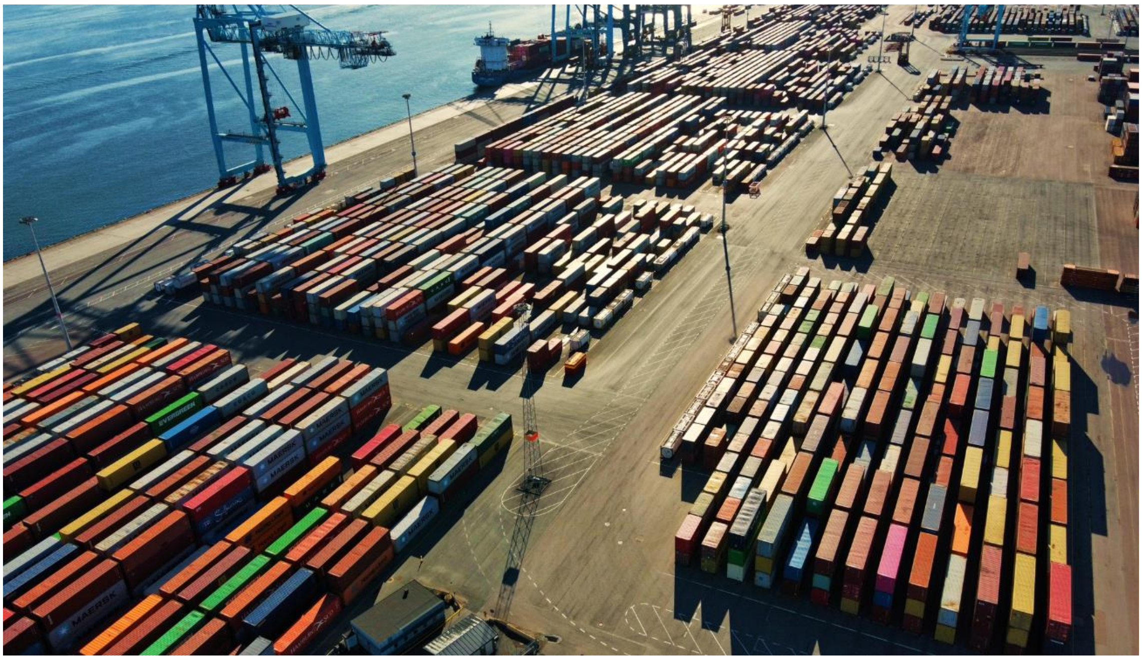

Assessing the Economic and Environmental Effects of Dry Port and Triangulation Transport on the Empty Container Repositioning Problem

- A Case of Inland Container Transport System in Sweden

Master's thesis in Supply Chain Management

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Division of Service Management and Logistics

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Abstract: The hinterland container transportation chain is an extension of maritime freight transport, which is necessary and also generated extensive emissions and costs. Additionally, the movement of empty containers accounted for a significant share of these costs, which can be regarded as waste. Two of these solutions for this problem are: 1) using the dry port to convert part of the road transport into railway; 2) applying the triangulation transport to reduce the movements of empty containers - the dry port can store the empty containers and transport them to the consignors from there. In this thesis, we focus on a case in Sweden, building three simulation models (one with the dry port, one without the dry port, and the other one with the dry port and triangulation) to evaluate the economic and environmental effects of the dry port and triangulation transport on the inland container transportation network, especially the empty container repositioning (ECR) process. The result shows that the dry port can help reduce the transport costs by 66.36% and CO_2 emissions by 78.86% for the whole system. Moreover, the triangulation transport method can not only push the reduction further (25.12% for cost and 7.85% for emissions) based on the dry port solution, but also can reduce the share from empty container movements. The main contribution of this study is the improvement of the simulation methods (agent-based discrete-event simulation) and parameters setting (stochastic).

Keywords: dry port, agent-based discrete-event simulation, CO_2 emission, transport cost, intermodal transportation

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1. Introduction

This chapter is an introduction to this thesis, including background - describing the context and providing the necessary background knowledge to understand this thesis, aim and research questions - stating the aim of the research and explaining the main research questions that will be answered in the thesis, scope and limitations - the spatial and temporal scope of this research.

1.1 Background

In the past decades, increased market demands, advanced communication, and transportation technologies, and a stable global political environment have always pushed globalization forward, including trade liberalization (Beck, 2018; Wacziarg & Welch, 2008). In order to improve ocean transport efficiency, standardized containers are created and applied, which stimulates the surge of goods transported between countries, even continents (Levinson, 2016). A maritime transport-whose key segment is seaborne container transport-carried over 10.8 billion tonnes of cargo in 2017, i.e., over 81% of the world's trade volume (Grzelakowski, 2019). In 2020, there will be 815.6 million TEUs of containers managed all over the world. Although the value declined by 1.2% in 2019, it is still relatively moderate compared to the shrinking global trade, which shows the resilience of container shipping (UNCTAD, 2021).

However, the imbalanced trade brings some issues to the containers' flow. Imbalanced trade is always there, but in recent decades it has rapidly enlarged due to the economic opening of China. In particular, China, as the world's factory, exports much more to western countries than it imports, i.e., containers are full of goods from east to west but go back to east empty. After the outbreak of COVID-19, this imbalance became more severe-2020 saw an increase of 2.8% on the Transpacific route. However, at the port of Los Angeles, loaded imports were four times greater than loaded exports, which means many empty containers need to be transported back, namely empty container repositioning (ECR) (UNCTAD, 2021). The Drewry Shipping Consultant estimated that between 1998 and 2005, approximately 20% of all ocean container movements were the repositioning of empty containers (Drewry, 2006); this percentage increased to 24.7% in 2016 (Drewry, 2017). On the other hand, in the inland logistics networks, empty container movements would be higher as they are normally stored at ports or depots, which are far away from the demand points (Song & Dong, 2015). In some research, the share of inland ECR can range from 50% to 70% (Crainic et al., 1993b; Breakers et al., 2011; Finke & Kotzab, 2017). As an excellent manufacturing and developed country, Sweden's imports and exports are huge and equivalent. In 2021, even under the pandemic cases, the import and export of Sweden also reached 1,604,500 SEK and 1,627,900 SEK, respectively, which indicates a significant demand to reposition the empty containers (Swedish Statistics, 2022).

There are two types of waste from empty container repositioning: direct and indirect. Firstly, the direct waste includes all the costs generated in the process of repositioning, such as transport cost, handling cost, storing cost, CO2 emission, management cost, etc. In 2009, the cost of seaborne empty container repositioning was estimated at about $20 billion by the UN. Moreover, if the cost of inland empty container repositioning is considered, the value could be $30.1 bn and account for 19% of global industry income in 2009, which means the cost of inland has accounted for half of that on the ocean (UN, 2011). ECR cost a middle-sized global shipping line $300-500 million in 2016 and the industry as a whole $15–20 billion

(Schlingmeier, 2016). As for energy consumption, the International Maritime Organization discovered that container movements totally consumed 80 million metric tons of fuel in 2015, accounting for one-fourth of the whole shipping industry (IMO, 2018).Moreover, container shipping has the highest per-ship average international fuel consumption (IMO, 2021). Alongside the vast and growing energy consumption, the greenhouse gas (GHG) emissions from maritime transport are also non-negatable. The Forth IMO GHG Study (2021) estimated that all the container movements generated 235.8 million tonnes of CO2-equivalent greenhouse gas emissions in 2018, among which 232.1 million were CO2, and this is also the reason why this thesis focuses on the CO2 emissions. Besides, the whole maritime transport industry produced 2.5% to 3% of the total global CO2 emissions, of which the most prominent part came from container shipping (IMO, 2018). Besides, ECR also incurs another indirect cost—low ECR speed would cause a shortage of containers for exporters and therefore reduce their efficiency. COVID-19 exacerbates this situation because Asian countries (especially China) firstly resume production while Europe and America are still in lockdown. The latter countries need to import more than usual (UN, 2021). Many goods in China's port are waiting for the containers to get loaded. Thus, it is evident that the empty container repositioning problem is crucial to improving global transport efficiency. However, it is also becoming more and more difficult due to the complication of global trade.

In order to reduce the need for ECR and improve its efficiency, several solutions have been applied in practice - dry port, street-turns, container substitution, Internet-based systems, container leasing, and foldable containers, etc. Among these, the dry port is a relatively more mature and studied way. For the sake of improving the efficiency of inland logistics networks, the container movement has extended from the sea to the inland areas. Thus, a new infrastructure, a dry port, is created as a transfer station connecting the seaport and the customer points. The dry port not only can alleviate some loading and unloading burdens of its connected seaports but also can reduce the transport costs as well as emissions (up to 25%) by shifting more freight volumes from the road to rail or boat (Roso et al., 2009). Until 2019, there will be about 230 dry ports in Europe, nearly 400 and 100 in the US and Asia, respectively (Luo & Chang, 2019). As a result, the role of dry ports in transportation systems cannot be overlooked while studying empty container repositioning issues.

1.2 Aim and Research Question

This thesis aims to evaluate the economic and environmental effects of the dry port and triangulation transportation on the inland empty container movements networks on a regional level in Sweden. To reach the goal, three agent-based discrete-event simulation models will be developed using Anylogic, calculating the transport cost and CO2 emission and comparing the results of the two models. In order to better conduct this project, the following two specific research questions are proposed:

RQ1 - What are the effects of dry port on the empty container repositioning network and its associated externalities (cost and emissions)?

The RQ1 is aiming at evaluating the economic and environmental effects of the dry port.

RQ2 - What are the effects of the dry-port-based triangulation transportation on the empty container repositioning network and its associated externalities (cost and emissions)?

The RQ2 is aiming at evaluating the economic and environmental effects of the triangulation transportation strategy based on the dry port.

RQ3 - What are the effects of the dry-port-based street-turn on the empty container repositioning network and its associated externalities (cost and emissions)?

The RQ3 is aiming at evaluating the economic and environmental effects of the street-turn transportation based on the dry port.

1.3 Scope and Limitations

The focus of the thesis will be on the unequal movement of empty container repositioning activities in a specific geographic location in Sweden, especially from Goteborg port to Eskilstuna dry port and port-related locations. It is completely based on the clients of select importers and exporters. The purpose of this thesis is to evaluate and describe the model and performance of the empty container repositioning cost, associated externality emission, and environmental impact as well.

A case study can achieve many of the same goals as other approaches. For instance, a case study can be exploratory (to gain new knowledge), constructive (to fix a problem), or confirmatory (to provide proof) (to assess a hypothesis with empirical evidence). The case study might take either a primary (data collected by the researcher) or a secondary (data collected by the case company owner) approach. The authors of this paper used the provided data from the case owner company in order to assess empirical data using any logic simulation software. However, the case study has its own limitations and challenges for researchers, according to authors (Hallinan & Tornroos, 2013). They argue for an illuminating overview of the evident problems of network researchers, representativeness and sampling units issues, as well as network connectivity. The nature of networks as interdisciplinary and complex for the fields draws attention to the importance of taking the temporal dimension into consideration. The researcher emphasizes four major challenges of case research for a network researcher. 1. the network boundary problem2. The problem of Complexity 3. The Problem of Time 4. Case comparison problem (Hallinan & Tornroos, 2013).

There are two main flaws that have been widely criticized in case studies: For starters, the researcher's approach can be influenced by prejudiced viewpoints. According to Yin (2010), researchers should endeavor to expel the major concerns and keep biases down by treating any evidence fairly and keeping away from concentrating on a single aspect. He added and emphasized that conducting a productive case study is not simple to accomplish.

2. Methodology

In this chapter, the methods used in the thesis project will be described: research design, literature review, case study, the agent-based discrete-event simulation model and research quality. Among these, the simulation model is the core part of this thesis.

2.1 Research Design

This **Fig 2.1** shows the design and process of this research, which mainly includes two parts: a case study and building three simulation models. Our research started by solving the pragmatic problem, which has been stated above. Then, some theoretical readings would help to learn the background of the problem and the latest academic progress related to it. After this step, a comprehensive understanding of the problem should be formed and an initial direction of the solution should have emerged, such as the mathematical methods that will be used (here, the simulation). Next, we can start to collect the data that will possibly be helpful for the research. The data we derived will be analyzed, which can help us gain a deeper understanding of the specific case and problem. Additionally, the information extracted from the analysis can contribute to building up the simulation models; the results from the analysis can be the input data for the models. Finally, we will run the three models to generate the results, which will be compared and analyzed to get the findings.

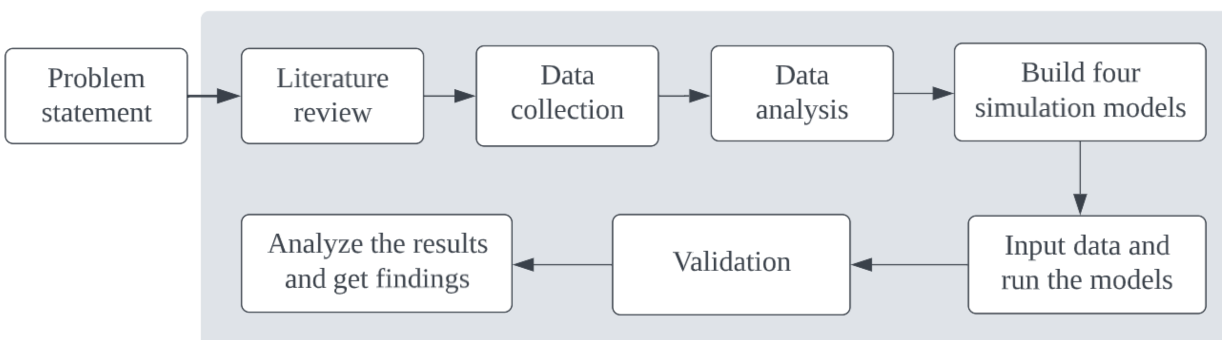


Fig 2.1. The process of the research.

2.2 Literature Review

The theoretical reading, which forms the basis of the frame of references, should be the first step in the research process. SpringerLink, ScienceDirect, Cambridge Core, Routledge, Scopus, and Emerald, all offered by Chalmers University of Technology, as well as Google Scholar, were utilized to access literature. Empty container repositioning, intermodal logistics, container transportation chain, marine transport, and other keywords were used in the search. When looking for similar literature, we would also consider the year of publication—the more recent, the better.

2.3 Case study

A case study is an appropriate methodology in situations where scant knowledge about the phenomenon exists and current theories are inadequate. It is also an empirical, in-depth investigation of contemporary phenomena in real life about an individual and their family group (Yin, 2014). They are also valuable in analyzing change processes due to their ability to consider contextual factors (Tegbrant & Karlander, 2021). It is also particularly useful for studying change processes, as it allows the connection of contextual factors. Case research is an undeniably important method in studying business networks. After considering the advantages and disadvantages of the case study, the procedure approach is primarily driven by data collection, associated literature analysis, model building and validation, and close collaboration with the project supervisor for result validation.

2.3.1 Case Description

This thesis focuses on part of the inland intermodal container transportation network in Sweden, with the Port of Gothenburg as the sea port and the Eskilstuna terminal as the dry port. Sweden is the largest country in North Europe in terms of population, territory area, economy, etc. In particular, Sweden has a strong manufacturing sector that accounts for about 20% of the total GDP, which will generate a high demand for material exchange with other areas all over the world (S-AM, 2021). The Port of Gothenburg is the largest port in Scandinavia, located on the west coast of Sweden, and also takes the most responsibility as the gateway for Swedish industry to the world. Eskilstuna is the largest dry port located in the Stockholm/Mälardal region and also one of the leading intermodal terminals in Sweden.

The locations of these sites are illustrated in **Fig 2.2**, in which the purple ship icon represents the port of Gothenburg, the black train icon the Eskilstuna intermodal terminal, the red shop icons the top 5 importers and the blue factory icons the top 4 exporters. The blue tracks are the routes of the trucks connecting the end customers with Eskilstuna; the black line is the railway route.

