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Optimizing Empty Container Repositioning at Inland Terminals

Using Data Analytics to Make an Informed Decision for a Seaport in Sweden

Master's Thesis in Supply Chain Management

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Cover: A Seaport with vessels docked for loading and unloading.

Gothenburg, Sweden 2023

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Abstract

Sweden, as a country, maintains a fair balance between imports and exports. However, in this post-pandemic era, there has been a rise in both imports and exports. Consequently, the transportation of goods involves extensive movement of containers. This thesis focuses on optimizing the existing container transport network from the perspective of the seaport, shipping lines, inland terminals, and rail operators. The network and flows are modelled as a mixed integer linear programming problem using Python and Gurobi. The goal is to meet the demand for empty containers while reducing turnaround time, container kilometres, the number of containers, and emissions. The results of the optimization model aid decision-making in selecting inland terminals for triangulation. The selection criteria for inland terminals include the number of containers handled, total emissions, triangle distance factor, and container kilometres. Currently, the flow of containers does not employ any strategies for utilizing empty containers. However, through the analysis of the optimization model, the thesis achieves the reuse of empty import containers by implementing triangulation and storage at inland terminals. Implementation of these strategies holds significant potential for cost savings for large shipping lines. In the current container transport system, there are four legs of transport: two for import flows (from port to importer and back) and two for export flows (from port to exporter and back). By implementing the proposed strategies, the number of legs in the transportation system can be reduced from four to three, resulting in increased efficiency. The results of the optimization model have demonstrated promising potential for cost savings across various inland terminals. The implications for different actors involved in the container transport network are thoroughly investigated in this study. Moreover, this research addresses the gap between qualitative decision-making and the need for substantial quantitative analysis. By utilizing the optimization model, decision-makers now have a valuable tool that provides quantitative insights, enabling more informed and data-driven decision-making processes.

Keywords: triangulation, optimization, containers, inland terminals, strategies

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Rahul R Kowshik, Gothenburg, May 2023

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

| | |
|------|---|
| CIR | Container Imbalance Ratio |
| ECR | Empty Container Repositioning |
| H&S | Hub and Spoke |
| IT | Inland Terminal |
| IP | Integer Programming |
| LP | Linear Programming |
| MILP | Mixed-Integer Linear Programming |
| MPC | Multi-Port Calling |
| Q | Triangle Distance Factor |
| RBV | Resource-Based View |
| SL | Shipping Line |
| TEU | Twenty-foot Equivalent Unit |
| TIR | Triangle Imbalance Ratio |
| VRIO | Value, Rarity, Imitability and Organization |

Nomenclature

Below is the nomenclature of indices, sets, parameters, and variables used throughout this thesis.

Indices

| | |
|--------|--|
| i, j | Indices for network nodes |
| k | Indices for shipping line operators/container owners |
| t | Index for time step |

Sets

| | |
|-------------------------------|---|
| $N \in \text{Nodes}$ | Set of all nodes in the network. |
| $IT \subset N - \{P\}$ | Set of all Inland Terminals except Seaport. |
| $SL \in \text{Shipping Line}$ | Set of all shipping lines which own the containers. |

Parameters

| | |
|--------------------------------------|---|
| $S_{(P,j,k)}^t e$ | Supply of empty export container at node |
| $D_{(P,j,k)}^t e$ | Demand of empty export container at node |
| $C_{(i,j)}$ | Cost of movement of containers between nodes. Unit in kilometres. |
| $X_{(i,j,k)}^t e f \in \mathbb{R}^+$ | Flow of laden export containers. |
| $X_{(i,j,k)}^t i f \in \mathbb{R}^+$ | Flow of laden import containers. |
| $\delta_{(i,j)}^t$ | Binary parameter for having at most one active supply arc between inland terminals. |

Variables

- $X_{ee^t(i,j,k)} \in \mathbb{R}^+$ Flow of empty export containers from node i to node j
for $k \in SL$.
- $X_{ie^t(i,j,k)} \in \mathbb{R}^+$ Flow of empty import containers from node i to node j
for $k \in SL$.

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1

Introduction

Global is the new local for the world. Due to disruptions caused by the pandemic and the invasion of Ukraine, there are some shifts to local production and supply with increased back-shoring and a focus on sustainability goals. No matter how global or local, transportation and logistics are ubiquitous in keeping the supply chain persistent. Global and local supply chains are the backbone of the system making goods available to consumers and enabling globalization. These chains refer to the interconnected network of manufacturers, suppliers, distributors, and retailers transporting goods and services worldwide (Cohen & Mallik, 1997). Supply chains are made up of individuals, businesses, and organizations connected to ensure the efficient production, delivery and sales of goods. They allow companies to source materials, products and services from around the world to create a competitive advantage in their respective markets. Aided by these chains, the majority of things present around us have been transported at some point. There are several modes enabling transport; rail, air, sea and road transport. Earth is 29% land and 71% water, instantly making sea/maritime transport the largest and most practical between destinations.

As much as 90% of everything around us has been on a vessel at some point (Faber et al., 2021). To move such quantities, the maritime sector requires containers to store goods and commodities during transport. Containers are standard in the maritime sector and are available in certain standard sizes. The calculation of volume is by TEUs (twenty-foot equivalent units). The movement of containers in the chain leads to benefits enabled by shipping but comes with a cost and some negative impacts. The goal in general is to minimize the cost and negative impacts while maintaining reliability and quality. Before reaching the origin port and after reaching the destination port, the containers are moved using road and/or rail transport. The loaded containers are delivered to customers and stripped. Once the containers are empty, the containers occupy the same space in the system. They need to be moved to customers who want to export goods or sent back to the port into storage or sometimes even shipped empty to fulfil demand in other locations. The movement of these empty containers is termed empty container repositioning (ECR) (Song & Carter, 2009). Dealing with several empty containers and ECRs reduces the percentage utilization of resources and leads to high costs for some or no value addition in the chain. The estimated incurred losses due to ECR was \$20 billion in 2015 (Sanders et al., 2015). A solution with high potential to reduce cost and emissions is the use of dry ports/inland terminals (Lättilä et al., 2013; Roso & Lumsden, 2010). In their article Roso and Lumsden (2010) defines a

dry port as: 'dry port is an inland intermodal terminal directly connected to seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardized units as if directly to a seaport'.

Upon reaching the country of destination, there are numerous operations to be conducted in the hinterland. The movement of loaded containers cannot be avoided but can be reduced by having a higher container fill rate and utilization. On the other hand, the movement of empty containers is necessary and can only be reduced but not stopped completely. The transport of empty containers creates several new instances of travel. The cost of logistics is high predominantly and further adds to commotion, emissions and delays. However, ECR can be reduced drastically to improve the utilization of the containers in the supply chain resulting in the reduction of the number of containers in flows and the turn around time mainly via street turns and triangulation (Tarudin, 2013). Turnaround time for a vessel is the time a vessel takes from the day of arrival at a port to the day of departure from the port (Ducruet & Merk, 2013). The same applies to containers as well, the time difference between the day a container is sent from the port to the day it is returned to the port. Street turn is defined as the movement of empty containers from the local assignee directly to the local shipper, reducing extra trips (Jula et al., 2006). Along similar lines, an import followed by an export using the same container is called triangulation (Reinhardt et al., 2012). An illustration of flows without and with triangulation is shown in Fig.1.1,1.2 based on (Feng & Moreno Sanchez Briseno, 2021).

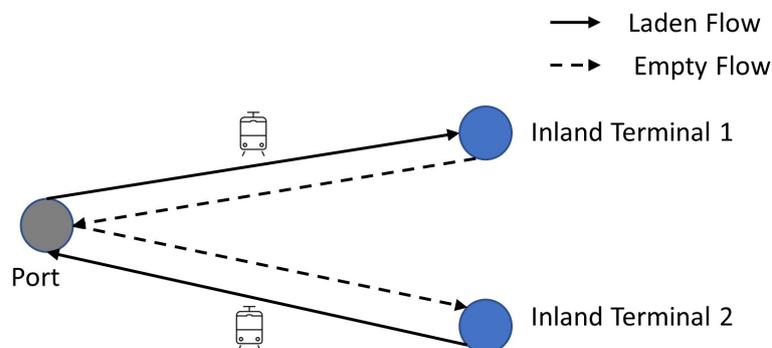


Figure 1.1: Flows without Triangulation

Maritime movements globally are responsible for 3% of all anthropogenic CO₂ emissions (Faber et al., 2021), 15% of nitric oxides (NO_x) and 4-9% of sulphur oxides (SO_x) (Eyring et al., 2010). Focusing on Europe, where the maritime sector is a major contributor to the economy of a country, emissions produced are lowest at 13,5% compared to 71% and 14,4% from road transport and aviation respectively (EEA & EMSA, 2021). The long-term goal set forth by the European Union is to reduce emissions from the transport sector by 60% by 2050 (Santén & Rogerson, 2018).

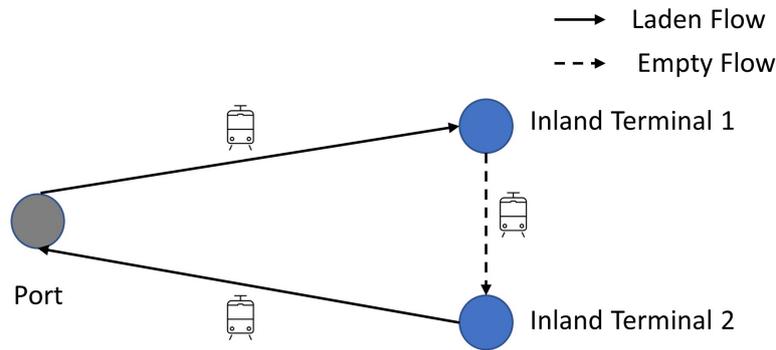


Figure 1.2: Flows with Triangulation

Sweden **imported** goods approximately worth **SEK 173,2 billion** and **exported** worth **SEK 172,1 billion** in 2022 (Statistics, 2022). The value resembles a 50-50 share from a monetary value perspective and does not represent the same for the number of containers. Sweden handled nearly 1,65 million TEUs in 2022 (Placek, 2022). Sweden imports several of its commodities. This in turn translates to having great waterways and maritime control across the country. Handling such quantities is no small feat which leads to substantial emissions from all operations. The transport of the containers between the port and inland terminals is mainly by rail. The use of rail between the Seaport and inland terminals reduces emissions as the source of energy for rail is from renewable sources (NTM, 2023). Rail is a greener alternative to road and air (EEA, 2021). The use of rail benefits the Seaport in handling larger volumes in a greener way.

Based on requests from shipping lines, along with the self-interest of the Seaport have led to the inception of this project led by Maritime at RISE (previously SSPA) in collaboration with Chalmers University of Technology and other organizations. A first study proposed a simulation to show the feasibility of implementing street turns in Eskilstuna, Sweden (Hao & Ibrahim, 2023). The study focused on the clients connected to the dry port in Eskilstuna. Similar studies have been conducted in other countries and be highly beneficial (Song & Carter, 2009; Meng & Wang, 2011; Furió et al., 2013; Kolar et al., 2018; Kuzmicz & Pesch, 2019; Gusah et al., 2019). This study will focus on implementing triangulation as a solution for ECR reduction from the Seaport's perspective and the inland terminals it is connected to. Thus, shedding light on the possibility of potential savings for all actors with the bigger and more complex model established across the country to optimize ECR.

This master thesis proposes a quantitative study to assess potential benefits and disclose the potential improvements, consequently reducing lead times and costs, traffic, energy consumption and emissions in Sweden's hinterland transport sector. The study from the Seaport's perspective will give an idea of potential savings for

other ports globally.

1.1 Purpose and Scope

The concept of re-utilization and triangulation is an initiative with significant potential for reducing empty container repositioning (ECR) and has already been implemented in the hinterlands of several other countries. A data analysis approach can provide valuable insights for decision-making regarding the feasibility of implementing these strategies. In Sweden, a case study is conducted from the perspective of a seaport, with a specific focus on container flows and interactions between the seaport and inland terminals. The objective of this thesis is to assess the demand for empty containers while minimizing container movements, presenting a supply and demand problem. Achieving economies of scale would result in greater benefits. The most suitable triangulation scenario would involve terminals that handle a large volume of containers and are located near each other, relative to the seaport. Another important parameter is the comparison of total container numbers before and after implementation, considering different models. Terminals meeting these conditions will be identified as suitable candidates for triangulation. Regarding re-utilization, inland terminals with substantial import activity will have greater potential for re-utilizing containers. This can be measured using the container imbalance factor (CIR).

The goals of the thesis are: to identify the best triangle that can be formed between inland terminals and to analyse the feasibility, cost savings, energy consumption and emissions reductions, and implications of implementing it. The best inland terminals where re-utilization is highest resulting in substantial savings. The current network will be compared with the optimized model based on time, and distance travelled by the empty containers to reduce the turnaround time and the total number of containers in the network and distance travelled.

1.2 Research Questions

To meet the scope of the project and fulfil the requirements, the following research questions have been formulated:

1. What cost savings can be achieved through the practice of triangulation at inland terminals? Additionally, which specific inland terminals are considered optimal choices for implementing triangulation?
2. What are the potential cost benefits associated with container re-utilization at individual inland terminals?
3. What are the benefits of implementing the strategies for optimizing the utilization of empty containers, and how does it impact seaports, shipping lines, and inland terminals?

1.3 Limitations

The study is based on the data for import and export containers between 1/1/2022 to 30/6/2022. The data is provided by the Seaport which is confidential and thus, actual data will be masked.

The potential solutions presented in this report are just a few of the alternatives which meet the requirements of the project to a great extent. The terminals dealing with certain container quantities are considered and others are removed from the study. Some shipping lines did not have a high activity level with the Seaport and thus were neglected from the study. Different types of containers are not considered in the analysis. 90% of containers are 40ft. eq containers based on information and statistics from the Seaport. Thus all containers are considered to be the same and not differentiated further. The model does not consider the potential of storage at inland terminals and how this can change the triangles and utilization of empty containers. We do not have details on the actual costs of container handling, and train schedule. The study does not cover the potential savings from a monetary aspect.

1.4 Thesis Outline

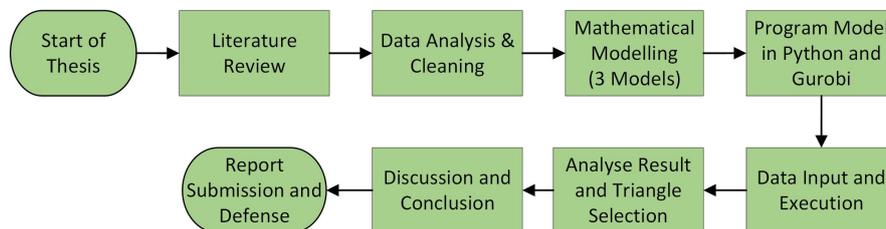


Figure 1.3: Thesis Flow Chart

This thesis is divided into six chapters. The introduction feeds into Chapter 2, containing the background information about empty container repositioning in the hinterland, triangulation and strategies developed for ECR reduction.

Chapter 3 presents the method of examining the Base Case to investigate improved models and feasibility, including the data description.

In Chapter 4, the results are presented for different test models with descriptive and prescriptive models. The results are analysed for the practicality of the solutions.

Chapter 5 leads to the discussion of the interaction between various actors involved and the implications of the proposed solutions on the actors.

1. Introduction

Finally, chapter 6 concludes the discussions, in addition to the general conclusions drawn from the study and the future scope and suggestions.

2

Literature Review

2.1 Key Actors for Inland ECR

The movement of loaded containers is a value addition but the movement of empty containers is an added expense with little to no value addition as discussed above. Several actors are working and interacting with containers in the supply chain. The shipping line is the owner of the containers and controls the long-distance segments of global freight distribution. The carrier (including freight forwarders and transport providers) enables the transport of containers to ensure it reaches their destination (Rodrigue, 2020). Different carriers use different modes of transport as per their core competencies, geographical market locations and area of focus. Carriers could be using rail, inland waterways, trucks and air transport. The importers and exporters are customers in this case and are generating the demand for containers (Rodrigue, 2020).

Shipping lines are responsible for owning more than 50% containers globally and are also tasked with ensuring availability at different locations as per demands. They are owners of vessels, operating them on trade routes (Tegbrant & Karlander, 2023). The focus is on high volumes and high vessel fill rates for each trip. The formation of strategic alliances is fueled by such goals with other shipping lines having common goals (Rodrigue, 2020). This also leads to cooptation, a situation when alliances are formed but everyone focuses on optimizing their profits (Lin, Huang, & Ng, 2017). The shipping lines have several customers and to ensure a high level of service, 80% of transport functions have been outsourced to freight forwarders (Balci, Caliskan, & Yuen, 2019). The underlying reason could be a lack of competency in inland logistics (Lun, Lai, & Cheng, 2010). To improve this shortcoming, shipping lines have started to focus on door-to-door deliveries (Tegbrant & Karlander, 2023). They also are sceptical about implementing new strategies without enough existing data. This feeds into analysing the desirability, viability and feasibility framework (Konietzko et al., 2020; Fitzsimmons & Douglas, 2011).

Inland carriers' different modes of transport focus on using the established network for enabling transport for the shipping lines and attracting more shipping lines, importers and exporters (Walter & Poist, 2003). Inland terminals are established by private operators with support from governing bodies (Wilmsmeier, Monios, & Lambert, 2011). Freight forwarders and transport providers enable transport from

inland terminals to importers and exporters. They have the resources and knowledge of local geographical layout enabling themselves to attract customers (Lai, Xue, & Hu, 2019). Furthermore, several services are also provided by freight forwarders to ensure customer retention and attract more customers. Customs clearance, warehousing and repackaging are some common ones. Collaboration with importers and exporters also ensures that they are up-to-date with different demands (Tegbrant & Karlander, 2023; Saeed, 2013).

Playing the role of end consumers, importers and exporters are driving the change in the industry (Rodrigue, 2010). The profits for the other actors in the chain are directly linked to the customers, inadvertently putting customer satisfaction as the priority which feeds into customer retention and long-term relations and profits (Raza, Woxenius, Vural, & Lind, 2023). However, their role in ECR is unintentional, but has a big factor in leading to an increase or decrease in ECR (Johansson & Willisicroft, 2022).

The extra costs incurred due to ECR is generally borne by the carrier and the shipping lines. On average 20-30% of the total containers on vessels are empty (Kuzmicz & Pesch, 2019). Approximately 50% of containers are transported empty in the hinterland (Lee & Meng, 2014). That is a significant number of containers that are being underutilized. The customers return the container as soon as they are stripped or loaded to save costs (Jula et al., 2006). Back in 2009, the estimated cost of ECR was around \$15 billion which accounts for almost 27% of the total operating costs (Song & Carter, 2009). When sent back, the containers must be stored and/or transported empty, reducing percentage utilization. In 2009, the potential of optimizing ECR by 10% would have resulted in 30-50% profitability for the industry (Theofanis & Boile, 2009).

