of trailers and the number of containers. In this section, number of container analysis is excluded as the goal of the hybrid network is only to reroute these containers, so the number of containers is fixed. Overall findings show that there is a slight increase in the number of active trailers. This means that the number of active trailers is not affected by any factor. Results are represented by comparing the current study with results from the four-tier network. Table 6.5 illustrates the percentage change in the maximum number of active trailers when demand is high with warehouses, and includes analysis of spikes, as well. This analysis focuses on the 28-foot trailer as it is the most frequently used. Following the same analysis as in previous studies, spikes in the number of active trailers can be eliminated by taking the 90th percentile. Findings show that the hybrid network uses additional trailers compared to the four-tier network, which indicates an increase in the number of vehicles used. The highest increase in the number of active trailers is found when the trip time factor is ten hours and the trailer fill level threshold is 60%. When the destination factor is set to hubs and final destination, trip time is set to eight, slack is set to zero, and the trailer threshold is 90%, the smallest increment of 1% is observed.

Table 6.5: Percentage of increase or decrease in the maximum number of active trailers for each design point per trailer type when the demand pattern is high with warehouses.

Destination	Slack	Trip time	TFL threshold	Type 6 - Spikes	Type 6 – No spikes
Final Destinations	0	8	60%	11%	7%
			75%	9%	6%
			90%	8%	5%
		10	60%	12%	8%
			75%	10%	7%
			90%	9%	6%
	4	8	60%	9%	6%
			75%	7%	4%
			90%	4%	3%
		10	60%	13%	8%
			75%	10%	6%
			90%	8%	5%
Hubs & Final Destinations	0	8	60%	10%	7%
			75%	8%	6%
			90%	7%	5%
		10	60%	10%	7%
			75%	9%	6%
			90%	7%	5%
	4	8	60%	6%	4%
			75%	3%	2%
			90%	1%	1%
		10	60%	10%	7%
			75%	8%	5%
			90%	6%	4%

6.2.3 KPI Analysis

This section analyzes each of the six KPIs by comparing them with results obtained from Chapter 5. Findings show that there is a noticeable improvement in network performance due to implementation of the newly developed network structure, parcel lockers, and crossdocking scanning. As discussed before, each of these methods and techniques has its effect on performance. This section illustrates their overall impact on network performance and compares it with the four-tier network in Chapter 5.

Significant improvements can be made to lessen the percentage of late parcels. This KPI could be reduced using the new hybrid network and parcel lockers, where each of these is capable of decreasing late parcel percentage by on average 15-20%. As shown in Table 6.6, lateness is enhanced in all demand patterns. As expected, results illustrate that slack has a significant effect on the percentage of late parcels, while other factors (destination shortcut, trip time, and trailer fill level threshold) do not affect it. If slack is zero, average improvement is 33%, which involves using both the new network and parcel lockers. However, when slack is four hours, average improvement in all demand patterns is 41%. On the other hand, if slack is zero and demand level increases, then improvement decreases from 36% to 30%. Trip time factor does not affect most legs that use the hybrid network instead of the four-tier, requiring less than eight hours to arrive at the final destination. Furthermore, the trailer fill level threshold factor indicates that these legs usually have a high number of parcels to be shipped, so there is no difference in setting it to 60% or 90%.

Operational cost is affected negligibly by all these factors, which is an encouraging finding. The main reason why this is a good result is due to the fact that if performance can be improved with no additional cost, then implementation of these methods and techniques is feasible. The other major finding is that as demand level decreases operational cost increases up to around 5%, which is anticipated. Hence, the developed network is preferable over the four-tier when demand is high since there is no additional associated cost. Table 6.7 illustrates that destination factor does not vary the operational cost. However, an increase in slack from zero to four hours increases cost by approximately 3-6% due to the need for additional trucks. Results also show that trip time does not affect cost. Finally, an increase in trailer fill level threshold causes a minor decrease in cost of roughly 1%, since the number of legs that use the hybrid network is decreased, which in turn reduces the required number of trucks. The highest increase in operational cost of nearly 12% is observed when slack is four hours, and trailer threshold is 60%. If the destination factor is hubs and final destinations, slack is zero, and trailer threshold is 90%, then cost is reduced by around 2%.

Table 6.6: Percentage of increase or decrease in percentage of late parcels at each design point.

Destination	Slack	Trip time	TFL threshold	Low	Low W	Mod	Mod W	High	High W
Final Destinations	0	8	60%	-36%	-32%	-28%	-29%	-28%	-29%
			75%	-36%	-33%	-28%	-29%	-28%	-29%
			90%	-34%	-32%	-28%	-30%	-28%	-28%
		10	60%	-37%	-34%	-29%	-30%	-29%	-29%
			75%	-37%	-34%	-29%	-30%	-29%	-29%
			90%	-36%	-33%	-29%	-31%	-28%	-29%
	4	8	60%	-38%	-41%	-43%	-44%	-43%	-44%
			75%	-38%	-41%	-39%	-41%	-42%	-43%
			90%	-36%	-41%	-38%	-38%	-41%	-43%
		10	60%	-42%	-43%	-44%	-45%	-44%	-45%
			75%	-43%	-44%	-40%	-42%	-43%	-44%
			90%	-42%	-42%	-39%	-40%	-43%	-44%
Hubs & Final Destinations	0	8	60%	-35%	-34%	-29%	-31%	-30%	-30%
			75%	-35%	-35%	-30%	-31%	-30%	-30%
			90%	-34%	-34%	-30%	-31%	-29%	-30%
		10	60%	-36%	-35%	-30%	-31%	-30%	-30%
			75%	-36%	-36%	-30%	-31%	-30%	-30%
			90%	-35%	-35%	-31%	-32%	-29%	-30%
	4	8	60%	-42%	-42%	-42%	-43%	-42%	-42%
			75%	-41%	-42%	-40%	-41%	-41%	-43%
			90%	-38%	-41%	-39%	-40%	-40%	-43%
		10	60%	-43%	-42%	-42%	-44%	-42%	-43%
			75%	-42%	-44%	-41%	-42%	-42%	-43%
			90%	-41%	-43%	-40%	-41%	-41%	-43%

Table 6.7: Percentage of increase or decrease in operational cost at each design point.

Destination	Slack	Trip time	TFL threshold	Low	Low W	Mod	Mod W	High	High W
Final Destinations	0	8	60%	5%	3%	2%	2%	1%	0%
			75%	3%	2%	1%	1%	0%	0%
			90%	2%	1%	0%	0%	-1%	-1%
		10	60%	7%	4%	2%	2%	1%	0%
			75%	5%	3%	1%	1%	0%	-1%
			90%	3%	1%	0%	0%	-1%	-1%
	4	8	60%	6%	8%	7%	7%	7%	7%
			75%	4%	6%	3%	5%	5%	5%
			90%	2%	4%	3%	4%	5%	4%
		10	60%	8%	12%	11%	11%	9%	9%
			75%	9%	9%	7%	8%	9%	8%
			90%	6%	7%	6%	6%	7%	7%
Hubs & Final Destinations	0	8	60%	3%	3%	1%	2%	0%	0%
			75%	2%	2%	0%	1%	-1%	-1%
			90%	0%	0%	-1%	0%	-1%	-2%
		10	60%	4%	4%	2%	2%	0%	0%
			75%	2%	2%	0%	1%	-1%	-1%
			90%	1%	1%	0%	0%	-1%	-2%
	4	8	60%	8%	9%	6%	7%	5%	5%
			75%	5%	5%	3%	5%	4%	4%
			90%	3%	6%	4%	4%	3%	3%
		10	60%	12%	9%	10%	11%	10%	9%
			75%	9%	10%	8%	10%	8%	8%
			90%	6%	7%	7%	8%	7%	7%

Total traveled miles and total number of vehicles used KPIs both experienced growths. These increases are reasonable as the number of legs for hybrid networks equals the number of legs in the four-tier plus new legs that use the hybrid network. Table 6.8Table 6.9 show that these KPIs are not affected by destination factor but are slightly affected by other factors where each increases KPIs by around 3-5%. The greatest increase in these two KPIs occurs when slack is four hours, and trailer threshold is 60%, while the lowest is when the demand pattern is high and slack is zero.