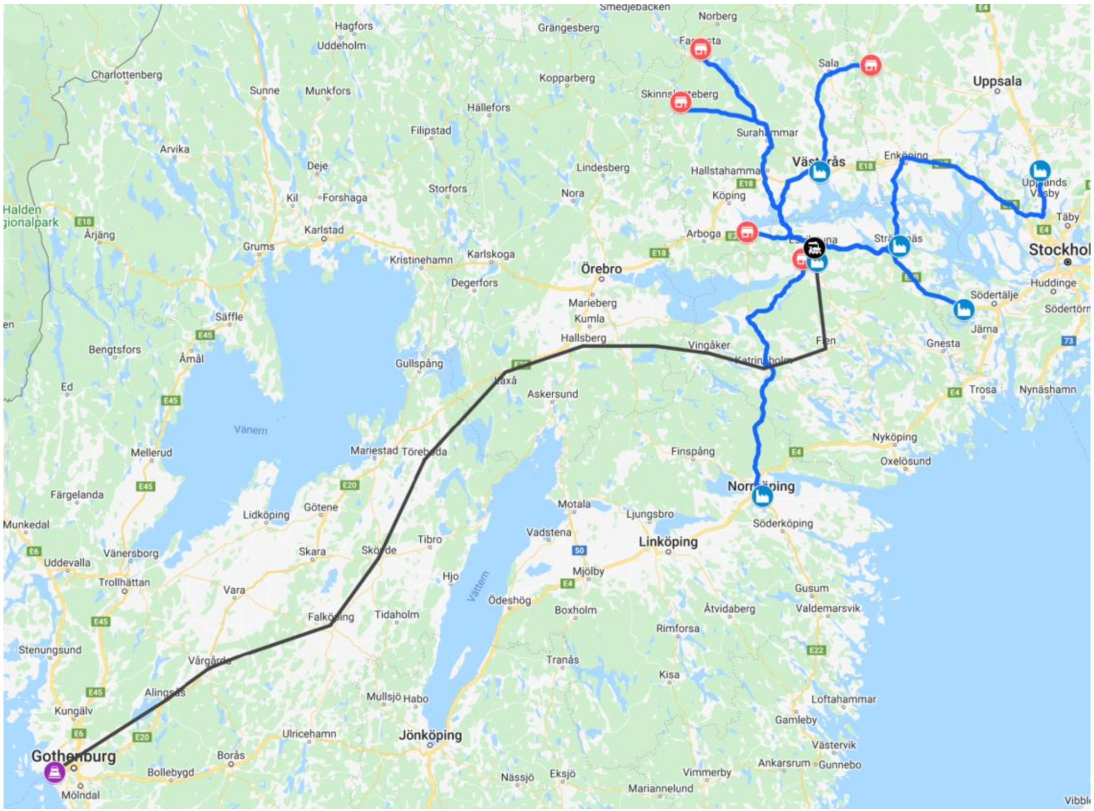


Fig 2.2. The map of the case container transportation system.

As for the transportation methods, the port of Gothenburg is connected with Eskilstuna by freight train; then the trucks will take the responsibility to connect the Eskilstuna with the end receivers. The operation of the transportation network is shown in **Fig 2.3**.

Every weekday, the freight train will depart from the APM terminal (in the port of Gothenburg) at 23:00. Then, it will drive to the Eskilstuna intermodal terminal and will arrive there at 05:00 the next day, which means it takes 6 hours on the way. Upon the train's arrival, the unloading and loading work can start. Firstly, the empty containers and import-laden containers will be unloaded from the train onto the trucks that will take them to the customers—the former will be transported to the exporters who reserved them, and the latter will go to their own importers. Next, the laden containers from the exporters will be loaded onto the train. Besides, in this case, the empty containers are stored at the sea port, which means that the return empty containers from the importers will also be loaded onto the train and transported back to the port of Gothenburg with the laden containers. When the unloading and loading work is finished at the intermodal terminal, the train will depart at 10:30 and arrive at the sea port at 18:30 on the same day. The train can take up to 44 containers, or 600 tonnes of cargo. The whole transport system works 5 days a week, from Monday to Friday.

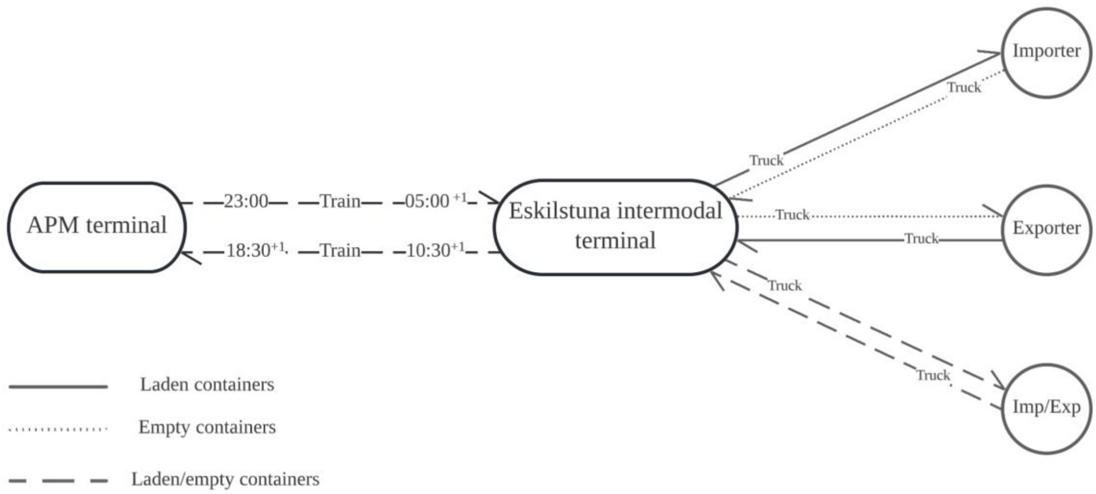


Fig 2.3. The flow chart of the current intermodal transport system.

2.4 Agent-based Discrete-event Simulation

In comparison to other mathematical methods, simulation excels at solving problems involving large and complex systems, particularly those that change over time.The simulation methods can be categorized into three types: discrete-event, system dynamics and agent-based (Borshchev, 2013). However, in some cases, different methods can be combined and applied in one model to better describe the system (Maidstone, 2012). In this thesis, the agent-based method and discrete-event method would be combined to construct the simulation model, which is highly suitable for distributed problem solving since they can divide the main task into a few sub-tasks (Smith & Davis,1981). Specifically, on the upper level, some active agents would be created to model the logistics network; on the lower level, some discrete events would be set to model the operation of each facility. To successfully build up a simulation model, there are seven steps normally should be conducted (see **Fig 2.4**).

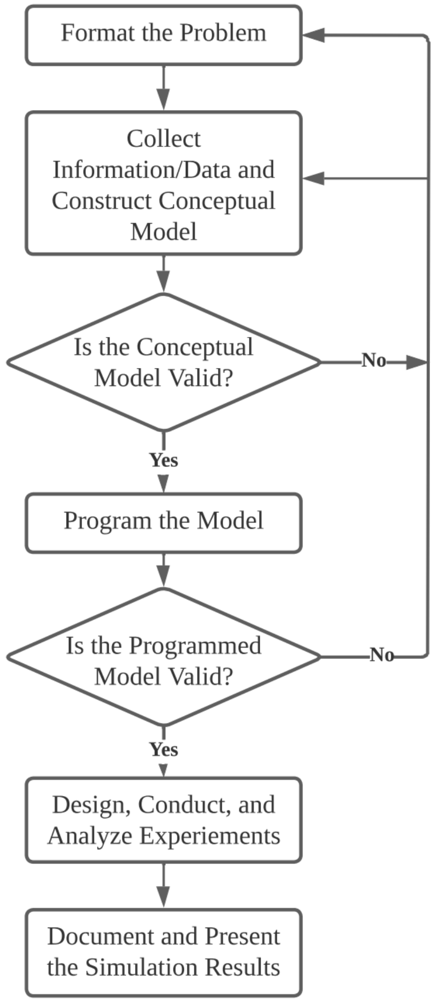


Fig 2.4. A seven-step approach for conducting a successful simulation study (M.low, 2009).

Any study, like this simulation study, would start from the demand to solve some problems. At first, the exact problem may not be precisely stated or even understood. Thus, a kickoff meeting is required at this stage to discuss some things, such as the objective, the specific questions that should be answered, the performance measures for the simulation model, the scope of the model, etc. Next, when the exact problem has been formed, the data collection work can start. The data can be from many sources, mainly the Internet and the case company. As the data collection goes on, the conceptual model, which is a logic description (like the flow chart) of the target system or process that needs to be modeled, should be drawn at the same time. During this stage, some important elements should be documented, such as the assumptions of the model, the level of model detail, etc. It is worth mentioning that the data collection and the construction of conceptual models can be interwoven. For instance, the data collected can determine the final level of the model detail; the constructed conceptual model can determine the required data. It is always important to ensure the correction of the conceptual model before moving on, for which a careful walk-through of the model would be helpful. If the errors are found, go back and update the conceptual model.

After completing the conceptual model and making sure its corrections are made, the programming work can start. At this stage, it is important to select the programming software or language, mainly two choices: general programming languages (e.g. C, C++, Python, or Java) and simulation software. In this research, the Anylogic simulation software was chosen to build the models. It is necessary to ensure the validation of the programmed model. The best way (also applied in our research) is to compare the results of the model with the real data collected, to see if the model produces similar results.

If the simulation model was correct, then it is time to design and conduct the simulation experiments, including the run length, length of the warmup period, and the number of replications. Finally, the presentation of the simulation results should include the animations for better understanding and an explanation of the model building and validating process.

2.5 Research Quality

For any research, validity and reliability are two of the most important aspects to measure the quality, which need to be considered before coming to the solution (Merriam & Tisdell, 2015).

Validity is to ensure the results are correct and match the real system (Tegbrant & Karlander, 2021). In our research, the simulation models and their results have to be validated. There are many validation methods, the most suitable one in our case is to compare the model results with the collected data, to validate whether the models can describe the real world well or not.

According to Merriam and Tisdell (2015), reliability refers to how well the repeatability and stability of the results. Therefore, in our research, it is necessary to run the models many times and check the confidence interval, which should be as narrow as possible. If the confidence intervals are two wide, the models will not pass the reliability check. Then, the average values should be calculated as the final results.

3. Frame of Reference

This chapter will introduce the needed background knowledge, which can help readers better understand the research. It includes how the container transportation chain works, what the empty container repositioning (ECR) is, and the modeling solutions for the ECR issues.

3.1 The Container Transportation Chain

As containerization goes on, the container transportation chain has been an ignorable component of the global supply chain, which includes both the land and maritime transport networks. Although the container transportation chain is quite complex and long, it can be broadly described by **Fig 3.1** (D. P. Song & Dong, 2015).

Firstly, the consignors (mainly the manufacturers), also called exporters in the case of exporting businesses, request a demand for empty containers from the shipping companies, which are normally the owners of containers and provide the transportation service. The empty containers may be stored in an inland depot, a dry port or a sea port. When the shipping company received the request from consignors, they would arrange and send the empty containers to the latter. After consolidating the cargoes into the containers at the consignors' sites, the laden containers will be transported to the depot or port and wait for vessels. Sometimes, the consignors will bring the cargoes to the empty containers' site and thus do the consolidating there. At the sea port, the laden containers will be lifted by cranes onto the vessel, after which the hinterland part will be finished and the maritime part will be started. Before arriving at the destination seaport, the laden containers may need to pass through a few intermediate ports for the transshipment services. When those laden containers reach the destination port, they will be unloaded from the vessels and transported to the consignees or a nearby depot for unpacking. After finishing the unpacking work, the containers become empty and can either be stored at the depots, dry ports, or other sea ports for the next request in the future. Obviously, there are two main and distinct flows in the container transportation chain: forward-laden container flows and backward-empty container flows. A significant characteristic of the chain here is that both laden and empty container flows are moving and stored in the same logistics network, using the same set of facilities and resources.

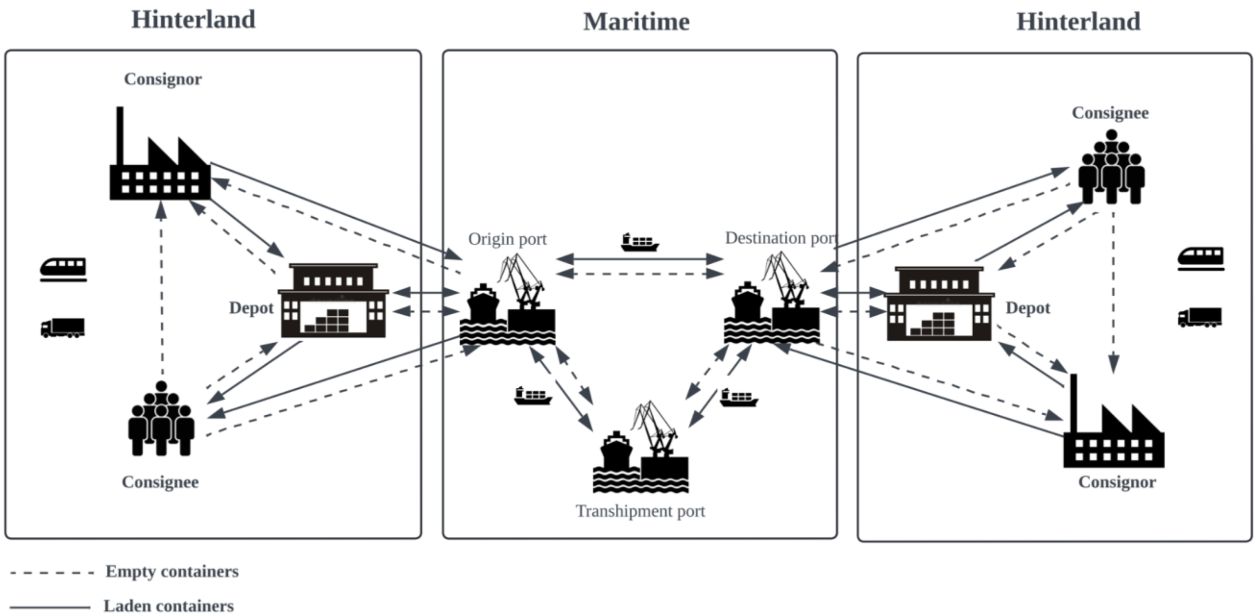


Fig 3.1. The container transportation chain (D. P. Song & Dong, 2015)

3.2 Empty Container Repositioning

Since the beginning of containerization, empty container repositioning (ECR) as an inherent issue has always been there. Nonetheless, it has become more prominent in recent decades as a result of the advancement of globalization, specifically the global division of labor, which has resulted in a huge demand for transport of various goods all over the world. From the containers' point of view, about 56% of their 10-15 years of life will be spent on being idle or being repositioned empty (Rodrigue, 2020).
Additionally, due to the increased focus on environmental protection, ECR problems have received more attention in recent years. This section will discuss the main causes of the empty container repositioning issues and give some different solutions to them, mainly referring to the study conducted by Song and Dong (2015).

3.2.1 The Causes of ECR Problems.

There are hundreds of various factors causing the movement of empty containers. According to Song and Dong (2015), they listed the following five - trade imbalance, dynamic operation, different size and type of containers, lack of visibility and uncertainty.

Trade Imbalance

The trade imbalance between different nations and regions—the amount of trade in one direction is greater than that in the reverse direction—is the primary factor causing the ECR problems. As mentioned above, the global division of labor is the root cause of the trade imbalance. In particular, the Trans-Pacific and Europe-Asia trades are heavily imbalanced due to China's huge export volume as the world's factory. **Table**

3.1 shows a summary of maritime trade transport among the three main economies—East Asia, North Europe and the Mediterranean, and North America—from 2014 to 2021, which illustrates the severe trade imbalance between East Asia and the other two. This also incurs the ECR problems at the highest level, the world level. On a regional level, a geographical trade imbalance also exists—normally the factories are built remote from cities, but the latter will consume most of the products.

Table 3.1

Containerized trade on major East-West trade routes, 2014–2021 (UN, 2021).

(million TEU and percentage annual change)

Years	Eastbound	Westbound		Eastbound	Westbound		Eastbound	Westbound	
	East Asia to North America	North America to East Asia	Difference value (abs)	Nothern EU and Mediterranean to East Asia	East Asia to Nothern EU and Mediterranean	Difference value (abs)	North America to Nothern EU and Mediterranean	Nothern EU and Mediterranean to North America	Difference value (abs)
2014	16.1	7	**9.1**	6.3	15.5	**9.2**	2.8	3.9	**1.1**
2015	17.4	6.9	**10.5**	6.4	15	**8.6**	2.7	4.1	**1.4**
2016	18.1	7.3	**10.8**	6.8	15.3	**8.5**	2.7	4.2	**1.5**
2017	19.3	7.3	**12**	7.1	16.4	**9.3**	2.9	4.6	**1.7**
2018	20.7	7.4	**13.3**	7	17.3	**10.3**	3.1	4.9	**1.8**
2019	19.9	6.8	**13.1**	7.2	17.5	**10.3**	2.9	4.9	**2**
2020	20.6	6.9	**13.7**	7.2	16.9	**9.7**	2.8	4.8	**2**
2021	24.1	7.1	**17**	7.8	18.5	**10.7**	2.8	5.2	**2.4**

Dynamic Operation

Dynamic operation is the inherent characteristic of a transport system. Firstly, and geographically, any transport system must cover a large area of regions, and traveling time will be needed from one site to another. And also, due to various factors, such as the weather conditions, traffic conditions, etc., this time cannot be constant. Besides, in the real world, the supply of empty containers (and the arrival of laden containers) and the demand for empty containers will change over time. For instance, on the demand side, the sellers of seasonal products like agricultural products need empty containers at some certain time period; on the supply side, to celebrate some festivals, people normally need many laden containers in certain places and times period;

Hence, even if the trade between two regions is balanced, the dynamic operation will prevent the perfect match between the supply and demand of empty containers.