2.2 Factors Contributing to ECR

Trade imbalance is defined as the ratio of net trade by gross trade, where exports do not match imports and vice versa (Greenaway & Milner, 1981). This can be extended to imbalances between continents and imbalances within a country. The major contributor to ECR is trade imbalance on a global scale (Song & Carter, 2009). The difference in the share of imports and exports is also a contributing factor for ECR in a country or location. There are several other factors affecting ECR like dynamic behaviour, uncertainty, technological aspects, withholding information/lack of communication, actor's operational strategies and planning (Song & Carter, 2009; Basarici & Satir, 2019).

- Dynamic behaviour refers to the change in the demands at different geographical locations at any given time. Though the actual demand can be predicted to a larger extent using historical data. The demand for empty containers and the arrival of loaded containers will also vary due to imbalances (Basarici & Satir, 2019). Storing and accumulating empty containers in advance might help reduce the dynamism of the network.

Holiday seasons like Christmas and Chinese New Year, trigger greater demand at a certain period of the year in a particular location. (Greenaway & Milner, 1981; Song & Carter, 2009).

- Uncertainty in aspects of customer demands, consolidation, handling, customs, discharges, disruptions caused due to weather, condition of containers, delays due to human errors, and construction work at port leading to a change in schedules for vessels will lead to deviation in the movements of containers (Song & Carter, 2009; Borg, 2021; Basarici & Satir, 2019). According to Song and Carter (2009), demand uncertainty is the most common phenomenon. For example, the delays and disruptions due to Evergreen blocking the Suez Canal combined with the sudden surge in demand in the later stage of the pandemic are still witnessed today by the industry (Ramos et al., 2021; Kuźmicz, 2022).
- Technological aspects related to the types of containers that are used. Containers are varying in dimensions and functionality. Furthermore, the capacity and infrastructure of ports and terminals also play a role in increasing/reducing ECR (Song & Carter, 2009).
- Withholding information/lack of communication arises due to reasons related to trust in the network and the advantage an actor possesses aided by the information. Information is viewed as a resource and relies on the resource-based view (RBV) and the value, rarity, imitability and organization (VRIO) framework actors try to withhold information (Franc & Van der Horst, 2010). Forecasting and data analytics combined with open communications can go a long way in reducing turnaround time and the number of containers in the network (Heilig, Stahlbock, & Voß, 2020).
- Actors' operation strategies and planning are tools for them to reduce costs and are highly based on actual empty container movements. Though these are also sometimes the reason for specific movements (Song & Carter, 2009; Basarici & Satir, 2019). For example, a rail operator might have specific requirements for consolidation and a minimum number of containers to run the trains. This is planned to aid them to save costs, however, might increase/decrease the turnaround time (Ülkü, 2012).

2.3 Analytical Strategies for ECR Reduction

The inefficiencies in the hinterland due to ECR can be categorized as a generic supply and demand problem. Such problems are modelled and solved as transport problems having constraints such as multiple destinations, time periods, quantities and storage. The transportation problem is a popular type of linear program that has been used in numerous fields (Chanas & Kuchta, 1996). It is modelled as a network of nodes and paths that can be used to simulate flows of goods to form a virtual network similar to that of the actual one (Patrick, 2022). Based on the

results of the model, the finer details related to specific destinations, commodities, and periods can be focused on. The dynamic nature of supply and demand can be modelled through this method (Chanas & Kuchta, 1996). The transport problems fall under the category of linear programming and have parameters, constraints, variables and an objective function depending on the case (Chanas & Kuchta, 1996; Patrick, 2022). The complex versions of the transport problems consider multi-echelon, multi-product, multi-modal and multi-period and may be deterministic or stochastic depending on the requirements of the scenario (De et al., 2020). For more examples kindly refer to Table 2 in Kuzmicz and Pesch (2019) and Table 3.2 in Hao and Ibrahim (2023).

Increasing global demand resulting in higher movements calls for improvements in efficiency and utilization of available resources. One of the aspects to improve is to reduce ECR movements and reduce strain on hinterland supply chains and networks. Different methods ranging from qualitative studies to fold-able containers to data analytics have been implemented and tested at various levels and by different actors in the supply chain. The involvement of dry ports plays a vital role in ECR movements as they act as a centre for carrying out several terminal functions like consolidation, transshipment, storage, cross-docking, sorting, etc (Roso & Lumsden, 2010; Hao & Ibrahim, 2023). In 2019, the number of dry ports was 230, 400 and 100 in Europe, the USA and Asia respectively (Luo & Chang, 2019). The number of dry ports within Sweden in 2022 was 12 (Khaslavskaya & Roso, 2022).

Numerous studies have been conducted to check the potential for reducing ECR within Europe. While some focused on the hinterland and some on the global scale, they analysed different methods. Furió et al. (2013) studies the optimization of ECR using street turns in Valencia, Spain. Their study focuses on the cost of operations with and without street turns. The focus was from a single-port perspective. The integer programming (IP) program considers the time which increases the complexity due to its dynamism (Furió et al., 2013). The scope of improvement in large ports using street turns was also studied in Central and Eastern Europe hinterland. The study was a qualitative study discussing the strategies of carriers and their unwillingness to revise them. The results also reveal the global orientation of ECR instead of local or regional orientation (Kolar et al., 2018).

Building on the study, Kuzmicz and Pesch (2019) approaches ECR problems with a focus on Eurasian intermodal transportation. The area of focus is the Chinese One Belt One Road initiative. The model is a mixed integer linear program with stochastic demand and uncertain future demands. Their approach falls under the category of dynamic programming (Kuzmicz & Pesch, 2019). Moving further away from Europe, Gusah et al. (2019) carried out a systematic analysis for empty container analysis in Melbourne, Australia. The study is categorized as agent-based modelling with simulation. In the United States, at Los Angeles and Long Beach, Jula et al. (2006) studied the dynamic use of empty containers based

on a two-phase optimization problem. Eventually concluding that the reduction in ECR will save costs, but also reduce congestion, noise and emissions in the local area around the port and boost the economy as a result (Jula et al., 2006). In New York and New Jersey, a study on the location of inland terminals/depots wrt. the port shows that the location and demand around there plays a major role in ECR (Boile et al., 2008).

A generalized approach using quantitative methods along with mathematical modelling provides insights for better decision-making to implement strategies and construct policies for ECR reduction. An approach of flow balancing considering multiple shipping lines but without considering the dynamic characteristics of container shipping is studied by Song and Carter (2009). The relation between internal coordination and external container sharing is modelled as a mathematical problem in a macro environment (Song & Carter, 2009). Moving ahead, Meng and Wang (2011), examined a hub and spoke (H&S) system combined with a multi-port-calling (MPC) shipping line(port calling sequence). The study focused only on a single shipping organization and their operations. The optimization model used a CPLEX solver and the result reflected large cost savings achieved by combining H&S and MPC(Meng & Wang, 2011).

2.4 Research and Management Strategies for ECR Reduction

The examples above are from an analytical perspective to check the potentiality of methods to reduce ECR. However, quantitative checks need to be based on some strategies and theories which are a more qualitative approach. Some methods that have been analysed are based on policy-making, decision-making, collaborations, communication, openness to information sharing and trust.

Braekers, Janssens, and Caris (2011) mention the different levels of decision-making leading to empty container movements. The strategic level deals with the network design while the tactical level deals with the services in the network design. Further down in the value stream, the operational level is linked to the container allocations and routing problems (Braekers et al., 2011). While the different levels are a demarcation of different functions, factors like trust, risks and commitment also play a role in shaping the supply chains.

"Trust is most elusive but also the most sought after" (anonymous) (Sahay, 2003). For collaborations between actors having similar market value and size, trust and risks are two factors that are most commonly a barrier forcing organizations to act in an individualistic manner. Vilko, Ritala, and Hallikas (2019) has developed a model to show how the size of an organization, visibility and control play their part in an alliance/collaboration. Similar models developed by Kwon and Suh (2005); Ireland and Webb (2007); Dekker, Sakaguchi, and Kawai (2013) portray the detailed path to study trust and risk in large multi-modal supply chains and

organizations. Strategic alliances have been analysed and several barriers have been identified that show that alliances may not be the best solution always (Panayides & Wiedmer, 2011). The contracts and policies are only a part of the alliances but the operational synergies also play an important part (Pierre & du Tertre, 2000).

Container leasing merged with internet-based systems will drastically reduce ECR if planned and executed properly (Chang et al., 2008; Braekers et al., 2011). Container leasing focuses on the shipping lines leasing out containers instead of owning them permanently. Containers could be leased for long-term or short-term depending on the needs of the customers (Hao & Ibrahim, 2023; Braekers et al., 2011). Internet-based systems using continuous tracking and information sharing make it easier for all actors to know their containers. Theofanis and Boile (2009) mentions that the success of these methods relies heavily on the willingness of firms to share information, which eventually returns to the basic need for trust.

Kuzmicz and Pesch (2019) elaborate on the possibility of container substitution and sharing. For satisfying the demand for 2 empty 20-foot containers, a single 40-foot container could be used instead. The substitution depends on several factors and might not work in multi-commodity scenarios for instance. If the capacity, destination and other factors overlap then container substitution can have a beneficial impact (Chang et al., 2008; Kuzmicz & Pesch, 2019). Increasing the chances of substitution container sharing will also increase the savings. However, sharing of containers has its own set of problems which are related to container types, location mismatch, import-export time mismatch, etc (Chang et al., 2008; Hellekant & Rudal, 2021).

Foldable containers are one way to overcome barriers and save space. Six folded containers stacked upon one another will occupy the same space as that of one container (Konings & Thijs, 2001). The upfront purchasing cost of foldable containers is high, maintenance is high and lifespan is lower compared to generic containers. Research shows even after considering these factors, usage of fold-able containers can bring about 50-60% savings in cost (Goh & Lee, 2016). Another research estimates a savings of 75% in storage space with the use of foldable containers (Moon, Do Ngoc, & Konings, 2013).

Connectainers is a new design for a 20-foot container which can be joined with another 20-foot container to form a 40-foot container (Connectainer, 2018). The company manufacturing the connectainers also claim the containers to be the same dimensions as the standard containers and are watertight and resistant. Furthermore, they are multi-modal transport compatible. The connecting and disconnecting of such containers can take 30 minutes by skilled workers (Connectainer, 2018; Kuzmicz & Pesch, 2019).

3

Methodology

3.1 Case Study: Seaport

The Seaport plays a vital role in the imports and exports in Sweden and Scandinavia, as mentioned in Section.1. The data received from the Seaport contains the details of individual container movements. For modelling, we use the data related to the **origin, destination, line operator, and date**. The data is further divided into sub-categories. The type of container is based on import or export type. The owner of the container is a different shipping line. The different rail operators handling each container and the unique container ID.

The total supply and demand are the same in all cases and the inland terminals are the same as well. The total demand for empty export is ≈ 27000 containers. The total supply of laden import containers is ≈ 28000 containers.

The current network under operation functions with flows originating from the Seaport and terminating at the Seaport. The import containers are loaded and brought into Sweden from other countries. These are then loaded onto trains and sent to inland terminals for importers to collect and strip them. Once the containers are stripped they are sent back to the port empty from the inland terminals. Upon demand from exporters, empty containers are shipped from the port to the exporters, then filled with goods and sent back to the port for export. This movement of empty containers results in ECR (Song & Carter, 2009). The port stores these empty containers unless exporters request for them or shipping lines take them back to be used in another location, which also falls under ECR. At present, the inland terminals do not store empty containers. The rail operators currently shuttle between the Seaport and the inland terminals. There are no trains scheduled by the shipping lines to run between the inland terminals. Thus, triangulation is not possible in the current network. However, the rail network is present and other trains are operating on those routes. The turn-around time at present is around 5 days for importers and 7 days for exporters.

However, it can vary depending on the type of contract that a customer has with the shipping line. There are a few instances when a container is reused instead of having to send a new container with a new ID to meet the demand. However, such instances are very rare and are not pre-planned as a solution to reduce ECR but rather a coincidence resulting in some savings. The container flows in the network

are distinguished by the container activity, the state of the container and the purpose of the container. There are four types of container flows:

1. Laden Import Containers
2. Empty Import Containers
3. Empty Export Containers
4. Laden Export Containers

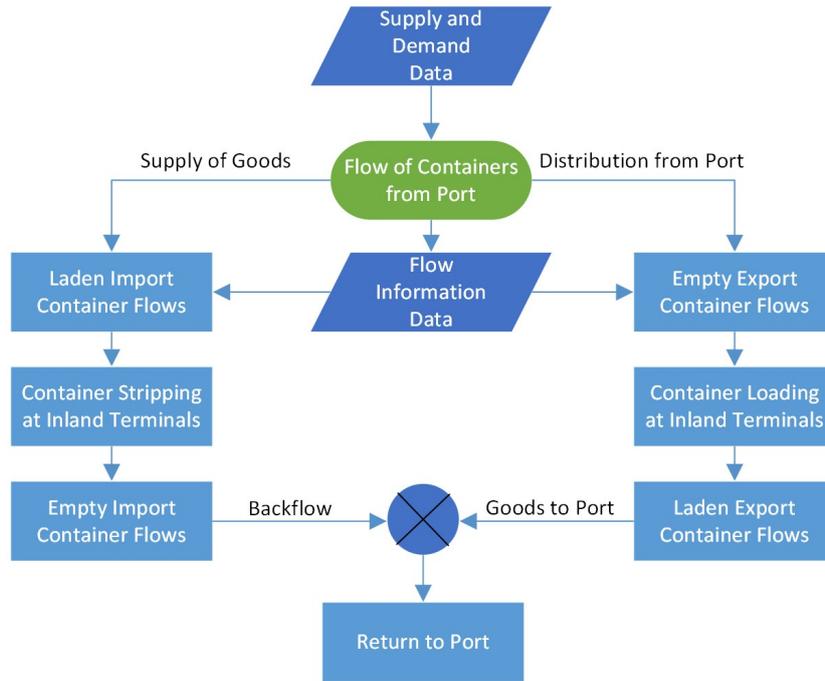


Figure 3.1: Process Flow Chart for Base Case

| Container Flow Type Based on Activity and State | Function | | |
|---|----------------------------|--------------------------|--------------------------|
| | Base Case | Utilization Strategies | |
| | | Re-utilize | ECR |
| Laden Import | Supply Goods | Supply Goods | Supply Goods |
| Empty Import | Backflow | Re-utilize | Triangulate |
| Laden Export | Goods to Port | Goods to Port | Goods to Port |
| Empty Export | Supply of Empty Containers | Supplementary Containers | Supplementary Containers |

Table 3.1: Functions of Different Types of Container Flows

The laden import containers carry the import goods to the receiver. Backflow can be defined as the return flow of empty import containers from inland terminals to the Seaport. The empty import containers in the base case contribute entirely to the backflow. If the strategies are implemented, the empty import containers can either be re-utilized at the inland terminal or transported to other inland terminals

to meet the demand for empty export containers(triangulation). If both strategies are not possible, it is then allocated to backflow. The laden export containers are responsible for the transport of goods from the shippers to the Seaport. The empty export containers are supplemented by the Seaport in the event of a shortage when the demand is not fulfilled by the implementation of utilization strategies.

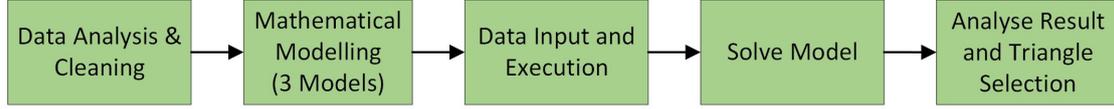


Figure 3.2: Methodology Flow Chart

The approach towards optimization of the network through triangulation is promoted by the existing literature and simulations carried out by others. The quantitative analysis using operational research tools will further reinforce the findings. This will help broaden the transferability, improve quality and help with validity. In this case study, from the perspective of the Seaport, the focus is on flows originating and terminating at the Seaport. With similar ports across Sweden, a similar model could be used to optimize flows from the perspectives of other ports.

The case study of the Seaport is a transportation problem which can be further categorized as a multi-period, single-commodity supply and demand problem. A transport problem deals with minimizing the cost function or maximising the profit for the entire network as modelled where the objective function is decided by the shareholders. The approach used is to model it as a mixed-integer linear program (MILP). The mathematical approach ensures that the quantitative half of the analysis supports the qualitative half.

The Base Case represents the current modus operandi. The data on current operations are used to calculate the total cost, which will be used for comparison with the cost from the proposed models. The Seaport is the only node in the network supplying containers. There is no triangulation and re-utilization of containers.

3.2 Inland Network Model

The mathematical model used for optimization for all scenarios is elaborated below. The total cost of operations is given by Eq 3.1.

$$\begin{aligned}
 \text{Min } Z &= \sum_{t \in T} \sum_{k \in SL} \sum_{(i,j) \in N} (X_{-ee}^t_{i,j,k} + X_{-ie}^t_{i,j,k}) \cdot C_{i,j} + \\
 &\quad \sum_{t \in T} \sum_{k \in SL} \sum_{(i,j) \in N} (X_{-if}^t_{i,j,k} + X_{-ef}^t_{i,j,k}) \cdot C_{i,j} \\
 Z &= \sum_{t \in T} \sum_{k \in SL} \sum_{(i,j) \in N} (X_{-e}^t_{i,j,k} \cdot C_{i,j}) + \sum_{t \in T} \sum_{k \in SL} \sum_{(i,j) \in N} (X_{-f}^t_{i,j,k} \cdot C_{i,j})
 \end{aligned} \tag{3.1}$$

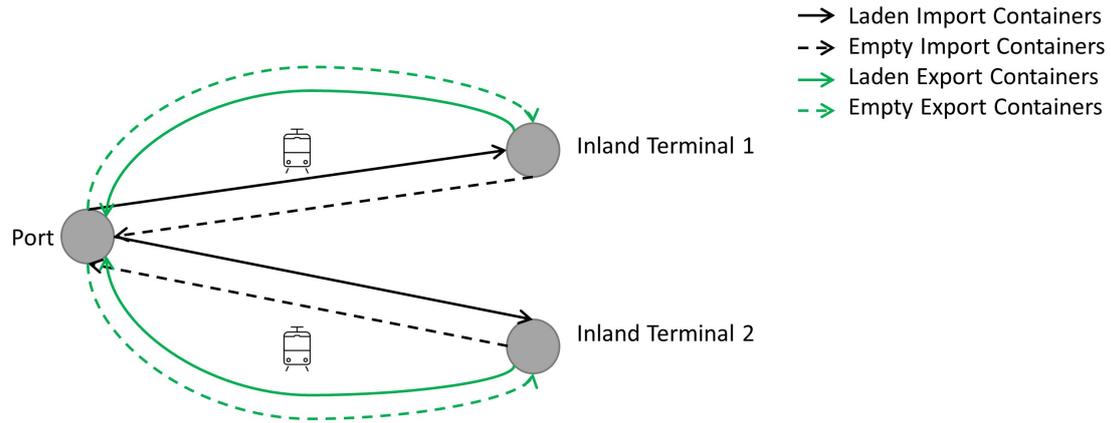


Figure 3.3: Representation of Flows in the Base Case

Subject to:

$$\sum_{ij} \delta_{(ij)} \leq 1$$

$$\text{if } \delta_{(ij)} = 1 \implies X_{(ij)}^t \geq 0$$

$$\text{if } \delta_{(ij)} = 0 \implies X_{(ij)}^t = 0$$
(3.2)

$$\sum_{k \in SL} S_{-}e_{(P,j,k)}^t + \sum_{k \in SL} \sum_{i \in IT} (X_{-}e_{(ijk)}^t - X_{-}e_{(jik)}^t) + \sum_{k \in SL} X_{-}e_{(P,j,k)}^t = \sum_{k \in SL} D_{-}e_{(P,j,k)}^t$$

$$\forall i, j \in IT, \text{ if } i \neq j, k \in SL, t \in T$$
(3.3)

$$\sum_{k \in SL} X_{-}e_{(ijk)}^t \leq \sum_{k \in SL} S_{-}e_{(P,i,k)}^t \quad \forall i, j \in IT, \text{ if } i \neq j, k \in SL, t \in T$$
(3.4)

$$\sum_{k \in SL} X_{-}f_{(j,P,k)}^{(t+1)} = \sum_{k \in SL} D_{-}e_{(i,j,k)}^t \quad \forall i, j \in IT, k \in SL, t \in T$$
(3.5)

The notations used in the mathematical model are elaborated below:

3.2.1 Sets and Indices

$N \in \text{Nodes} = \{\text{Seaport, Terminal 1, Terminal 2, Terminal 3, Terminal 4, Terminal 5, Terminal 6, Terminal 7, Terminal 8, Terminal 9, Terminal 10, Terminal 11}\}$ - All nodes in the network.

