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Master's Thesis

Evaluating the Benefits of Floating Container Terminals in Maritime Shipping: A Sustainability Perspective Using Facility Location Models

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Abstract

Study purpose: This study explores how Floating Container Terminals (FCTs) located in the North and Baltic Seas can support the maritime shipping industry's growth while promoting sustainability. As freight transportation volumes rise and sustainability regulations tighten, ports face increasing demands to accommodate Ultra-Large Container Vessels (ULCVs) in an environmentally responsible manner. Traditional port expansion is costly and often requires extensive land use and environmentally disruptive dredging. In contrast, FCTs offer an innovative offshore solution capable of unloading ULCVs and transferring cargo to feeder vessels bound for mainland ports without additional mainland infrastructure or dredging. This study evaluates the potential of FCTs to meet industry demands sustainably and efficiently.

Methodology: This quantitative study applies data-driven methods to identify the optimal location for a Floating Container Terminal (FCT) in the North and Baltic Seas. Using the Facility Location Problem (FLP) framework, the study analyses relevant data, including shipping routes and container transport volumes. The FLP approach facilitates the selection of an ideal subset of potential locations from a predefined set of mainland ports and prospective FCT sites. By integrating these data points, the study seeks to pinpoint the most strategic FCT location to enhance logistical efficiency across these maritime regions.

Findings: This study's findings are derived from seven scenarios and network configurations using the Facility Location Problem (FLP). The findings predicted that appropriate location and FCT capacity would be needed to achieve economically optimal solutions. Additionally, vessel fleet composition contributes significantly to environmental sustainability. FCT implementation has been shown to lower carbon emissions, benefit local communities, and contribute to broader regional sustainability goals.

Implications: Practically, the study demonstrates cost and carbon reductions in transshipment by integrating FCTs. Theoretically, this research advances the literature by providing predictive models and addressing a gap in optimal FCT location selection. Additionally, at the policy level, the study underscores the need for regulatory frameworks to safeguard the professionals working on FCTs and the associated investments.

Keywords: Maritime shipping, Floating Container Terminal, Ports, Terminals, Containers, Triple Bottom Line, Sustainability.

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List of Abbreviations

AHP – Analytical Hierarchy Process
CAPEX – Capital Expenditure
ECA – Emission Control Areas
FCT – Floating Container Terminal
FLP – Facility Location Problem
FLM-Facility Location Model
HSFO – High Sulphur Fuel Oil
IRR – Internal Rate of Return
LCC – Life Cycle Costing
LSFO – Low Sulphur Fuel Oil
MCDM – Multicriteria Decision-Making
MDO – Marine Diesel Oil
MGO – Marine Gas Oil
MOB – Mobile Offshore Base
MSP – Maritime Spatial Planning
MUP – Multi-Use Platform
MUS – Multi-Use Space
OCP – Offshore Container Port
OPEX – Operational Expenditure
PSO – Particle Swarm Optimization
PSP – Pneumatically Stabilized Platform
SDG – Sustainable Development Goal
STFT – Sea Technology Floating Terminal
TBL – Triple Bottom Line
TEU – Twenty-foot Equivalent Unit
TOPSIS – Technique for Order of Preference by Similarity to Ideal Solution
ULCS / ULCV – Ultra-Large Container Ship/Vessel
VLFP – Very Large Floating Platform
VLFS – Very Large Floating Structure
VLSFO – Very Low Sulphur Fuel Oil
VOT – Value of Time
VTOL – Vertical Take-off and Landing

1 Introduction

1.1 Research background

Maritime trade is one of the cornerstones of the global economy, facilitating approximately 90% of the world's trade by volume and 70% by value. Maritime trade is pivotal in connecting nations, sustaining international commerce, and driving economic growth. Maritime transportation ensures efficient logistics systems and global competitiveness. Within the European Union (EU), naval trade is significant, with three-quarters of its international trade conducted via sea routes. EU ports serve as indispensable hubs, handling billions of tons of goods annually and linking Europe to the rest of the world. The EU's status as the world's largest trading bloc emphasizes the central role of maritime transport in its economic engine. Container shipping, an essential aspect of marine trade, further accentuates its importance, with millions of containers navigating the seas annually (Gurning et al., 2022; UNCTAD 2019; UNCTAD 2023; EMSA (n.d.)).

As global trade is increasing continuously, reliance on ultra-large container ships (ULCS) is growing due to the world's constantly expanding freight transportation volumes. Major container shipping companies have been reshaping their fleet profiles with larger vessels to achieve better economies of scale. Today, the largest container ships have dimensions reaching more than 60 m in beam and 400 m in length with a capacity exceeding 24000 TEUs (Ahmed, 2023; Kim & Morrison, 2011; Kurt et al., 2021; Sukeyasu et al., 2005; Y. Y. Kim et al., 2014). Ultra Large Container Vessels (ULCV) cause operational challenges for the ports, particularly those with dense traffic, due to shallow water depth, short quay length, and crane reach. These operational challenges create more congestion in container terminals, lower productivity, and a decline in port performance. Higher port time and handling challenges hinder the cost advantage and economy of scale resulting from the higher ship capacity of ULCVs (Davidson, 2014; Hacegaba, 2014; Kurt et al., 2021; Lane & Moret,2014; Merk et al.,2015; UNCTAD, 2018).

Traditionally, ports have coped with the growing demand for capacity by building new berths, adding more and faster cranes, and improving existing resources. However, constructing new, longer berths is costly and requires extensive shorelines and suitable infrastructure for yard operations. Since most of the world's population resides in coastal regions where land is scarce, expanding port facilities faces significant challenges. Additionally, rising sea levels due to global warming may necessitate the reclaiming or repurposing of existing land near waterfronts in the future. Authorities and governments grapple with rising dredging costs to accommodate larger vessels, environmental constraints in sensitive and historical areas, limited land availability, insufficient landside infrastructure and heightened security concerns. These factors collectively pose considerable obstacles to addressing the increasing demands on port capacities sustainably and efficiently (European Commission, 2017; Flikkema & Waals, 2019; Kim & Morrison, 2011; Pachakis et al., 2016).