Table 6.8: Percentage of increase or decrease in total traveled miles at each design point.

Destination	Slack	Trip time	TFL threshold	Low	Low W	Mod	Mod W	High	High W
Final Destinations	0	8	60%	14%	11%	9%	10%	8%	7%
			75%	11%	9%	8%	9%	7%	6%
			90%	9%	8%	7%	7%	6%	6%
		10	60%	16%	12%	11%	11%	9%	8%
			75%	13%	11%	9%	10%	8%	7%
			90%	11%	9%	8%	8%	7%	7%
	4	8	60%	15%	17%	17%	17%	16%	16%
			75%	12%	14%	12%	14%	14%	14%
			90%	9%	12%	12%	12%	13%	13%
		10	60%	18%	23%	23%	23%	21%	21%
			75%	19%	20%	17%	19%	20%	19%
			90%	15%	16%	16%	16%	18%	18%
Hubs & Final Destinations	0	8	60%	11%	11%	9%	9%	8%	7%
			75%	9%	9%	8%	8%	6%	6%
			90%	7%	7%	6%	7%	6%	5%
		10	60%	12%	12%	10%	11%	8%	7%
			75%	10%	10%	9%	9%	7%	6%
			90%	8%	9%	7%	8%	6%	6%
	4	8	60%	17%	19%	15%	16%	14%	14%
			75%	14%	14%	12%	14%	13%	12%
			90%	10%	14%	12%	12%	11%	11%
		10	60%	22%	19%	22%	23%	21%	20%
			75%	19%	20%	19%	21%	19%	19%
			90%	15%	17%	18%	18%	17%	17%

Table 6.9: Percentage of increase or decrease in number of vehicles used at each design point.

Destination	Slack	Trip time	TFL threshold	Low	Low W	Mod	Mod W	High	High W
Final Destinations	0	8	60%	10%	11%	11%	11%	10%	9%
			75%	7%	8%	9%	10%	8%	8%
			90%	5%	6%	7%	8%	7%	7%
		10	60%	12%	13%	13%	13%	11%	10%
			75%	9%	10%	10%	11%	9%	9%
			90%	7%	8%	9%	9%	8%	8%
	4	8	60%	8%	8%	6%	7%	5%	4%
			75%	5%	6%	5%	6%	3%	3%
			90%	3%	3%	4%	4%	3%	2%
		10	60%	8%	11%	9%	10%	7%	6%
			75%	7%	8%	7%	8%	6%	5%
			90%	5%	5%	6%	7%	5%	4%
Hubs & Final Destinations	0	8	60%	10%	10%	10%	10%	9%	9%
			75%	7%	7%	8%	8%	8%	7%
			90%	5%	5%	6%	7%	6%	6%
		10	60%	11%	12%	11%	12%	10%	9%
			75%	9%	9%	9%	10%	8%	8%
			90%	6%	7%	7%	8%	7%	6%
	4	8	60%	7%	8%	5%	6%	3%	3%
			75%	4%	4%	4%	4%	2%	2%
			90%	2%	4%	3%	3%	1%	1%
		10	60%	10%	8%	8%	9%	6%	5%
			75%	6%	7%	6%	7%	5%	4%
			90%	4%	4%	5%	6%	3%	3%

Driving time per leg is not particularly affected under this study's factors and methods. Table 6.10 illustrates the percentage of change in average driving time per leg. Results show that there is up to a 40% increase in driving time per leg when slack is four hours, trip time factor is ten hours, and demand is high. However, this 40% increment is equivalent to two additional driving hours, which means that the average driving time per leg is about six hours instead of four hours. It is expected that more legs are using the hybrid network when demand is high and slack is four hours, which causes the shift in this KPI; however, six hours is still conventional compared to eight hours of the two-tier network. The rest of the results are negligible because in most cases there is no increase in the average driving time per leg or that increment is only less than 30 minutes. The best results are observed when slack is zero without low demand. This increase in the average time per leg requires a need to have a feeder team or drivers are sleepover at their destinations instead of driving back to their homes. Carriers provide this service to their drivers, where both scenarios increase the operational cost. In this work, this additional cost is not included in the operational cost calculations, but a feasibility study should be done to help managers to decide whether to use the hybrid or 4-tier networks for each pair of locations.

Table 6.10: Percentage of increase or decrease in average driving time per leg at each design point.

Destination	Slack	Trip time	TFL threshold	Low	Low W	Mod	Mod W	High	High W
Final Destinations	0	8	60%	3%	1%	0%	0%	-1%	-1%
			75%	4%	1%	0%	1%	0%	0%
			90%	4%	1%	1%	1%	0%	0%
		10	60%	3%	0%	-1%	-1%	-1%	-1%
			75%	4%	1%	0%	0%	-1%	-1%
			90%	4%	1%	0%	1%	0%	0%
	4	8	60%	5%	6%	16%	16%	23%	25%
			75%	6%	6%	11%	12%	22%	23%
			90%	5%	6%	12%	12%	22%	23%
		10	60%	8%	9%	23%	23%	27%	39%
			75%	9%	9%	16%	18%	30%	31%
			90%	7%	10%	16%	15%	28%	33%
Hubs & Final Destinations	0	8	60%	2%	1%	1%	1%	0%	0%
			75%	2%	1%	1%	1%	0%	0%
			90%	3%	1%	2%	2%	0%	0%
		10	60%	2%	1%	1%	1%	0%	0%
			75%	2%	1%	1%	1%	0%	0%
			90%	3%	1%	1%	1%	0%	0%
	4	8	60%	7%	10%	16%	20%	24%	28%
			75%	7%	8%	15%	19%	24%	24%
			90%	6%	6%	16%	16%	23%	24%
		10	60%	12%	11%	24%	26%	35%	39%
			75%	11%	14%	23%	25%	35%	38%
			90%	8%	11%	24%	23%	34%	37%

Results show an average decrease in actual trailer fillrate by around 5%. This indicates that normal four-tier legs are affected by the number of parcels shipped using the hybrid network. Almost none of the factors affect fillrate, which means that the percentage of parcels shipped by the hybrid network is similar in all demand patterns. Table 6.11 shows the percentage of reduction in the average actual trailer fillrate.

Table 6.11: The percentage of increase or decrease in the average actual fillrate at each design point.