$IT \subset N - \{P\}$ Inland Terminals = All nodes except Seaport.

$SL \in \text{Shipping Line} = \{\text{SL1, SL2 ... SL10}\}$ - All different owners of containers.

Note: For the Alliance Collaboration scenario, certain shipping lines in an alliance are modelled differently. For example $SL1=SL2=SL5$.

$t \in T = \{02/01/2022 \dots 30/06/2022\}$ - Range of dates.

$i, j \in N$: Indices of nodes (N).

$k \in SL$: Index of the shipping line.

3.2.2 Parameters

Parameters are numerical constants which help define the attributes of a system. It is used to set up the scenarios for the model.

$S_e^t_{(P,j,k)}$: Supply of empty export container at node $Seaport \in N$, $i \in IT$ and $k \in SL$.

$D_e^t_{(P,j,k)}$: Demand of empty export container at node $P \in N$, $i \in IT$ and $k \in SL$.

$C_{(i,j)}$: Cost of movement of containers between nodes $(i,j) \in N$. Unit in kilometres.
Note: Notice that the cost from node i to node j is the same as the cost from node j to node i i.e. $C_{(i,j)} = C_{(j,i)}$.

$X_ef^t_{(i,j,k)} \in \mathbb{R}^+$: Flow of laden export containers from node i to node j for $k \in SL$.

$X_if^t_{(i,j,k)} \in \mathbb{R}^+$: Flow of laden import containers from node i to node j for $k \in SL$.

$\delta^t_{(i,j)}$: Parameter for having at most one active supply arc between inland terminals $i, j \in IT$ for $t \in T$.

3.2.3 Variables

All variables are non-negative integers.

$X_ee^t_{(i,j,k)} \in \mathbb{R}^+$: Flow of empty export containers from node i to node j for $k \in SL$.

$X_ie^t_{(i,j,k)} \in \mathbb{R}^+$: Flow of empty import containers from node i to node j for $k \in SL$.

The objective function, Eq 3.1 includes two parts. The first part deals with the total cost of empty container movements. The second with the total cost of laden container movement. The constraints are the conditions that delimit the feasible set for the decision variables. The constraints are explained further below elaborating on their function in the model.

Binary Flow Constraint: Eq 3.2 is modelled to restrict incoming flows into an inland terminal. This ensures that an inland terminal can receive empty containers from only one other inland terminal. It is structured so, to create a one-to-one relationship between inland terminals to facilitate triangulation.

Flow Constraint: Eq 3.3 is responsible for ensuring that the demand is met for every time instance at each terminal. The equation includes all types of possible container providers, i.e., flows from the Seaport, containers available for re-utilization and through triangulation.

Flow Conservation Flow: The flow conservation for each inland terminal is denoted by Eq 3.4. The flow conservation focuses on the containers that are received through the supply flow and are the only ones that can be used for re-utilization or triangulation.

Laden Container Flows: Eq 3.5 represents the flow of laden containers which are constant throughout all the scenarios. The laden import containers are sent from the Seaport to the inland terminals and the laden export are sent from the inland terminals to the Seaport.

3.3 Scenario Description

Building further on the Base Case and incorporating the utilization strategies, some assumptions are necessary and are listed below. These assumptions are used for modelling the different scenarios.

1. The Seaport has infinite supply and storage capacity. It is always available to support any inland terminal when there is a demand which is not fulfilled by either of the utilization strategies.
2. All containers are considered to be the same size i.e., 40ft. containers (2 TEUs).
3. Trains are available and running between inland terminals.
4. The laden import containers are stripped in a day and available the next day for use at the inland terminal. They are termed as "*supply of empty export containers*" during modelling.
5. The empty export containers are filled with goods in a day and available the next day for return transport to the Seaport.

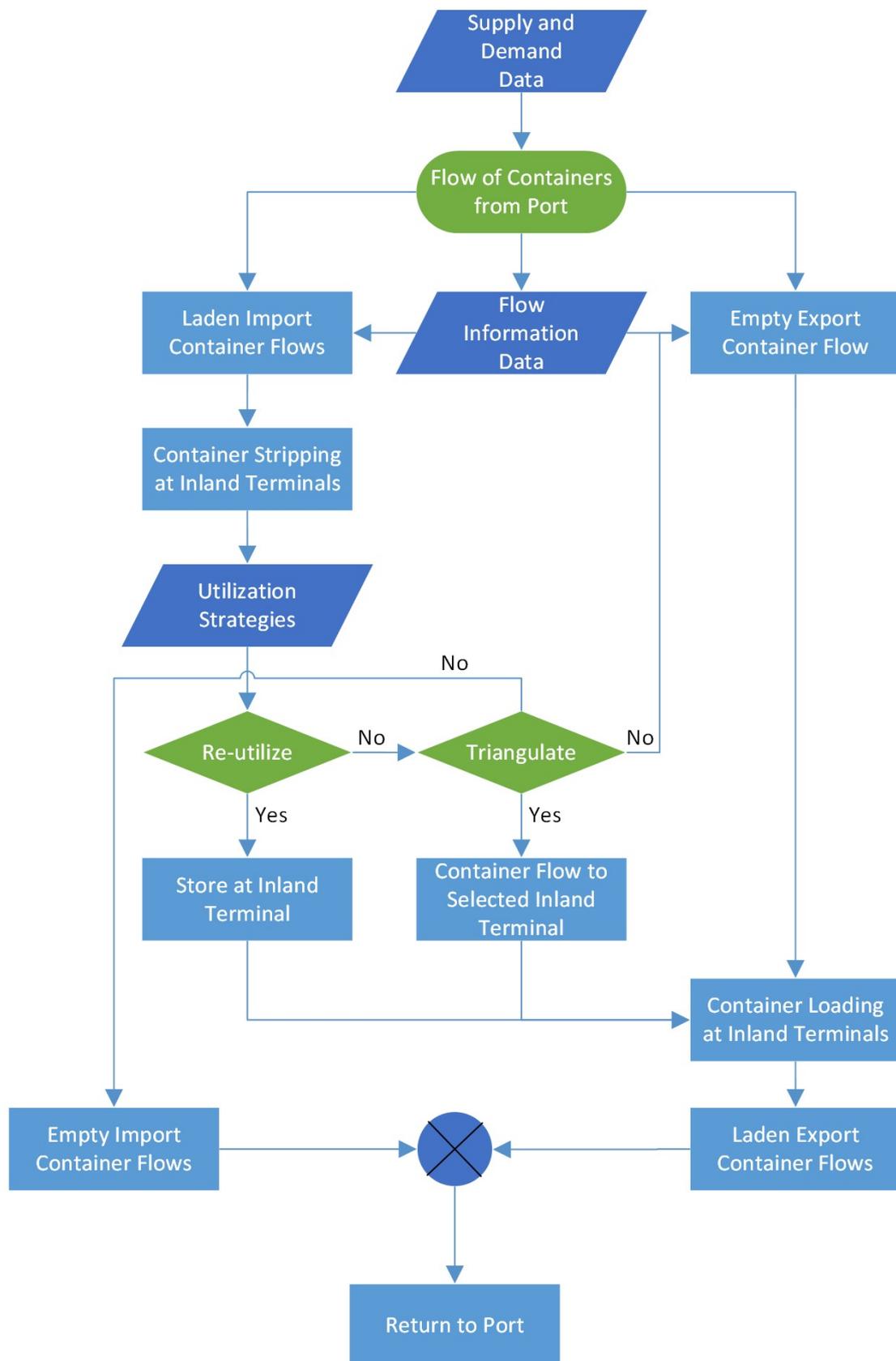


Figure 3.4: Process Flow Chart with Utilization Strategies

Based on the data and assumptions, three different scenarios are formulated and analysed. The costs for transporting all laden containers will remain the same in all cases. Hence, the objective functions in the proposed models do not have a term focusing on the flows of laden containers. Rather, we focus just on the variable associated with empty containers.

1. Complete Collaboration
2. No Collaboration
3. Alliance Collaboration

3.3.1 Complete Collaboration Scenario

In this scenario, the model is a triangulation model with an assumption that the containers are common for all shipping lines. This allows any container to be used by any customer at any time by surpassing the need for container matching. The remaining containers at the end of each day are returned to the Seaport. The idea is to reduce the constraints on the model and thus resulting in lower costs. The SL set does not apply to this scenario.

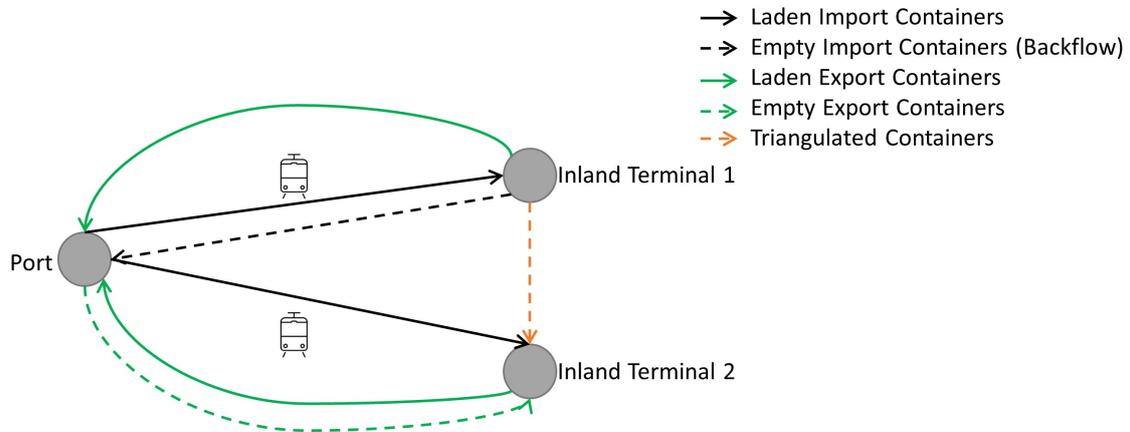


Figure 3.5: Representation of Flows in the Base Case

3.3.2 No Collaboration and Alliance Collaboration Scenario

The containers are differentiated based on the shipping line and thus container matching is a constraint on the system. Simply put, a container owned by SL1 cannot be used by a customer of SL2. The SL set is applicable here and each shipping line is individually used. This scenario is also constrained by other flow constraints. The Alliance Collaboration scenario is similar to the No Collaboration scenario but the number of shipping lines involved is reduced as shipping line alliances are formed, under which the SLs in an alliance can use each other's containers. The

SL set is based on the alliances. The alliances are based on the existing alliances in the maritime industry. The three major alliances operate almost 80% of the flows (Zheng & Luo, 2021).

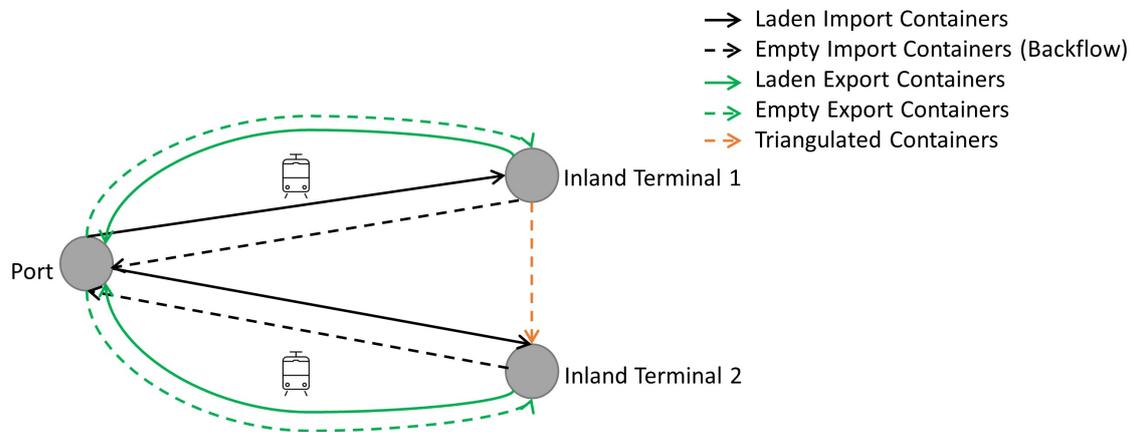


Figure 3.6: Representation of Flows in the No Collaboration Scenario and the Alliance Collaboration Scenario

3.4 Performance Metrics and Indicators

These metrics are measured as an output from the optimization model. They help with comparisons and investigate further into the scenarios. The indicators are also dependent on the data related to distances, quantities and flows.

- **Container*km:** Container-kilometer is directly proportional to the number of containers as it is a product of the distance and the number of containers in a link. This is also the output obtained as a result of the optimization model. As the result is simply a value calculated by multiplying a constant with a variable. The constant is the distance between two nodes and the variable is the number of containers in flow between the said two nodes. Hence, the reduction in the number of containers and the reduction in container kilometres means the same. The percentage savings will be the same for both values. However, the monetary savings would significantly vary.
- **Energy Consumption:** Energy consumption is another criterion that acts as a deciding factor for triangle selection. Higher the savings in energy consumption the better the triangle. The procedure for energy calculations is explained further in this chapter.
- **Triangle Distance Factor, Q :** The triangle distance factor is the ratio of the distance between two inland terminals to the sum of the distances between

the Seaport and each inland terminal. The energy and emission savings are inversely proportional to the factor. The lower the factor, the higher the potential for savings and vice versa. This is true only if decision-making is based on the triangle distance factor. Since the number of containers directly affects the energy values, the proportionality does not hold always.

$$\text{Savings} \propto \frac{1}{Q}$$

Q is formulated as:

$$Q = \frac{dt}{dp_1 + dp_2} \quad (3.6)$$

Where,

dt = Distance between inland terminals, in kilometres.

dp₁ = Distance between the Seaport and inland terminal 1, in kilometres.

dp₂ = Distance between the Seaport and inland terminal 2, in kilometres.

- **Container Imbalance Ratio (CIR):** CIR is used as an indicator to depict the imbalance in import and export containers at each terminal. It measures the proportion of containers imported versus exported. An inland terminal will have more imports as compared to exports if CIR is positive. If the CIR is negative, there are more exports as compared to imports. A high positive magnitude will indicate significantly higher imports compared to exports. A low negative magnitude will indicate higher exports compared to imports. Eq 3.7 is the formula for CIR.

$$CIR = \frac{(\text{Total Import Containers} - \text{Total Export Containers})}{(\text{Total Import Containers} + \text{Total Export Containers})} \quad (3.7)$$

- **Triangle Imbalance Ratio (TIR):** When triangles are selected, a TIR value is calculated for each triangle to check the imbalance. TIR is based on CIR but calculated for two terminals involved in the triangle. The import and export containers are aggregated before using them in Eq 3.7. The TIR will provide insight into whether the triangle is import-dominated or export-dominated. If a triangle is import dominated there are higher potential for savings. If a triangle is export-dominated the potential savings are reduced. This relation might not hold true if there is a significant imbalance between the individual terminals within a triangle. For example, if terminal A has very high exports and terminal B has low imports, the potential for savings is reduced. In an opposite scenario where terminal A has low exports and terminal B has high imports, the savings are higher as more containers are available for re-utilization and triangulation. If TIR is zero, it may not provide any significant insights about how the triangle might perform but shows that there is no imbalance. In such a case, other parameters and indicators will have to be studied to analyse the triangle. TIR is one of the many indicators supporting decision-making.

3.4.1 Criteria for Triangle Selection

The triangles are selected based on criteria put together with the results of the optimization model. The performance metrics and indicators are dependent on the number of containers that are transported in each flow. The container*km, energy consumption, emissions, CIR and TIR are also directly proportional to the number of containers. However, the triangle distance factor is calculated based on the distances between two nodes in the network and is not affected by the number of containers.

- **Number of Containers in Flows:** The commodity in transport is a shipping container. Each additional container in the network requires space and adds a cost. An important factor to consider while selecting triangles post-optimization is the reduction in the number of containers to satisfy the same demand under different conditions. The goal is also to reduce the number of containers that are added to the flow from the Seaport. More containers that can be re-utilized or triangulated reduce the number of new containers entering the system to fulfil the required demand.

3.5 Energy Consumption and Emissions

The use of rail as transport saves time, emissions and costs. To transport containers across the country, rail is the best choice, given the flexibility and access to a wider already existing rail network at a significantly reduced cost and lower emissions. Trains help increase consolidation as well. The following method is used to calculate the energy consumption and the emissions due to train movements to satisfy the demand in the case study.

The trains in Sweden are electrified and run on electricity generated from a mix of hydro and wind energy. The average train used by the Seaport in Sweden is 630m long and carries 40 containers, as per information from NTM (2023). The energy consumption for an electric train using electricity generated from a mix of wind and hydro is estimated at 0.08 kWh/tonne-km from a well-to-wheel scenario. The estimation includes a correction factor for topography as well. It is calculated based on the total weight the train pulls when loaded and empty, the fill rate and the extra distance travels when empty. Similarly, the value for emissions is estimated at 0.9 g/tonne-km of CO_{2e} (NTM, 2023). Based on assumptions, all containers are 40-foot containers and the average weights for empty and loaded containers are selected from Table 1 in Yildiz (2019). For calculating the total energy consumption and emissions for all types of flows, it is necessary to include the weights of empty and loaded containers. When focusing only on empty container flows, 3.75 tonnes is considered for calculations (Yildiz, 2019).

The calculation procedure for energy consumption and emissions is presented below:

D = Distance travelled by containers, in *container-km*.

E_c = Total energy consumption, in *kWh*.

q = Energy consumed for 1 tonne-km, in kWh/tonne-km.

E_m = Total emissions, in *tonnes CO₂e*.

e = Emission generated for 1 tonne-km, in g/tonne-km.

W = Weight of a 40-foot container.

W_t = 3.75 tonnes - Average tare weight of a 40-foot container.

W_p = 26.7 tonnes - Average net weight (payload + container weight).

W_m = 30.4 tonnes - Average maximum weight when fully loaded.