The interconnected nature of container shipping has caused local supply chain issues to have global repercussions, posing challenges across regions. In Europe, shippers and freight forwarders are encountering significant rises in ocean freight rates and need help to secure cargo space despite stable demand and minimal port congestion. Since the start of 2020, container shipping costs have sharply increased. Concurrently, ship schedule reliability witnessed a notable decline, with two out of three ships arriving late. Turnaround times at ports in China and the United States have doubled since 2020, whereas in Europe, the increase was less pronounced, at under 15%. Many countries in Europe, Latin America, and sub-Saharan Africa saw fewer direct liner connections following the reconfiguration of liner shipping networks. The operational profit margin of the top ten container shipping companies reached an estimated USD 160 billion in 2021, with a considerable portion being used to ensure vertical integration by acquiring port terminals, forwarders, and freight airlines (ITF,2022).

Seaports, vital for global trade, face the challenge of expanding container handling capacity amidst land scarcity. As demand for container transport increases, industry and academia are motivated to investigate non-traditional port service concepts such as offshore operation. Offshore, floating platforms offer a solution to extend port infrastructure beyond land constraints. These platforms can serve as additional container terminals and logistic hubs, yet their implementation presents decision hurdles (Gharehgozli et al., 2019; Kim & Morrison, 2011; Lamas-Pardo et al., 2015; Souravlias et al., 2020). Despite a less common solution for port expansion, offshore container ports can adapt quickly to the latest container ships. Researchers studied flexibility, advantages, technical feasibility, economic viability, and operational cost analysis of offshore container ports integrated with container shipping networks as transshipment hubs. Little attention has been paid to finding the optimum locations and capacity of floating container terminals (FCTs) to serve the demands of the North and Baltic Sea ports so that FCTs can supplement the changed reconfiguration of liner shipping networks. Previous research investigates the possibility of using natural islands within the North Sea as a transshipment hub, whereas this research applies to any transshipment location. Moreover, no comprehensive analysis of FCTs has been done in the European context to study the sustainability impact of FCTs on the Maritime Shipping Industry (Baird & Rother, 2013; Gurning et al., 2022; Kim & Morrison, 2011; Kurt et al., 2021).

1.2 Research problem

As maritime trade will grow steadily in the coming years, urgent action is required to address sustainability issues within the maritime shipping industry. Despite comprising only 3% of global greenhouse gas emissions, emissions from maritime shipping have increased by 20% over the last decade. Without intervention, projections suggest a staggering 130% increase in emissions by 2050 compared to 2008. In contrast, the road transport sector, responsible for the highest proportion of transport emissions, is projected to decrease within 15 years due to rigorous decarbonization efforts. Such improvement in road transport highlights the pressing need for the maritime sector to adopt effective decarbonization measures to mitigate its significant environmental impact and align with global sustainability goals (UNCTAD, 2023; UNECE, 2021). The shipping industry faces mounting pressure to rapidly decarbonize due to regulatory requirements, commercial incentives, and increasing sustainability demands. However, achieving emissions reduction targets outlined by the IMO's Revised Strategy remains a significant challenge. Uncertainty surrounds the most effective methods for reducing carbon emissions and transitioning to lower or zero-carbon fuels. Transitioning to cleaner fuels poses considerable financial challenges, given that fuel costs already comprise a substantial portion of overall ship voyage and operating expenses, sometimes up to two-thirds. Moreover, alternative fuels remain comparatively expensive. Collaboration across the shipping and energy sectors involves carriers, port operators, manufacturers, shippers, investors, energy producers, and distributors to decarbonize maritime shipping (ITF, 2022; UNCTAD, 2023).

Since March 2020, container ships' time in ports has increased by 50%. Poor ship schedule reliability disrupts terminal planning, worsening congestion, and further lowering reliability. Congestion creates a detrimental cycle, underscoring the need for improved terminal management to enhance efficiency and mitigate congestion. Ocean carriers are adapting to strengthen their market position by investing in new assets and broader logistics. Top ten shipping line operators evolved into service integrators by investing in end-to-end solutions. These carriers are expanding their portfolios by focusing on port acquisition and terminal operation. Despite these efforts, the loading and unloading cargo like containers and breakbulk present significant challenges, requiring calm waters and ample storage areas. Bi-directional cargo flows necessitate careful planning for export and import cargoes, including advanced storage and enhanced inspection regimes. Vertical integration between shipping liners and terminals can spur transshipment hub development, attract volumes, and stimulate feeding services. Shippers, port authorities, and governments must evaluate the overall logistics integration benefits against costs (Bhonsle, 2023; ITF,2022; Pachakis et al., 2016; UNCTAD, 2023).

1.3 Research aim and question

This paper explores how floating container terminals (FCTs) can be a supplementary solution for shipping liners and ports to reduce overall costs and carbon emissions. In other words, the paper tries to find ways to optimize maritime container flows in two European seas (the North Sea and the Baltic Sea) by integrating floating ports as container transshipment hubs because of ever-changing liner route configurations for various reasons. This study investigates floating container terminals from a systems perspective so that the overall supply chain can be less expensive door to door. So far, in the business-as-usual case, all costs for the ocean leg, as well as the transshipment (e.g., Dalian – Gothenburg), should be compared to a new system with new costs for all parts (e.g., Dalian – Floating port – Gothenburg). Consequently, this research compares transshipment costs to measure the economic impact of implementing floating container terminals as hubs and explore their effectiveness in promoting sustainability within the maritime sector. Moreover, it sheds light on the potential impact of implementing floating container terminals as transshipment hubs as a sustainable solution to address environmental challenges. A negligible existing study demonstrates the environmental, economic, and social impact of FCTs within a modular network as a floating transshipment hub. The study was conducted with a positivist methodological approach as it tried to generate explanatory associations or causal relationships that ultimately lead to prediction. Quantitative data were mainly used to determine the impact of FCT implementation. As a result, the research can be termed as deductive. The following research question was explored to achieve the research aim:

RQ: **How can Floating Container Terminals (FCTs) benefit the maritime shipping industry and contribute to sustainability?**

In order to study how implementing Floating Container Terminals (FCTs) can ensure sustainability in the Maritime shipping industry, researchers have used the Triple Bottom Line (TBL) theory. The TBL theory expands conventional business success metrics to include an organization's contributions to social well-being, environmental health, and economy. These bottom-line dimensions are often called the three "P's": people, planet, and prosperity. To provide the foundation of sustainability is systems thinking; a single initiative that falls under people, planet, or prosperity will also impact others (Collaboratives, 2022).