Destination	Slack	Trip time	TFL threshold	Low	Low W	Mod	Mod W	High	High W
Final Destinations	0	8	60%	-5%	-4%	-4%	-4%	-4%	-4%
			75%	-5%	-4%	-4%	-4%	-4%	-4%
			90%	-5%	-4%	-4%	-4%	-4%	-4%
		10	60%	-5%	-5%	-5%	-5%	-4%	-4%
			75%	-5%	-4%	-4%	-4%	-4%	-4%
			90%	-5%	-4%	-4%	-4%	-4%	-4%
	4	8	60%	-6%	-7%	-7%	-6%	-5%	-5%
			75%	-6%	-7%	-6%	-6%	-5%	-5%
			90%	-6%	-7%	-6%	-6%	-5%	-5%
		10	60%	-7%	-7%	-7%	-7%	-6%	-6%
			75%	-7%	-7%	-7%	-6%	-6%	-6%
			90%	-7%	-7%	-6%	-6%	-6%	-6%
Hubs & Final Destinations	0	8	60%	-5%	-5%	-5%	-5%	-4%	-4%
			75%	-4%	-4%	-4%	-4%	-4%	-4%
			90%	-4%	-4%	-4%	-4%	-4%	-4%
		10	60%	-5%	-5%	-5%	-5%	-4%	-4%
			75%	-5%	-5%	-5%	-5%	-4%	-4%
			90%	-5%	-4%	-5%	-4%	-4%	-4%
	4	8	60%	-7%	-7%	-7%	-6%	-6%	-5%
			75%	-7%	-7%	-6%	-6%	-5%	-5%
			90%	-7%	-7%	-6%	-6%	-5%	-5%
		10	60%	-8%	-7%	-7%	-7%	-6%	-6%
			75%	-8%	-8%	-7%	-7%	-6%	-6%
			90%	-7%	-8%	-7%	-7%	-6%	-6%

6.3 Conclusions

This study introduced a new proposed hybrid parcel delivery network that is used to reroute containers through the network to enhance performance. The developed network is constructed based on the two- and four-tier networks from Chapter 5. Each of the two- and four-tier networks has its advantages. The main advantage of the two-tier is visiting a minimal number of hubs, which reduces the number of scans, while the four-tier network has the advantage of reducing average driving time per leg. The proposed network combines these main advantages to improve network performance. Another two techniques implemented to boost network performance are parcel lockers and crossdocking scanning. Parcel lockers have been widely used to reduce the number of late parcels and improve delivery security, while the crossdocking scanning is proposed to speed the scanning process of containers at hubs. Overall performance of the hybrid network is compared to the four-tier network as the four- and multi-tier networks are expected to replace traditional hub-and-spoke networks in the near future. Simulation models have been developed to evaluate the hybrid network performance with AnyLogic® based on the previous study in Chapter 5, experimenting with six different demand patterns.

Findings indicate that all factors and several two-way and three-way interactions significantly affect network performance. Based on these results, the best set of factor levels were specified to run the network under a given set of circumstances. Results show that the proposed network is superior to the four-tier network when managers' priorities are lateness, operational cost, driving time per leg, or operational cost and lateness II. However, other priorities should be run using the four-tier network to achieve better performance. For example, if the demand pattern is high, and the priority is solely on lateness, then the network should run under these factor levels: Hubs and final destination, 90% trailer fill level threshold, zero slack, and ten hour trip times.

The second part of the analysis was to specify the required number of trailers to run eac network. As expected, the hybrid network requires additional trailers as new legs are generated. The number of trailers increased by around 7%. Later investigations of all KPIs illustrated that hybrid network KPIs lateness results are better than the four-tier network with a reduction in percentage of late parcels by around 35%. Percentage of late parcels is affected mainly by slack and demand level. The other KPIs observed were close to four-tier network results. Positive results observed using the hybrid network allow for improvements to be made to the four-tier network without incurring additional cost. Moreover, results show that average driving time per leg will not exceed six hours, which is close to the four hour average in the four-tier network.

Chapter 7 Effect of Changing Container Capacities and Types on Parcel Delivery Network Performance

The added value of using containers in a parcel delivery network has been discussed in previous studies. These studies evaluate and illustrate the effect of using containers on network performance. However, switching from bags to containers is just one of the first steps to enhance parcel delivery networks in the future and to reach the Physical Internet goals. This study focuses on selection of the best container capacities and types to demonstrate the effect of such changes on network performance. A mixed-integer programming model is used to find outputs to reduce operational cost and increase vehicle and container utilization. Then, the four-tier network is assessed using study outputs compared to results from Chapter 5.

Some KPIs are affected when container capacities and types are changed, while others are not. These new capacities are not used to redesign the containerization process or the number of parcels in each container. Rather, the goal is to reduce unused space in these containers in order to decrease the required number of trucks and operational cost, as well. Findings indicate that selecting inaccurate container capacities and types increases operational cost because of the additional requested vehicles to ship these containers. Also, one of the major findings is that companies should seriously study the effect of using standard containers on their network because it could increase operational costs. A standard set of containers will not fit all service providers' demands, but the PI aims and researches focus on designing these containers to minimize unused space and operational cost.

This chapter is organized as follows: Section 7.1 summarizes the study methodology. The results are analyzed and discussed in Section 7.2. While Section 7.3 contains study conclusions.

7.1 Methodology

Maximizing container utilization is the optimal method to minimize operational cost. Many studies have discussed optimization of container numbers using the Container Loading Problem (CLP) (Leung et al. (2008); Tlili et al. (2013)). However, the number of containers is not in our scope as it is fixed. As mentioned in previous chapters, containers are loaded to trucks after each sort, where these containers are filled up with parcels that are ready to be shipped. Since the number of ready parcels is fixed, then the shipment volume, where a shipment is an aggregation of parcels that share the same destination, and the number of containers are fixed, but their capacities or types could be changed. Figure 7.1 shows the distribution of shipment volumes after running the network model which is used to find new container types. Leung et al. (2008) presented the basic version of the CLP to maximize container space utilization and reduce the number of container types required. As expected, they conclude that unused space decreases with increasing number of types. They found that using five types of containers is the best option, while additional types will cause unused space to be slightly affected.

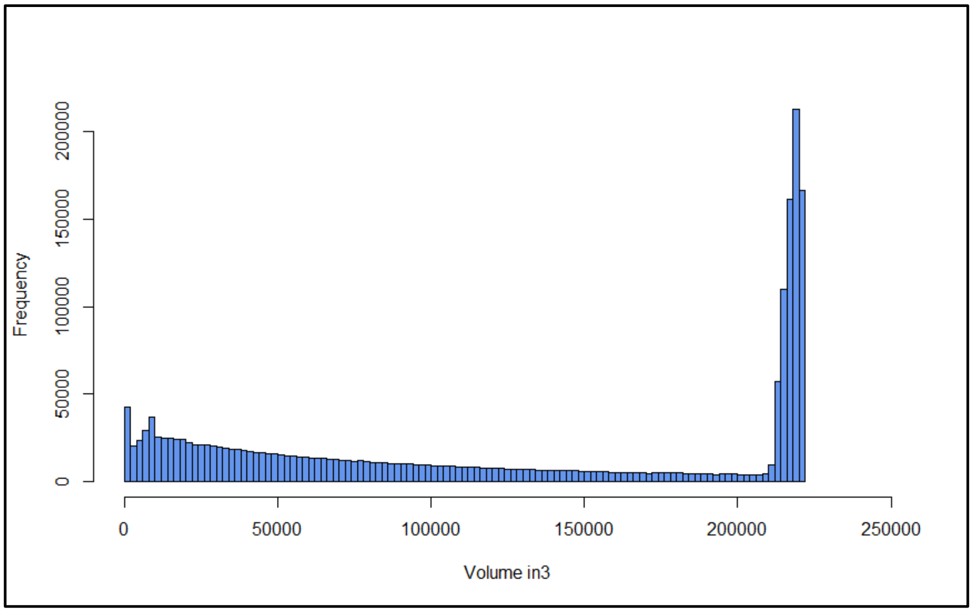


Figure 7.1: Distribution of shipment volumes and their frequencies.

Figure 7.2 shows a summary of proposed flow to reduce operational cost based on our investigations and previous study results. This flow starts with increasing container space utilization and ends with reducing overall operational cost by reducing total traveled miles of trucks.