E_{ct} = Energy consumption of an empty container.

E_{cp} = Energy consumption of a loaded container at an average weight.

E_{cm} = Energy consumption of a fully loaded container at maximum weight.

E_{mt} = Emissions generated from the transport of an empty container.

E_{mp} = Emissions generated from the transport of a loaded container.

E_{mm} = Emissions generated from the transport of a fully loaded container.

Total energy consumption is denoted by:

$$\begin{aligned} E_c &= D \cdot q \cdot (W_t + W_p + W_m) \\ E_c &= E_{ct} + E_{cp} + E_{cm} \end{aligned} \quad (3.8)$$

Total emission is denoted by:

$$\begin{aligned} E_m &= D \cdot e \cdot (W_t + W_p + W_m) \\ E_m &= E_{mt} + E_{mp} + E_{mm} \end{aligned} \quad (3.9)$$

3.6 Triangle Selection Process

The selection of triangles is based on analysing the results in three steps. The first step deals with investigating the output from the optimization model. The total output file is exported to Excel and the number of containers in each flow is calculated. The top 10 triangles based only on the number of containers are shortlisted as potential candidates. This gives an overview of all potential triangles that can be implemented in the entire network based only on the criterion. Upon selection of all potential triangulation candidates, the optimization model is executed again in the second step. However, this time the inland terminals in a triangle are isolated and optimized as a smaller model consisting of only the Seaport and the two inland terminals. This presents the maximum savings possible in a triangle without any interference or overlap with other triangles. It also eliminates the chances of cannibalization of containers. When individual triangles are analysed, the focus is only the flows within the triangle and the rest of the network is not considered at all for analysis. The savings are calculated within the triangle and compared to the Base Case. Moving further, the performance metrics and indicators for each triangle are calculated. The third step is a deep dive into performance metrics and indicators

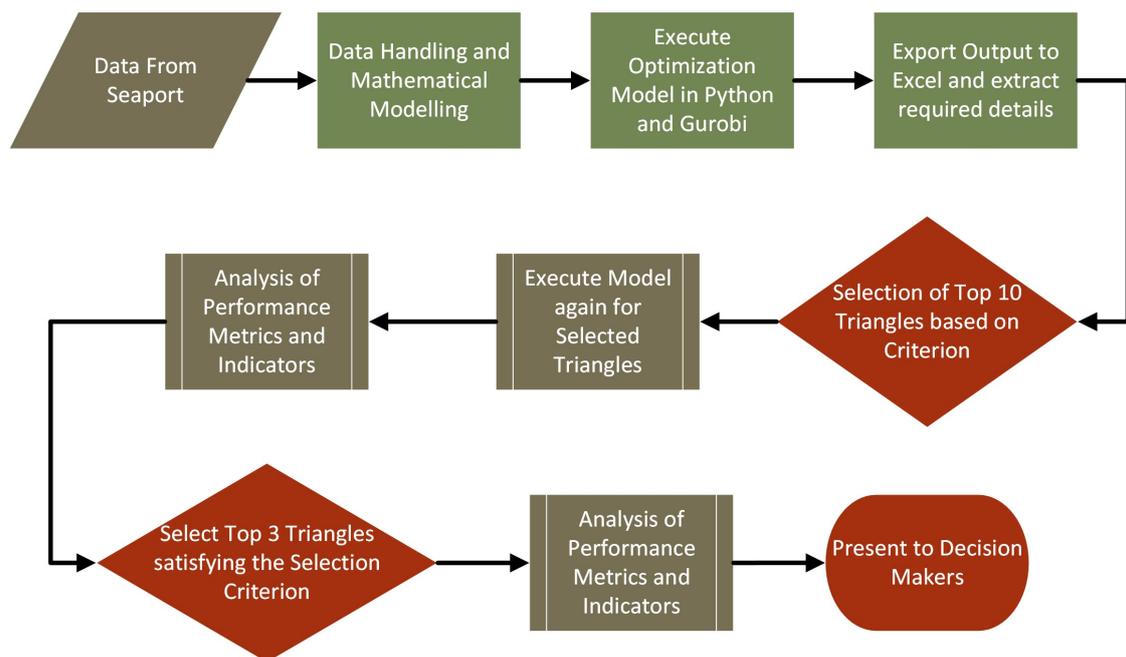


Figure 3.7: Triangle Selection Process Flow Chart

for each triangle to select the top 3 triangles that are most beneficial to implement from a holistic view. However, this method is only a quantitative approach helping prioritize the best triangles in the network. Moving ahead the stakeholders will have the option of ranking the different criteria as per their requirements and then comparing the triangles to finalize on one or a few that can be implemented.

4

Results and Analysis

4.1 Case Study Descriptive Analysis

The results from the different scenarios are analyzed and compared with each other to have a better understanding of the optimization models. The triangles and terminals are selected which meet the requirements of the utilization strategies. The total number of containers are same in all scenarios. Table.4.1 shows the total containers in each category.

| Container Type | Quantity |
|----------------|----------------|
| Import | ≈28000 |
| Export | ≈27000 |
| Total | ≈ 56000 |

Table 4.1: Total Containers

As seen in Table 4.1. there are 51% import containers and 48% export containers. These are distributed over the first half of 2022 i.e., January to June. To segregate the flow, it is divided into four types. The focus is on the reduction of containers and the percentage re-utilization without creating fresh/new flows originating from the Seaport to satisfy demands. There are four types of container flows:

1. Laden Import Containers
2. Empty Import Containers
3. Empty Export Containers
4. Laden Export Containers

| Scenario | Container Flows (million cont-km) | | | | Total (million cont-km) |
|------------------------|-----------------------------------|--------|--------|--------|-------------------------|
| | Laden | | Empty | | |
| | Import | Export | Import | Export | |
| Base Case | 7.03 | 10.5 | 7.03 | 10.5 | 35.06 |
| No Collaboration | 7.03 | 10.5 | 4.53 | 8.39 | 30.45 |
| Alliance Collaboration | 7.03 | 10.5 | 3.71 | 7.6 | 28.84 |
| Complete Collaboration | 7.03 | 10.5 | 2.5 | 6.35 | 26.38 |

Table 4.2: Costs from Optimization Models

The costs of transporting laden import and laden export containers remain the same in all scenarios as these flows are invariable. These flows are value-addition flows

4. Results and Analysis

and are based on the orders placed by customers (importers and exporters). The actual savings will be measured across the empty import and empty export container flows and the re-utilization of empty containers. The figures visualizing flows are differentiated based on colours and the thickness of the lines represents the quantity transported. Thick lines indicate higher quantities and thin lines represent lower quantities. The visuals of flows are divided based on distances into three sub-figures to avoid overlapping of lines. To keep the names confidential the shipping lines are masked. The total costs in each scenario decrease as there are fewer constraints allowing the relaxation of flows in the network, as seen in Table 4.2.

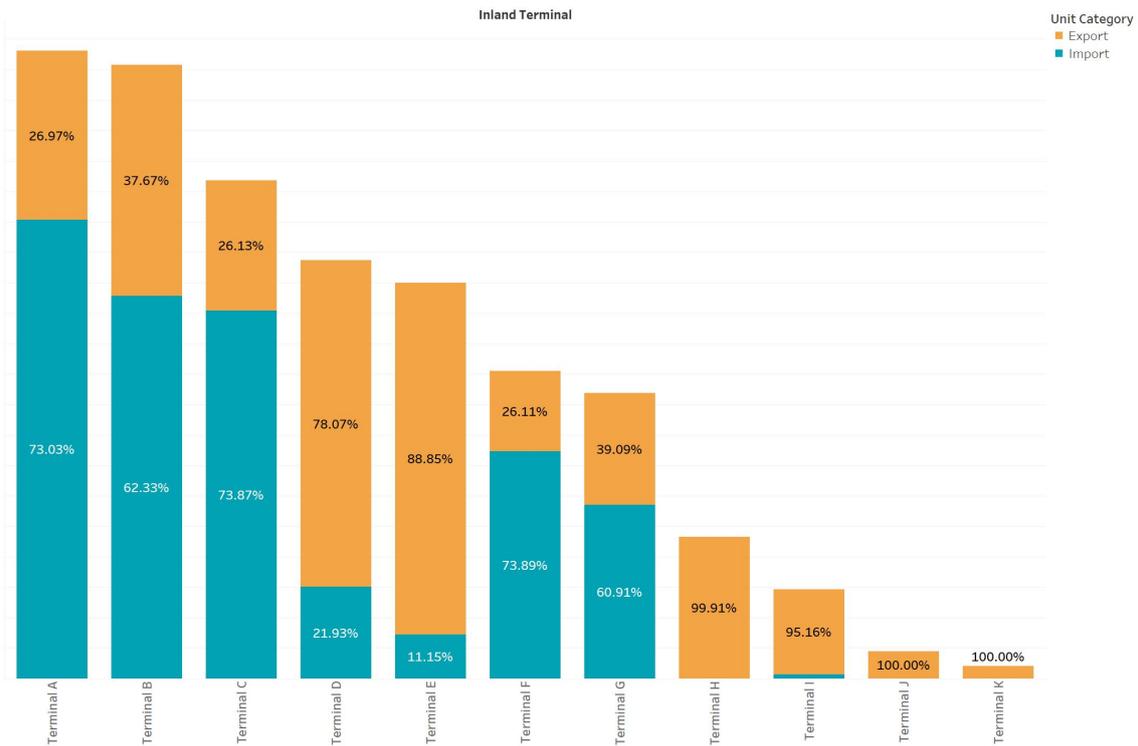


Figure 4.1: Share of Import and Export Containers for every Inland Terminal

The constraints are mainly associated with the shipping lines which translates to container-sharing restrictions. The relative percentage savings compared to the Base Case for **empty** containers are calculated and presented in Table 4.3.

| Scenario | Empty Import | | Empty Export | |
|------------------------|----------------------------|---------|----------------------------|---------|
| | Distance (million cont-km) | Savings | Distance (million cont-km) | Savings |
| Base Case | 7.03 | - | 10.5 | - |
| No Collaboration | 4.53 | 36% | 8.39 | 20% |
| Alliance Collaboration | 3.71 | 47% | 7.6 | 28% |
| Complete Collaboration | 2.5 | 64% | 6.35 | 40% |

Table 4.3: Relative Savings of Empty Container Distance Travelled

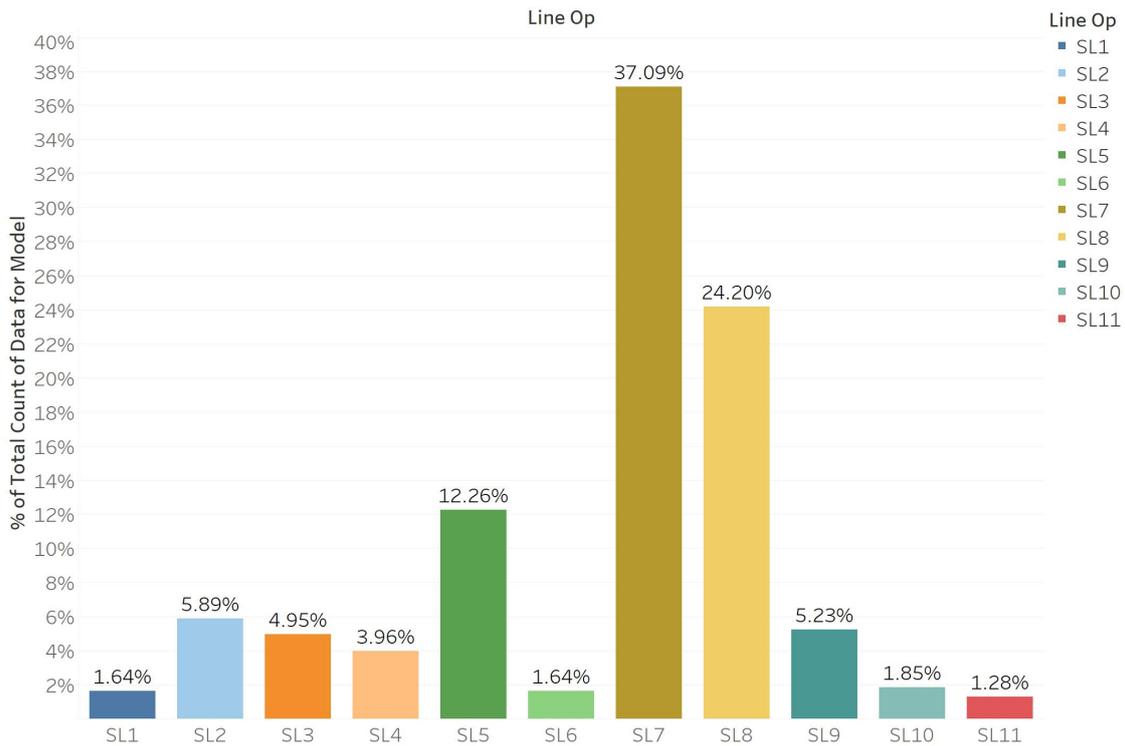


Figure 4.2: Percentage Share of Shipping Lines

The saving in distance is a parameter that indicates the possibility of savings by changing the constraints of the network and the flows in the network. Another vital parameter for shipping lines is the savings in the number of containers required to satisfy the demand for empty export containers. In the Base Case, there are ≈ 27000 unique containers that are used to meet the total demand. However, with re-utilization and triangulation, the number of unique containers required reduces drastically as the empty import containers are re-utilized at the inland terminal or transported through the triangle to satisfy the demand at the other terminal. The number of containers originating from different sources is mentioned in Table 4.4.

| Scenario | Source of Empty Container and Contribution | | |
|------------------------|--|-------------|---------------|
| | Port | Re-utilized | Triangulation |
| Base Case | 0 | - | - |
| No Collaboration | 62% | 20.4% | 17.5% |
| Alliance Collaboration | 49.3% | 28.8% | 21.8% |
| Complete Collaboration | 32.6% | 40.7% | 25.6% |

Table 4.4: Savings and Contribution in Number of Containers in each Scenario

The re-utilized containers belong to the laden import containers which are stripped and then available at the inland terminal to be used again as an empty export container. If there is no demand it is transported back to the Seaport or for triangulation. With the Seaport as the source, fresh containers are requested to fulfil the demand. If an inland terminal receives containers from another inland

terminal instead of the Seaport, triangulation is possible in that instance and this contributes to the share of re-utilized empty containers.

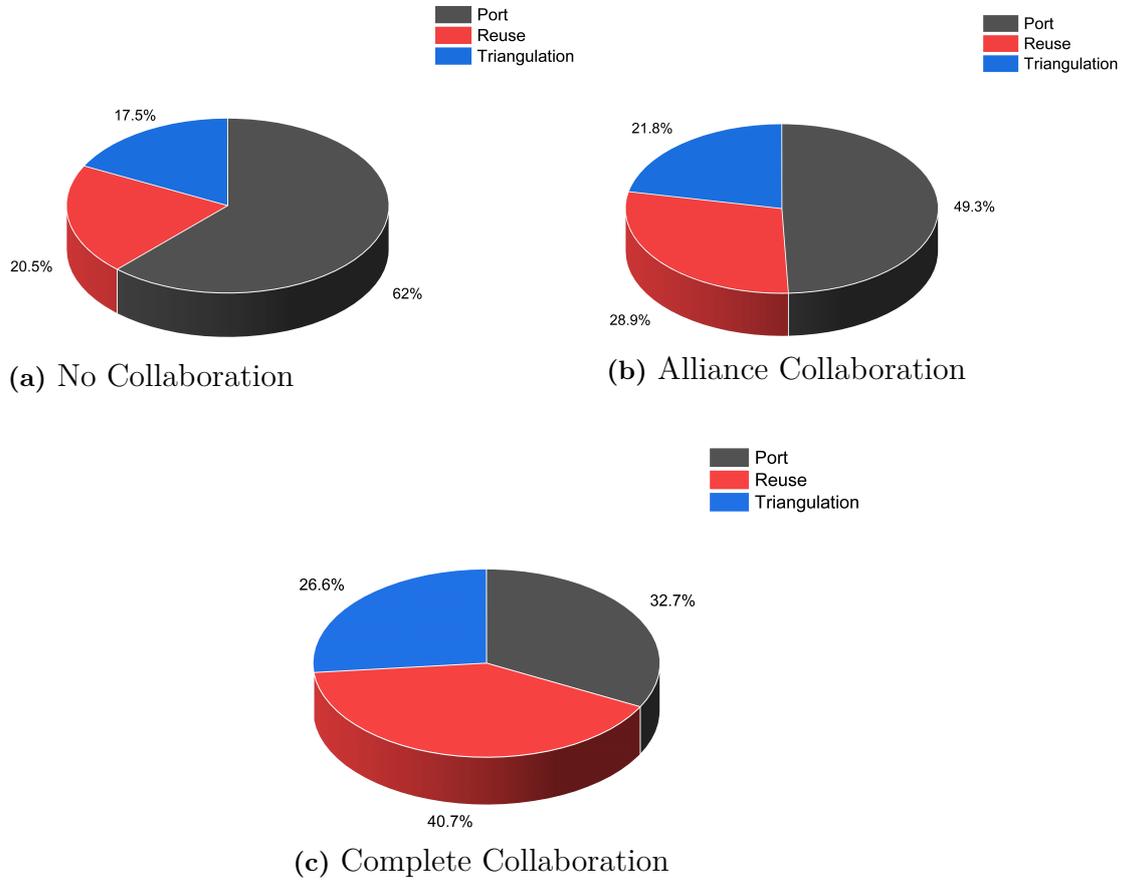


Figure 4.3: Source of Empty Containers

4.2 Base Case

Base Case represents the current cost incurred by the Seaport to transport all containers. The transport includes flows from the Seaport to inland terminals and vice versa. The table represents the break-up of the costs for different flows. The total cost is a result of Eq 3.1.

| Container Type | Cost (million cont-km.) |
|----------------|-------------------------|
| Laden Import | 7.03 |
| Empty Import | 7.03 |
| Empty Export | 10.5 |
| Laden Export | 10.5 |
| Total | 35.06 |

Table 4.5: Cost Break-Up per Container Flow Type

The cost calculated is for the total containers mentioned in Table4.1. This scenario is only a representation of the current network that is in use. There are no provisions

for flows between inland terminals and for reusing empty import containers. This results in the same costs for flows to and from the Seaport.