1.4 Thesis structure

The upcoming chapters of this thesis are structured as follows: The second part is a literature review. This part first discusses the previous literature on blue economy, maritime spatial planning (MSP), Very Large Floating structure and sustainability, the role of maritime logistics hub in container transshipment, enhancing supply chain reliability through hybrid mode, location selection for floating container terminals (FCTs)/hubs, the potential economic, environmental and social benefits of integrating CFTs in liner shipping network. The assessment of the social dimension of CFT implementation was solely based on a literature review. The literature review also discussed the TBL framework and Facility Location model to understand their application in logistics. The third section included methodology, which introduced the choice of research method and reason in detail. This paper adopts positivism as the model is based on facility location problems. Data were collected from secondary sources. The fourth part includes results. This part presents the results obtained from the Facility Location Model. The following part is a discussion in which the paper explores the results of the data in more depth, compares different alternatives, and forms relations between findings. This section also summarizes and analyzes the findings according to the TBL framework. It also presents the implications of this research. The last section concludes the thesis, mentioning its limitations and future directions.

2 Literature review

2.1 Blue Economy

The blue economy is a sustainable approach to utilizing oceans, seas, and coastal areas for economic growth. With over 70% of the Earth's surface covered by oceans and more than 40% of the global population living in coastal regions, the demand for land in coastal cities has increased, pushing these areas to their limits (Dalton et al., 2019). As population growth continues, the ocean presents a viable option for expansion (Lamas-Pardo et al., 2015; Suzuki et al., 2006; Wang & Tay, 2011). The blue economy includes marine-based industries like shipping and fisheries and land-based sectors such as ports and coastal tourism. It emphasizes low-polluting, resource-efficient practices that balance economic development with environmental sustainability. Innovative sectors like marine renewable energy, blue biotechnology, and sustainable ocean-based food production offer significant potential for growth, decarbonization, and job creation. Investment in the blue economy can yield substantial returns. A €2.5 trillion investment in areas like offshore wind farms, sustainable ocean food production, decarbonizing shipping, and habitat conservation could generate net benefits of €14 trillion by 2050. Such potential highlights the blue economy's role in driving economic value while ensuring ocean health (Tagliapietra & Crespo, 2023).

2.2 Maritime Spatial Planning

Maritime spatial planning (MSP) has emerged as an essential tool for achieving a more rational use of marine areas to promote the blue economy. MSP is based on the multipurpose use of a given space to increase economic opportunity while preserving marine ecosystems. MSP’s potential lies in its ability to provide collaborative structures on local, regional, national, and international levels. It can help bring stakeholders from various economic sectors and countries together to establish long-term development plans for traditional activities such as shipping, fishery, and tourism

(Tagliapietra & Crespo, 2023). As maritime space is limited and demand for ocean space is rising both for conventional uses, such as fisheries, maritime transport, and tourism, and new uses, such as renewable offshore energy and aquaculture, there is a need to optimize social, economic, and environmental objectives. The EU aims to realize blue growth more efficiently using multi-use space (MUS) and multi-use platforms (MUP) (Ansong et al., 2017; Dalton et al., 2019).

MUP (Multi-Use Platform) involves two blue growth sectors or a combination of blue growth and blue economy sectors that use the exact location and platform facility. The Maribe project awarded by European Union could identify economically viable cases for MUS and MUP, showing a lucrative Internal Rate of Return (IRR). MUP of floating wind and desalination demonstrated the highest positive results in all investment metrics. The project collaborated with industry experts to accurately forecast Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). Though it was assumed that large-scale platforms would be more commercially viable, the case studies with lower CAPEX and niche market projects appeared most economically feasible. It demonstrated that such MUP business models can be profitable, create jobs, and add value to the economy, aligning with the blue growth goal (Dalton et al., 2019).

2.3 Very Large Floating Structure (VLFS) and Sustainability

A Very Large Floating Structure (VLFS) or Very Large Floating Platform (VLFP) is an exceptional concept of oceanic structure that reaches a range of extraordinary parameters of length (up to 10,000 Meters), displacement (up to Tons) and cost (up to $15,000 Million). A floating structure can only be considered as VLFS exceeding the base length of 1000 meters. The size and flexibility of VLFS require consideration of design, analysis, assembly, and operation. VLFS has a long design life (up to 100 years based on design), low maintenance cost and durability, and fatigue resistance. An airport or port size is enormous compared to the existing floating structures, such as pontoons, barges, ships, and offshore platforms. Hence, the concept of a Very Large Floating Structure (VLFS) emerged as VLFS is designed primarily for floating airports and ports, whether on calm waters on the coast or the open sea (Lamas-Pardo et al., 2015; Suzuki et al., 2006; Zhang et al., 2015).