Size and Type

The size and type of containers would also cause the empty container movement—there are around 16 different sizes and types of containers that are normally used, and some are designed specifically for one type of goods (Anish, 2021). In fact, most types of cargo have a compulsory requirement or it is more convenient to use a specific type of container. Thus, in many cases, the ECR problem not only happens to the number of containers but also to the type of containers. For example, the port of Gothenburg, the biggest port in Sweden, imports a huge amount of goods in 20ft containers but exports in 40ft containers, which indicates there is a deficit of 40ft containers but a surplus of 20ft containers in that port—also an ECR issue (Santén et al., 2018).

Lack of Visibility

In any business chain, including the container flow chain here, the lack of visibility is always one of the factors reducing effectiveness and efficiency by limiting the scope of information a company can receive from the others in the chain. The lack of visibility in the container transport sector may prohibit shipping lines from tracking each container's real-time location and status in order to improve productivity by precisely stacking empty containers.

Uncertainty

The last cause of ECR is uncertainty, which is the inherent characteristic of the real world. Uncertainty may come from the internal and external aspects of the container transport chain. The former mainly includes the variation of time during the operational activities like loading and unloading, transporting, and repairing. The latter includes the fluctuation of market demand, the breakdown of manufacturing, bad weather conditions, etc. Uncertainty is also the most difficult to eliminate or improve; even external uncertainties are impossible to anticipate and avoid.

Five factors causing the empty container movements have been presented above, among which the trade imbalance is the most prominent. Moreover, the discussion above also indicated that the ECR problems cannot be eradicated. But some solutions have been proposed and implemented to prove that they can alleviate the ECR problems to a large extent.

3.2.2 The Solutions to ECR Problems

Braekers et al. (2011) have introduced six methods to reduce the need for empty container movement - inland deports, street-turns, container substitution, an internet-based system, container leasing, and foldable containers.

Inland Depots

Inland depots have various formats: inland ports, inland intermodal terminals, and dry ports. However, their primary functions are similar—linking seaports to inland depots by road or rail and operating as centers of transshipment of sea cargo to inland destinations. In addition to that, it facilitates the movement and clearance of goods through the ports' overcrowded freight by transferring them to inland depots and temporarily keeping an empty container until the process is completed or a consignor is assigned. It also improves container flow, lowers congestion, and allows for the pickup and delivery of empty containers and all activity at destination seaports. Even though there are advantages for inland depots, there is a complaint about the shipping line side and users. Using a moderate inland depot could incur extra costs since the inland depot and seaport charge for two storage points. Each of these fees is a cost duplication for a single unit (Hellekant & Rudal, 2021).

However, as others argue, most inland depots are provided by other modes of transport, such as rail yards, from which shipping companies can rent only the space they need and automatically adjust it following the flow variation. Therefore, the resulting cost will only be the additional storage cost and not the duplicate operations. Since container shipping operations at ports are typically more expensive, inland depots can reduce total storage costs (Braekers et al., 2011; Hellekant & Rudal, 2021).

Ansah et al. (2020) argue that an inland port is a solution for port congestion, overcrowded ports, and other four logistics tools of freight stations: freight movement amid two conveyance modes; freight gathering to be transported; warehouse of freight pending gathering; supply and freight logistic management. Ansah et al. (2020) talked about service handling carried out in portland at customs, such as checking or controlling freight for exportation and importation. It also added that the portland should reach specific standards regarding offering services such as custom process, the existence of 3pl logistics workers, and other facilities.

Street-turns

The second strategy is street turns, which represents the primary strategy to be adopted by shipping companies for the profitability of shipping supplying container-based transportation. Hellekant and Rudal, 2021; Deidda et al., (2008). It consists of distributing a truck that delivers the loaded container to the importing customer, assigning an empty container to the exporting customer, and shipping the last loaded container to the port of departure. In other words, it indicates the deliverance of empty containers from the consignee to the consignor with the absence of a middle part of inland dry port involvement. In the absence of an intermediator, it alleviates both parties' burden of determining a complex task of truck routes activity for the shipping companies, which should have to process a high amount of information, demands of high time-consuming, span exceeding human skills, and other extra cost related CO2 emission. Street turn benefit also reduces the empty container number. Hence it reduces the total transport distance and related transport costs, and minimizes the congestion at the terminal as the movements to and from the terminal are deducted in half is another benefit for the street turn. Overall, it reduces the shipping line terminal handling cost (Deidda et al., 2008; Hellekant & Rudal, 2021).

Apart from the logistical obstacles of changing pick-up and drop-off times and locations, container ownership and container types, institutional impediments to turnaround implementation, and commercial, insurance, and liability concerns, it is vital to emphasize that there are no guarantees. Repair cost management, inspection, paperwork concerns, a lack of consistent procedures for replacement, and limited free time (under typical conditions, customers are from collection to terminal within the hour) are all examples of institutional bottlenecks. Breakers et al., 2011; Hellekant & Rudal, (2021), trade, insurance, and liability issues are specifically related to liability for container damage after the container is released from the terminal.

Container Substitution

Container substitution refers to filling the demand for one type of container with another. The merit of this is that it enhances the flexibility of the ECR system since there is no need to identically match container types, providing further opportunities to reduce costs and move empty containers. The excellent point about reducing empty movement comes from its ability to manage technical imbalances in the container transport chain. (Chang et al., 2007; Hellekant & Rudal, 2021). Container substitution of different types intends to reduce the cost of empty container exchange. However, there is a challenge in allocating empty container reuse scenarios, which should inscribe many operational issues, such as import-export timing and location mismatch, owner mismatch, container type mismatch, and legal issues regarding off-hire leased containers. Thus, it is advisable to consider implementing some issues. A transition must be made to create a fast and reliable, efficient, and seamless system before considering empty container reuse outside the terminals.

(Chang et al., 2008; Hellekant & Rudal, 2021). Types of containers can be distinguished according to three aspects: purpose - the intended use of the container (dry cargo, refrigerated goods, etc.), size - the physical dimensions of the container (20ft, 40ft, tall-high-cube shape, etc.), and possession - the possession of the container by a shipping line or other stakeholders (Chang et al., 2008; Hellekant, and Rudal, 2021).

Internet-based System

Many of the specific ECR reduction strategies have been identified as being implemented. For example, coordinates between shipping lines, freight carriers, and terminals are dependent on valid information exchange and data surveys and data surveys, and prerequisites use of Internet-based systems. Technologies often used to track containers, known as RFIDs, can improve visibility and control by tracking internal connection and date container movement (D. P. Song & Dong, 2015; Hellekant & Rudal,2021). However, among many technologies that need to be implemented in the industry are Internet-based platforms for information or market exchange. For example, virtual containers and online markets such as delivery lines can provide information about the current container's deficit or excess export load to meet the needs of the empty container. Some researchers claim that the challenge of implementing these technologies in the shipping line is that the companies are hesitant to share personal (confidential) business information (Theofanis & Boyle, 2009; Hellekant & Rudal, 2021).

Container Leasing

Container leasing is another option that may reduce empty container handling. Instead of owning the container permanently, the shipping company can lease it out of stock and lease the container in the surplus area. Shipping companies can reduce the need to transport empty containers around the world (Braekers et al., 2011; Hellekant & Rudal, 2021). Currently, 43.4% of the world's container leasing (ISO) is owned by container leasing companies, and 56.6% is owned by shipping companies (Neise,2018; Hellekant & Rudal,2021). Containers can be rented both long-term and short-term: long-term leased containers are treated like their own containers associated with ECR in most respects, as opposed to short-term leased containers. As explained, moving containers in and out of the regional system through operational on and off-hire can manage container shortages and abundance by leasing rather than relocating (repositioning) when the lessor is in the immediate vicinity. Therefore, it helps to reduce the ECR distance. However, container lenders (lessors) face the same imbalances as shipping companies, and rents are priced accordingly, allowing shipping companies to reduce costs. The container leasing industry is working to introduce a shared container pool, sometimes referred to as a "gray box," to facilitate capacity sharing between shipping companies. Due to the confidentiality of information sharing between shipping companies, these initiatives have not been successful (Boyle et al., 2008; Hellekant & Rudal, 2021). Hellekant & Rudal (2021) stated that internet-based container exchange and leasing platforms have also emerged, making sharing containers among competing transportation lines and other stakeholders easier.

Foldable Containers

Foldable containers can reduce ECR by minimizing the space required to transport empty containers, which can reduce transportation and storage costs by transporting more containers at one time. Nevertheless, it also incurs additional costs due to the additional personnel and equipment required to fold and deploy the container (Braekers et al., 2021; Hellekant & Rude, 2021). Foldable containers are rarely being applied today because of some other problems, such as high manufacturing and maintenance costs and a high vulnerability to damage. Another drawback is the complexity and time required for the folding and unfolding process (Braekers et al., 2011; Hellekant & Rude, 2021).

3.3 The Modeling Solutions for (Empty) Container Transportation

The empty container repositioning problems have received many studies in the past decades, which can be classified into three types based on the different transport contexts - the first is seaborne containers transport, the second is inland or intermodal transport networks, and the third is addressing the issues in which the empty container repositioning problems are regarded as a sub-problem or a constraint under other decision-making problems (Song & Dong, 2015). In this part, some literature on ocean and inland (empty) container transportation will be presented to have an overall understanding of the existing problems and solutions. Additionally, the value of dry ports in the container or empty container transport network will also be illustrated.

3.3.1 The Maritime Container Transportation

As globalization goes on, the advantages of low cost and convenience has made container shipping become the mainstream in ocean transportation, which has been stated in detail above. Meanwhile, to improve the efficiency of the container shipment chain, it is the earliest that received many studies.

Mathematical Programming

Moon et al. (2010) developed a mixed-integer programming model—minimizing the total cost, considering the leasing and purchasing of containers—to reduce the imbalance between ports that is solved by a genetic algorithm. Guericke and Tierney (2015) took the service level into account as a measurement metric in the liner shipping cargo allocation chain and developed a deterministic mixed-integer nonlinear programming model to figure out the optimal vessel speed at different service levels. Wang and Meng (2012) studied the impact of liner ship routes on the uncertainties in port operations and developed a mixed-integer nonlinear stochastic programming model to design robust schedules for container shipping routes by minimizing the total expected costs. Cheung and Chen (1998) developed a dynamic container transport network model solved by stochastic linear programming to support linear companies allocating empty containers at lower costs. Chou et al. (2010) first proposed a mixed fuzzy decision-making model to determine the optimal stock of empty containers at a seaport and then developed a nonlinear programming model to determine the optimal number of empty containers allocated between ports.

Simulation

Lai et al. (1995) simulated a shipping company's operational activities and used a heuristic method to determine the lowest cost solution to reposition empty containers on the ocean. Lam et al. (2007) developed an approximate dynamic stochastic programming model to optimize the empty container repositioning issues for a two-ports two voyages (TPTV) system, which is solved by the simulation approach.

Others

Epstein et al. (2012) described an Empty Container Logistics Optimization System (ECO) that is applied in the world's largest shipping companies. Li et al. (2004) used the Markov decision process to qualitatively optimize the pairs of critical policies for containers under both the infinite horizon discounted criteria and the long-term average criteria in the case of single port. In 2007, Li and some others extended the former work into a multi-port case.

3.3.2 The Inland Container Transportation

On the one hand, the inland container transport is necessary because most destinations of the goods are normally in the hinterland; on the other side, the ECR problems are more severe in the inland transport networks (Song & Dong, 2015). Therefore, there are many studies conducted on the inland empty container transport problems.

Mathematical Programming

Crainic et al. (1993a, b) developed two dynamic deterministic formulations for the empty container repositioning issues in the cases of single and multicommodity in the inland transport networks. Erera et al. (2005) also used the dynamic deterministic model for an intermodal and multicommodity logistics network. Moreover, they considered integrated container booking and routing decisions. Olivo et al. (2005) used an integer programming model to get the optimal solution for the empty container movements between seaports and depots via inland transport networks. Shintani et al. (2007) proposed a design method for container transport networks (including empty container repositioning) and developed a model that is solved by a heuristics method based on genetic algorithms. Boile et al. (2008) built a linear programming model to study the value of the inland empty container depots, in which the new depot locations are selected. The results proved that the inland depots could improve the efficiency of the empty container repositioning system by reducing the empty container movements' distance. Bandeira et al. (2009) developed a management procedure using a heuristic method to distribute the empty and full containers. Zhang et al. (2010) used the multiple traveling salesman problem with time windows (m-TSPTW) to develop a mixed-integer linear programming model for a truck scheduling problem for regional container transport with multiple depots and terminals. Zehendner et al. (2014) added some additional constraints into a min-cost multicommodity transport network model, forming a mixed-integer linear programming model to determine the number of truck appointments to accept and the number of straddle carriers to allocate to transport vehicles with the objective of reducing the overall delays at the terminal. Funke et al. (2016) conducted a study on the pre-and end-haulage of the intermodal container transport network in which both the 20-feet and 40-feet containers are considered, and they also developed a mixed-integer linear programming model to figure out the optimal solution. Wadhwa et al. (2019) developed a mixed-integer linear programming model to find the optimal location for new empty container depots in a region. Shan et al. (2020) studied the inland location problem with container route scheduling (IDLPCRS) and developed a robust model which is transformed into an integer linear programming model for the convenience of calculation.

Simulation

Dong et al. (2009) developed three simulation models to solve the optimal container fleet sizing problem—how the inland container transport times and variability impact the optimal fleet size in the liner services. Yun et al. (2011) applied the (s, S) method to solve the empty container repositioning problem in the inland logistics networks in the context of probabilistic demand and supply under seasonal demand variability. Dang et al. (2013) reviewed and compared two types of empty container repositioning politics—state-feedback control policy and OD-based matrix solutions—in the context of realistic and dynamic logistics networks with multiple depots under uncertainties. Irannezhad et al. (2018) considered the cooperation between importers and exporters, developing a simulation model to evaluate its influence on transportation costs and CO_2 emissions.

3.3.3 The Dry Port-based Container Transportation

Dry port is a relatively newer concept that is used as an extension of the seaports - as an inland terminal to and from which shipping lines could issue their bills of lading (UNCTAD, 1982). The implementation of dry ports has proved some of its functions, such as alleviating congestion, operation and storage pressure in the seaports, and reducing the transport cost in the hinterland by shifting the road to rail (Padilha & Ng, 2011). Roso et al. (2009) firstly categorized the dry ports (close, mid-range, and distant) according to the distance from seaports and then built up a simulation model to study the impact of dry ports on the inland container transport networks in terms of CO_2 emission, congestion and waiting time of trucks. Given the significant value of dry ports in the inland container transport networks, research on this concept has been conducted in the last three decades (Henttu & Hilmola, 2011).

Mathematical Programming

Crainic et al. (2013) built up a mixed integer programming model to solve a tactical planning problem of optimally scheduling a fleet of high-capacity vehicles. Fazi and Roodbergen (2018) conducted experimental research to assess the impact of the effect of demurrage and detention with different fees on dry port-based inland container transport networks. Tsao and Thanh (2019) developed a multi-objective mixed robust possibilistic flexible programming model under the uncertain environment to determine the optimal decision for establishing the dry ports, including the numbers, location, and capacity. Digiesi et al. (2019) developed a linear programming model to help identify the best container handling strategy for intermodal facilities by considering the total cost and carbon footprint. Sarmadi et al. (2020) proposed a dry port-based transport network model that integrated strategic decision making (including dry port location) with operational decision making under an uncertain demand environment and developed a robust two-stage stochastic programming model to solve it. Facchini et al. (2020) developed a non-linear programming model to determine the optimal stock of containers in seaports and/or in dry ports, minimizing the total cost and carbon footprint.

Simulation

Roso (2007) built a simulation model for two scenarios (with and without the dry port) based on the Port of Gothenburg to evaluate the dry port concept from an environmental perspective. Lättilä et al. (2013) constructed a discrete-event simulation model to minimize the shipping cost, and the best result includes a dry port. Their model can be suited at a regional (covering multiple countries), national, or even international level. Kurtulus et al. (2019) conducted a four-scenario case study of Turkey's inland container transport network. They applied the simulation method, finding that the dry port-based intermodal transport system could decrease the GHG emission.