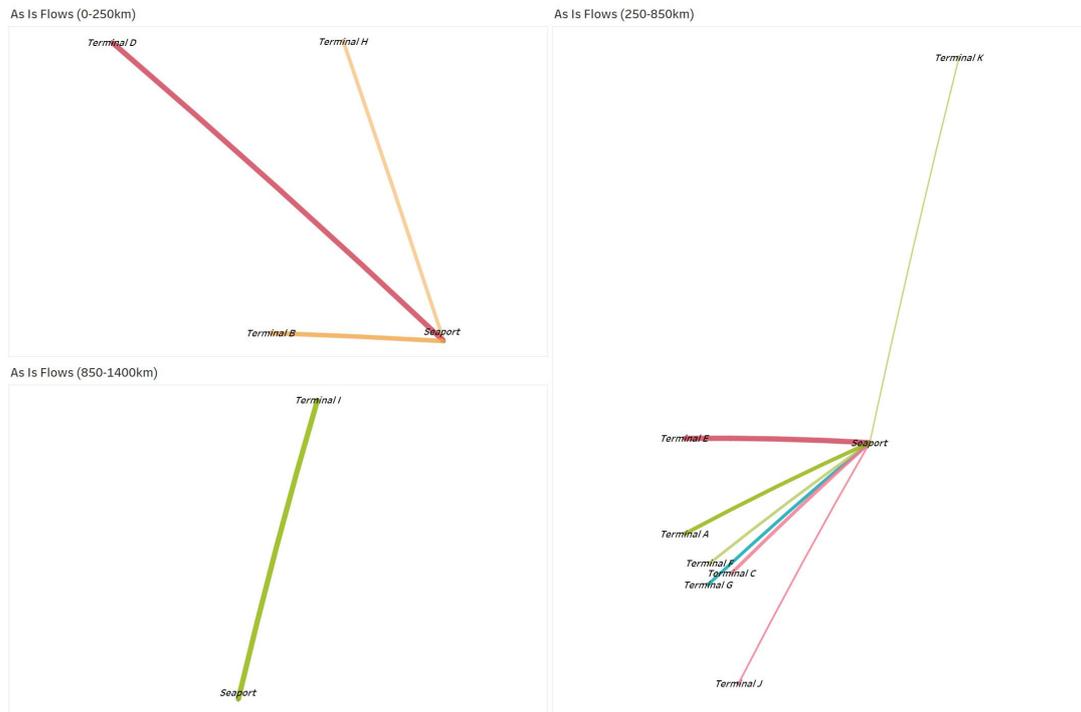


Figure 4.4: Base Case - Flows of Empty Export Containers

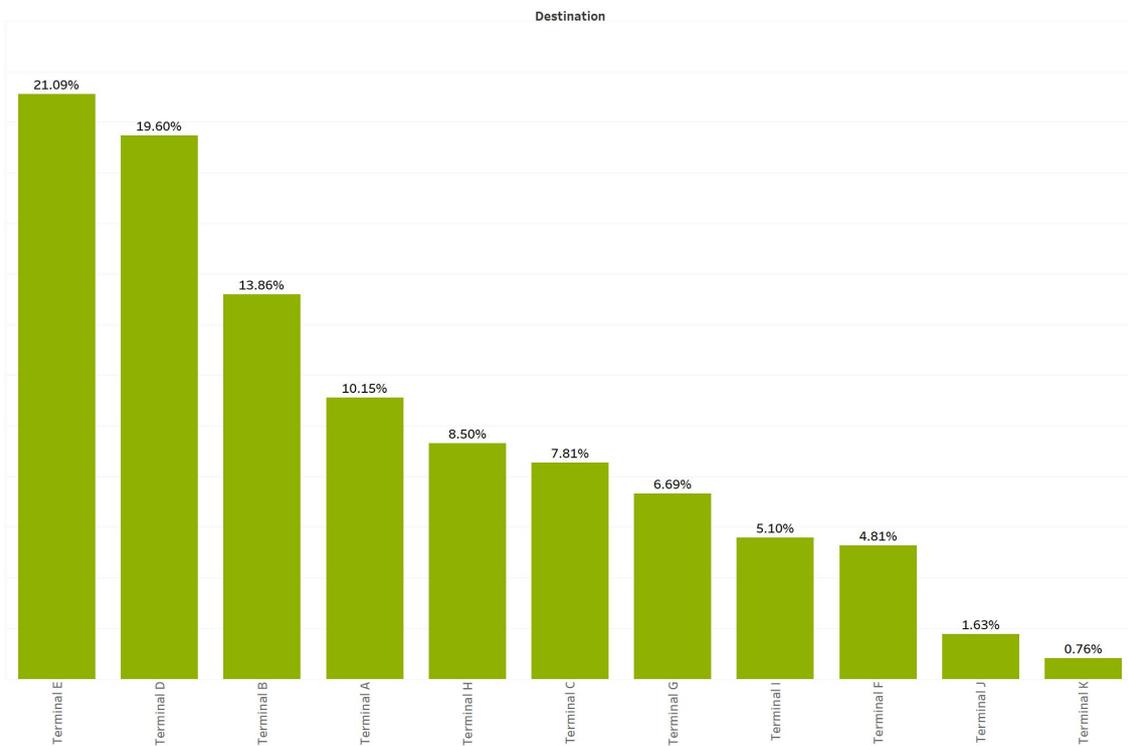


Figure 4.5: Base Case - Share of Empty Export Containers

4.3 No Collaboration Scenario

Similar to the Base Case with some variations to incorporate triangulation. Containers are distinguished based on ownership. There is a reduction in the total number of containers used as the total cost reduces due to triangulation between inland terminals. The total cost is a result of Eq 3.1.

| Container Type | Cost (million cont-km.) |
|----------------|-------------------------|
| Laden Import | 7.03 |
| Empty Import | 4.53 |
| Empty Export | 8.39 |
| Laden Export | 10.5 |
| Total | 30.45 |

Table 4.6: Cost Break-Up per Container Flow Type

Compared to the base case only 62% of the containers need to be requested from the Seaport since 20.4% can be solved through re-utilization within the same terminal and 17.5% through triangulation from another terminal. This amounts to a 38% reduction in fresh containers from the Port required to satisfy the demand.

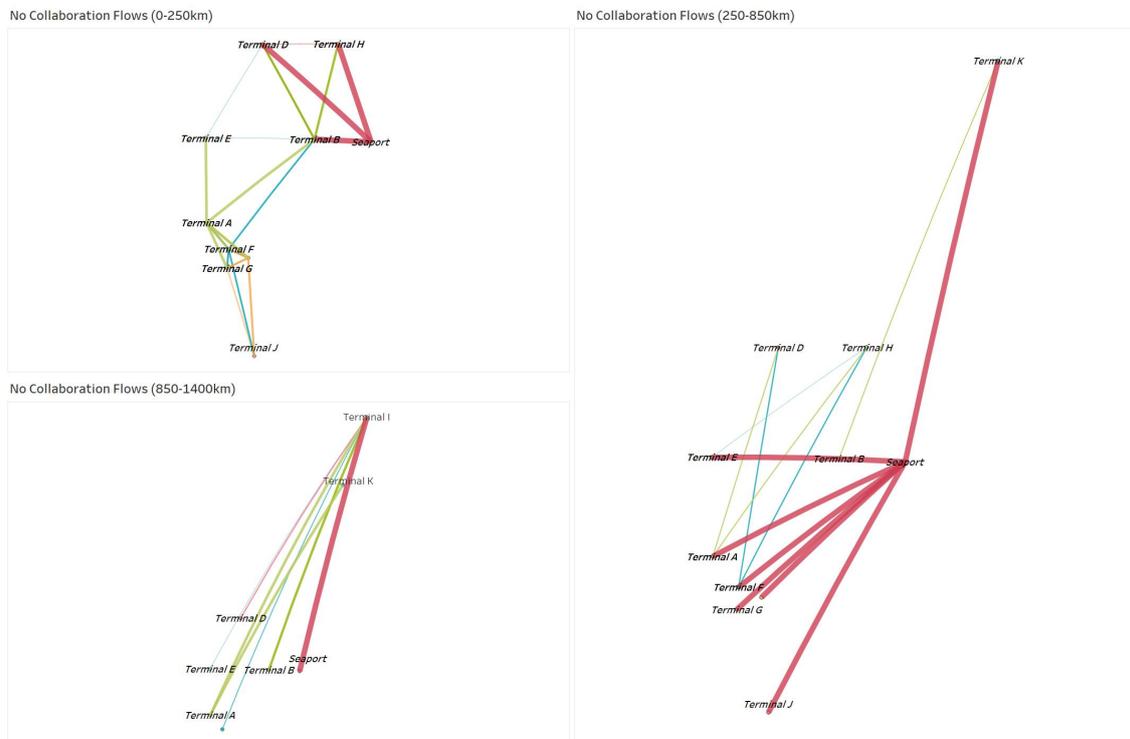


Figure 4.6: No Collaboration - Flows of Empty Export Containers

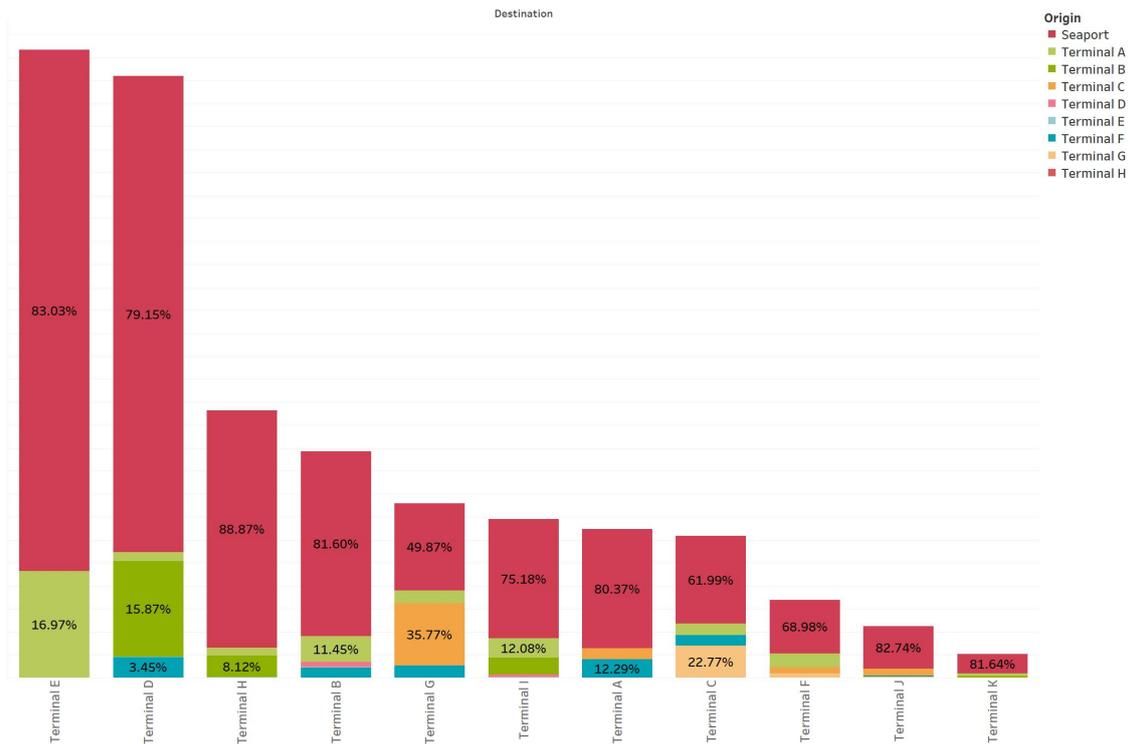


Figure 4.7: No Collaboration - Share of Empty Export Containers

4.4 Alliance Collaboration Scenario

The alliances existing in the maritime industry do not allow container sharing but focus on vessel fill rate, wherein the partners in the alliance can load their containers on partner vessels. The alliance in our modelling is an extended version of the same but also extends to container sharing along with vessel sharing. Theoretically, this reduces the number of constraints and results in a lower cost which is seen mathematically as well. The total cost is a result of Eq 3.1.

| Container Type | Cost (million cont-km.) |
|----------------|-------------------------|
| Laden Import | 7.03 |
| Empty Import | 3.71 |
| Empty Export | 7.6 |
| Laden Export | 10.5 |
| Total | 28.84 |

Table 4.7: Cost Break-Up per Container Flow Type

Compared to the base case only 49.3% of the containers need to be requested from the Seaport since 28.8% can be solved through re-utilization within the same terminal and 21.8% through triangulation from another terminal. This amounts to a 50.6% reduction in fresh containers from the Port required to satisfy the demand.

4. Results and Analysis

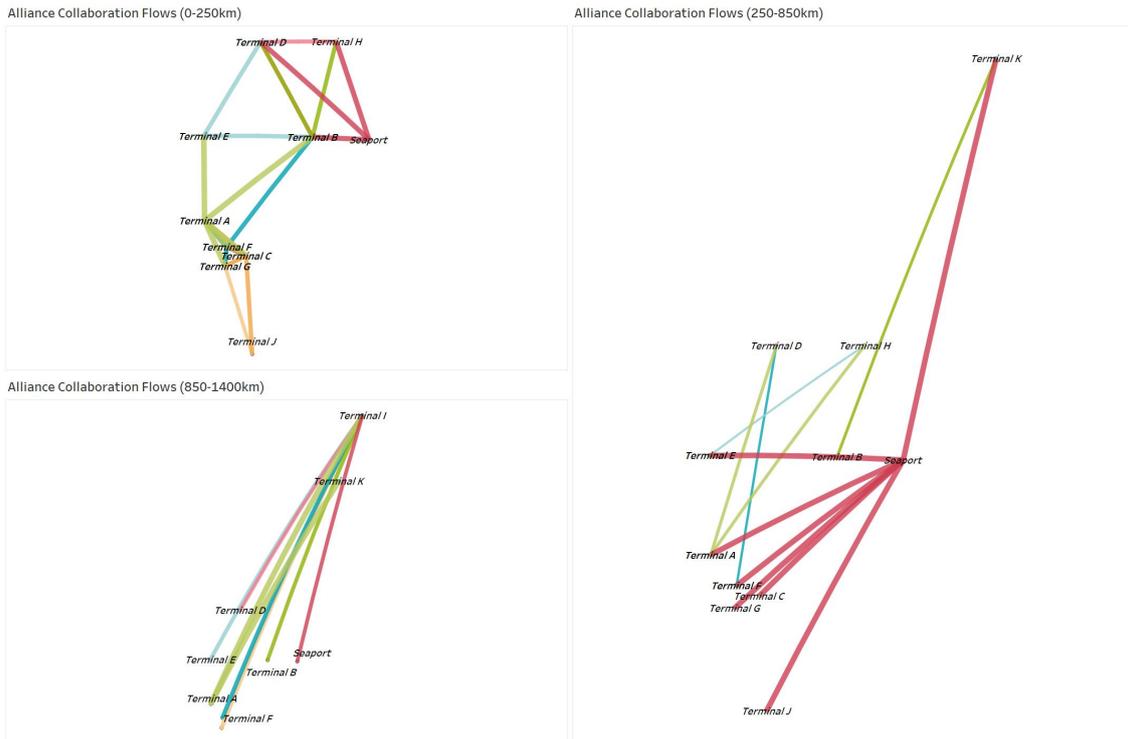


Figure 4.8: Alliance Collaboration - Flows of Empty Export Containers

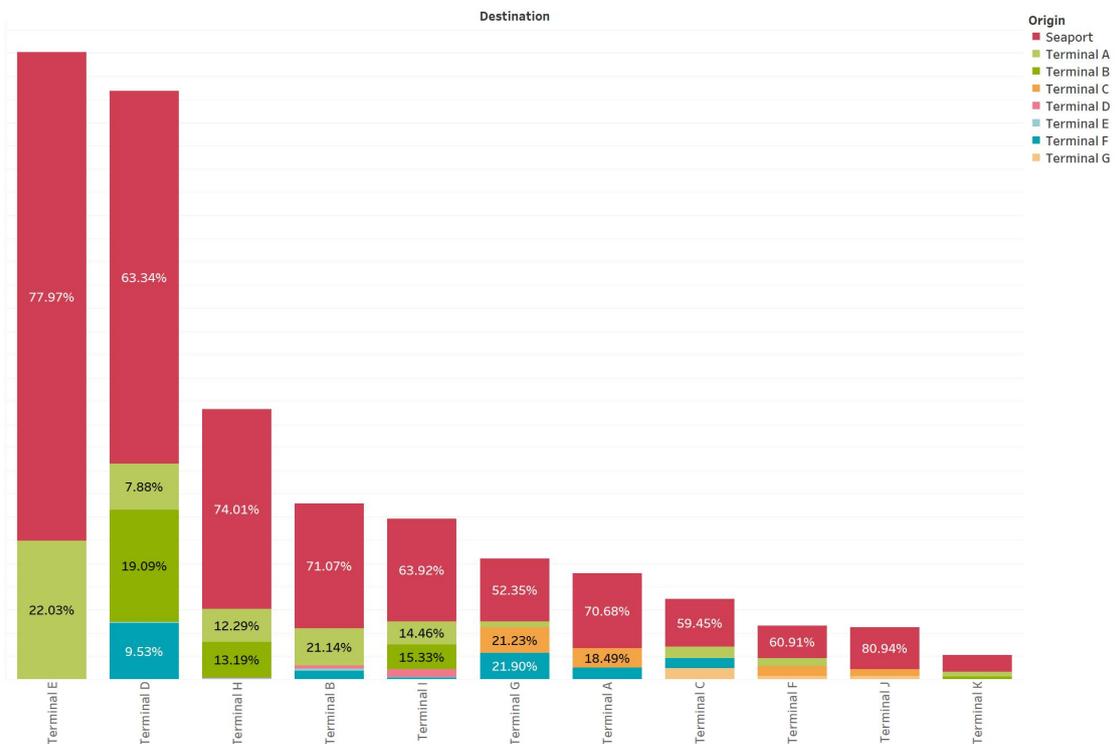


Figure 4.9: Alliance Collaboration - Share of Empty Export Containers

4.5 Complete Collaboration Scenario

Modelled as an ideal scenario where all shipping lines willingly let go of container ownership and matching. There is no constraint for containers to belong to the same shipping line which enables complete freedom to be transported anywhere in the network. This also reduces the total number of containers. As expected from an ideal scenario, the solution from this scenario is the lowest and the best out of others. The total cost is a result of Eq 3.1.

| Container Type | Cost (million cont-km.) |
|----------------|-------------------------|
| Laden Import | 7.03 |
| Empty Import | 2.5 |
| Empty Export | 6.35 |
| Laden Export | 10.5 |
| Total | 26.38 |

Table 4.8: Cost Break-Up per Container Flow Type

Compared to the base case only 32.6% of the containers need to be requested from the Seaport since 40.7% can be solved through re-utilization within the same terminal and 25.6% through triangulation from another terminal. This amounts to a 66.3% reduction in fresh containers from the Port required to satisfy the demand.