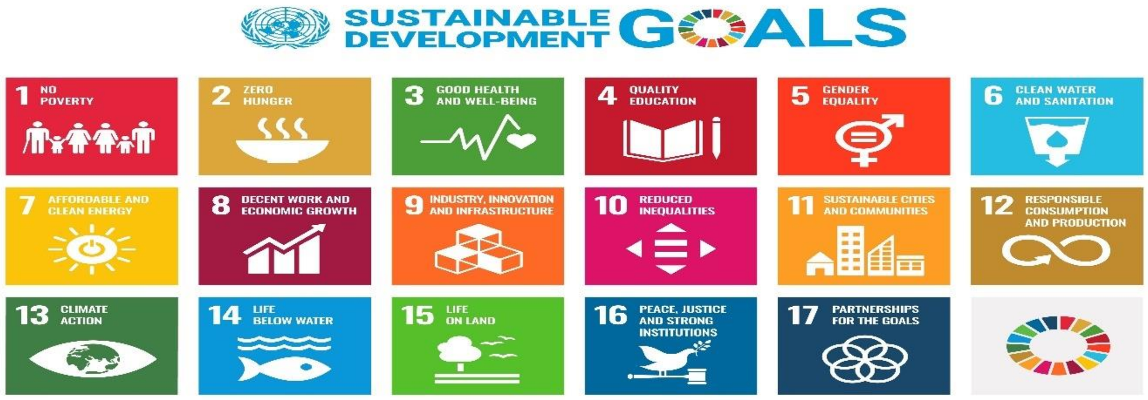
There are four different types of VLFS such as Megafloat, Mobile Offshore Base (MOB), Pneumatically Stabilized Platform (PSP), and Versabuoy. Regardless of the VLFS design, VLFS has two main advantages over traditional solutions for land recovery: cost and low environmental impact. (Lamas et al., 2013; Lamas-Pardo et al., 2015; Wang & Tay, 2011). Floating structures cost less when the water depth is sizable (30 Meters or more). As floating designs are easier and faster to carry out, economic benefits are reaped. Floating structures are easy to expand and disassemble if required due to the modular system. The construction of offshore mega-ports will make it easy for larger vessels to pass through, ensuring savings through economies of scale. As a result, comparatively modest ports will be benefitted as significant vessel traffic will be discharged at mega ports. Containers from mega-ports can be transported through smaller vessels to ports much closer to their final destination, thus increasing short-sea shipping (Fousert, 2006; Lamas-Pardo et al., 2015; Wang et al., 2008).

The environmental impact of VLFS is minimal. VLFS are environment-friendly because no permanent structure is installed over the sea bed. As a result, these structures do not damage ecosystems and interrupt marine currents. The VLFS structures are protected from seismic impacts because they are isolated from the base. Such a structure's position on water is also constant and unaffected by tides. For being immune to rising sea levels, floating solutions utilizing VLFS technology have been embraced by land-scarce countries such as Singapore, Monaco, the Netherlands, and Japan. Large floating piers are also suitable for marine sites with significant tidal variation. South Korea has built two sizable floating cruise ship piers in the Incheon Golden Harbor, where tidal variation can be 10 meters. In Japan's Ujina port, a few floating piers have operated for a few decades. Alaska has a floating prestressed concrete terminal dock. It is foreseen that many floating ports will be built as ships get longer and heavier than before, and longer wharves and deeper water depths are needed for berthing (Jung et al., 2019; Lamas-Pardo et al., 2015; Riyansyah et al., 2010; Wang et al.,2008; Wang & Wang, 2020).

Wang and Wang (2020) explained how floating structures can significantly contribute to achieving several sustainable development goals (SDGs). Traditional approaches to coastal urbanization and land reclamation conflict with SDG 14 (Life Below Water), SDG 15 (Life on Land), and SDG 11 (Sustainable cities and communities) because these approaches destroy marine ecosystems by destroying habitats, fragment coastal environments, alter natural wave patterns, harm aquatic life, destroy land ecosystems as materials for these projects are often extracted from earth leading to habitat degradation. Floating structures responsibly address this coastal urbanization and land reclamation to tackle urban space shortage while mitigating the impact on marine ecosystems, harnessing clean energy, and supporting sustainable communities, directly aligning with SDG 11, SDG 14, and SDG 15 goals. Floating structures can harness clean energy through wind turbines, floating solar farms, wave energy converters, and ocean thermal energy conversion exploitation, reducing dependency on fossil fuels and biomass for energy generation while attaining SDG 7(Affordable and Clean Energy) and SDG 13 (Climate Action). Establishing floating desalination plants achieves SDG 6 (Clean water and sanitation). Floating structures can also support the blue economy through installations for tourism, cultural space, and fish, vegetable, and dairy farming, achieving SDG 9 (Industry, innovation, and infrastructure) (Wang & Wang, 2020).

Figure 1

The Global Goals of Sustainable Development



Note: The figure includes UN Sustainable Development Goals. https://www.un.org/sustainabledevelopment/news/communications-material/. *In the public domain*

2.4 The Role of Maritime Logistic Hub in Container Transshipment

Maritime logistics involves planning, implementing, and managing the movement of goods and information through ocean carriage, highlighting the role of marine transportation in global logistics and supply chains. Maritime logistics is strategically significant in logistics integration. Shipments from varied origins are consolidated at major terminals named hubs, and these shipments are redirected to their destinations through radial links called spokes. The logistics hub concept is represented by varied terminologies such as logistics center, logistics zone, distribution center, warehouse, and intermodal terminal. According to Nam and Song (2011), A maritime logistics hub serves as a nodal point of cargo transit or transshipment, assuring flawless door-to-door cargo movements, a principal distribution center functioning as temporary storage and sorting and a place creating and facilitating value-added services on the regional and international scale. The growth of containerization traffic has led shipping lines to focus on acquiring Ultra Large Container Vessels (ULCVs) to gain the advantages of economies of scale while attracting the interest of influential shippers with a variety and volume of products to be shipped. The movement of large vessels geographically restructured sea transport by dividing container ports into hub and feeder ports, as few hub ports can accommodate ultra-large vessels (Cavinato, 1989; Fremont, 2007; Lu, 2000; Nam & Song, 2011; Panayides & Song, 2008).