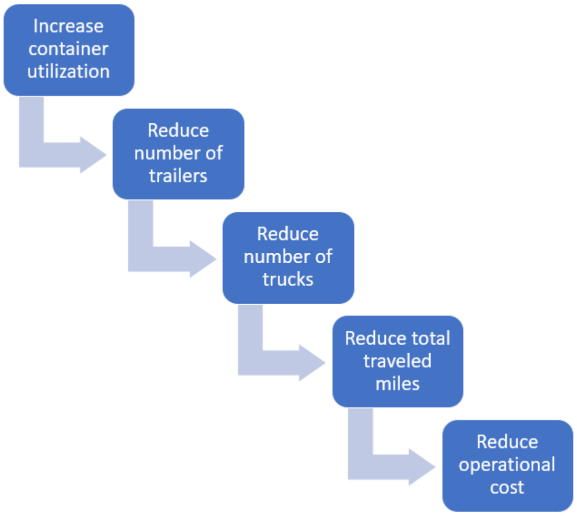


Figure 7.2: Proposed flow to reduce network operational cost by increasing container utilization.

We aim to minimize unused containers while satisfying practical constraints described below:

- Each shipment is to be loaded entirely in a container.
- Each container has one shipment only.
- The capacity of the biggest container is predefined.

- Each container is loaded in exactly one trailer.

Notation	Explanation
Inputs	
i	*Number of shipments*
j	*Number of containers*
v_i	*Shipment volume*
Decision variables	
V_j	*Container capacity*
$C_{ij} = \begin{cases} 1 \\ 0 \end{cases}$	*if the shipment i is placed in container j* *otherwise*

Given a number j different container types with capacities V_j . Let i be a set of parcel shipments. For each shipment i corresponds to its volume v_i. We formulate the problem by the following mathematical model:

$$Min \sum_i \sum_j C_{ij}(V_j - v_i) \tag{7.1}$$

Subject to

$$\sum_j C_{ij} = 1 \tag{7.2}$$

$$v_i \leq V_j C_{ij} \tag{7.3}$$

$$V_j \leq \max(v_i) \tag{7.4}$$

$$C_{ij} \ \epsilon \ 0,1 \tag{7.5}$$

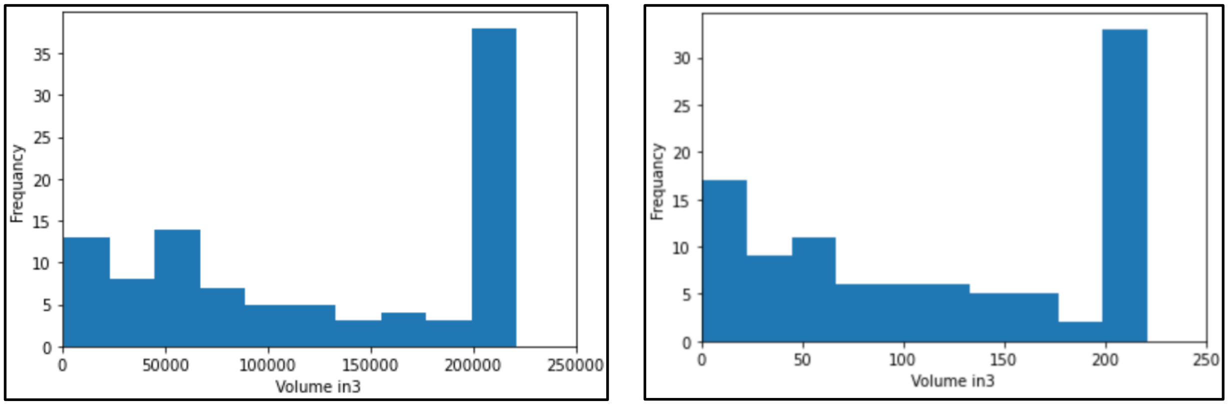
$$V_j \geq 0, \ Integer \qquad (7.5)$$

Objective (7.1) states that unused container space is to be minimized. Constraint (7.2) ensures that every shipment is packed in exactly one container. Constraint (7.3) imposes that the maximum volume of containers should be respected. Constraint (7.4) guarantees the container capacity is less than or equal to the maximum shipment volume, which is 128 ft^3.

Total number of shipments exceeds one million, which means that searching for the optimal solution cannot be achieved easily. Also, CLP is classified as an NP-hard optimization problem. Many attempts were made to run the optimization using the entire data set, but the problem became unbounded or no feasible solution was found. Hence, two methods are used to find a solution to this problem:

1. Sampling from the original data: a sample of shipments is extracted from the shipment volumes data set. This sample is used to run the optimization and find near-optimal container capacities. Figure 7.3 (a) shows distributions of sampled shipments and how it emulates original data in Figure 7.1. Sampled data assist in reducing the number of shipments, which allows the optimization model to run and search for a solution.

2. Sampling from the original data with scale reduction: another technique is used to run the optimization and find a solution by sampling from the original data set of shipments, then dividing the shipment volumes by 1,000. This method reduces search space and finds a solution faster than the previous method. Figure 7.3 (b) represents sampled shipments after dividing shipment volumes by 1,000.



(a) (b)

Figure 7.3: (a) Distribution of sampled shipments without scale reduction. (b) Distribution of sampled shipments with scale reduction.

7.2 Results and Discussion

In this section, implementation of the discussed method is described first, followed by an analysis of the KPIs. KPIs that are affected by this study are network total traveled miles, number of vehicles used, operational cost, and trailer fillrates. This analysis is done using high and low demand patterns to study the effect of the demand level on overall performance.

The goal of implementing this study is to answer the following research questions:

1. If the number of container types is specified, then what is the effect of using different container capacities on the parcel delivery network?
2. If the number of container types is not specified, then what is the effect of using a different number of container types?
3. What is the effect of using one set of standard container types for all companies compared to using custom container types for each company?

To answer each of these questions, the following steps should be taken:

1. Select the number of container types: four sets of container types are used to run this optimization and the simulation model, as well. These types are 3, 5, 7, and 10 container types.
2. Run both optimization methods (with and without scale reduction) to find the container capacities for each set of container types. For example, if the number of container types is three, then the optimization solution has three values which are the container capacities.

3. For each number of container types, obtain standard container capacities from the proposed PI-containers (Montreuil et al., 2017). When the number of container types is five, standard containers used in the previous studies are applied to run the network.
4. Run the four-tier network simulation model using capacities obtained from the previous two steps to get performance results.
5. Compare all run KPIs to study the effect of changing container capacities and types on network performance.

Results are categorized into three groups: Standard, Optimal I, and Optimal II. Standard refers to the use of PI-containers, Optimal I to container capacities obtained without a scale reduction, and Optimal II to container capacities obtained with a scale reduction.

First, average trailer fillrates are not affected by changes in container capacities and types when demand is high. However, when demand is low, this KPI decreased slightly when those factors are changed. Although this is a slight decrement, it indicates that demand level influences trailer fillrate. Figure 7.4 shows the effect on average fillrate for both demand levels. The other trailer fillrate KPI is the actual trailer fillrate, which is illustrated in Figure 7.5. Changes in container capacities and types have a clear effect on fillrate. As expected, average actual trailer fillrates increase with an increasing number of container types. The difference between using three or ten container types, on average, equals 12% when the demand is high, and 16% when the demand is low. The effect of using different container capacities when container types are fixed does not affect this KPI.