Others

Xie et al. (2017) applied the game theory to study the coordination issue in empty container repositioning in a dry port-based transport network and designed a bilateral buy-back contract to coordinate the decentralized system. Jeevan et al. (2019) conducted an empirical study with exploratory factor analysis (EFA) in Malaysia and find that the respondents think the dry ports can improve the seaports' performance by increasing the variability of seaport services, reducing the distance from seaport to hinterland and seaport capacity, etc.

Table 3.2 summaries the literature review section, which is classified according to: focuses, method, parameter feature and the objective of the paper. From the literature review above, it shows that the two mainstream approaches to quantitatively model the empty container repositioning problems are by linear programming or simulation. In this thesis, the simulation method will be adopted. Besides, it shows that as the time goes on, more studies do not only focus on minimizing the transport cost, but also paying more attention to the greenhouse gas emission, which is one of the trends of the transportation industry.

Table 3.2
A classification of literature reviews

Focuses	References	Method	Parameter feature	Objective
Maritime	Lai et al. (1995)	Simulation	Stochastic	Optimize the seaborne empty container repositioning by minimizing the total operational cost
	Moon et al. (2010)	MILP	Deterministic	Optimize the seaborne empty container repositioning transport by minimizing the total transport, operation and storage cost
	Li et al. (2004)	MDP	Stochastic	Optimize the pairs of critical policies for stochastic containers problem in the case of single port
	Li et al. (2007)	MDP	Stochastic	Optimize the pairs of critical policies for stochastic containers problem in the case of multi-port
	Lam et al. (2007)	Simulation	Stochastic	Optimize the ECR issues by minimizing the average cost
	Guericke and Tierney (2015)	MINLP	Deterministic	Optimze the ships' speed in the linear shipping cargo allocation chain by maximizing the revenue
	Wang and Meng (2012)	MINLP	Stochastic	Optimize the container shipping route by minimizing the total cost
	Cheung and Chen (1998)	LP	Stochastic	Optimize the allocation of empty containers by minimizing the total cost
	Chou et al. (2010)	FDM/NLP	Stochastic	Optimize the stock of empty containers in a sea port and also the number of empty containers allocated between ports
Inland	Crainic et al. (1993a, b)	MILP	Deterministic/Stochastic	Optimize the allocation of the empty containers by minimizing the total transport and storage cost
	Erera et al. (2005)	ILP	Deterministic	Optimize the routing of (empty) containers by minimize the total transport and storage cost
	Olivo et al. (2005)	ILP	Deterministic	Optimize the real-time management of empty containers by minimizing the total transport and storage cost
	Shintani et al. (2007)	LP	Deterministic	Optimize the routing of (empty) containers by minimize the total transport, storage and penalty cost
	Boile et al. (2008)	MILP	Deterministic	Optimize the location of inland deport for empty containers
	Bandeira et al. (2009)	ILP	Stochastic	Minimized the total operation cost of the distribution and transportation of empty and full containers
	Dong et al. (2009)	Simulation	Stochastic	Optimize the container fleet size and operational policy by minimizing the total cost
	Zhang et al. (2010)	MILP	Deterministic	Optimize the truck scheduling problem for container transport by minimizing the total operating time
	Yun et al. (2011)	Simulation	Stochastic	Optimize the inventory policy by minimizing the cost rate
	Dang et al. (2013)	Simulation	Stochastic	Optimize the replenishment policies for empty containers by minimizing the total cost
	Zehendner et al. (2014)	MILP	Stochastic	Optimize the allocation of trucks by minimizing the deviations and delays
	Funke et al. (2016)	MILP	Deterministic	Optimize the allocation of trucks by minimizing either the total travel distance or the total service time
	Irannezhad et al. (2018)	Simulation	Stochastic	Assess the impact of the cooperation between importers and exporters in terms of the transport cost and CO2 emission
	Wadhwa et al. (2019)	MILP	Deterministic	Optimize the location of inland deport for empty containers by minimizing the total cost
	Shan et al. (2020)	ILP	Deterministic	Optimize the location of inland deports and the orders of fulfilling container requests by minimizing the total cost
Dry port-based	Roso. (2007)	Simulation	Deterministic	Show there is a way to improve the operations in container flow which can achieve better productivity and reduce environment impact
	Lättilä et al. (2013)	Simulation	Deterministic	Compare and find if the dry port is valuable in terms of reducing the transport cost and CO2 emission
	Crainic et al. (2013)	MILP	Stochastic	Optimize the scheduling of daily shuttles by minimizing the total transport cost
	Xie et al. (2017)	GM	Deterministic	Optimize the empty container delivery policy when the dry port and searport are the central planners
	Fazi and Roodbergen (2018)	MINLP	Deterministic	Optimize the departure time of trucks by minimize transport costs, D&D fees and dwell times at the seaport
	Jeevan et al. (2019)	EFA	-	Investigate the impact of dry port operations on container seaport competitiveness
	Tsao and Thanh (2019)	MILP	Stochastic	Optimize the decision for the establishment of the dry ports by minimizing the total cost, environmental and social impacts
	Kurtulus et al. (2019)	Simulation	Deterministic	Assess the impact of the implementation of dry ports on the environment and train capacity usage
	Digiesi et al. (2019)	LP	Deterministic	Optimize the containers' handling strategy for intermodal facilities by minimizing the total cost and carbon footprint
	Facchini et al. (2020)	NLP	Stochastic	Optimize the stock of containers by minimizing the total cost and carbon footprint
	Sarmadi et al. (2020)	LP	Stochastic	Optimize the location and allocation decisions of the dry ports by minimizing the total transport and storage costs

LP: Linear programming; MIP: Mixed-integer programming; MILP: Mixed-integer linear programming; MINLP: Mixed-integer nonlinear programming; ILP: Integer linear programming; NLP: Nonlinear programming; SP: Stochastic programming; GM: Game theory; FDM: Fuzzy decision making

4. Descriptive analysis

To investigate deeper into the case, some container transportation data is derived from the case company, in which each row represents one transportation of a container. In this chapter, the data will be presented, and some variables will be explained. Some information derived from the descriptive analysis will help develop the simulation model; some results of this chapter will be used as input data for the models.

4.1 Explanation of the variables

Time Span

The time span of the data is three years, which starts from the beginning of 2019 (2nd January) to the end of 2021 (30th December). The time series of the number of containers is shown in **Fig 4.1**. It shows that the import volume had a slight growth as the export volume saw a reduction in the last three years in terms of both the number and the weight of the containers.

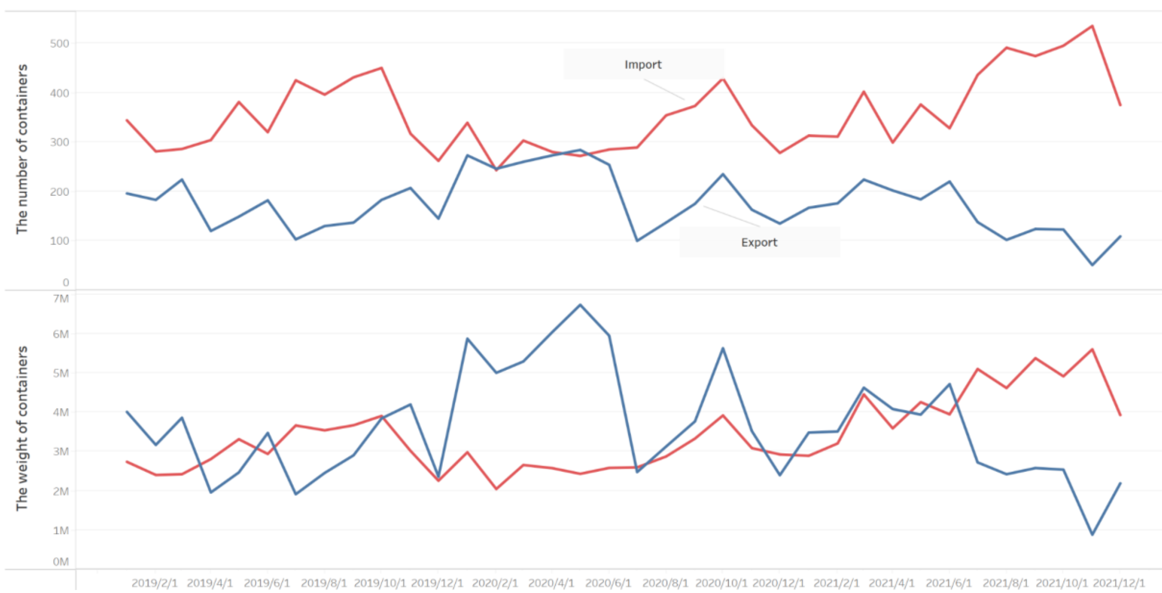


Fig 4.1. The change of the number and weight of import and export containers over time from 2019 to 2021.

Customers

There are 98 receivers in this case, but at the same time, it is a concentrated market. **Fig 4.2** shows the number of containers of some receivers and their shares, in which the top 10 receivers account for 92.44% of the total. Therefore, just the top 10 receivers will be left to build up the model to simplify the question. Besides, it is worth noticing that most receivers are either exporters or importers. Specifically, five customers can be regarded as pure importers - Nykvarn, Väster, Arlandastad, Strängnäs, and Norrköping; four pure exporters - Heby, Skinnskatteberg, Fagersta, and Kungsör; and only Eskilstuna has import and export containers.

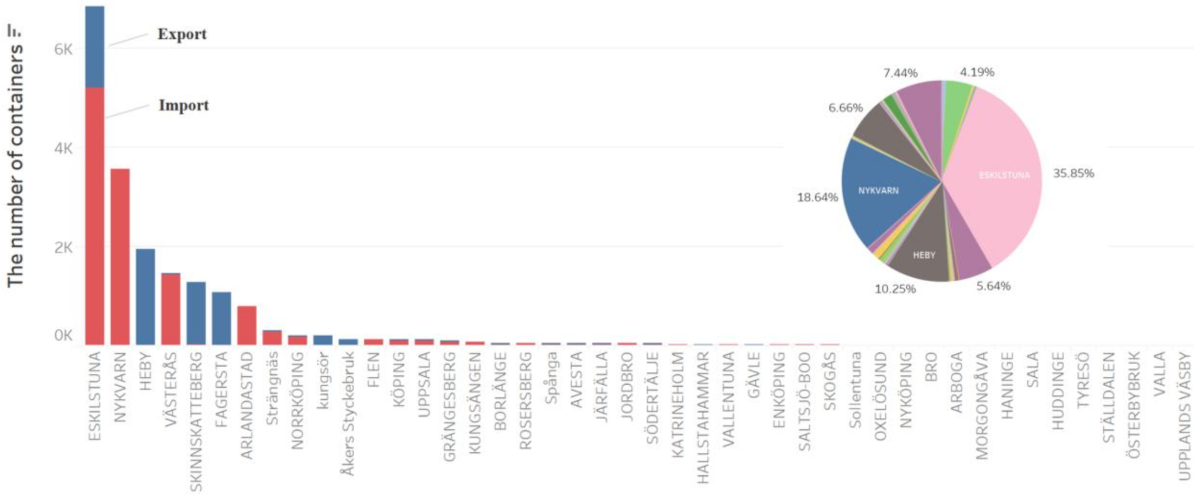


Fig 4.2. The number of containers of each importer and exporter and its share.

Import/Export

The variable "Imp/Exp" indicates the status of the containers-an import container or an export container. Fig 4.3 presents the number of imported and exported containers each year from 2019 to 2021, which shows an extreme trade imbalance in this case. The number of imported containers is more than twice as high as that of exported containers. Hence, not all the empty containers will be stored in the hinterland for export activities; some will be shipped to other countries directly.

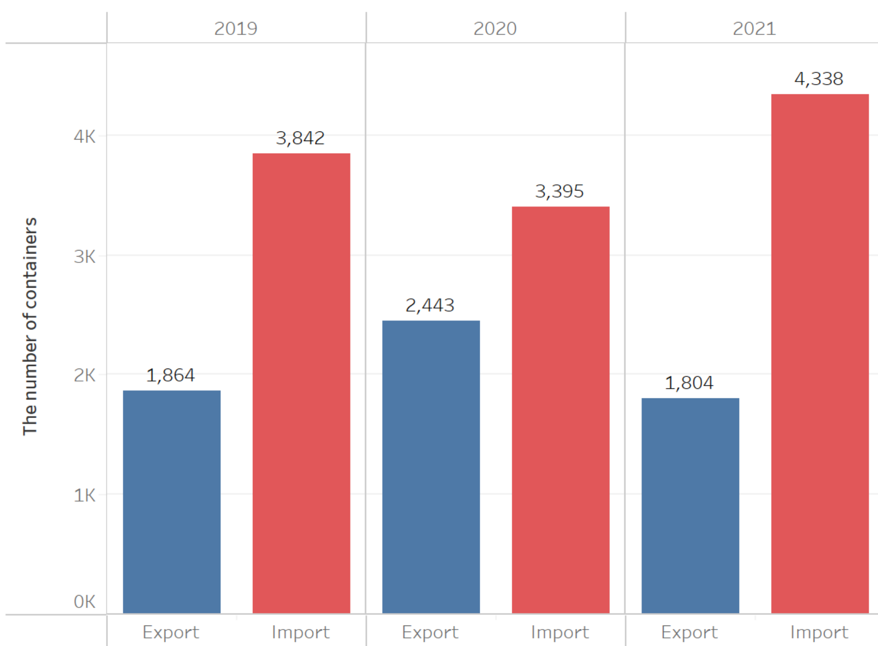


Fig 4.3. The number of import and export containers in each year in the data.

Weight

The weight indicates the weight of the cargoes in the containers, i.e., import cargoes and export cargoes. **Fig 4.4** shows the weight of cargoes in export and import flows, respectively, which is concentrated in the export containers but fragmentary in the import ones. Nearly 75% of the export cargoes are weighed at 25000 kg, and the top 3 account for about 86% of the total. However, among the imported cargoes, the most significant share accounts for 1.82% of the total.

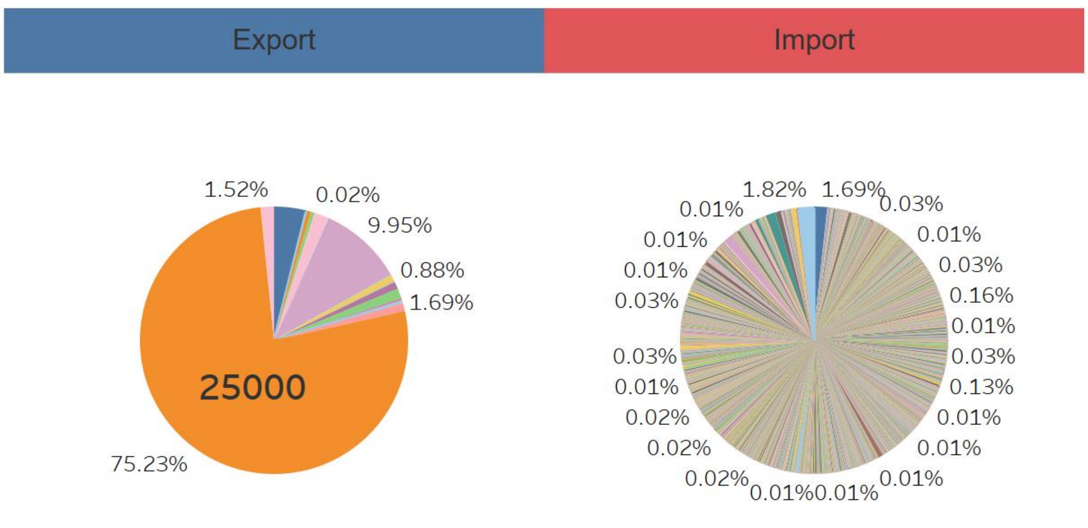


Fig 4.4. The pie chart showing the share of the weight of import and export containers.

4.2 The Distribution of Data

The probability distribution of the historical data will be analyzed, which will help generate the input data for the simulation model. Specifically, the R would be used here: 1) use the *fitdistrplus()* library to do an initial exploration to the data, finding out which several distributions it will possibly follow in the Cullen and Frey graph; 2) use the *fitdist()* and *gofstat()* library to select the most fit distribution.

The Number of Containers per Day

Fig 4.5 shows the frequency histogram graph of the number of import (left) and export (right) containers per day.