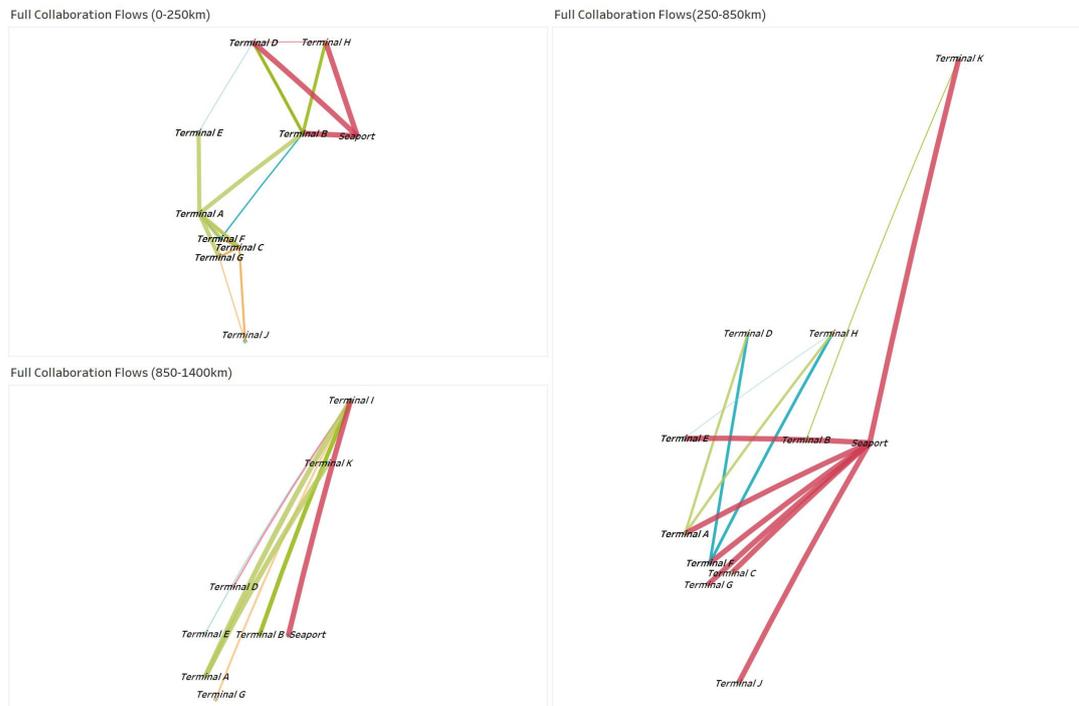


Figure 4.10: Complete Collaboration - Flows of Empty Export Containers

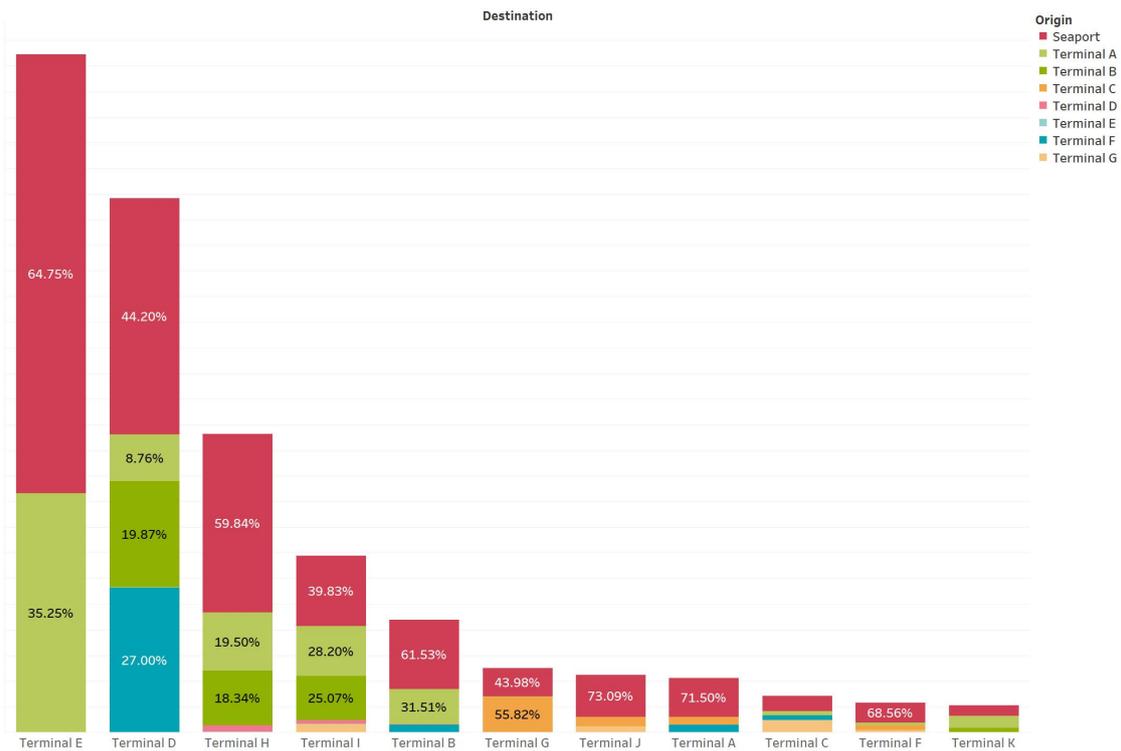


Figure 4.11: Complete Collaboration - Share of Empty Export Containers

4.6 Savings from Scenarios

The savings in container-kms are shown in Table 4.2. The savings in energy and emissions are substantial from the network perspective, shown in the table below. The energy and emission savings are low as the mode of transport is rail and the emissions from rail transport are lowest due to the source of the electricity, as mentioned in Section.3.5.

| Scenario | Cont-km | | Energy (million kWh) | Emissions (ton. CO ₂ e) | Energy & Emission Savings (%) |
|------------------------|---------------|-------------|----------------------|------------------------------------|-------------------------------|
| | (in millions) | Savings (%) | | | |
| Base Case | 35.06 | - | 42.7 | 480 409.65 | - |
| No Collaboration | 30.45 | 13% | 41.32 | 464 850.9 | 3.2% |
| Alliance Collaboration | 28.84 | 18% | 40.84 | 459 417.15 | 4.4% |
| Complete Collaboration | 26.38 | 25% | 40.1 | 451 114.65 | 6.1% |

Table 4.9: Energy Consumption and Emission Savings

4.7 Inland Terminal Selection based on Re-Utilization

4.7.1 Asymmetry and Container Imbalance Ratio (CIR)

To get the individual values for which feed into CIR, each inland terminal's total import and export was calculated and has been plotted as a butterfly chart in Fig.4.12.

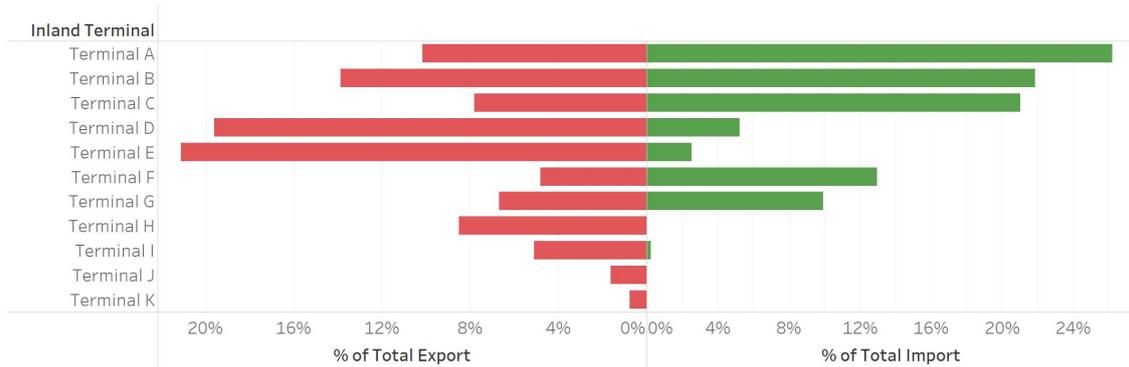


Figure 4.12: Import - Export Asymmetry



Figure 4.13: Container Imbalance Ratio (CIR)

While Fig.4.13 depicts the imbalance ratio for each inland terminal. There are 5 terminals that are import dominant and 6 terminals that are export dominant. Terminal H, Terminal J and Terminal Q are entirely export-dominant terminals with no incoming flow of import containers. Terminals with only export containers have a CIR of -1.0. The CIR is directly dependent on the number of containers. It acts as the first step in identifying the top inland terminals which have high imports, which eventually result in high % re-utilization. The re-utilization strategy is analyzed only for the No Collaboration scenario.

| Inland Terminal | CIR | % Re-uti. & % Savings | Base Case | | | No Collaboration Reuse Contribution | | |
|-----------------|-------|--------------------------|--------------------------------|-------------------------------|---|-------------------------------------|---------------------------------|--|
| | | | Total Cont-km (in 1000s) | Total Energy (1000 kWh) | Total Emission (ton. CO ₂ e) | Cont-km Savings (in 1000s) | Energy Savings (1000 kWh) | Emission Savings (kg. CO ₂ e) |
| Terminal A | 0.46 | 53% | 334 | 100 | 1.13 | 178 | 53 | 602 |
| Terminal B | 0.25 | 48% | 1473 | 442 | 4.97 | 708 | 212 | 2390 |
| Terminal C | 0.48 | 42% | 483 | 143 | 1.63 | 204 | 61 | 689 |
| Terminal D | -0.56 | 2% | 2623 | 787 | 8.85 | 60 | 18 | 203 |
| Terminal E | -0.78 | 5% | 1484 | 445 | 5.01 | 78 | 24 | 265 |
| Terminal F | 0.48 | 49% | 241 | 72 | 0.81 | 117 | 35 | 396 |
| Terminal G | 0.22 | 17% | 398 | 119 | 1.34 | 68 | 20 | 230 |
| Terminal H | -1.0 | - | 1187 | 356 | 4.01 | - | - | - |
| Terminal I | -0.9 | 1% | 1959 | 588 | 6.61 | 15 | 5 | 52 |
| Terminal J | -1.0 | - | 146 | 45 | 0.5 | - | - | - |
| Terminal Q | -1.0 | - | 236 | 71 | 0.8 | - | - | - |

Table 4.10: Percentage Re-utilization and Savings due to Re-utilization at Each Inland Terminal

4.8 Triangle Selection

In the base case, we looked at the whole sending system between many inland terminals. Here it is investigated if flows would be established only between specific terminals. The selection of triangles is based on the criteria mentioned in Section.3.4.1. The top 9 links with the maximum containers transported are selected for the triangles as quantities lower than those are unfavourable for triangulation. Quantities over 250 containers for the entire duration of 6 months are considered as high. The most frequent flows that result in the transport of significant quantities over the time period are selected. From Fig.4.6, the inland terminals that have the highest shares from Fig.4.7 are considered. The flows originating from the Seaport (the Seaport) are disregarded during the selection of triangles.

The top nine triangles selected for triangulation are:

- Seaport - Terminal A - Terminal B
- Seaport - Terminal A - Terminal E
- Seaport - Terminal A - Terminal F
- Seaport - Terminal A - Terminal I
- Seaport - Terminal B - Terminal I
- Seaport - Terminal B - Terminal H
- Seaport - Terminal B - Terminal D
- Seaport - Terminal F - Terminal D
- Seaport - Terminal C - Terminal G

The comparisons between the triangles and the different scenarios are presented in a tabular format below. The percentage savings provide insight into the potential triangles where the new changes can be implemented. Savings only from triangulation are shown in the table and not from re-utilization. A deep dive into the data based on shipping lines will help with decision-making related to individual shipping lines and optimization within their operations. If a shipping line has a large market in a country, it can implement triangulation in an individualistic manner. Individual triangles are visualized on the map in Fig4.15. The thickness of the lines indicates the quantity. The names of nodes are denoted by the starting letters of their names. The key for the table is presented below:

P - Seaport, TA - Terminal A, TB - Terminal B, TC - Terminal C, TD - Terminal D, TE - Terminal E, TF - Terminal F, TG - Terminal G and TI - Terminal I.

Q is the triangle distance factor. TIR is the triangle imbalance ratio.

Column '*Containers*' shows the total number of empty containers that are transported between the three nodes in a triangle. Energy consumption and emissions are calculated as shown in Section.3.5.

4. Results and Analysis

| Triangles | Shipping Lines Container Share | | | | | | | | | | |
|-------------|--------------------------------|------|------|------|------|------|------|------|------|-------|-------|
| | SL 1 | SL 2 | SL 3 | SL 4 | SL 5 | SL 6 | SL 7 | SL 8 | SL 9 | SL 10 | SL 11 |
| P - TC - TG | - | 1% | 5% | 1% | 4% | - | 55% | 31% | 3% | - | - |
| P - TA - TF | 1% | 4% | 2% | 4% | 24% | 1% | 18% | 39% | 6% | 1% | - |
| P - TB - TH | - | - | - | 2% | - | - | 98% | - | - | - | - |
| P - TB - TD | - | 1% | - | 3% | 4% | - | 85% | 5% | 2% | - | - |
| P - TF - TD | - | - | - | 5% | - | 4% | 62% | 25% | 3% | - | - |
| P - TA - TB | - | 5% | 3% | - | 25% | - | 30% | 28% | 1% | 8% | - |
| P - TA - TE | - | 16% | - | - | 16% | - | 12% | 53% | 3% | - | - |
| P - TB - TI | - | - | 1% | 23% | 6% | - | 2% | 63% | 5% | - | - |
| P - TA - TI | - | 2% | - | 1% | 19% | - | - | 77% | 1% | - | - |

Table 4.11: % Share of Containers for Each Shipping Line in Triangulation

Table 4.11 represents each shipping line and its share of containers transported within the triangle. It is evident that there are certain shipping lines stand out with their quantities. The approach moving forward for the shipping lines should be to realize the potential for savings within the suggested triangles and further work on implementing the strategies. The imbalance in triangles is shown in Fig.4.14. It presents the overall imbalance when both the inland terminals are considered.