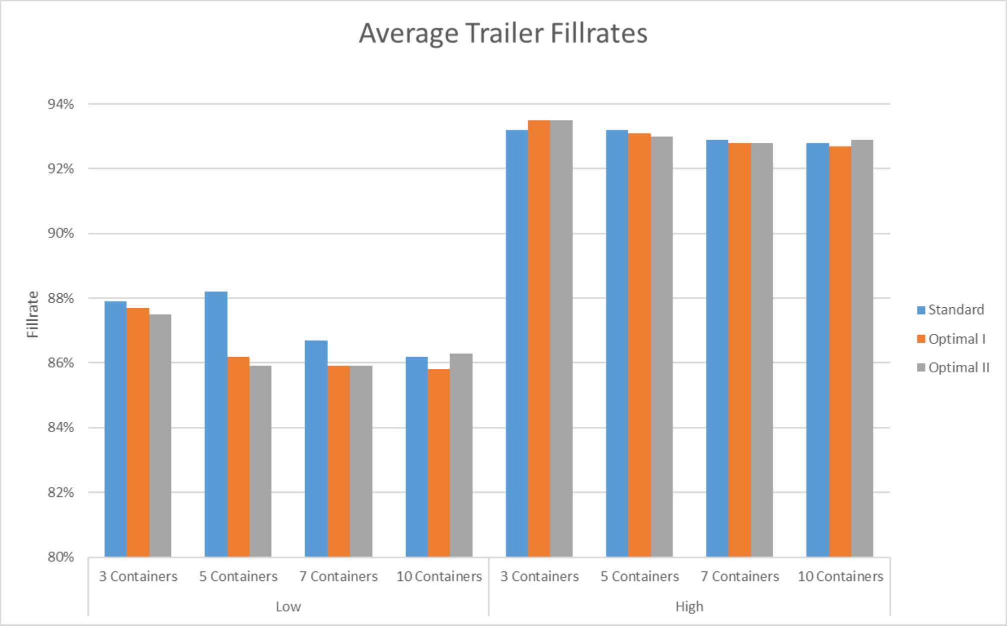


Figure 7.4: Effect of changing container capacities and types on average trailer fillrate.

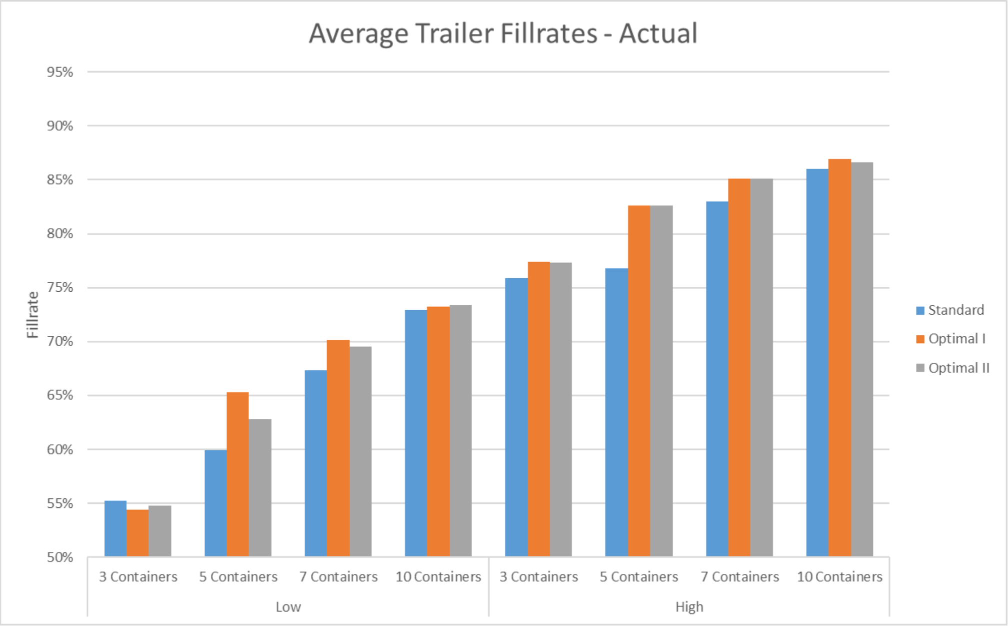


Figure 7.5: Effect of changing container capacities and types on average actual trailer fillrate.

Based on obtained results of trailer fillrates, the number of trailers decreases with an increasing number of container types due to more parcels allocated in trailers. However, unused space increases when three types are used requiring additional trucks to ship these containers. Switching from three to five container types causes a significant drop in number of vehicles when demand is high. Reduction in number of vehicles when demand is low does not exceed 10,000 vehicles during the 2-week running period. Figure 7.6 illustrates the effect on number of vehicles used.

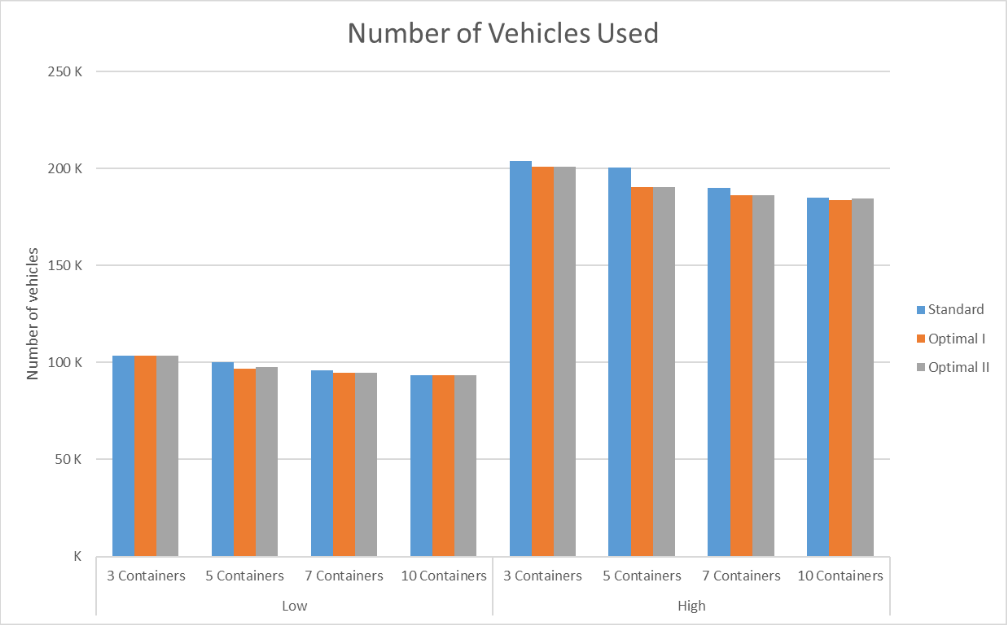


Figure 7.6: The effect of changing the container capacities and types on the number of vehicles used.

Fuel cost, which is the first component of operational cost, is correlated with total traveled miles. When demand level is high and the number of container types increases, total traveled miles decreases by around 3 million miles. On the other hand, a low demand level shows a reduction in this KPI by around 2.5 million miles. Figure 7.7 indicates that using seven or ten container types has similar results, which leads to the conclusion that there is no added value to network performance if the number of container types is greater than seven.

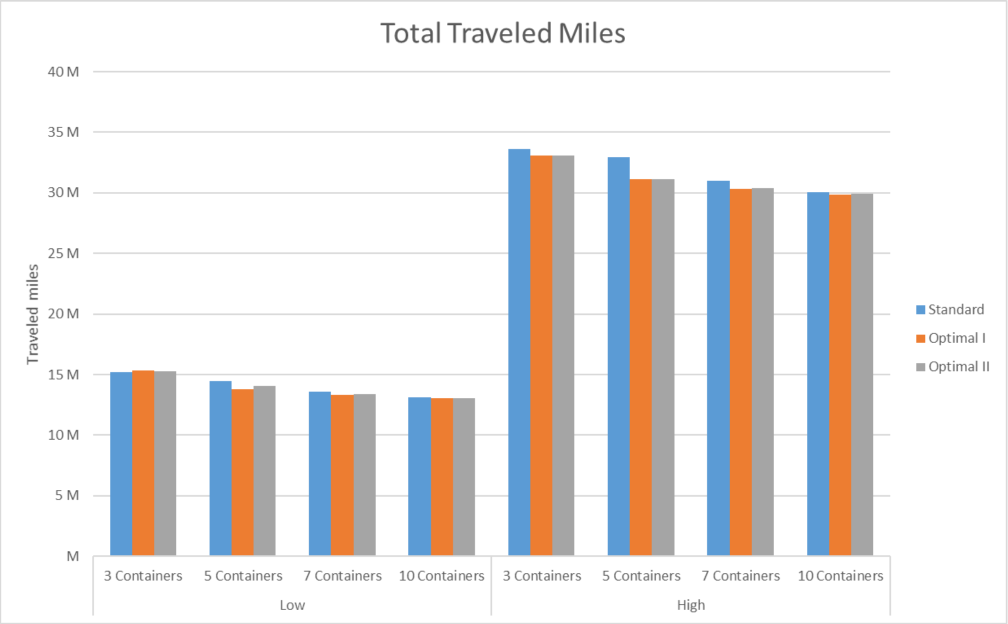


Figure 7.7: The effect of changing the container capacities and types on the total traveled miles.