Notteboom and Rodrigue viewed traditional seaports as infrastructure hubs for receiving ships and handling cargo between ship and shore. However, ports increasingly play a crucial role in managing materials and information within the supply chain, with a growing emphasis on their ability to provide value-added logistics services. For this reason, Nam and Song (2011) proposed that hub ports, especially container ports, should be evaluated based on their TEU throughput and their connections with shipping lines regionally and globally. They suggest applying network-based analyses in the context of maritime logistics hubs (Carbone & De Martino, 2003; Nam & Song, 2011; Notteboom & Rodrigue, 2005; Paixão & Marlow, 2003).

Shifting from a multiple gateway system to a single hub and feeder model requires careful investigation. Hub-and-spoke networks offer significant economies of scale but may incur additional expenses, such as feeder charges and container lift fees. Transshipment hubs develop in regions with favorable geographic and market conditions (Notteboom, 2010). The design of liner services, including the number and order of port calls, is critical (Notteboom, 2006). Though

Baird's (2006) cost model supported the development of a transshipment facility at the natural deep-water harbor at Scapa Flow in the Orkney Islands, the concept has yet to get traction in the European context (Baird, 2006; Notteboom, 2010). In contrast, Nottebom (2010) demonstrated that South African import and export cargo has a slight cost disadvantage when relying on a hub port configuration due to the high cargo transshipment rate and terminal handling cost. The success of the hub configuration depends on the chosen hub becoming an efficient, cost-effective, and well-serviced hub (Notteboom, 2010). Ishfaq and Sox (2012) showed that the availability of sufficient hub resources is a significant determinant of the network structure. A lack of adequate hub resources can considerably increase the dwell time of hub shipments, consequently discouraging the use of inter-hub shipments. Increasing the inter-hub shipment discount factor did not significantly increase hub flows due to limited hub resources (Ishfaq & Sox, 2012).

2.5 Enhancing Supply Chain Reliability through Hybrid Mode

Offshore logistics islands can improve supply chain reliability by avoiding the risks and delays associated with congested mainland ports. Shippers historically struggled with balancing cost and transit time in intercontinental freight decisions. The growing importance of transit time reliability, fuelled by just-in-time delivery and lean supply chains, has intensified this dilemma. Congestion at container ports, exacerbated by labour issues, trucking problems, and chassis shortages, has escalated uncertainty in ocean-based transport (Khouri, 2015; NCFRP, 2011; Whelan, 2015). A hybrid model that combines ocean vessels, vertical take-off and landing (VTOL) aircraft, and offshore ports, providing a cost-effective compromise. This option is cheaper and slower than air transport yet faster and more reliable than traditional ocean routes. Hyland et al. (2020) devised a mathematical model to determine the shipper value of time (VOT), pinpointing when the hybrid option becomes favourable. Sensitivity analysis underscores the strategic importance of offshore port and onshore facility locations in enhancing competitiveness. However, this study needed to assess the cost-effectiveness of this hybrid mode. This route is especially beneficial for shippers prioritizing transit time reliability, ensuring smooth operations and fewer disruptions (Hyland et al., 2020).

2.6. Location Selection for Floating Container Terminals (FCTs)/Hubs

Hub port location plays a vital role in optimizing liner shipping networks by affecting the allocation of feeder ports and route planning. Transshipment hubs enable container consolidation, achieving economies of scale due to the use of large container ships. These hubs and transshipment operations are essential for growing container shipping networks (Cheng & Wang, 2020; Corey et al., 2022; Imai et al., 2006; Kavirathna et al., 2018). Corey et al. (2022) developed two mixed-integer linear programming models with single and multiple allocations of feeder ports to regional hub ports to select locations for regional hub ports in the Caribbean Sea. Jamaica or the Bahamas was selected as a potential regional hub port in the Caribbean Sea region (Corey et al., 2022). Kavirathna et al. (2018) identified and categorized the criteria for hub location selection, including monetary, time, port traffic, location, operation, and liner-related factors. It was concluded that shipping lines operating within a hub and spoke network strongly emphasize operational efficiency, time performance, and the availability of feeder services when selecting transshipment hub ports. Based on these factors, Singapore can best serve as a hub for the Southeast Asia region, particularly concerning the Bay of Bengal and the East-West trunk sea route.

The single-allocation hub-and-spoke network model consists of two problems: hub location and configuration (An et al., 2015). Baird (2006) compared established ports (e.g., Le Havre and Hamburg) and the proposed transshipment terminal at Scapa Flow in the Orkney Islands. This analysis established that container ports in Northern Europe are inefficient for transshipment, suggesting that a new hub at Scapa Flow could significantly reduce costs by minimizing mainline ship deviation distances and enhancing overall operational efficiency, aligning with global trends towards optimized port locations. Huang et al. (2022) used a 0–1 nonlinear programming model with particle swarm optimization (PSO) to optimize hub-and-spoke network design, focusing on efficiency and resilience amid hub port failures and congestion. They identified vital hub ports and backups for Asia-Europe trade: Kaohsiung (Backup hub: Xiamen), Singapore (Backup hub: Kaohsiung), Le Havre (Backup hub: Laem Chabang), and Felixstowe (Backup hub: Singapore), aiming to minimize transportation costs and ensure reliable container flow during disruptions (Huang et al., 2022).

The number of offshore port projects is expected to rise due to the growing interest in alternative port systems in response to the development and growth of the container industry and container ship size. As the port is a critical node of export and import for cargo transportation and distribution, the proper location selection for an offshore port is not only associated with the operations and competitiveness of a country’s foreign trade. However, it is also highly connected to developing the country’s economy. The offshore port system comprises mooring facilities far from shore, where vessels can be berthing, mooring, and cargo handling. The farther facilities are located from the shoreline, the lesser dredging required for initial and maintenance constructions of the water areas, and environmental impacts are therefore minimized, but construction and operation costs for the facilities and transportation means might be increased, and more complex weather attacks to the port activities (Ablanedo-Rosas et al., 2010; Jiang et al., 2018; Kurt et al., 2021; Minh et al., 2023).