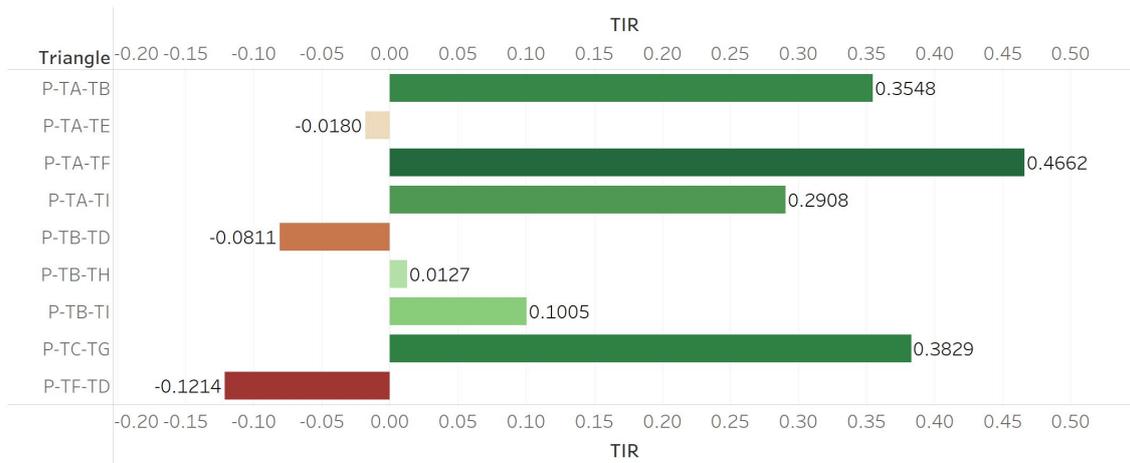


Figure 4.14: Triangle Imbalance Ratio (TIR) for Selected Triangles

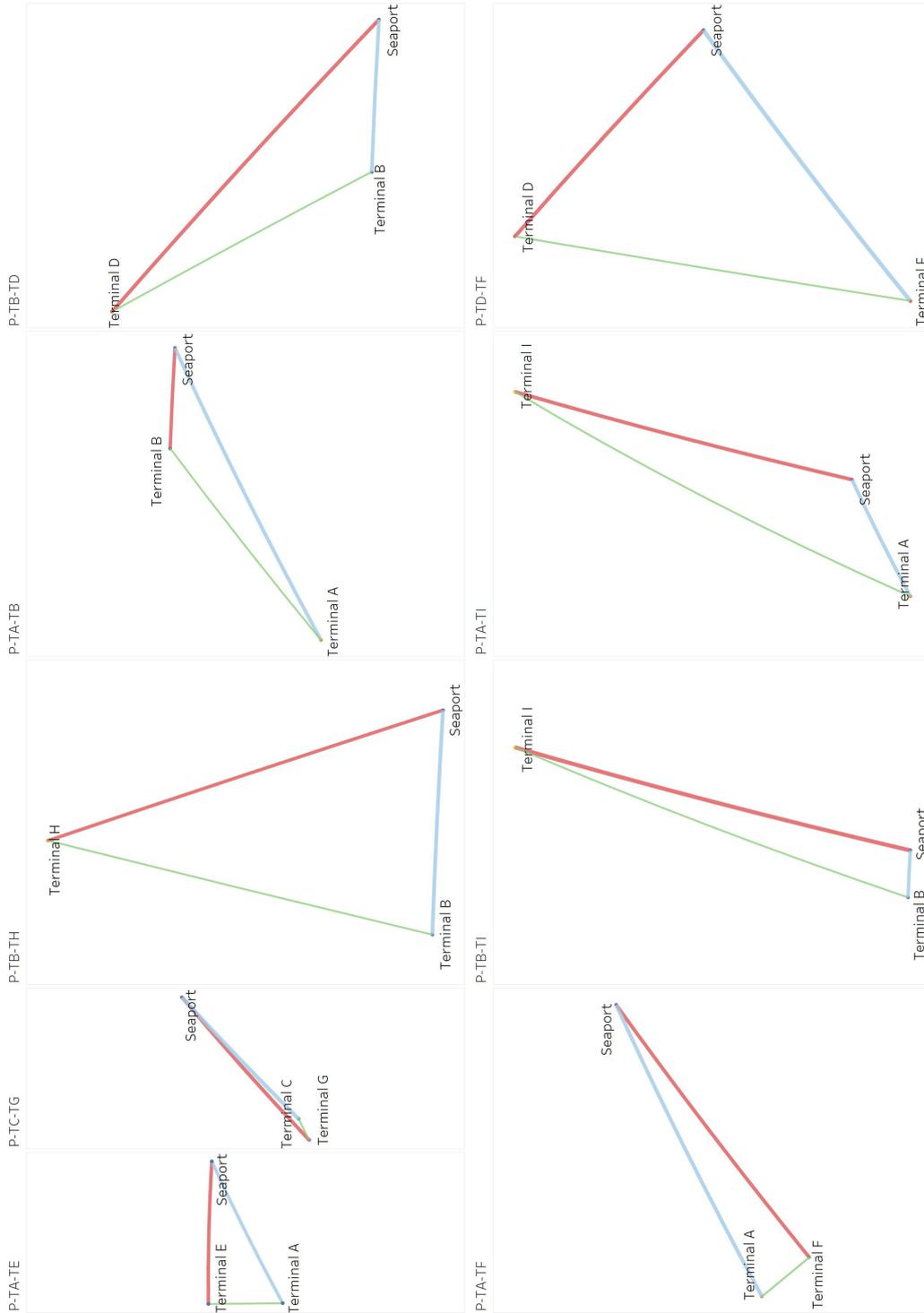


Figure 4.15: Selected Triangles

| Triangles | Q | TIR | Base Case | | No Collaboration | | Savings | | | | | | |
|-------------|------|-------|---------------------------|-------------------|--------------------------------------|---------------------------|-------------------|--------------------------------------|----------------------------|-------------------|--------------------------|-------------------------|----------------------------|
| | | | Container - km (in 1000s) | Energy (1000 kWh) | Emissions (tonnes CO ₂ e) | Container - km (in 1000s) | Energy (1000 kWh) | Emissions (tonnes CO ₂ e) | Energy & Emissions Savings | Container Savings | Absolute Savings cont-km | Absolute Energy Savings | Absolute Emissions Savings |
| P - TC - TG | 0.09 | 0.38 | 880 | 264 | 2.97 | 370 | 111 | 1.25 | 58% | 31% | 510 | 153 | 1.72 |
| P - TA - TF | 0.23 | 0.47 | 574 | 172 | 1.94 | 218 | 65 | 0.74 | 62% | 52% | 356 | 106 | 1.2 |
| P - TB - TH | 0.24 | 0.13 | 2,660 | 798 | 8.98 | 1,720 | 516 | 5.81 | 35% | 30% | 939 | 281 | 3.17 |
| P - TB - TD | 0.25 | -0.08 | 4,096 | 1,228 | 13.83 | 2,845 | 853 | 9.6 | 31% | 21% | 1,250 | 375 | 4.22 |
| P - TF - TD | 0.33 | -0.12 | 2,864 | 859 | 9.67 | 2,153 | 646 | 7.27 | 25% | 11% | 710 | 213 | 2.4 |
| P - TA - TB | 0.53 | 0.35 | 1,806 | 541 | 6.1 | 810 | 243 | 2.73 | 55% | 50% | 996 | 298 | 3.36 |
| P - TA - TE | 0.57 | -0.02 | 1,817 | 545 | 6.13 | 1,490 | 447 | 5.03 | 18% | 21% | 327 | 98 | 1.1 |
| P - TB - TI | 0.62 | 0.1 | 3,420 | 1,026 | 11.55 | 2,247 | 674 | 7.59 | 34% | 35% | 1,173 | 352 | 3.96 |
| P - TA - TI | 0.84 | 0.29 | 2,292 | 687 | 7.74 | 1,797 | 539 | 6.07 | 22% | 36% | 494 | 148 | 1.67 |
| Triangles | Q | TIR | Base Case | | Alliance Collaboration | | Savings | | | | | | |
| P - TC - TG | 0.09 | 0.38 | 880 | 264 | 2.97 | 224 | 67 | 0.76 | 75% | 56% | 656 | 196 | 2.22 |
| P - TA - TF | 0.23 | 0.47 | 574 | 172 | 1.94 | 40 | 12 | 0.14 | 93% | 66% | 533 | 160 | 1.8 |
| P - TB - TH | 0.24 | 0.13 | 2,660 | 798 | 8.98 | 1,361 | 408 | 4.6 | 49% | 37% | 1,298 | 389 | 4.38 |
| P - TB - TD | 0.25 | -0.08 | 4,096 | 1,228 | 13.83 | 2,208 | 662 | 7.45 | 46% | 28% | 1,888 | 566 | 6.37 |
| P - TF - TD | 0.33 | -0.12 | 2,864 | 859 | 9.67 | 1,730 | 519 | 5.84 | 40% | 17% | 1,134 | 340 | 3.83 |
| P - TA - TB | 0.53 | 0.35 | 1,806 | 541 | 6.1 | 580 | 174 | 1.96 | 68% | 63% | 1,225 | 367 | 4.14 |
| P - TA - TE | 0.57 | -0.02 | 1,817 | 545 | 6.13 | 1,416 | 424 | 4.78 | 22% | 26% | 401 | 120 | 1.35 |
| P - TB - TI | 0.62 | 0.1 | 3,420 | 1,026 | 11.55 | 1,893 | 568 | 6.39 | 45% | 44% | 1,527 | 458 | 5.16 |
| P - TA - TI | 0.84 | 0.29 | 2,292 | 687 | 7.74 | 1,575 | 472 | 5.32 | 31% | 45% | 716 | 215 | 2.42 |

Table 4.12: Comparison of Savings in Triangles

| Triangles | Q | TIR | Base Case | | | Complete Collaboration | | | Savings | | | | |
|-------------|------|-------|---------------------------|-------------------|--------------------------------------|---------------------------|-------------------|--------------------------------------|----------------------------|-------------------|--------------------------|-------------------------|----------------------------|
| | | | Container - km (in 1000s) | Energy (1000 kWh) | Emissions (tonnes CO ₂ e) | Container - km (in 1000s) | Energy (1000 kWh) | Emissions (tonnes CO ₂ e) | Energy & Emissions Savings | Container Savings | Absolute cont-km Savings | Absolute Energy Savings | Absolute Emissions Savings |
| P - TC - TG | 0.09 | 0.38 | 880 | 264 | 2.97 | 89 | 26.78 | 0.3 | 90% | 78% | 791 | 237 | 2.67 |
| P - TA - TF | 0.23 | 0.47 | 574 | 172 | 1.94 | 335 | 100 | 1.13 | 42% | 84% | 239 | 71 | 0.81 |
| P - TB - TH | 0.24 | 0.013 | 2,660 | 798 | 8.98 | 1,010 | 303 | 3.41 | 62% | 48% | 1,649 | 494 | 5.57 |
| P - TB - TD | 0.25 | -0.08 | 4,096 | 1,228 | 13.83 | 1,292 | 387 | 4.36 | 68% | 45% | 2,804 | 841 | 9.46 |
| P - TF - TD | 0.33 | -0.12 | 2,864 | 859 | 9.67 | 1,175 | 352 | 3.97 | 59% | 34% | 1,688 | 506 | 5.7 |
| P - TA - TB | 0.53 | 0.35 | 1,806 | 541 | 6.1 | 583 | 175 | 1.97 | 68% | 80% | 1,223 | 366 | 4.13 |
| P - TA - TE | 0.57 | -0.02 | 1,817 | 545 | 6.13 | 1,315 | 394 | 4.44 | 28% | 33% | 502 | 150 | 1.69 |
| P - TB - TI | 0.62 | 0.1 | 3,420 | 1,026 | 11.55 | 1,360 | 408 | 4.59 | 60% | 57% | 2,060 | 618 | 6.95 |
| P - TA - TI | 0.84 | 0.29 | 2,292 | 687 | 7.74 | 807 | 242 | 2.72 | 65% | 57% | 1,485 | 445 | 5.01 |

Table 4.13: Comparison of Savings in Triangles (continued)

5

Discussion

The results will be discussed and the final triangles and the top inland terminals with re-utilization will be decided in this chapter. The Complete Collaboration provides a theoretical maximum for each strategy. However, its feasibility is limited based on the discussion with the different stakeholders and the Seaport. Thus, this section will focus on the No Collaboration scenario and its potential benefits which are more likely to be realized. The No Collaboration scenario is closest to the current conditions. The Alliance Collaboration scenario is under the assumption that the shipping lines that are in alliance now for improving vessel fill rate would also agree to share containers within the alliance.

The comparison between the selected triangles with data about the different indicators and performance metrics is discussed below. The utilization of containers has significantly increased across all scenarios. The No Collaboration scenario has a 36.2% utilization. The Alliance Collaboration scenario increases utilization to 48.3% and further to 64.1% with Complete Collaboration. The reduction in the number of containers leads to fewer lifts and reduced container tracking data to handle. The container request is reduced by 37.9%, 50.6% and 66.3% for the No Collaboration, Alliance Collaboration and Complete Collaboration scenarios respectively. From Table.4.12, the analysis will focus on the No Collaboration scenario. This will be the most intuitive for decision-making as the No Collaboration scenario is the most realistic representation of the existing conditions. The optimization and analysis have led to an interesting crossroads where two ECR reduction solutions are possible. One is triangulation which still involves ECR but with high savings as compared to Base Case operations. The other solution is to re-utilize. Re-utilizing available empty import containers at the same inland terminal looks highly promising and has the potential for high savings. When reading ahead, please remember that the percentages are only relative. A higher percentage does not mean that the inland terminal or the triangle is better. The actual number of containers each terminal deals with is sensitive data and thus cannot be disclosed here. However, they are taken into consideration during the selection process.

5.1 Re-utilization of Containers

A surprising outcome of optimizing container flows showed the possibility of reusing containers at the same inland terminal that received them from the Seaport as a

laden import container. This results in a reduction in empty container requests sent from inland terminals to the Seaport. The re-utilization is also discussed in Tegbrant and Karlander (2023). The container imbalance ratio (CIR) is calculated directly based on the number of containers. In this case, a high positive ratio has greater potential for re-utilization.

5.1.1 Top 3 Inland Terminals

Based on the No Collaboration scenario the highest re-utilization of containers without any additional ECR of any kind, the top three inland terminals are listed below in the lowest to highest % re-utilization quantity order.

- Terminal B: 48%
- Terminal F: 49%
- Terminal A: 53%

The re-utilization approach is more alluring as it requires little to no investments from the actors involved. It is instead a greater focus on optimizing the existing transport and operations. The empty import containers present at an inland terminal before being returned to the Seaport are considered to satisfy a part of the demand in this approach. There is no repositioning of the containers except for moving them around within the inland terminal as per convenience. There will be instances when the containers cannot be matched for re-utilization. The next best option is to triangulate the containers with another inland terminal. This will reduce the distance a new container travels from the Seaport and reduce the time to satisfy the demand at the inland terminal. In the Base Case, all containers were requested from the Seaport. Table 5.1 represents the savings achieved due to re-utilization. There are other inland terminals in Table 4.10 with higher savings in container-km and energy, however, the criteria for selection is the number of containers re-utilized and not based on other performance indicators of the inland terminal itself.

| Inland Terminal | Cont-Km Savings (in 1000s) | Energy Savings (1000 kWh) | Emission Savings (kg. CO ₂ e) |
|-----------------|-------------------------------|------------------------------|---|
| Terminal B | 708 | 212 | 2390 |
| Terminal F | 117 | 35 | 396 |
| Terminal A | 178 | 53 | 602 |

Table 5.1: Re-utilization Savings

5.2 Triangulation of Containers

The selection of the top 3 triangles is dependent on numerous factors as discussed above. However, the results of our study and information from the Seaport have led us to fixate on two most important factors for the decision makers; the total number of containers in triangulation flows and the total container-kms, the energy

& emissions savings. We discuss the two different perspectives when each factor is given priority individually.

5.2.1 Containers in Triangulation Flows

Focusing mainly on the containers in triangulation flows from Table 4.12,4.13, the top three triangles are:

1. Seaport - Terminal B - Terminal D
2. Seaport - Terminal A - Terminal E
3. Seaport - Terminal C - Terminal G

Based entirely on the containers re-positioned through triangulation, the three triangles have significant quantities. The table below represents the total % contribution from triangulation. The number of containers triangulated in each triangle is ≈ 1000 .

| Triangle | Q | TIR | % Containers Contributed | | |
|-------------------|------|-------|--------------------------|----------------|-----------|
| | | | Triangulation | Re-utilization | From Port |
| Seaport - TB - TD | 0.25 | -0.08 | 12% | 21% | 67% |
| Seaport - TA - TE | 0.57 | -0.02 | 13% | 21% | 66% |
| Seaport - TC - TG | 0.09 | 0.38 | 23% | 31% | 46% |

Table 5.2: Percentage Triangulation within a Triangle

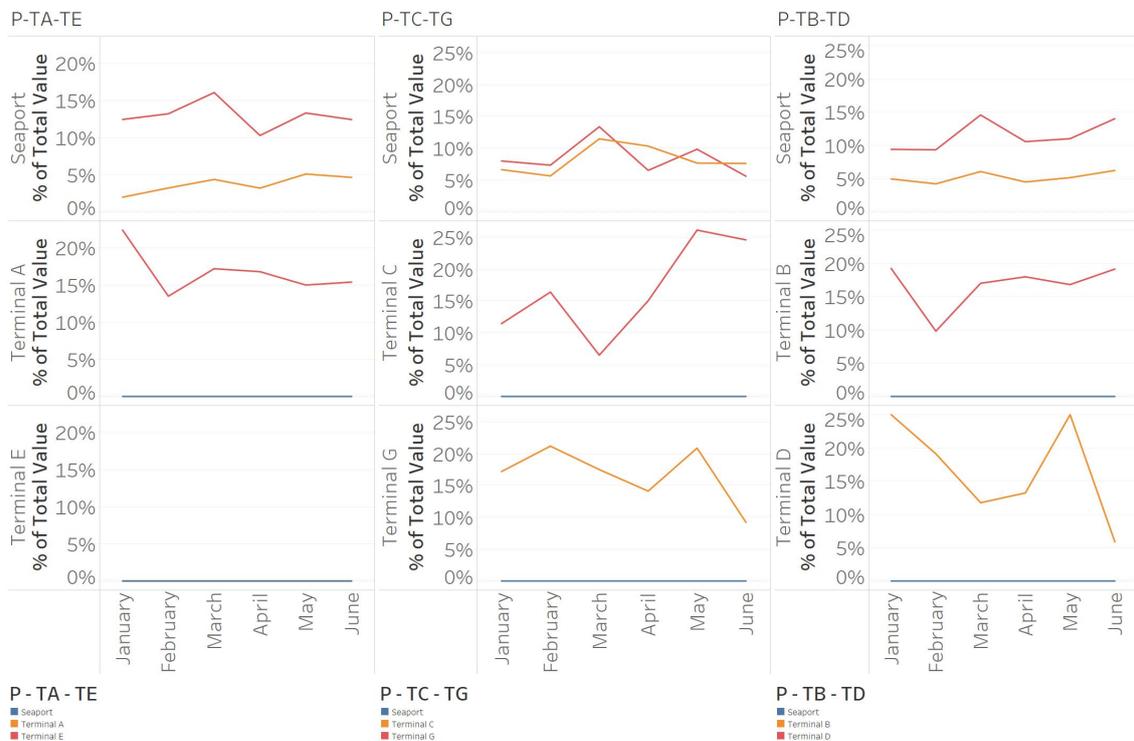


Figure 5.1: Container Triangulation Over Time (in Months)

Triangles 1 and 2 are the triangles having the highest total demand for empty containers. Though they have a negative TIR showing that they are slightly export dominant, the 2 triangles have the highest number of containers in triangulation flows. In contrast, Triangle 3 has the lowest demand for empty containers while having the 3rd highest number of triangulated containers. The underlying reason is the lowest value of Q. Due to the short distance between the inland terminals, though having low demand, the possibility of triangulation is quite high. This is also supported by the high TIR, showing that Triangle 3 is import-dominant and has several containers which can be triangulated easily without having to request fresh ones from the Seaport. Fresh containers from the Seaport would travel 3-4 times more distance to satisfy the demand. The direction of flows in the triangles will aid with fixing the direction of trains as seen in Fig.5.1. In Triangle 1, there are 93.8% of container flows from TB to TD and 6.2% of container flows from TD to TB. In Triangle 2, 100% of container flows are from TA to TE. In Triangle 3, 64.3% of containers flow from TC to TG and 35.7% of containers flow from TG to TC. Considering the information on the direction of flows and as all triangles have different terminals, all three triangles can be implemented simultaneously. There will be no cannibalization of containers. Furthermore, Fig.5.1 shows the distribution of containers over time for each month. Such distribution charts will help accurately plan train timetables and the number of trains required within each triangle.

5.2.2 Container-kms, Energy & Emissions Savings

Giving priority to container-kms, energy and emissions savings, from Table4.12,4.13, the top three triangles are:

1. Seaport - Terminal B - Terminal D
2. Seaport - Terminal B - Terminal I
3. Seaport - Terminal A - Terminal B

Based only on container-kms the three triangles have the absolute maximum savings in distance travelled. This also translates to savings in energy consumption and emissions. This approach also reduces the time factor linked while transporting over longer distances. Table 5.3 represents the absolute values and % savings.

| Triangles | Absolute Cont-kms Savings (1000 kms) | Absolute Energy (1000 kWh) | Absolute Energy Savings (ton.CO ₂ e) | % Savings |
|-------------------|--------------------------------------|----------------------------|---|-----------|
| Seaport - TB - TD | 1251 | 375 | 4.22 | 31% |
| Seaport - TB - TI | 1174 | 352 | 3.96 | 34% |
| Seaport - TA - TB | 996 | 299 | 3.36 | 55% |

Table 5.3: Savings in Container-kms, Energy and Emissions

Terminal B is repeated in all three selections. With this approach, the possibility of implementing triangles 1 and 2 simultaneously will lead to the cannibalization of containers. The flows will try to satisfy demand from the same pool of containers

which will result in lower savings. In Triangle 1, there are 93.8% of container flows from TB to TD and 6.2% of container flows from TD to TB. In Triangle 2, 100% of container flows are from TB to TI. In Triangle 3, 100% of container flows are from TA to TB. Having the details of direction and quantity inflows, it can be concluded that Triangles 1 and 3 can be implemented together as there are no conflicts. It should be noted that the selection is entirely based on factors and has no relation to the quantities of containers it handles.

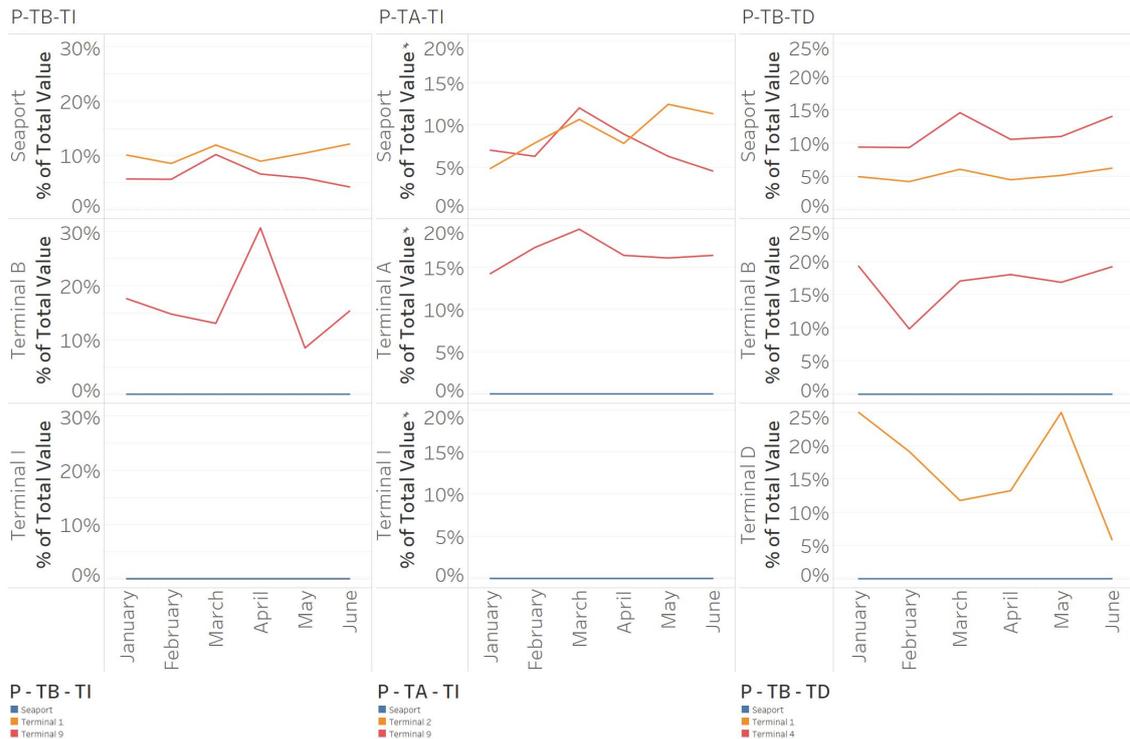


Figure 5.2: Container Distribution Over Time (in Months)

5.3 General Discussions

The above selections are entirely based on factors and criteria. This answers both research questions. However, implementing such changes is not limited to a quantitative approach. A mix of policies, collaborations between shipping lines, technology, strategic planning and operational excellence can make the implementation smoother and more efficient. As the models have been named on the interaction of different actors in the supply chain, trust and openness in the system is the sine qua non for the maritime industry. In a list of numerous factors, the inertia around data sharing can be one of the top concerns hindering the potential for savings. A previous thesis, Hao and Ibrahim (2023) discuss the economic and environmental effects of ECR reduction from the perspective of an inland terminal and its flows to customers. This focuses on the last segment of the value chain. A more detailed analysis from a recent study focusing on the last segment, using data analytics and a take on urban logistical problems (Castrellon,

Sanchez-Diaz, & Kalahasthi, 2023). Tegbrant and Karlander (2023) and Hellekant and Rudal (2021) discuss the improvements in transport efficiency and different ECR reduction strategies that can be implemented across the board by one or several actors involved in the supply chain. Hagelin and Knutsson (2020) investigate the drivers and barriers in ECR reduction.