The last KPI to be analyzed is operational cost. Managers are interested in the cost value because decisions are made based on its analysis. Results in Figure 7.8 show that operational cost is similar whether demand is high or low. The difference in cost when the number of container types increases is equal to $8 million for high demand, and $6.5 million for low demand. The effect of selecting different container capacities when the number of types is fixed can be noticed in Figure 7.8. In this study, the simulation model was run for two weeks only. Hence, if operational cost could be reduced by around $6.5 million in two weeks, then $169 million could be saved annually by increasing the number of container types and finding their optimal or near-optimal capacities.

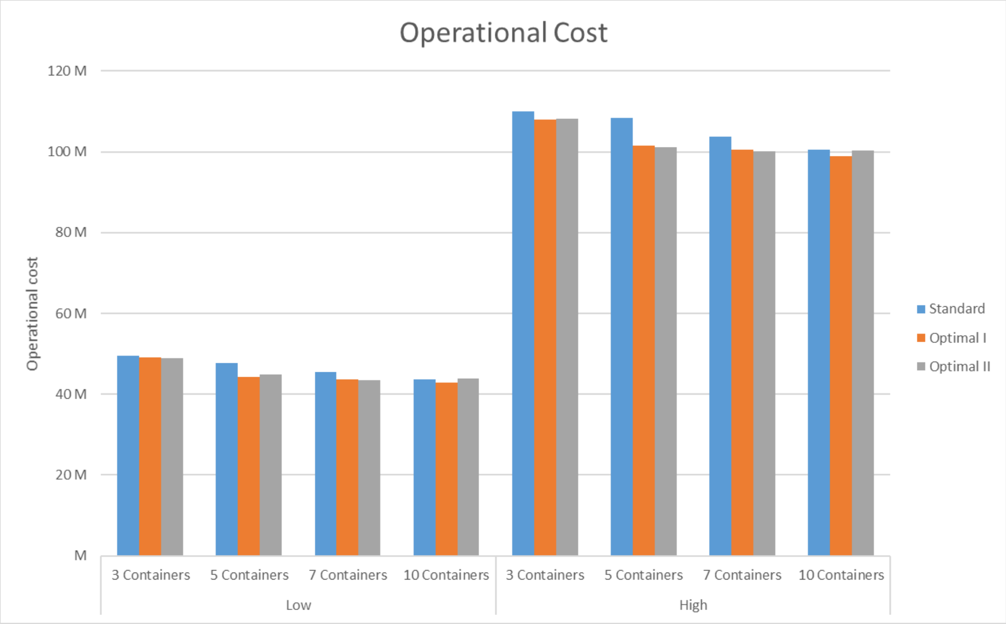


Figure 7.8: The effect of changing the container capacities and types on the operational cost.

Following are answers along with the three questions that should be asked,:

1. If the number of container types is specified, then what is the effect of using different container capacities on the parcel delivery network?

   Finding the optimal container capacities is not facile. Hence, near-optimal or standard PI-container capacities could be found to run the network. Selecting inaccurate container capacities can lead to an increase in operational cost. However, results indicate that is minor influencer on performance, and in most of the previous cases was negligible.
2. If the number of container types is not specified, then what is the effect of using a different number of container types?

   This study and literature illustrate that this has a major effect on minimizing unused container space. Operational cost could decrease by around 8% if the number of types increased to seven or ten. As the number of container types increases, container utilization increases.
3. What is the effect of using one set of standard container types for all companies compared to using custom container types for each company?

   The answer to this question is close to the answer of the first question. The idea behind the PI is to standardize and simplify the shipping process. However, if companies use only a set of standard containers, at least one of them will have issues regarding unused space. If these companies do not receive any form of compensation, they will not be interested in joining the PI. This should be studied more critically to provide a set of containers to fit all company demands.

7.3 Conclusions

In this chapter, we evoked the effect of using different container capacities and types on parcel delivery network performance. A one-dimension of the CLP with the objective to minimize unused container space is used to obtain near-optimal container capacities. This optimization was run using Gurobi Optimizer®. In addition, this chapter studies the effect of using different container capacities and types under different demand levels.

Findings conclude that network performance is affected by changing the number of container types. There is potential to decrease operational cost by around 6-8% when the number of container types is increased to at least five. However, increasing the number of container types to exceed seven will not provide a noticeable drop in cost. Moreover, the effect of demand pattern on performance with a changing number of container types is negligible, which means that selecting optimal or near-optimal container capacities and types are not correlated with high demand only. Finally, each company can run their data to find container capacities that fit their specific demand, but they need to study the effect of using a standard set of containers if they decide to work under the PI umbrella.

Chapter 8 Final Conclusions and Future Work

8.1 Final Conclusions

Many techniques and methods have been developed by scholars to enhance the performance of a parcel delivery network. One of the newly developed proposals to change and improve these networks and the entire supply chain system is the PI. The multi-tier network is a PI product that was proposed recently. Many advantages can be obtained by implementing the multi-tier network such as simplifying network flow, enhancing driver's lives, speeding hub operations, and improving delivery accuracy. In this work, the focus was on assessing the multi-tier network and comparing it with the traditional hub-and-spoke network.

In this dissertation, we presented four studies to reach the goal of selecting the best network configuration based on specific circumstances such as demand level. The first study goal was to evaluate and compare the performance of both the two- and four-tier hub-and-spoke networks under traditional operations such as bagging of small parcels. Findings show that the two-tier network is superior to the four-tier network except for average driving time per leg. Also, our investigation showed that the number of tiers, slack time, and maximum trailer fill level significantly affect such networks' performance. Operational cost analysis shows that the four-tier have an average 25% increase in cost compared to the two-tier due to increase in number of scans. Additionally, driving time per leg was reduced from about eight hours for the two-tier to about four hours for the four-tier. Based on these results, switching from a two-tier to a four-tier network is not recommended if bags are used. However, the four-tier network is a good option if managers' priority is helping drivers live a healthier life by reducing driving hours and giving them a better chance to work close to their families.

The second study focused on evaluating and comparing the performance of both the two- and four-tier hub-and-spoke networks using the containerization technique from PI, where a set of containers instead of bags were used for shipping. Results indicate that containerization is one of the crucial techniques to be implemented to enhance parcel delivery network performance. The number of tiers, slack time, maximum trailer and container fill levels are found to be noteworthy factors. The four-tier network requires additional containers, but these containers are less occupied than the two-tier network. Moreover, percentage of late parcels is affected by use of containers and is lowered by around 55%. Operational cost analysis indicates that using containers reduces operational cost when increasing the maximum container fill level. Results show that driving time per leg is similar to the network with bags.

In the third study, a hybrid network was developed by combining two- and four-tier networks to reduce the drawbacks of each and enhance performance by reducing delivery time and cost. Results show that the multi-tier parcel delivery network has a huge potential for improvement. The proposed hybrid network, which combines two- and four-tier networks, is superior to the four-tier network when managers' priorities are lateness, operational cost, driving time per leg, or operational cost and lateness II. Additional priorities should be run using the four-tier network to obtain better performance. Getting similar results to the four-tier network is a good outcome because the four-tier network can be improved using the hybrid network with no additional cost.