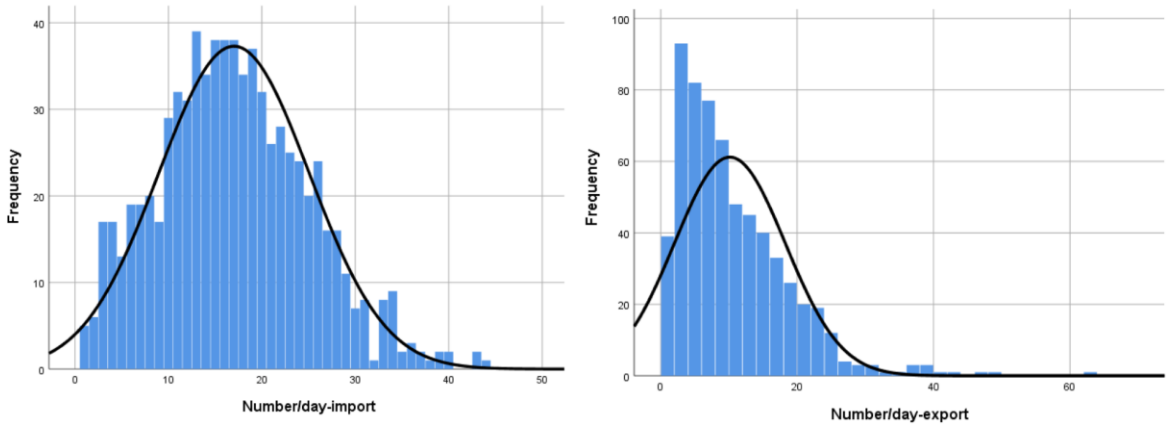
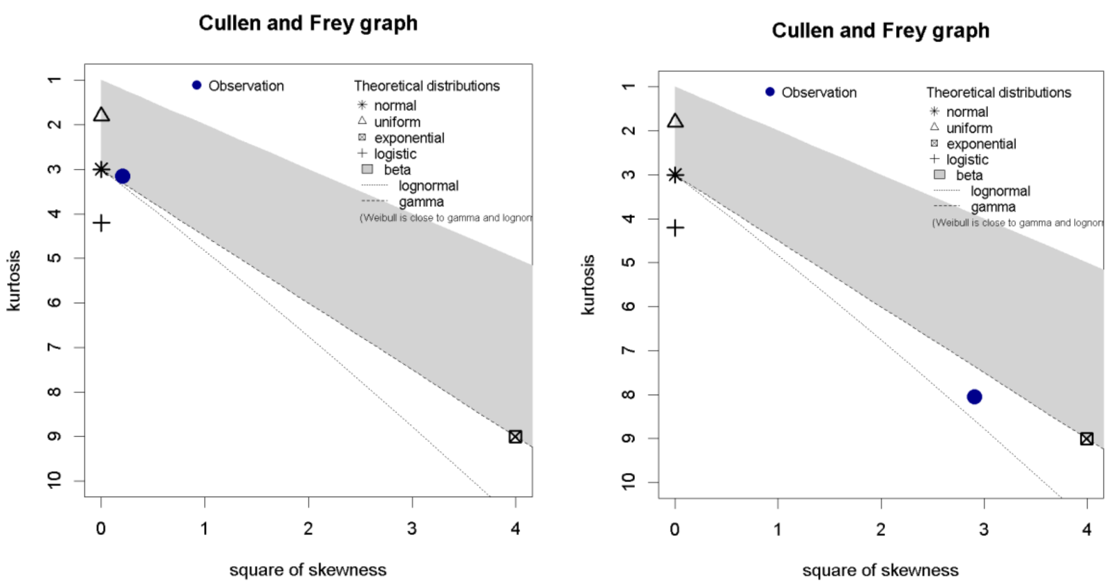


Fig 4.5. The frequency histogram graph of the number of containers per day.

Fig 4.6 are two Cullen and Frey graphs of the number of import and export containers per day. In the left figure, the observation point is located close to normal, lognormal, and gamma distributions; in the right figure, the point is close to exponential, lognormal, and gamma distributions. After applying the fitdist() and gofstat() library, the most fit distributions are normal distribution (mean: 15.40, std: 7.8) and gamma distribution (shape: 1.64, rate: 0.16), for import and export data respectively.



a) Import containers

b) Export containers

Fig 4.6. The Cullen and Frey graph of the number of containers

The Weight of Containers

Fig 4.7 shows the frequency histogram graph of the weight of import (left) and export (right) cargoes. Here, 75% of export cargoes are 25000 kg. Thus, it is assumed that all the export cargoes are 25000kg.

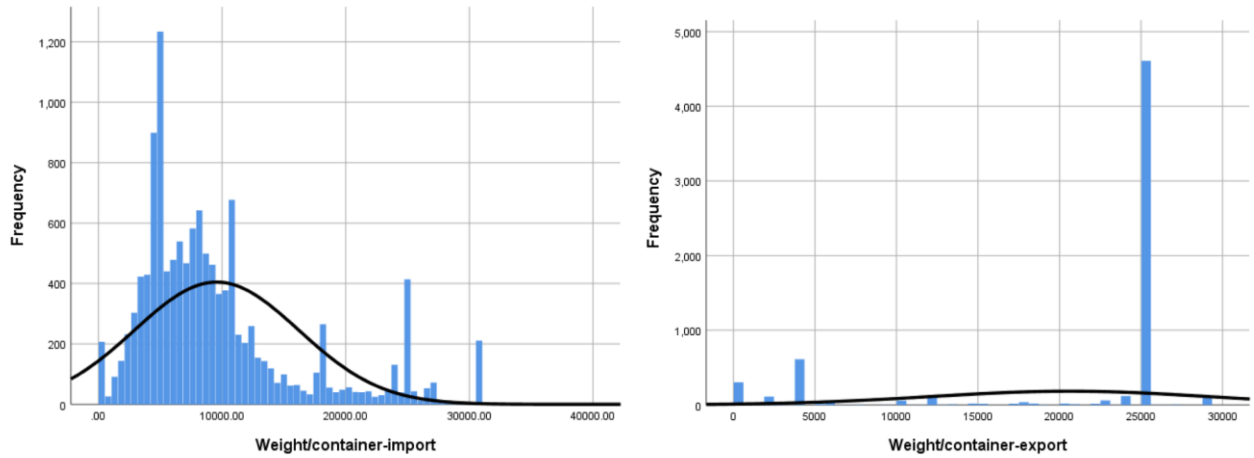


Fig 4.7. The frequency histogram graph of the weight of cargoes.

Fig 4.8 presented the Cullen and Frey graphs of the weight of the import cargoes, in which the observation point is close to exponential, lognormal and gamma distributions. After applying the *fitdist()* and *gofstat()* library, the most fit distribution is lognormal distribution (mean: 8.96, std: 0.63).

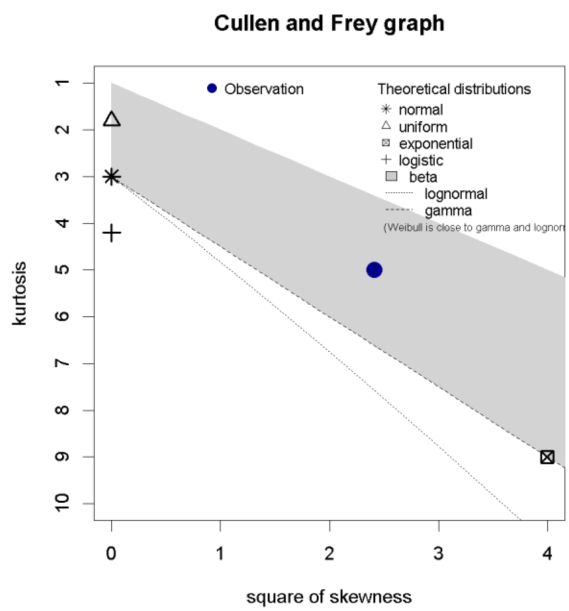


Fig 4.8. The Cullen and Frey graph of the data of the weight of import containers.

The Number of Containers for each Importer or Exporter

Fig 4.9 shows the share of containers for each importer and exporter, which indicates the possibility to generate the container arrival to each receiver.

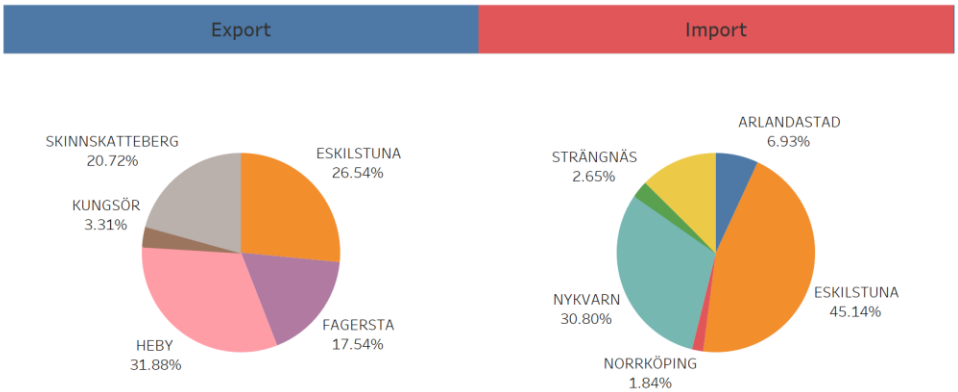


Fig 4.9. The pie chart showing the share of containers for each importer and exporter.

Container Size per receiver

There are two sizes of containers used in the case - 20ft and 40ft, which also need to be considered in the modeling process due to the different tare weight. **Table 4.1** shows the share of each of two sizes of containers for each receiver. For the sake of simplification, the share is processed into the last two columns.

Table 4.1
The share of each of two sizes of containers for each receiver.

Receivers	20ft	40ft		20ft	40ft
Skinnskatteberg	0.79%	99.21%		0.00%	100.00%
Eskilstuna (exp)	0.06%	99.94%		0.00%	100.00%
Heby	0.05%	99.95%		0.00%	100.00%
Fagersta	16.36%	83.64%		16.36%	83.64%
Kungsor	40.69%	59.31%	→	40.69%	59.31%
Arlandastad	53.88%	46.13%		53.88%	46.13%
Eskilstuna (imp)	25.41%	74.59%		25.41%	74.59%
Norrkoping	26.42%	73.58%		26.42%	73.58%
Nykvarn	0.34%	99.66%		0.00%	100.00%
STRÄNGNÄS	87.66%	12.34%		87.66%	12.34%
VÄSTERÅS	21.38%	78.62%		21.38%	78.62%

The Probability Distribution of "the number of days- the number of orders" for Each Exporter

In the model, we need to simulate the order generated from each exporter, i.e., how many empty containers does an exporter need for one day? Hence, the probability distributions of the number of orders for each day for each exporter need to be extracted from the historical data. This is similar to the first part of this section, thus here just the results are shown (see **Table 4.2**). The difference is for any single exporter, they do not order empty containers on most days. Thus, for better estimating the distribution, the days with 0 orders are excluded when calculating the distribution.

Table 4.2
The possibility of generating orders and the distribution of "the number of days- the number of orders" for each exporter.

Exporter	The possibility of orders	Distribution
Heby	0.37	gamma (1.28, 5.56)
Eskilstuna	0.31	lognormal (1.64, 0.84)
Skinnskatteberg	0.31	gamma (1.47, 3.70)
Fagersta	0.38	gamma (1.90, 2.00)
Kungsor	0.13	normal (0.99, 2.05)

5. Simulation Model and Result

Four agent-based discrete-event simulation models are built by Anylogic (a general simulation software) to assess the inland intermodal container transportation system - one with the dry port (the real case), one without the dry port, the third one with the dry port and triangulation transportation, and the last one with the dry port and street-turn transportation. In this section, the logic of the models, the input data, and the results of the models will be presented and explained.

5.1 Scenario 1 - with Dry Port

Scenario 1 is the container transport system with the Eskilstuna dry port, which is the current real case.

5.1.1 Model Description

The activity flow chart of the simulation model is illustrated in **Fig 5.1**, which includes two flows: 1) import flow - the laden containers will be transported to its importers and unloaded there, then the empty container will be returned back to the port and stored there; 2) export flow - the exporters will reserve an empty container from the port, and when the cargoes are loaded at the exporter's site the laden container will be transported to the port.

Import Flow

The import flow starts from the arrival of import containers at the Port of Gothenburg - everyday there are some containers arriving at the seaport and waiting there for the train. Each of the containers has a receiver, to which it will be transported later. The train will arrive at 18:30. When the train has been ready for loading work, these containers will be loaded onto it at 19:00, which also means those import containers arriving after that time will have to wait for the next train shift. However, the order processing is at 18:00, which means the orders received before this point will be delivered at the same day; otherwise, wait for the next train shift.

Firstly, the containers will be transported from the Port of Gothenburg to Eskilstuna by train, departing at 23:00 every weekday night. After 6 hours on the way, the train will arrive at Eskilstuna terminal at 05:00 the next day. Then, the laden containers will be unloaded from the train to the trucks that have been waiting there, which will transport the containers to their importers by road. The trucks will depart at 8:30 in the morning.

Upon the trucks arrive at the importers' site, the import cargoes will be unloaded out of the container. After that, the return empty containers will be carried by the same truck back to Eskilstuna on the same day and will wait there for the next train shift. When the next train arrives and everything is ready, these return empty containers will be loaded onto the train back to the Port of Gothenburg and then be stored there. The train departs from Eskilstuna at 10:30 and arrives at the Port of Gothenburg at 18:30.

Export Flow

The export flow is going on simultaneously with the import flow, both of which are happening on the same transport system. Thus, the export flow is similar to the import flow. The export flow begins with the exporters' reservation of empty containers—if they have an export demand, the exporters must reserve the number of empty containers one day in advance. Reservations made before 18:00 will be delivered the same day (those empty containers will be loaded at 19:00 as the import ones); otherwise, they will have to wait until the next shift. In the import flow illustrated above, the empty containers for export demand will be loaded onto the train and transported to Eskilstuna together. Similarly, the empty containers will then be transported by trucks to the exporters who need them.

When the trucks arrive at the exporters' site, the export cargoes will be loaded into the container. After that, the laden export containers will be carried by the same truck back to Eskilstuna on the same day and will wait there for the next train shift. Lastly, they will be transported together with the return empty containers by train back to the Port of Gothenburg, where they will be loaded onto the ships to other countries.

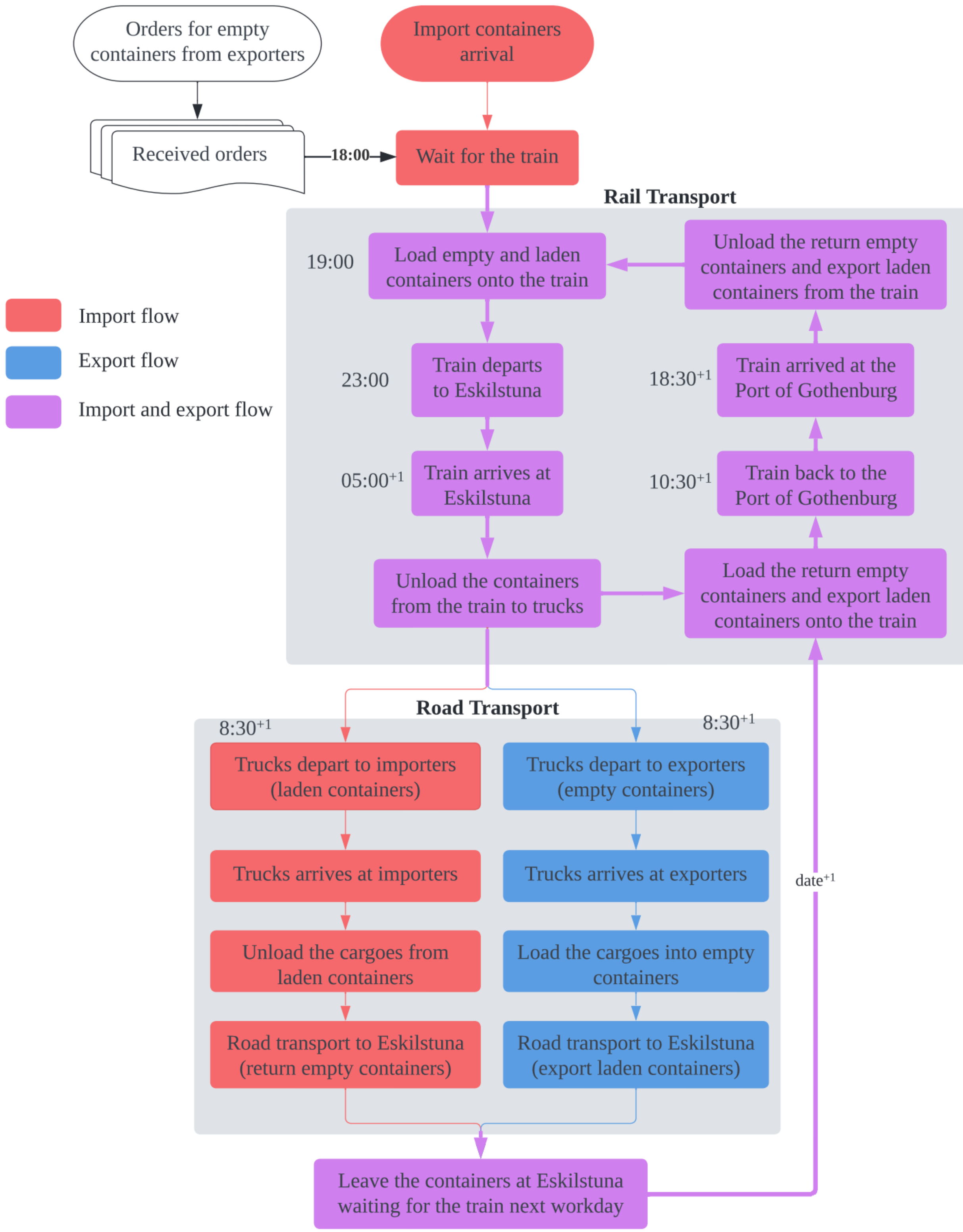


Fig 5.1. The activity flow chart of the model with the dry port.