5.3.1 Global Implementation and Disruptions

The effects of disruptions in the supply chain were not considered during the modelling of the scenarios. The time period of the data in this study is at a state when the pandemic was over but the invasion of Ukraine had started. However, the data does not reflect these disruptions in any manner and neither have we added any constraints to recreate disruptions in the model. The disruptions affect the flows in the waterways and indirectly affect the hinterland flows. The optimization is focused on the hinterland flows and thus disruptions on a global scale are not considered. Similarly, the strategies are applicable in all regions globally, however, they cannot be implemented together on a global scale. The strategy implementation has to begin small in a country with good volumes. All shipping lines cannot implement the strategies since it does not apply to low volumes. The collaboration between the shipping lines, Seaport and freight forwarders is necessary to have complete implementation. Once implemented, based on the results, the shipping line can approach other global markets in a similar manner. Once the strategies are implemented all over, the flows will be optimized from a global perspective. Scalability is something that should be considered when implementing such strategies.

5.3.2 Turn Around Time

All actors in the supply chain are looking for opportunities to increase their profit by improving their operations efficiently. In the maritime sector, while the transport on vessels itself is slow, actors try to make up for the lost time on land if possible. This increases the vitality of turnaround times. The possibility of reducing turnaround times is a win-win for all. The carriers and forwarders get their containers faster. The customers get their products faster. The optimization model from a quantitative perspective shows that it is possible to achieve this by reducing the distance travelled by containers to reach their destinations. The use of trains reduces travel times and the option to consolidate saves emissions and funds. The modelling in this thesis does not consider turnaround times as that would make the model dynamic. However, it can be observed from the results that if containers are available immediately for re-utilization at an inland terminal or available through triangulation, it can significantly save time. The average time for transport from a port to an inland terminal is one day. For every container re-utilized, the entire process saves one day. This not only helps the inland terminal but also the port as it reduces the total lifts the port workers have to carry out. The same time and energy could be utilized for other tasks.

5.3.3 Number of Containers and Utilization

Manufacturing a container today with technological advances is highly automated and consumes an insignificant amount of time when compared to the time containers take to travel across the world. The focus is on the storage, utilization and availability of containers rather than buying them every time there is a shortage. The containers occupy large spaces and are difficult to handle. They generate costs whether they are loaded or empty but only generate value when loaded (Kuzmicz & Pesch, 2019). The goal should be to have containers loaded and moving for the maximum amount of time. In the base case, every time a container is required, a fresh container from the port is sent to the inland terminal. This reduces the utilization of the containers. The stripped import containers could be used instead of a container from the port. The number of containers re-utilized and triangulated will lead to the percentage utilization of empty import containers. The empty import containers are returned to the port without having any re-utilization in the base case. As changes are introduced, there is a significant rise in percentage utilization. The re-utilization also needs to ensure that the container type and size also have to match Tegbrant and Karlander (2023).

5.3.4 Trust, Alliances and Collaborations

Several studies have linked trust and collaboration. For collaborations to work, an immense amount of trust between the organizations and the people leading the collaborations is required. The studies also link risk and collaborations, as there is a certain degree of control that is lost by all involved in collaborations. The control over decisions when working individually is now a joint decision which takes more time and effort. Such wrinkles have to be ironed out through contracts, meetings and discussions. Trusting the decision-making capability of others in the collaboration during difficult times will help such alliances and collaborations go a long way. As seen from the results in Table 4.12, there are higher savings as compared to a scenario without collaboration. Comparing the triangle further with the least savings in the No Collaboration and Alliance Collaboration, we see that 5% more containers are saved. In this case, the 5% amounts to almost 450 containers. That is 450 containers which do not even need to move anywhere because there is trust and there is openness in communication. The 5% container savings translated to a 4% higher savings in energy consumption and emissions. Such savings are possible across the board with more organizations taking slightly higher risks and having more trust (Tegbrant & Karlander, 2023). The savings do show the positives but as Panayides and Wiedmer (2011) mentions, the outcomes of alliances may not always be positive and profitable.

5.3.5 Energy Consumption and Emissions

The energy consumption and emission numbers are important and there are savings wrt. each model. However, the electricity for trains is supplied from a mix of hydro and wind, one of the cleanest energy sources. As mentioned in the introduction, the focus of the thesis is only on flows between the port and the

inland terminals. The flows responsible for higher emissions would be the flows between the inland terminals and the customers. As customers rely on road transport, energy consumption and emissions are greater in the last segment of the value chain. If similar strategies could be employed in this segment, the savings will be substantially higher. This is not just restricted to the port and inland terminals. Implementing these strategies will reduce congestion in the locality, reduce emissions, save time and reduce turnaround time for all actors. The energy consumption depends on the number of containers in the flows and thus there is no significant trend with the values. The results from Hao and Ibrahim (2023) conclude that there will be significant savings when street turns are implemented for a single inland terminal. Building on the same, with triangulation, re-utilization across the inland terminals supported further by street turns will result in enormous savings.

5.4 Implications on Actors

5.4.1 Shipping Line Perspective

Triangulation requires several changes and investments. Train timetables and trains must be planned by the individual shipping lines willing to implement triangulation. The scheduling and number of trains have to be decided depending on forecasts of imports and exports at the inland terminals involved in the triangle. There could be several trends in the historical data that need to be factored in for each inland terminal in the triangle. This requires high-quality data from the past years. It also requires additional competence in the field of optimization. Shipping lines decide based on the quantities they forecast to handle in the future in a particular geographical region. Using the forecast data along with the performance metrics from the past data and potential savings, an informed decision will help select the most potential triangles.

In the Alliance Collaboration scenario, there are two aspects to container sharing; sharing with other shipping lines and with different customers. The shipping lines are sceptical of sharing containers with other shipping lines as they lose complete control over the container once it leaves their system. Shipping lines also sell capacity to their customers in the form of containers. If a container is unavailable for a customer when required, it will be detrimental to the business (Panayides & Wiedmer, 2011). When containers are shared with customers to consolidate goods, containers could end up getting stuck in customs over longer checks. The goods could get mixed up due to no differentiation. This mix-up is a risk for the shipping lines leading to loose control of their assets. Furthermore, they are also a medium of marketing and advertisement. A combination of strategic alliances with operational synergies makes it extremely difficult to form alliances, as the maritime sector works on a global scale (Pierre & du Tertre, 2000; Panayides & Wiedmer, 2011).

5.4.2 Freight Forwarder Perspective

The freight forwarders dealing with the import container flows and ensuring that the empty import containers are returned to the Seaport on time will have a slightly difficult time with the implementation of the above-discussed strategies. The re-utilization scenario can be perceived as a loss of business for the freight forwarders as the return flow of empty containers to the port is drastically reduced. This will reduce the requirements put forth by the shipping lines on the freight forwarders. However, with triangulation the freight forwarders can still provide service to the shipping lines by changing the direction of flows. The purpose of the study was to reduce one leg of transport to achieve savings. Depending on situations where freight forwarders handled this extra leg, upon implementation of the strategies they will be forced to reduce their operations.

5.4.3 Seaport Perspective

The Seaport focuses on providing services which attract higher volumes from different shipping lines. This is done by providing services, like an existing platform of the rail network, triangulation possibilities and savings. The possibility of implementing such ECR reduction strategies with support from the seaport will also attract shipping lines to approach them in the future. It will help shipping lines improve their container utilization and operational efficiency. The seaport will also have to ensure that the inland terminals are well equipped to handle increased numbers and have some storage space for the re-utilization containers while they are on hold until the customer demands it. Such transportation facilities will also reduce turnaround times for containers and shipping lines always have a high priority for savings time.

5.4.4 Inland Terminal Perspective

The inland terminals act as the centre for receiving and further sending shipping containers to the respective customers. The timeline for receiving the containers back is not controlled by the inland terminals. It is dictated as per the contracts the customers have with the shipping line they use. This leads to varying time windows for receiving back containers once sent out from the inland terminals. Using the utilization strategies mentioned in this thesis will also help reduce the variation in the return time. However, it has to be ensured that all customers involved are on board with the new changes and optimize their process accordingly. The benefit for the customers could be that the shipping lines reduce the container prices if customers are willing to reduce the return times. This can act as a motivating factor for the customers. The inland terminals will be able to better consolidate containers on trains and have higher efficiency in turnaround times.

6

Conclusion

The literature review, mathematical modelling, and results have aided in the identification of a few inland terminals that can be considered for triangulation. The seaport now has the opportunity to engage in discussions with the shipping lines that handle the majority of containers and the rail operators to establish new trains in the triangles identified by this study. The top three triangles selected in Section 5.2, based on two different performance metrics, provide an answer to research question 1. Additionally, research question 2 is addressed through the selection of the top three inland terminals, supported by relevant metrics and indicators that indicate the highest percentage of re-utilization (as discussed in Section 5.1). The general discussions and implications concerning different actors encompass the scope of research question 3. Unfortunately, the thesis cannot delve into the analysis based on individual shipping lines, as the data is sensitive. It should be noted that certain shipping lines hold a larger market share in Sweden than others and they could potentially benefit from the findings of this study. When making a decision, the seaport should consider the cost perspective of establishing a new timetable for trains between the inland terminals. A comparison should be made between the savings achieved through container reduction, increased utilization, reduced distance travelled, decreased turnaround time, and lower energy consumption, against the initial fixed costs associated with setting up the triangle. The presented numbers are based on container movements for half of the year, and assuming similar quantities are handled in the second half, the savings are expected to attract actors to implement the proposed strategies.

If shipping lines determine that implementing the strategies shown in Fig. 6.1 is desirable, feasible, and viable, they can actively develop such strategies for their global markets (Fitzsimmons & Douglas, 2011; Konietzko et al., 2020). Desirability, feasibility, and viability are crucial factors when planning strategic changes. To assess the desirability, it is necessary to investigate the long-term savings achieved through utilization strategies and weigh them against the initial costs. Additionally, identifying the potential for redirecting containers to locations experiencing shortages would improve service quality. If containers cannot be allocated elsewhere after implementing the strategies, shipping lines could keep some containers in reserve and restructure flows to minimize surpluses and deficits in different regions worldwide. The feasibility of implementing such strategies on a national scale poses challenges. Factors such as large quantities of containers, availability of space at inland terminals for storage, and a well-developed rail network contribute to feasibility. The first shipping line to implement these

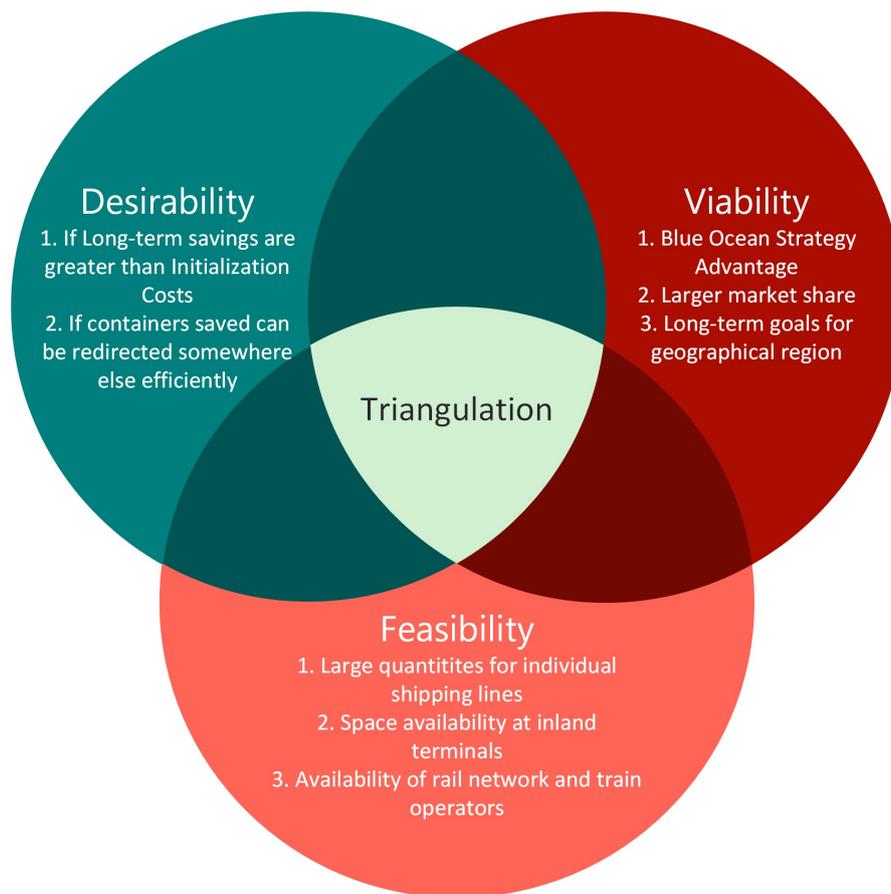


Figure 6.1: Desirability Feasibility Viability

utilization strategies would have the advantage of entering a blue ocean market, enabling them to reap the highest benefits before competitors follow suit (Kim & Mauborgne, 2014). Moreover, the implementation does not require venturing outside the shipping lines' core competencies, as it primarily relies on optimization and transport planning, which are existing core functions. The venture would be profitable if the shipping line has long-term goals for the geographical region in which they implement these strategies.

Although addressing desirability, feasibility, and viability, as mentioned by Konietzko et al. (2020), covers essential aspects of strategic decision-making, it does not encompass all considerations. Challenges related to forming alliances within the supply chain will always exist. When forming alliances, it is crucial to assess their impact on the entire supply chain, rather than solely focusing on the actors within the alliance. A broader understanding is necessary to explore how alliances can be formed with minimal barriers while maintaining strategic direction (Pierre & du Tertre, 2000).

6.1 Academic Contribution

The thesis covers a wide range of literature related to ECR and factors affecting ECR, shedding light on general solutions researched from both analytical and management strategy-based perspectives. The case study helps relate to a realistic scenario. Furthermore, the implementation of the optimization model reveals the potential of leveraging data analytics to support decision-making. Articles by Song and Carter (2009); Basarici and Satir (2019); Hao and Ibrahim (2023) are used as the foundation of the study. The methodology and analysis are carried out in a generalized systematic method that is easily transferable to other similar situations. The Python code is available upon request and can be used as a base to build a code with dynamic programming. It will be useful to research a storage-at-inland-terminal perspective, which can change the percentage utilization of containers and the turnaround time.

6.2 Industrial Contribution

The thesis contributes to the maritime industry, inland transport operators, and the energy sector. The calculations and analysis are based on realistic data. The seaport can build on the results and provide a holistic solution to the shipping lines. The shipping lines can request an individualistic analysis for their containers and flows. This increases their supply chain visibility and control over containers. The energy sector can use the numbers from savings and collaborate with transport operators to promote such approaches to save energy and reduce emissions. Policy-makers can investigate from a holistic perspective to recognize the full potential of such strategies. The implementation will become easier if more actors in the supply chain are involved and working towards the common goal.

6.3 Future Scope

There are multiple possibilities considering the flexibility of actors within the supply chain. The focus of this study is on a single port and its connections to inland terminals across the country. However, Sweden has multiple ports, each with its unique flows. Considering all the ports and inland terminals in Sweden, along with their respective flows, it is possible to formulate a multi-echelon, multi-actor, multi-period, single-commodity MILP model. The objective could be to emphasize the percentage of container reuse, reduction in container kilometres, and identify the most suitable nodes within the network for triangulation. It is important to consider the availability of storage at inland terminals might present a different perspective for the same strategy. The decision regarding storage and the duration for which shipping lines allow containers to be stored could be studied and compared to the potential savings. To validate the effectiveness of utilization strategies in real-life scenarios, simulation studies could be conducted. These studies would consider factors such as train travel times, container handling time, stripping and loading times, to construct an accurate representation of the

system. It would also be beneficial to incorporate the costs associated with each action, providing a comprehensive monetary perspective.

The models developed in this thesis could potentially be implemented in other countries as well. The utilization of big data, machine learning, and artificial intelligence has significantly improved forecasting capabilities. By utilizing forecast data to schedule trains, the efficiency of triangular operations could be enhanced. From a management perspective, it would be interesting to examine the approaches of shipping lines in addressing the ECR problem. Exploring how they test and implement new strategies from a feasibility standpoint would provide valuable insights. Methods for improving train networks, enabling clearance for longer trains, and exploring double-stacking options could be further investigated. Additionally, gaining a perspective from governing bodies would help in understanding how specific countries prioritize such requirements.

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A

Appendix 1

| Origin/ Destination | Seaport | Terminal 1 | Terminal 2 | Terminal 3 | Terminal 4 | Terminal 5 | Terminal 6 | Terminal 7 | Terminal 8 | Terminal 9 | Terminal 10 | Terminal 11 |
|--------------------------------|---------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-------------|-------------|
| Seaport | - | 388 | 120 | 510 | 489 | 183 | 333 | 257 | 226 | 1404 | 1142 | 217 |
| Terminal 1 | - | - | 268 | 214 | 219 | 324 | 556 | 261 | 495 | 1108 | 846 | 539 |
| Terminal 2 | - | - | - | 390 | 371 | 70 | 419 | 214 | 113 | 1284 | 1022 | 157 |
| Terminal 3 | - | - | - | - | 152 | 465 | 713 | 383 | 725 | 920 | 658 | 769 |
| Terminal 4 | - | - | - | - | - | 219 | 692 | 277 | 714 | 1072 | 810 | 659 |
| Terminal 5 | - | - | - | - | - | - | 320 | 284 | 43 | 1359 | 1097 | 35 |
| Terminal 6 | - | - | - | - | - | - | - | 584 | 277 | 1607 | 1345 | 258 |
| Terminal 7 | - | - | - | - | - | - | - | - | 327 | 1277 | 1015 | 312 |
| Terminal 8 | - | - | - | - | - | - | - | - | - | 1603 | 1054 | 40 |
| Terminal 9 | - | - | - | - | - | - | - | - | - | - | 324 | 1389 |
| Terminal 10 | - | - | - | - | - | - | - | - | - | - | - | 1094 |
| Terminal 11 | - | - | - | - | - | - | - | - | - | - | - | - |

Table A.1: Origin - Destination Matrix of Inland Terminals in kilometres (km)

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