The last study aimed to select the best container capacities and types in order to investigate their effect on network performance. Results indicate that the selection decision of capacities and types has a major effect on operational cost. Such a decision for an international level company could save more than $150 million annually. Moreover, increasing the number of container types to a certain threshold enhances network performance. Exceeding that threshold does not affect performance, but it could increase loading time of containers into trucks due to the need to stack them in a way that increases trailer utilization. Also, it is found that the PI could face a serious challenge related to selection of a standard set of container capacities and types. This issue is due to the variety of service provider demands, where each wants to utilize PI containers to reduce operational cost. Hence, scholars should focus on optimizing the container selection process to satisfy those carriers and convince with the PI.

8.2 Future Work

Throughout the work presented in the previous chapters, we discussed a set of research methods and their implementation. This work might be extended by the following:

The development of a PI network that has different service providers with different demand levels and parcel types to deeply study the effect of using different container capacities and types. This could be done by updating the model to simultaneously read different demand files, where each file refers to one of the carriers. Here, hubs will be shared between carriers, while pickup and delivery locations will be separated. Initial experiments will be run using the standard five container capacities and types as discussed in Chapter 5. KPIs and unused space will be analyzed, then the model will be run with different container capacities and types. Results obtained will be analyzed and compared to find the most proper way to decided how capacities and types will be selected. This will help in developing a set of modular PI containers to be used across PI networks by all carriers.

Another type of work that could be done to improve the quality of results is the expansion of parcel delivery network scale by the following:

- Develop different network levels such as international and city-scale delivery networks. This could be done by covering the entire North American continent, including Canada, USA, and Mexico. Also, all big cities such as Los Angele, will be modeled in a way that allows the use of access hubs, which is the smallest hub scale. These updates require management of the working hours and days in each country. Additional scenarios should be run to fully analyze the network. Also, running time should be increased due to the new network scale.
- Request a real demand data set instead of using a generated data set. Improving the result accuracy helps service providers to focus on implementing such updates in their networks. This could be done by collaborating with one of the international carriers to use their real data in the model.
- Simulate major operations at hubs. To minimize operation cost and service time at hubs, operations should be analyzed to detect any type of waste and simulate different working methods. This could be done by visiting several hubs to specify operations that could be modeled and improved.

- Simulate a fixed-size truck and trailer fleet with known schedules and expand the transportation system to include airplanes and trains. This is one of the most important steps that should be run to improve results to match real data. Implementing this in the model requires collaboration with many partners, such as parcel delivery carriers, third-party carriers, train stations, and airports to obtain schedules and fleet sizes.

Also, the development of a network decision tool that selects the best set of factor levels to run a network to enhance its performance. This could be done by having collaborations with many service providers to run all possible scenarios with their real data. A data set will be developed depending on these runs, where a manager could be able to enter current demand and network circumstances to obtain the best setup for their network.

Appendix

Table 1: The significant factors for each cost based on the ANOVA analysis when the demand pattern is low with warehouses – Study 1.

Low - Warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level								
Slack*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers								

Table 2: The significant factors for each cost based on the ANOVA analysis when the demand pattern is moderate - Study 1.

Moderate – No warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level								
Slack*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers	√	√		√				

Table 3: The significant factors for each cost based on the ANOVA analysis when the demand pattern is moderate with warehouses - Study 1.

Moderate – Warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level	√	√		√				√
Slack*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers	√	√	√	√	√		√	√

Table 4: The significant factors for each cost based on the ANOVA analysis when the demand pattern is high - Study 1.

High – No warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√		√	√	√	
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level								
Slack*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers								

Table 5: The significant factors for each cost based on the ANOVA analysis when the demand pattern is high with warehouses - Study 1.

High – Warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√		√	√	√	√	
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level								
Slack*Number of tiers	√	√		√		√		
Max trailer fill level*Number of tiers	√	√		√		√		
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers								

Table 6: The significant factors for each cost based on the ANOVA analysis when the demand pattern is low with warehouses – Study 2.

Low – Warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√		√	√	√
Max container fill level	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level								
Slack*Number of tiers	√	√	√	√	√	√	√	√
Slack*Max container fill level								
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Max container fill level	√	√	√	√	√	√	√	√
Max container fill level*Number of tiers	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers								
Slack*Max container fill level* Max trailer fill level								
Slack * Max container fill level *Number of tiers								
Max container fill level*Max trailer fill level*Number of tiers								
4-Way Interactions								
Slack*Max trailer fill level* Max container fill level*Number of Tiers								

Table 7: The significant factors for each cost based on the ANOVA analysis when the demand pattern is moderate – Study 2.

Moderate – No warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√	√	√	√	√
Max container fill level	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level					√	√		
Slack*Number of tiers	√	√	√	√	√	√	√	√
Slack*Max container fill level	√	√		√	√		√	√
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Max container fill level	√	√	√	√	√	√	√	√
Max container fill level*Number of tiers	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers			√		√	√	√	
Slack*Max container fill level* Max trailer fill level			√		√	√	√	
Slack * Max container fill level *Number of tiers					√			
Max container fill level*Max trailer fill level*Number of tiers	√	√	√		√	√	√	√
4-Way Interactions								
Slack*Max trailer fill level* Max container fill level*Number of Tiers					√	√	√	

Table 8: The significant factors for each cost based on the ANOVA analysis when the demand pattern is moderate with warehouses – Study 2.

Moderate – Warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√	√	√	√	√
Max container fill level	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level					√			
Slack*Number of tiers	√	√	√	√	√	√	√	√
Slack*Max container fill level								
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Max container fill level	√	√	√		√	√	√	√
Max container fill level*Number of tiers	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers					√			
Slack*Max container fill level* Max trailer fill level								
Slack * Max container fill level *Number of tiers								
Max container fill level*Max trailer fill level*Number of tiers					√			
4-Way Interactions								
Slack*Max trailer fill level* Max container fill level*Number of Tiers								

Table 9: The significant factors for each cost based on the ANOVA analysis when the demand pattern is high – Study 2.

High – No warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√	√	√	√	√
Max container fill level	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Max trailer fill level	√	√	√	√		√	√	√
Slack*Number of tiers	√	√	√	√	√	√	√	√
Slack*Max container fill level	√	√		√	√			
Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
Max trailer fill level*Max container fill level	√	√	√	√	√	√	√	√
Max container fill level*Number of tiers	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers	√	√	√	√		√	√	√
Slack*Max container fill level* Max trailer fill level								
Slack * Max container fill level *Number of tiers	√	√		√	√	√		
Max container fill level*Max trailer fill level*Number of tiers	√	√	√	√	√	√	√	√
4-Way Interactions								
Slack*Max trailer fill level* Max container fill level*Number of Tiers								

Table 10: The significant factors for each cost based on the ANOVA analysis when the demand pattern is high with warehouses – Study 2.

High – Warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack								
Max trailer fill level	√	√	√	√	√	√	√	√
Number of tiers	√	√	√	√		√	√	√
Max container fill level			√		√	√	√	
2-Way Interactions								
Slack*Max trailer fill level								
Slack*Number of tiers								
Slack*Max container fill level								
Max trailer fill level*Number of tiers								
Max trailer fill level*Max container fill level								
Max container fill level*Number of tiers			√			√	√	√
3-Way Interactions								
Slack*Max trailer fill level* Number of tiers								
Slack*Max container fill level* Max trailer fill level								
Slack * Max container fill level *Number of tiers								√
Max container fill level*Max trailer fill level*Number of tiers								
4-Way Interactions								
Slack*Max trailer fill level* Max container fill level*Number of Tiers								

Table 11: The significant factors for each cost based on the ANOVA analysis when the demand pattern is low with warehouses – Study 3.