5.1.2 Model Assumption

A simulation model is a kind of mathematical expression of the real world, which cannot take all the information into account. Therefore, some reasonable assumptions are fundamental and necessary for simulation models. The model in this thesis is based on the following two important assumptions:

- There are enough empty containers stored at the seaport to satisfy the demand from exporters;
- A truck can only carry one container.

5.1.3 Input Data

Table 5.1 shows the input data of the simulation model. The number and weight of containers are derived from the case data, which has been presented in section 2.1.2. The unit cost and CO2 emission rate of the trains and trucks are used to calculate the cost and CO2 emissions of the transport system, respectively. The prices of the trains and trucks are derived from the staff of the terminal and processed to fit our model. Here, only the CO2 emissions that occur during transportation are considered. The speed of the train is calculated by Anylogic automatically according to the departure and arrival schedule table. The speed of the trucks is 50 kilometers per hour. To be more precise, some costs from the operation at the dry port are also considered - here they are the storage cost of the return empty containers and the handling cost for the forward laden containers.

Table 5.1
Part of the input data of simulation model

Input data	Value / distributions
The number of import containers per day	normal(15.43, 7.8)
The weight of export cargoes per container	25000 kg
The unit cost of train	5800 kr per container for one round-trip
The unit cost of truck	30.43 kr per container per kilometer
The CO2 emission rate of train	12.7 g per tonne-kilometer (EEA, 2017)
The CO2 emission rate of truck	593.9 g per kilometer for empty containers; 915 g per kilometer for laden containers
The speed of train	Calculated by Anylogic according to the train time table and route
The speed of truck	50 km per hour
The storage cost at dry port	21.5 kr per day per container (after 7 days)
The handling cost at dry port	215 kr per container

Here, we use the possibility of generating orders and the distribution of “the number of days- the number of orders” for each exporter (see **Table 5.2**). Firstly, the program uses “the probability of orders” to judge if today this exporter would order the empty containers; then if yes, the distribution would be applied to generate the number of orders from this exporter (if the result is great than or equal to 1.5, the rounded result will be the number of empty containers in the order; otherwise, the number of empty containers in the order would be set as 1).

Table 5.2

The possibility of generating orders and the distribution of “the number of days- the number of orders” for each exporter.

Exporter	The possibility of orders	Distribution
Heby	0.37	gamma (1.28, 5.56)
Eskilstuna	0.31	lognormal (1.64, 0.84)
Skinnskatteberg	0.31	gamma (1.47, 3.70)
Fagersta	0.38	gamma (1.90, 2.00)
Kungsor	0.13	normal (0.99, 2.05)

The operation time at dry port and receivers are shown in **Table 5.3**. Here, the operation time at dry port is independent from the containers, assumed to follow the triangular distribution; the time at receivers would depend on the weight of the containers - one hour per 10 tonne. The operation time at the Port of Gothenburg is not considered in the model.

Table 5.3
The operation time at dry port and receivers.

Input data	Time (hour)
The time to unload the containers at importers	weight / 10000
The time to load the containers at exporters	weight / 10000
The time to move the containers from the train to truck	triangular(0.1, 0.2, 0.15)
The time to unload the containers off the truck at dry port	triangular(0.1, 0.15, 0.13)

The route of the train is derived from Google; the route of the trucks are requested from the OSM server in Anylogic.

5.1.4 Results

To improve the robustness of the result, we run the simulation model for 1 year for 25 times and then get the results. Additionally, the warm-up period - which is to run the model for a certain time and reach a steady state so that the results of the simulation analysis would not be affected by the statistics of the initiation phase - is set by 3 months in our model. **Table 5.4** shows the mean value as results; **Fig 5.2** shows one of the 25 results as an example.

Table 5.4
The result of the simulation model for scenario 1.

Measurements	Run							Average	Share
	1	2	3	…	23	24	25		
Import containers	4022	4158	4005	…	4011	4124	4083	4041.84	64.63%
Export containers	2298	2129	2076	…	2128	2057	2059	2212	35.37%
Sum	6320	6287	6081	…	6139	6181	6142	6254	
Cost (Empty Container) / kr	25854946	25990637	24961366	…	25521220	25646687	25257864	25853040	47.17%
Cost (Laden Container) / kr	25994162	25944903	25177539	…	25494119	25628509	25306914	25921285	47.30%
Handling cost / kr	3063840	2985920	2916475	…	2912175	2974310	2968935	3031134	5.53%
Sum	54912948	54921460	53055380	…	53927514	54249506	53533713	54805459	
CO2 emission (Empty Container) / t	254.50	255.61	247.38	…	252.63	254.54	248.75	255.68	24.29%
CO2 emission (Laden Container) / t	804.60	787.70	769.10	…	780.13	777.64	767.96	796.75	75.71%
Sum	1059.10	1043.31	1016.48	…	1032.76	1032.18	1016.71	1052.44	
Mileage (Empty Container) / km	2645544	2618999	2531558	…	2583576	2578047	2564442	2616142	49.95%
Mileage (Laden Container) / km	2651535	2630944	2540437	…	2579468	2584701	2559794	2621184.8	50.05%
Sum	5297079	5249943	5071995	…	5163044	5162748	5124236	5237326.52	

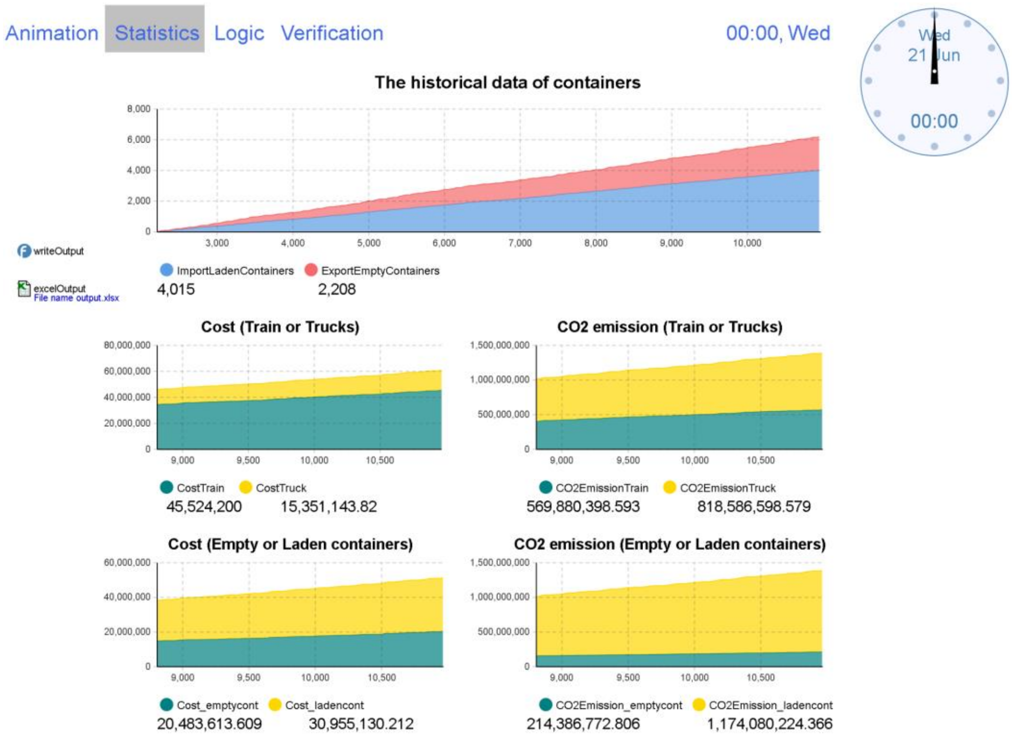


Fig 5.2. The example of the result of the scenario 1 simulation model.

5.2 Scenario 2 - without Dry Port

Scenario 2 is the container transport system without the Eskilstuna dry port, in which only the trucks are in charge of the transporting.

5.2.1 Model Description

The activity flow chart of scenario 2 - The Model without Dry Port - is illustrated in **Fig 5.3**, which includes both import and export flows. The main difference from scenario 1 is that no dry port and rail transport are involved, which makes it simpler than scenario 1.

Import Flow

The import flow still starts from the arrival of import containers at the Port of Gothenburg - everyday there are some containers arriving at the seaport. If it is the truck working time, the import laden containers will be directly loaded onto trucks and sent to their destination. The truckers work from 8:30 AM to 5:00 PM, 5 days per week, which means that the containers arriving within this time window can be directly loaded and transported.

Upon the trucks arrive at the importers' site, the import cargoes will be unloaded out of the container. After that, the return empty containers will be carried by the same truck back to the Port of Gothenburg. Lastly, the trucks will stay at port waiting for the next container and the return empty containers will be stored there.

Export Flow

The export flow starts from the reservation of empty containers from the exporters. The difference here is only if it is in the working time, the reservation will be processed immediately. Similarly, the empty containers will be transported to exporters by truck and loaded there, then be carried back to the port waiting for exporting.

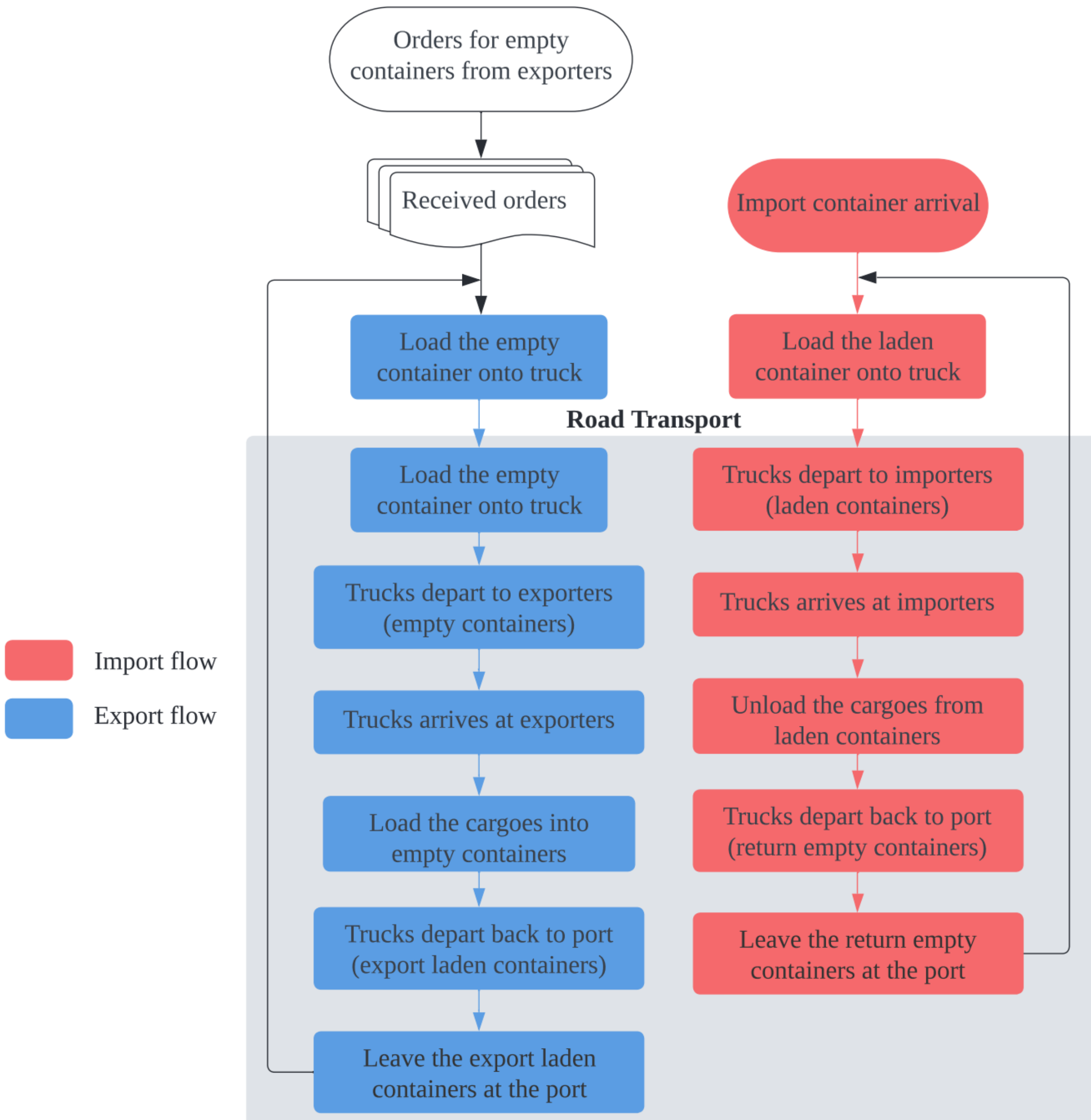


Fig 5.3. The activity flow chart of the model without the dry port.

5.2.2 Model Assumption (Same as 5.1.2)

5.2.3 Input Data (Same as 5.1.3 but here no operations in the dry port and no train involved)

5.2.4 Results

Same, we run the simulation model for 1 year for 25 times with a 3-month warm-up period, and then get the mean value as results (see **Table 5.5**). **Fig 5.4** shows one of the 25 results as an example.

Table 5.5
The result of the simulation model for scenario 2.

Measurements	Run							Average	Share
	1	2	3	...	23	24	25		
Import containers	4095	4039	3993	...	4003	4087	3991	4020.8	64.65%
Export containers	2308	2240	2211	...	2139	2068	2186	2198.68	35.35%
Sum	6403	6279	6204	...	6142	6155	6177	6219.48	
Cost (Empty Container) / kr	12811733	12488544	12400487	...	13018980	13341195	12724260	12780403	31.93%
Cost (Laden Container) / kr	25764949	25511355	25053290	...	25045514	25128999	25331219	25245357	63.07%
Handling Cost / kr	1758485	1735695	1716130	...	1719140	1761280	1715915	1731937	4.33%
Storage Cost / kr	280360	267202	262472	...	267181	288659	258516	268273	0.67%
Sum	40615527	40002796	39432379	...	40050815	40520133	40029910	40025970	
CO2 emission (Empty Container) / t	176.58	175.56	171.97	...	177.88	180.07	177.89	176.56	23.03%
CO2 emission (Laden Container) / t	782.23	774.26	761.16	...	761.65	755.93	774.23	766.71	100.00%
Sum	958.81	949.82	933.13	...	939.53	936.00	952.12	943.28	
Triangulation per cent	1	1	1	...	1	0.9971	1	0.997352	
Average storage at dry port	106.53	107.58	108.03	...	108.68	108.92	108.85	108.0508	

Fig 5.4. The example of the result of the scenario 2 simulation model.

5.3 Scenario 3 - with Dry Port and Triangulation

Scenario 3 is the container transport system with the Eskilstuna dry port and the triangulation transportation is also applied.

5.3.1 Model Description

The activity flow chart of scenario 3 - The model with dry port and triangulation - is illustrated in **Fig 5.5**, which includes both import and export flows. The main difference from scenario 1 is that the empty containers to exporters will be transported from the dry port, not the seaport, which will further reduce the cost and emission from empty container movements.