Minh et al. (2023) identified seven offshore locations (1–7) around Cua Lo, Vietnam, evaluating them based on wave, current, sediment, sub-soil, current use, environmental factors, construction costs, and operational costs. Using a multicriteria decision-making (MCDM) approach, specifically the Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), alongside simulation-based modeling and life cycle costing (LCC), Location 1 was deemed optimal. Meanwhile, Location 5 proved the most cost-effective, balancing construction and operational expenses with port efficiency. Kurt et al. (2021) analyzed ten locations for an offshore container port (OCP) on the west coast of North America, aiming to optimize the container shipping network for the USA, Canada, and Mexico. They selected the San Pedro and Oakland sites for shorter distances from other ports. Oakland emerged as the most cost-efficient hub based on Cost/TEU. The proposed OCP would be approximately 40 nautical miles offshore, with the distance to shore ranging from 15–60 nautical miles, as suggested in projects like the Portunus Project and Venice Offshore Onshore Port System (VOOPS) (Keefe, 2015; Kurt et al., 2021; Minh et al., 2023; Wampler, 2010).

2.7. Triple Bottom Line (TBL) of Sustainability

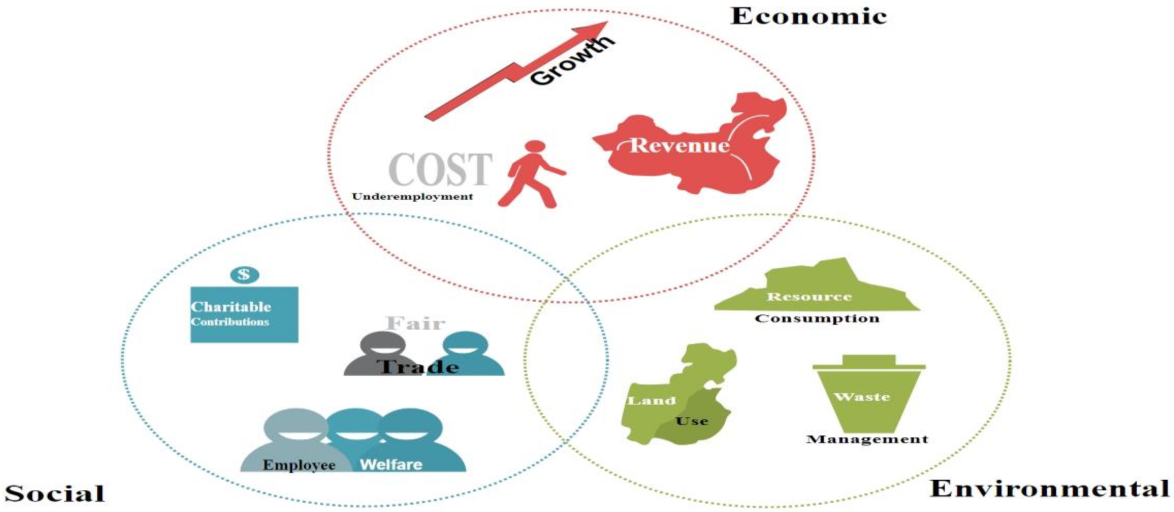
Sustainability is meeting the needs of the present without compromising the ability of future generations to meet their own needs. Elkington revealed the need to evaluate the performance of three basic dimensions of sustainability such as environmental, economic, and social dimensions, to make sustainability operational and named this the "triple bottom line (TBL) approach"

(Elkington, 1998; Özispa, 2021). The TBL dimensions are called the three Ps: people, planet, and profits. **(**Karakasnaki et al., 2023; Slaper & Hall, 2011). Assessing sustainability within the context of TBL is challenging as it is difficult to attribute performance to particular sustainable practices within the supply chain. Moreover, the lack of a systematic and integrated performance measurement framework hinders the effective deployment of sustainable practices. It has been found that industry experts tend to give the most importance to the economic dimension and the least importance to the social dimension. Contrarily, academic experts equally emphasized all three dimensions of TBL (Ahi & Searcy, 2015; Kuik et al., 2017; Laosirihongthong et al., 2019).

Financial/Economic sustainability concerns the cost-benefit analysis of an industry that aims to be profitable while producing products and services that contribute to society. The economic dimension of the bottom-line deals with the flow of money, such as generating revenue, controlling expenditures and taxes, maximizing profit, and generating employment. The environmental dimension of sustainability includes reducing negative impacts on the environment and protecting nature and ecosystems. It incorporates air and water quality, energy consumption, natural resources, solid and toxic waste, and land use/land cover. The social dimension of sustainability primarily focuses on human development. It also deals with cultural and social necessities like the permanent establishment of basic requirements such as food and shelter, security, equality, health, freedom, education, and employment. The social dimension of TBL refers to an organization's operations' impact on its stakeholders, including employees, customers, communities, and society. The International Maritime Organization (IMO) recognizes the pivotal role of maritime and actively promotes the 2030 Agenda for sustainable development, encouraging actors in the shipping industry to enhance their economic, environmental, and social sustainability (IMO, 2017; Özispa, 2021; Slaper & Hall, 2011; Tamplin, 2024).

Figure 2

Triple Bottom Line (TBL) of Sustainability



Note: https://en.wikipedia.org/wiki/Triple_bottom_line. In the public domain.

2.8 Economic Benefit of Floating Container Terminals (FCTs)

Ports and economic development are intertwined. Port development is an essential element of infrastructure development for economic growth. However, port development establishes forward and backward links with the rest of the economy by streamlining import-export and attracting companies to its hinterland. A study by Chudasama critically concluded that economic growth in the hinterland economy would affect cargo traffic at ports, making them more competitive (Azmi & Arof, 2022; Chudasama, 2020). Port authorities and governments are interested in offshore ports because they are challenged with increased dredging costs to allow ultra-large container vessels. Floating container terminals can provide numerous economic benefits, particularly for ports handling growing vessel sizes and high transshipment volumes (Pachakis et al., 2017). Deploying FCTs can improve economic port expansion by integrating into existing inter-terminal transport networks, establishing efficient direct connections to the hinterland through coastal and inland waterways, and effectively relieving port congestion caused by ultra-large vessels (Assbrock et al., 2020).