Low – Warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	
Trailer Fill Level Threshold	√	√	√	√	√	√	√	√
Destination shortcut	√	√	√	√	√	√	√	√
Trip Time			√			√		√
2-Way Interactions								
Slack*Trailer fill level threshold								
Slack*Destination shortcut	√	√	√		√		√	√
Slack*Trip time								
Trailer fill level threshold *Destination shortcut								
Trailer fill level threshold*Trip time								
Destination shortcut*Trip time			√		√			√
3-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut								
Slack*Trailer fill level threshold *Trip time								
Slack*Destination shortcut*Trip time								
Trailer fill level threshold *Destination shortcut*Trip time								
4-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut*Trip time								

Table 12: The significant factors for each cost based on the ANOVA analysis when the demand pattern is Moderate – Study 3.

Moderate – No warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Trailer Fill Level Threshold	√	√	√	√	√	√	√	√
Destination shortcut	√	√	√	√	√	√	√	√
Trip Time	√	√	√	√	√	√	√	√
2-Way Interactions								
Slack*Trailer fill level threshold	√	√	√	√	√	√	√	√
Slack*Destination shortcut	√	√	√	√	√	√	√	√
Slack*Trip time	√	√	√	√	√	√	√	√
Trailer fill level threshold *Destination shortcut	√	√	√	√	√	√	√	√
Trailer fill level threshold*Trip time	√	√		√	√	√	√	
Destination shortcut*Trip time	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut	√	√		√	√	√	√	
Slack*Trailer fill level threshold *Trip time								
Slack*Destination shortcut*Trip time	√	√	√	√	√	√	√	√
Trailer fill level threshold *Destination shortcut*Trip time	√	√	√	√	√	√	√	
4-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut*Trip time								

Table 13: The significant factors for each cost based on the ANOVA analysis when the demand pattern is Moderate with warehouse – Study 3.

Moderate – Warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Trailer Fill Level Threshold	√	√	√	√	√	√	√	√
Destination shortcut	√	√	√	√	√	√	√	√
Trip Time			√	√	√	√	√	√
2-Way Interactions								
Slack*Trailer fill level threshold	√	√	√	√		√	√	√
Slack*Destination shortcut	√	√	√	√	√	√	√	√
Slack*Trip time	√	√	√	√	√	√	√	√
Trailer fill level threshold *Destination shortcut			√	√	√			√
Trailer fill level threshold*Trip time								
Destination shortcut*Trip time	√	√	√	√	√	√	√	√
3-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut								
Slack*Trailer fill level threshold *Trip time								
Slack*Destination shortcut*Trip time	√	√	√	√	√	√	√	√
Trailer fill level threshold *Destination shortcut*Trip time								
4-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut*Trip time								

Table 14: The significant factors for each cost based on the ANOVA analysis when the demand pattern is high– Study 3.

High – No warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Trailer Fill Level Threshold	√	√	√	√	√	√	√	√
Destination shortcut	√	√	√	√	√	√	√	√
Trip Time	√	√	√	√		√	√	√
2-Way Interactions								
Slack*Trailer fill level threshold								
Slack*Destination shortcut	√	√	√	√	√	√	√	√
Slack*Trip time		√	√		√		√	√
Trailer fill level threshold *Destination shortcut							√	
Trailer fill level threshold*Trip time								
Destination shortcut*Trip time	√	√	√		√		√	√
3-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut								
Slack*Trailer fill level threshold *Trip time								
Slack*Destination shortcut*Trip time	√	√	√	√	√	√	√	√
Trailer fill level threshold *Destination shortcut*Trip time								
4-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut*Trip time								

Table 15: The significant factors for each cost based on the ANOVA analysis when the demand pattern is high with warehouse – Study 3.

High – Warehouse	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Linear								
Slack	√	√	√	√	√	√	√	√
Trailer Fill Level Threshold	√	√	√	√	√	√	√	√
Destination shortcut	√	√	√	√	√	√	√	√
Trip Time	√	√	√	√		√	√	√
2-Way Interactions								
Slack*Trailer fill level threshold								
Slack*Destination shortcut	√	√	√	√	√	√	√	√
Slack*Trip time		√	√		√		√	√
Trailer fill level threshold *Destination shortcut	√	√	√		√	√	√	√
Trailer fill level threshold*Trip time								
Destination shortcut*Trip time		√	√		√		√	√
3-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut								
Slack*Trailer fill level threshold *Trip time					√			
Slack*Destination shortcut*Trip time	√	√	√	√	√	√	√	√
Trailer fill level threshold *Destination shortcut*Trip time								
4-Way Interactions								
Slack*Trailer fill level threshold *Destination shortcut*Trip time					√			

Table 16: The container capacities and types using optimization without scale reduction.

Container types	Sample number	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10
3	1	32474	101563	221184							
	2	60076	142810	221184							
	3	42361	92642	221184							
	4	38489	110967	221184							
	5	47825	136668	221184							
Average		44245	116930	221184							
5	1	17812	63259	120620	183421	221184					
	2	29679	69821	104570	150748	221184					
	3	18454	44039	80136	161785	221184					
	4	18433	38824	78596	141043	221184					
	5	15613	50649	82447	162831	221184					
Average		19998	53318	93274	159966	221184					
7	1	10978	28248	54370	90026	134352	192352	221184			
	2	13231	31126	43767	102446	145280	179793	221184			
	3	11297	23967	49409	85000	113021	154176	221184			
	4	21830	51278	82498	112008	130755	174656	221184			
	5	21638	42178	71296	92298	137542	181894	221184			
Average		15795	35359	60268	96356	132190	176574	221184			
10	1	20725	32714	51243	57576	68030	94543	129770	155320	190665	221184
	2	13558	25207	45366	60649	83999	104434	126026	137913	179978	221184
	3	10997	25672	43032	64250	86114	108619	152584	174006	216907	221184
	4	9321	26497	37518	57214	77054	106597	146575	198462	217199	221184
	5	11383	32617	64125	86340	98596	123188	152150	185704	204785	221184
Average		13197	28541	48257	65206	82759	107476	141421	170281	201907	221184

Table 17: The container capacities and types using optimization with scale reduction.

Container types	Sample number	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10
3	1	37000	89000	221184							
	2	42000	113000	221184							
	3	49000	115000	221184							
	4	36000	108000	221184							
	5	50000	136000	221184							
Average		42800	112200	221184							
5	1	43000	72000	104000	150000	221184					
	2	33000	77000	114000	175000	221184					
	3	32000	72000	98000	158000	221184					
	4	19000	47000	83000	142000	221184					
	5	26000	65000	103000	173000	221184					
Average		30600	66600	100400	159600	221184					
7	1	16000	34000	67000	101000	129000	193000	221184			
	2	16000	39000	86000	118000	159000	191000	221184			
	3	19000	33000	71000	89000	117000	171000	221184			
	4	20000	42000	60000	90000	132000	180000	221184			
	5	16000	38000	62000	92000	123000	182000	221184			
Average		17400	37200	69200	98000	132000	183400	221184			
10	1	9000	24000	39000	53000	83000	119000	143000	163000	218000	221184
	2	9000	29000	48000	77000	107000	130000	177000	203000	218000	221184
	3	4000	21000	38000	61000	91000	125000	167000	201000	217000	221184
	4	4000	14000	29000	47000	69000	91000	126000	163000	217000	221184
	5	7000	22000	43000	64000	83000	100000	128000	173000	217000	221184
Average		6600	22000	39400	60400	86600	113000	148200	180600	217400	221184

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