Import Flow

The import flow starts from the arrival of import containers at the Port of Gothenburg - everyday there are some containers arriving at the seaport and waiting there for the train. Each of the containers has a receiver, to which it will be transported later. The train will arrive at 18:30. When the train has been ready for loading works, these containers will be loaded onto it at 19:00. Firstly, the containers will be transported from the Port of Gothenburg to Eskilstuna by train, departing at 23:00 every weekday night. After 6 hours on the way, the train will arrive at Eskilstuna terminal at 05:00 the next day. Then, the laden containers will be unloaded from the train to the trucks that have been waiting there, which will transport the containers to their importers by road.The trucks will depart at 8:30 in the morning.

Upon the trucks arrive at the importers' site, the import cargoes will be unloaded out of the container. After that, the return empty containers will be carried by the same truck back to the Port of Gothenburg. Lastly, the trucks will stay at port waiting for the next container and the return empty containers will be stored there. The difference from scenario 1 is that those return empty containers will not be transported back to seaport directly, instead they will be stored at the dry port for no more than 10 days. Those empty containers will be re-used for exporting directly, which means this time the request from exporters will be served by the empty containers stored at the dry port, not the seaport. The longer the container is in the dry port, the first it will be used. Every time when the train departs from the dry port, those empty containers stored for more than 10 days will be transported back to the seaport Additionally, if the storage of empty containers at dry port cannot satisfy the demand from exporters, some empty containers still will be transported from the seaport. (This will not happen in the simulation model, because the number of import containers would be about double that of the exporter containers).

Export Flow

The export flow starts from the reservation of empty containers from the exporters. The difference here is that the dry port will receive and process those reservations - every workday at 7:30 and 17:00, the dry port will process the received orders and transport the empty containers to the customers by trucks at 8:30 and 18:00. Similarly, the empty containers will be loaded there, then be carried back to the dry port waiting for the next train shift back to the seaport.

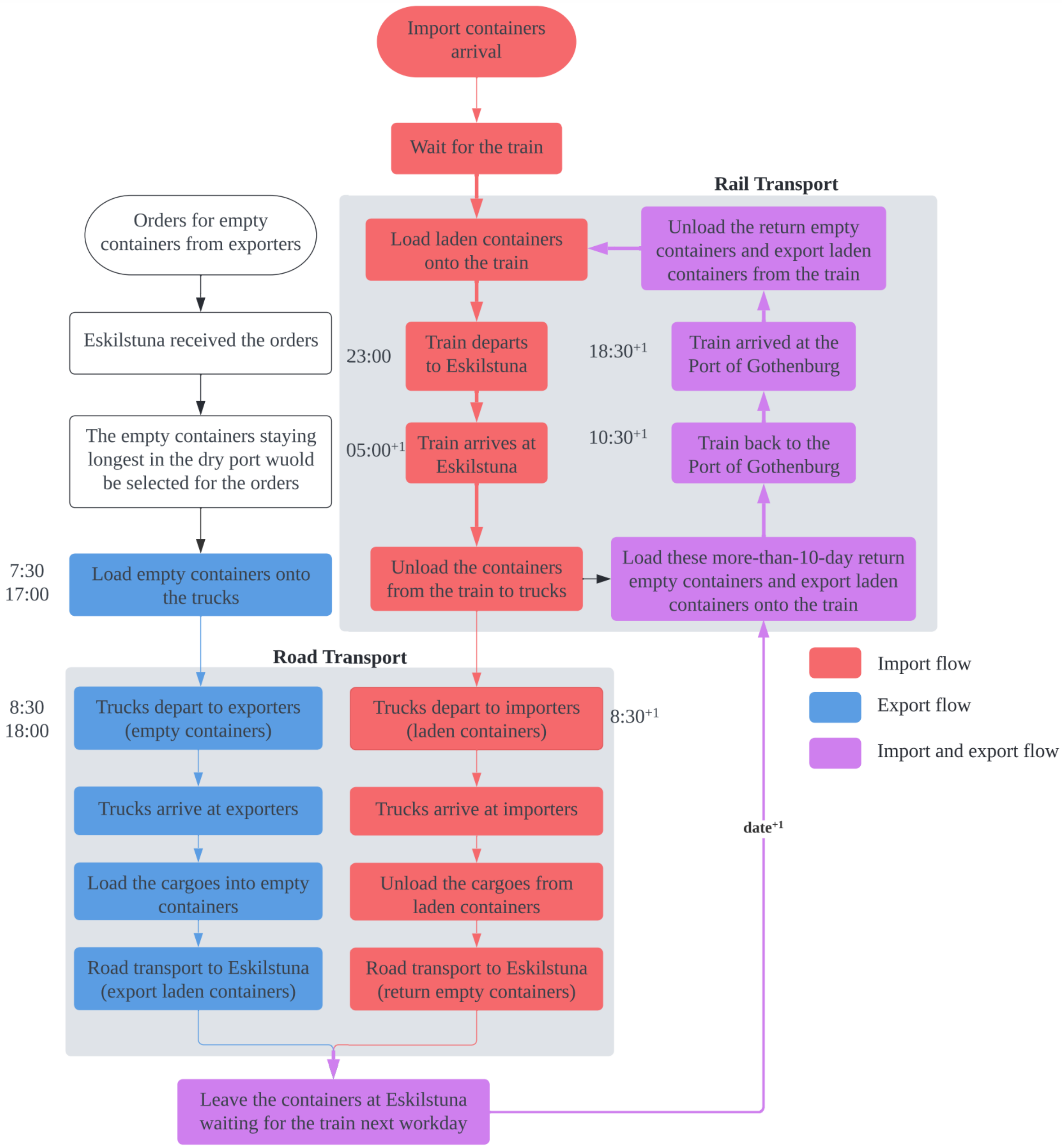


Fig 5.5. The activity flow chart of the model with the dry port and triangulation.

5.3.2 Model Assumption (Same as 5.1.2)

5.3.3 Input Data (Same as 5.1.3)

5.3.4 Results

Same, we run the simulation model for 1 year for 25 times with a 3-month warm-up period, and then get the mean value as results (see **Table 5.6**). **Fig 5.6** shows one of the 25 results as an example.

Table 5.6
The result of the simulation model for scenario 3.

Measurements	Run							Average	Share
	1	2	3	…	23	24	25		
Import containers	4095	4039	3993	…	4003	4087	3991	4020.8	64.65%
Export containers	2308	2240	2211	…	2139	2068	2186	2198.68	35.35%
Sum	6403	6279	6204	…	6142	6155	6177	6219.48	
Cost (Empty Container) / kr	12811733	12488544	12400487	…	13018980	13341195	12724260	12780403	4763.96%
Cost (Laden Container) / kr	25764949	25511355	25053290	…	25045514	25128999	25331219	25245357	9410.33%
Handling Cost / kr	1758485	1735695	1716130	…	1719140	1761280	1715915	1731937	645.59%
Storage Cost / kr	280360	267202	262472	…	267181	288659	258516	268273	100.00%
Sum	40615527	40002796	39432379	…	40050815	40520133	40029910	40025970	
CO2 emission (Empty Container) / t	176.58	175.56	171.97	…	177.88	180.07	177.89	176.56	23.03%
CO2 emission (Laden Container) / t	782.23	774.26	761.16	…	761.65	755.93	774.23	766.71	100.00%
Sum	958.81	949.82	933.13	…	939.53	936.00	952.12	943.28	
Mileage (Empty Container) / km	944010	895726	906144	…	970358	1010112	919616	938721.32	36.58%
Mileage (Laden Container) / km	2631237	2592966	2553758	…	2535947	2546876	2562769	2566176.8	100.00%
Sum	3575247	3488692	3459902	…	3506305	3556988	3482385	3504898.12	
Triangulation per cent	1	1	1	…	1	0.9971	1	0.997352	
Average storage at dry port	106.53	107.58	108.03	…	108.68	108.92	108.85	108.0508	

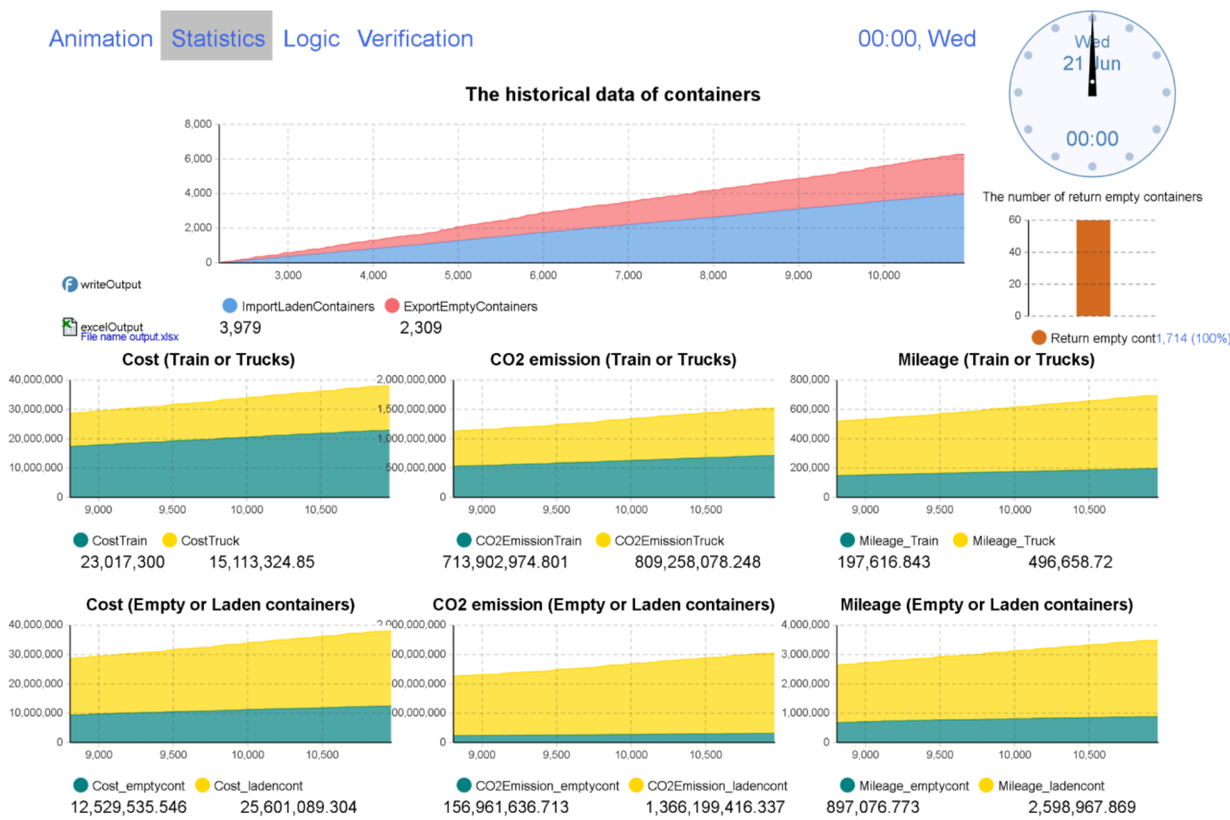


Fig 5.6. The example of the result of the scenario 3 simulation model.

5.4 Scenario 4 - with Dry Port and Street-turn

Scenario 4 is the container transport system with the Eskilstuna dry port and the street-turn transportation is also applied.

5.4.1 Model Description

The activity flow chart of scenario 4 - The Model with Dry Port and street-turn - is illustrated in **Fig 5.7**, which includes both import and export flows. The main difference from scenario 1 is that the request for empty containers from exporters will be served by the destuffed containers from the importers, not the seaport or dry port, which will further reduce the cost and emission from empty container movements.

Import Flow

The import flow starts from the arrival of import containers at the Port of Gothenburg - everyday there are some containers arriving at the seaport and waiting there for the train. Each of the containers has a receiver, to which it will be transported later. The train will arrive at 18:30. When the train has been ready for loading works, these containers will be moved onto it at 19:00. Firstly, the containers will be transported from the Port of Gothenburg to Eskilstuna by train, departing at 23:00 every weekday night. After 6 hours on the way, the train will arrive at Eskilstuna terminal at 05:00 the next day. Then, the laden containers will be unloaded from the train to the trucks that have been waiting there, which will transport the containers to their importers by road. The trucks will depart at 8:30 in the morning.

Upon the trucks arrive at the importers' site, the import cargoes will be unloaded out of the container. After that, the return empty containers will be carried by the same truck back to the Port of Gothenburg. Lastly, the trucks will stay at port waiting for the next container and the return empty containers will be stored there. The difference from scenario 1 is that those returning empty containers will not be transported back to seaport directly, instead they will be stored at the dry port for no more than 10 days. Those empty containers will be re-used for exporting directly, which means this time the request from exporters will be served by the empty containers stored at the dry port, not the seaport. The longer the container is in the dry port, the first it will be used. Every time when the train departs from the dry port, those empty containers stored for more than 10 days will be transported back to the seaport.

Export Flow

The export flow starts from the reservation of empty containers from the exporters. The difference here is that the requests will be served by street-turn as much as possible, because it can always save more due to the fact that the two sides of a triangulation are greater than the other side. At 19:00, the street-turn planning will be made based on the import containers and orders for empty containers at hand. Specifically, satisfy these empty container orders by the closest import containers with the same size. For example, if exporter A has an order, then it will be served by the import containers of the same size that are transported to the closest importers and these containers have not been assigned for other exporters. Then, check all the orders iteratively. If there are not import containers satisfying the conditions, the new empty containers will be used. The rest works are similar to the import flow.

After the importers destuffed the importer laden containers, those return empty containers will be checked if yes, they will be re-used for any exporter. If yes, the truck will carry it directly to its assigned exporter; if no, they will be transported back to dry port like in scenario 1.

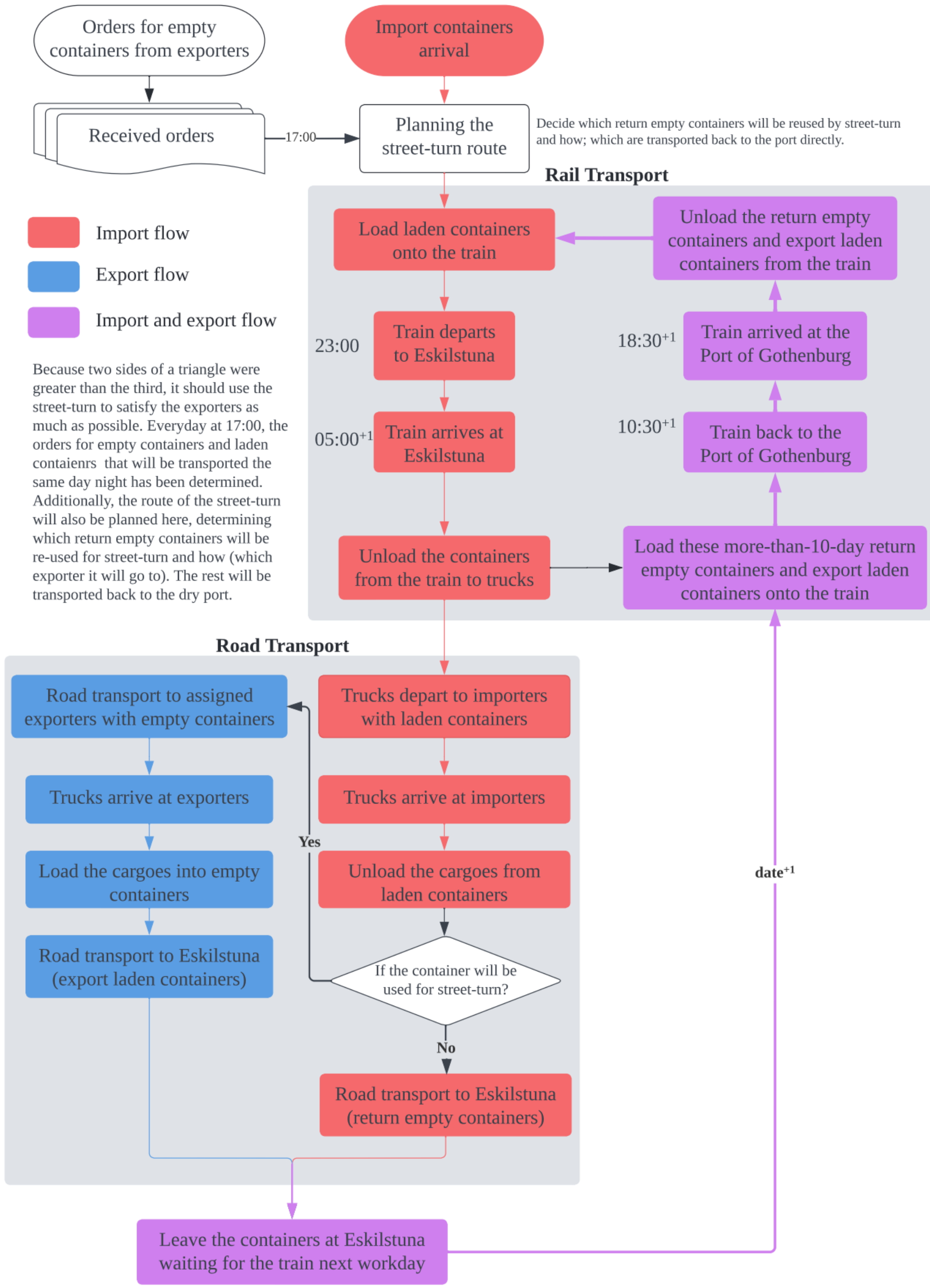


Fig 5.7. The activity flow chart of the model with the dry port and street-turn.