Floating container terminals provide a sustainable, economically viable solution aligned with the demands of expanding maritime logistics (Kurt et al., 2021). An enormous cost associated with accommodating ULCVs, estimated at around US$0.4 billion annually, covers equipment, dredging, and port infrastructure and poses significant financial burdens on ports (Azmi & Arof, 2022). Offshore container terminals offer a more flexible, lower-cost alternative, potentially reducing capital costs by up to two-thirds compared to land-based terminals of equal capacity. For example, constructing a floating terminal at around €50 million is significantly less than the €150 million needed for an equivalent land-based terminal, translating into shorter payback periods of approximately seven years versus the typical 20-year span of land terminals (Baird & Rother, 2013). Furthermore, FCTs provide operational cost savings due to the streamlined transshipment processes, lower equipment needs, and shorter port times for mega-ships. With reduced variable and operating costs, FCTs are economically advantageous, driving down per-container costs by leveraging economies of scale. The offshore terminal configuration minimizes transportation costs per TEU by approximately $300–$400 along significant routes, further promoting cost efficiency (Cullinane & Khanna, 2000; Kurt et al., 2021; Lindstad et al., 2012; Merk, 2015; Slack et al., 2017; Stopford, 2008).

2.9. Environmental benefits of FCTs

According to Pachakis et al. (2017), governments are increasingly interested in offshore ports to avoid increasing dredging costs and allow for ever-larger vessels. Land scarcity for port expansion, lack of landside infrastructure, and the need to protect ecologically and historically important areas are also significant concerns for the government. The offshore terminals can create new jobs, benefit the economy, and help the environment. It has been estimated that choosing the Port of Venice floating terminal will result in spending five fewer days at sea and cutting greenhouse emissions 97 CO2 kg less for each container transported to Munich via Venice instead of a Northern Europe port. Moreover, it will reduce the need to dredge the port channels, save money, help the environment, and increase the safety of navigation in the lagoon.

The environmental benefits of offshore establishments are yet to be identified, and there is not enough benchmark to measure against the alternatives (Lüth & Keles, 2024). Most environmental impact mitigation strategies related to port activities focus on onshore power supply, alternative fuel, reduced speed in waterway channels, and reduced turnaround time at berth (Yun et al., 2018). Chang and Jhang (2016) used an activity-based model to calculate fuel consumption and emissions of ships entering Kaohsiung Port, and results show that CO2 emissions can be reduced by about 40% after decreasing the speed to 12 knots (Yun et al., 2018). Winnes et al. (2015) analyzed and forecasted ship emissions in the Port of Gothenburg for 2030, showing that the emissions at berth are most efficiently decreased with the reduction of ships' berthing time. The environmental impact of SO2 from feeder container shipping is less damaging than road haulage as most of the emission occurs at sea out of populous areas. However, feeder service involves many port calls. Furthermore, the emission figures presented measure the two modes' SO2 efficiency in grams per TEU-km and conclude that maritime transport is generally more efficient than road haulage in terms of greenhouse gas emission (Svindland, 2016; Svindland & Hjelle, 2019). As FCT integration increases short sea feeder service, competes efficiently with road transportation networks, reduces berthing time, and involves low-speed feeders in the shipping network, it can be said that FCT has potential environmental benefits.

2.10. Social Benefits of FCTs

Traditionally, seaports as transport nodes generate remarkable social costs due to the emissions of pollutants and gases by ships and the operation of the port hinterlands. Other externality costs include road accidents and congestion in urban areas (Karimpour et al., 2020). Many have moved out of city areas, leaving the port city with less direct economic benefit. Negative local impacts, such as air, water, noise pollution, and traffic congestion in regional areas, remain to some extent (Karimpour et al., 2020). The total social cost of treating the CO2 emission and the opportunity costs for coping with all air pollutant emissions in the inefficient port cities are enormous. In particular, the average social cost is approximately 2 billion euros, and the average opportunity cost is roughly 60.8 billion USD (Hsu et al., 2023). Society benefits from offshore infrastructures primarily from reduced emissions, improved health, the transition to renewable energy, and the creation of jobs along coasts and at harbors in the North Sea region (Lüth & Keles, 2024).

The quality of the supporting infrastructure plays a significant role in ensuring added economic value and global competitiveness (Bensassi et al., 2015). Isolated and remote islands face challenges such as high transportation costs, limited access to goods, and delays in logistics, which hinder efficiency and increase costs (Amin et al., 2021; Briguglio, 1995; Pelling & Uitto, 2001). The floating logistic support facilities can serve as hubs for cargo operation and storage for distributing goods to small islands. The floating terminal solutions will enable remote populations to overcome geographical limitations and contribute to remote islands' economies and welfare (Gurning et al., 2022). The floating terminal could serve as a disaster relief hub, particularly in coastal areas where land access is difficult and time-consuming (Azmi & Arof, 2022). Floating terminals would be beneficial not only for port purposes but also for offshore energy production, aqua farming, and possibly as a future living location (Souravlias et al., 2020).

3. Methodology

This study seeks to determine the sustainability of floating container terminals (FCTs) in meeting global maritime demands through a network model that minimizes total operational costs. By configuring FCTs as hubs for smaller ports, the study optimizes their placement based on monthly FCT capacities and spoke port demands. A mathematical model was developed to find optimum locations for FCTs as hubs to minimize total cost. These findings will quantify the economic and environmental benefits of FCT integration, while a literature review will provide insights into potential social advantages.

3.1 Research Strategy

Research is the methodical use of scientific methods to examine a specific issue or research subject. "Research is a systematic inquiry to describe, explain, predict, and control the observed phenomenon," according to American sociologist Earl Robert Babbie (Fleetwood, 2024). A *research design* is a framework or structure for data gathering and analysis. The type of research question addressed influences the choice of research design, which reflects choices on the weight assigned to various aspects of the research process (e.g., generalization and causality) (Bryman, 2016).