5.4.2 Model Assumption (Same as 5.1.2)

5.4.3 Input Data (Same as 5.1.3)

5.4.4 Results

Same, we run the simulation model for 1 year for 25 times with a 3-month warm-up period, and then get the mean value as results (see **Table 5.7**).

Table 5.7
The result of the simulation model for scenario 4.

Measurements	Run							Average	Share
	1	2	3	…	23	24	25		
Import containers	3989	4091	4051	…	4023	4126	3949	4025.8	64.81%
Export containers	2035	2282	2289	…	2120	2253	2279	2186.28	35.19%
Sum	6024	6373	6340	…	6143	6379	6228	6212	
Cost (Empty Container) / kr	14135182	14476086	15083257	…	14880794	15247686	14386878	14599383	32.92%
Cost (Laden Container) / kr	26287215	28217987	28716308	…	27450331	28623894	27948124	27667964	62.39%
HandlingCost / kr	1998425	2099690	2093670	…	2078835	2183970	2084425	2079033	4.69%
Sum	42420822	44793763	45893235	…	44409960	46055550	44419427	44346380	
CO2 emission (Empty Container) / t	184.60	194.75	206.52	…	198.62	204.41	195.76	195.20	19.97%
CO2 emission (Laden Container) / t	744.80	803.45	813.84	…	778.01	805.85	792.04	782.45	80.03%
Sum	929.40	998.20	1020.36	…	976.63	1010.26	987.80	977.66	

5.5 Verification

Verification of a model refers to testing the model and judging if it works as intended (Rossetti, 2015). Various methods and techniques have been devised to verify the correction of simulation models. Firstly, the built-in debugger of the Anylogic simulation software can be used to detect the inconsistencies and misspecification of the model. Additionally, in this case, given that we already have the historical data, we can compare the results of the simulation model with it to verify the correction of the model. Here, three metrics are selected for comparison: the number of import laden containers to export empty containers (**Table 5.8**), the number of containers for each importer and exporter (see **Table 5.8**), and the distribution of the weight of import and export containers (see **Fig 5.8**). Because the four simulation models are all similar to each other, only the model of scenario 1 is verified. The model will be run 25 times to get the average results for verification.

Table 5.8
The comparison of the results of the simulation model and the historical data regarding the number of the import and export containers, and the number of containers to each importer and exporter.

Measurements	Run							
	1	2	3	Average	2019	2020	2021	Average
Import containers	4140	4060	3932	**4044**	3836	3391	4324	**3850**
Export containers	2031	2198	2174	**2134**	1870	2447	1818	**2045**
Sum	6171	6258	6106	**6178**	5706	5838	6142	**5895**
Nykvarn	1343	1249	1227	**1273**	1173	1163	1222	**1186**
VÄSTERÅS	552	507	513	**524**	364	288	807	**486**
Arlandastad	279	284	249	**271**	235	252	313	**267**
STRÄNGNÄS	106	105	96	**102**	88	73	147	**103**
Norrkoping	66	71	72	**70**	48	39	125	**71**
Eskilstuna (Imp)	1792	1834	1749	**1792**	1928	1576	1710	**1738**
Heby	587	697	607	**630**	620	887	449	**652**
Skinnskatteberg	421	464	511	**465**	425	451	395	**424**
Fagersta	351	388	335	**358**	401	328	347	**359**
Kungsor	85	59	58	**67**	132	53	19	**68**
Eskilstuna (Exp)	583	581	651	**605**	292	728	608	**543**

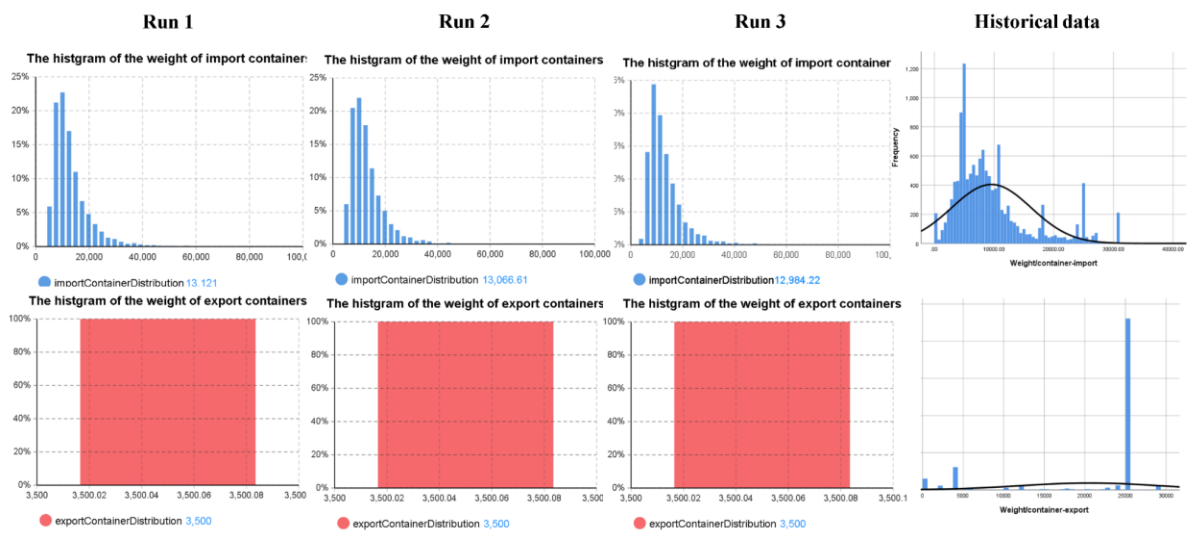


Fig 5.8. The comparison of the results of the simulation model and the historical data regarding the distribution of the weight of import and export containers.

Table 5.8 showed the number of import and export containers generated in the model for each receiver or sender can correspond to the historical data quite well; **Fig 5.8** demonstrated that the weight distribution of the import and export containers generated in the model is similar to the data we have. Thus, the correction of the models can be proved.

6. Discussion and Conclusion

In this section, five parts will be discussed: the comparison between different model results and the findings of this research, the contributions and differences of this research compared to the others, limitations and future improvable points.

6.1 Comparison and Findings

This research quantitatively assessed the value of Eskilstuna dry port and two dry-port-based transportation strategies in the container transportation network in Sweden in terms of the transport cost and CO2 emission by building up four agent-based discrete event simulation models by the Anylogic software. We run each model 25 times with a 3-month warm-up period and get the average value as the final results. Here, the four model results would be compared as follows.

The results of scenario 1 (see **Table 5.4**) showed that in the current transportation system, the economic cost and CO2 emission generated by transporting the empty containers account for 47.17% and 24.29% of the total, which is non-negligible. After comparing the first two results (see **Table 6.1**), we can see that both the value of the economic cost and CO2 emission from empty containers can be reduced by implementing the Eskilstuna dry port in the system. From the economic side, the dry port can help reduce the total transport cost by 62.55% (although the handling cost is introduced); from the environmental side, this reduction can even reach higher to 71% totally. When looking at the empty or laden containers separately, not only the cost and emission from both are reduced but also the share in emission from empty containers would drop down by around 38%.

There are two reasons for such a significant reduction in the cost and emission from the implementation of the dry port. Firstly, the most direct cause is the significant difference in the unit cost and unit emission rate of the train and truck, shown in Table 5.1. Besides, **Fig 2.2** also shows that the train is in charge of quite a big part of the transportation in the current logistics system. If we substitute the train with trucks, the effect of the higher unit cost and emission rate would be enlarged further.

Therefore, from the comparison between these two scenarios - with a dry port and without a dry port, it is obviously seen that the Eskilstuna intermodal terminal is quite valuable for the container transportation system in Sweden in terms of reducing transport costs and CO2 emissions. However, the dry port has few effects on reducing the ECR process. Here, the RQ1 has been answered.

Moreover, after introducing the triangulation transport method into the dry-port-based system, the transport cost and CO2 emissions can be further reduced. Specifically, the second comparison shows that the total cost can be reduced by 26.97%, among which the reduction of the ECR process would be higher - 50.57%. Compared to comparison 1, this time the share of cost from empty containers also decreased, which is one of our purposes. From the environmental view, the CO2 emission of the whole transportation system will decrease by 10.37%, and 30.94% for the ECR process. Not only the numerical results, the share of emission from empty container movements can also be reduced again further - 22.95%.

Therefore, from the comparison between scenario 3 and scenario 1 - with a dry port and with both dry port and triangulation, we can see that the cost and CO2 emission can decrease a step further. What is different here is that the share of cost from the ECR process in the whole system can be reduced by introducing the triangulation method. Here, the RQ2 has been answered.

In comparison 3, we can find that the dry-port-based street-turn strategy can also reduce the economic cost and CO2 emission based on the model 1. Here, the RQ3 has been answered. Nevertheless, when comparing model 4 to 3, the result shows the triangulation performs better than street-turn. Specifically, compared to model 3, the street-turn would increase the value of cost and emission from empty and laden containers and also totally. Besides, the share of both indicators will also increase a bit for empty containers. All of these are at the opposite side to our target.

Table 6.1
The comparison of results for three scenarios.

Summary	Model 1 with dry port		Model 2 without dry port		Model 3 Triangulation (10 days) with dry port		Model 4 Street-turn with dry port	
	Value	Share	Value	Share	Value	Share	Value	Share
Cost (Empty Container) / kr	25,853,040	47.17%	73,174,244	50.00%	12,780,403	31.93%	14,599,383	32.92%
Cost (Laden Container) / kr	25,921,285	47.30%	73,181,130	50.00%	25,245,357	63.07%	27,667,964	62.39%
Handling cost / kr	3,031,134	5.53%			1,731,937	4.33%	2,079,033	4.69%
Storage Cost / kr					268,273	0.67%		
Sum	54,805,459		146,355,374		40,025,970		44,346,380	
CO2 emission (Empty Container) / t	255.68	24.29%	1,428.14	39.36%	176.56	18.72%	195.20	19.97%
CO2 emission (Laden Container) / t	796.75	75.71%	2,200.48	60.64%	766.71	81.28%	782.45	80.03%
Sum	1,052.44		3,628.62		943.28		977.66	

Triangulation rate: 99.57%   Street-turn rate: 69.63%
Average storage: 108

Comparison	Comparison 1 (M1-M2)/M2		Comparison 2 (M3-M1)/M1		Comparison 3 (M4-M1)/M1		Comparison 4 (M4-M3)/M3	
	Value	Share	Value	Share	Value	Share	Value	Share
Cost (Empty Container) / kr	-64.67%	-5.65%	-50.57%	-32.31%	-43.53%	-30.21%	14.23%	3.10%
Cost (Laden Container) / kr	-64.58%	-5.41%	-2.61%	33.35%	6.74%	31.91%	9.60%	-1.08%
Handling cost / kr			-42.86%	-21.76%	-31.41%	-15.23%	20.04%	8.35%
Storage Cost / kr								
Sum	-62.55%		-26.97%		-19.08%		10.79%	
CO2 emission (Empty Container) / t	-82.10%	-38.27%	-30.94%	-22.95%	-23.65%	-17.81%	10.56%	6.67%
CO2 emission (Laden Container) / t	-63.79%	24.84%	-3.77%	7.37%	-1.79%	5.72%	2.05%	-1.54%
Sum	-71.00%		-10.37%		-7.11%		3.64%	

6.2 Conclusions

After comparing and analyzing all the results from the 4 models, some conclusions can be drawn up. The implementation of dry port in the transportation system can indeed reduce the cost and emissions quite significantly, although it cannot reduce the share of cost from empty container movements. Then based on only the dry port, the triangulation strategy can further reduce the cost and emission, and also the shares from the ECR process. However, the street-turn strategy can also have positive effects based on only the dry port but does not perform better than the triangulation. Therefore, in our analysis throughout the 4 models, the dry-port-based triangulation strategy is the best option in our case.

In this thesis, four types of transportation systems for empty and laden containers are analyzed with a case study in Sweden. As illustrated above, from both the economic and the environmental sides, the container transport chain accounts for a quite large part in the global and regional logistics and the supply chain. And also, when searching for the relevant papers in Sweden, very few studies are found. Thus, the models and findings from this thesis can not only be used for this single case, but also can be referred and extended to some other similar ones, dedicating to improve the supply chain efficiency and reduce the waste,

6.3 Contributions and Differences

This section will compare and discuss three most related articles in the literature review section with our thesis, finding out the differences and contributions of our research. The comparison contains five aspects: simulation methods, parameter features, geographical scope, network structure and performance measurements (see **Table 6.2**).

Table 6.2

The comparison of the previous research and our thesis.

Literatures	Simulation method	Parameter feature	Georgraphical scope	Network structure	Performance measurements
Roso. (2007)	-	Deterministic	National	1 SP, 1 DP and 19 destinations	CO2 emission
Kurtulus et al. (2019)	Discrete event	Deterministic	Reginal	2 SP, 2 DP and 4 container terminals	GHG emission
Lättilä et al. (2013)	Discrete event	Deterministic	National	1 SP, 2 DP and 193 municipalities	Tranport cost, CO2 emission
This thesis	Agent-based and discrete event	Stochastic	National	1 SP, 1 DP and 10/98 Customers	Tranport cost, CO2 emission

SP: sea port; DP: dry port

First, all these four studies used the simulation model to solve the problems. However, compared to the previous research, we adopted a better simulation method - combining the agent-based and discrete-event methods, whose advantages have been stated in section 2.4. Next, in the input data and parameters setting, a stochastic input was applied in our research, which can better simulate the uncertainty of the real world. As for the geographical scope, our research is national, focusing on the intermodal container transportation network within Sweden. Compared to the cases in the other three studies, our case is relatively more uncomplicated, with just one seaport and one dry port, involving five exporters and six importers (two are located in the same city). Lastly, we take both the economic and environmental costs into account as the performance measurements for the simulation model. Therefore, our research mainly has contributions to the simulation models for the inland intermodal container transportation chain, in terms of the modeling methods and parameter features. It is the model itself that is the most valuable thing.

6.4 Limitations

The limitations mainly come from two sources: input data and simulation model itself. The input data can be divided into two categories: case-specific data and general data. Firstly, for the case-specific data, there is some misdata in the Excel that has a negative impact on the correction of the output. Besides, the exact routes of the train and trucks are unknown, which are estimated according to some other sources (for train) and calculated by Anylogic program (for trucks) respectively. However, this also has a direct influence on the final results. Secondly, other general data, like the operation time in the dry port and customers' sites, the speed of trucks, the unit cost of transportation and the CO2 emission rate (actually, the train is powered by electricity, so we need to transfer the consumed electricity into CO2 emission) also have a significant influence on the results.

Additionally, the simulation model is also limited by the insufficient information about the real case. For example, to simplify the mode, only top-10 customers are simulated. Nevertheless, most shortcomings on the model are caused by lack of enough information about the transportation system. For instance, due to the unknown operation processes in the dry port and customers' sites, we cannot simulate them and include related costs into the model.

Therefore, the mistakes on the data and the lack of information about the simulation case together limited the correction of the simulation model and the accuracy of the results.

6.5 Future Research Perspective

Based on our work, there are some points that can be improved further. First and foremost, it is not only the costs and emissions generated by transportation that should be calculated, those related to the operations in dry port or seaport should also be considered. Because if the dry port is applied, the extra operations are inevitable. Secondly, from the environmental view, we should take more types of emissions into account, such as CH4, NO2, and so on, not only the CO2. Specifically, the CO2-equivalent greenhouse gas emissions - which converts the number of other gasses to the equivalent amount of CO2 with the same global warming potential - would be a better metric. Besides, the ownership of the containers could also be taken into account, for the reason that in most cases the triangulation and street-turn transportation can only happen within the same company. Additionally, the simulation models have been good enough for this case study, thus if the input data mentioned above can be improved, the results would be much more accurate and reliable.

Moreover, the sensitivity analyses can also be performed to see which factors (like the unit cost, emission rate, containers' weight, or the operations in dry port) have the most significant impact on the results and how they impact. The result of sensitivity analyses can help to determine the improvement directions and strategies for the real business.

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