Research strategy is the general orientation to the conduct of research. Quantitative and qualitative research are the two broad clusters of research strategy. Quantitative research can be represented as a research strategy that emphasizes quantification in the collection and analysis of data and that entails a deductive approach to the relationship between theory and research, in which the accent is placed on the testing of theories. The quantitative strategy incorporates the practices and norms of the natural scientific model and the positivist paradigm. By contrast, qualitative research is a strategy that usually emphasizes words rather than quantification in the collection and analysis of data. The interpretivist paradigm is often used in research conducted using qualitative methods. It refers to the subjective meaning of social action and the understanding of human behavior instead of explaining human behavior. Research strategy, design, or method choices must be tailored to the research question being investigated (Bryman, 2016).

3.2 Research Method

A research method is simply a technique for collecting data. Research methods are associated with different kinds of research design. Research design is explained as the framework of the research itself, including the collection and analysis of data. However, it shall not be mixed with research methods, which refers to the specific techniques used to collect data. Research design describes the overall nature of the research and reflects on the decisions about the priority given to different dimensions of the research process (Bryman, 2016). As this research focused on achieving sustainability dimensions with optimization of cost and reducing carbon emission through identifying optimum locations for FCTs as hubs, this research had both descriptive and predictive orientation.

3.2.1 Descriptive Research

Descriptive research is an exploratory method that helps a researcher describe a population, circumstance, or phenomenon. It does not involve changing the study variables or seeking to establish cause-and-effect relationships. Its primary significance lies in its ability to provide a comprehensive overview of a phenomenon, enabling researchers to understand the variables at play. This method aids in forming hypotheses, generating insights, and laying the groundwork for further in-depth investigations. It is often employed in the initial stages of a study before progressing to more complex research designs (Singh, 2023).

Descriptive research can be both quantitative and qualitative (Singh, 2023). To get a detailed understanding of the maritime shipping industry, we gathered information related to container ports, the capacity of different container ports, container traffic, hub ports, spoke ports, shipping routes, shipping networks, mother vessels, feeder vessels, operational costs, labor costs, fuel costs, currency exchange rates, travel distance, travel time, different sizes of ships, travel speed from varied sources. Gathering knowledge from different sources and scientific literature regarding carbon emission, sustainability concerns, the need for sustainable solutions, upcoming innovations related to ports, and their impact were also part of our descriptive research, which helped us craft our research question. The literature review in our study focused on different themes within the maritime sector, more precisely within various floating innovations and container terminals. Based on the overview of the maritime shipping industry in Northern Europe, a self-descriptive network diagram was drawn, and nineteen ports were selected and ranked according to their monthly capacity. While doing a literature review, we could also understand FCT's social impact.

3.2.2 Predictive Research

Predictive research is mainly concerned with forecasting (predicting) outcomes, consequences, costs, or effects. This type of research tries to extrapolate from analyzing existing phenomena, policies, or other entities to predict something that has yet to be tried, tested, or proposed. A Predictive research project often asks how - or how well – something might work or what the impact of something might be. Predictive research is often more hypothetical, theoretical, or experimental – it concerns ideas that have not been tried and did not previously exist (Wollman, n.d.).

Predictive analysis is extensively used in businesses to predict the future. Predictive research is primarily quantitative and needs historical data to forecast future trends. For predictive analysis, it is necessary to feed it with historical, real-life scenario examples (Efe, 2024). Location decisions always have a financial impact on profitability. There are different quantitative ways to decide locations (Singla, 2018). In this predictive research, a mathematical model was formulated based on the Facility Location Model (FLM) to minimize the total cost of maintaining a network of FCT hubs. Facility location model (FLM) is a quantitative model of location science. Facility location models are designed to consider the number of facilities to be located, the place of facilities to be located, the capacities of facilities to be located, and the rule of allocating the demands to facilities for service (Church & Murray, 2018; Daskin & Owen, 1999; Liu et al., 2021). Daskin and Owen (1999) listed five trends for facility location problems, including multiple objectives, stochastic inputs, dynamic decisions, vehicle routing considerations, and network interaction with facility locations (Daskin & Owen, 1999; Liu et al., 2021).

3.3 Model Formulation

The Facility Location Problem (FLP) involves selecting a suitable subset of potential locations from a given set of demand centers (spoke ports) and potential facility sites (floating container terminals, FCTs). The cost of opening each facility (FCT) and servicing demand centers (spoke ports) from distant facilities (FCTs) should be considered while choosing the subset. The number of facilities (FCTs) required to service the demand centers (spoke ports) from short distances may vary from few to many. The objective is to select the subset that minimizes the total cost (Megiddo & Tamir, 1982; Vargas-Santiago et al., 2023).

In the context of floating hubs for transshipment, the FLP can be used to find locations of the FCTs. The goal is to arrange the FCTs as transshipment hubs in the North Sea and the Baltic Sea with the smallest number of hubs while still guaranteeing demand fulfillment of the spoke ports and minimizing the Total cost (Fixed facility cost and variable shipping costs).
To formulate the facility location for FCTs through a mathematical optimization model, “m” spoke ports and “n” floating container terminal (FCT) locations were considered.

Sets:
F: The set of floating container terminal locations, indexed on i= 1,2,3……n
D: The set of spoke ports, indexed on j= 1,2,3……….m

Parameters:
Facility cost, fi; fixed cost of operating floating container terminal i.
Capacity ki; capacity of floating container terminal i.
Here, n is the potential number of floating container terminals.

$x_{ij} \geq 0$, where spoke port "j" is serviced through the floating container terminal "i."

The binary Variable is yi =1 if a floating container terminal is established in location i. yi=0 if a floating container terminal is not constructed in location i.

Demand= Dj; Monthly demand from spoke port j.

Here, m is the number of spoke ports.

Cost, Cij: Transshipment Cost of 1000 TEU containers from floating container terminal i to spoke port j (including fuel and personnel costs).

xij = Quantity of 1000 TEUs transshipped from floating container terminal "i" to spoke port "j."

Objective Function: Minimize total cost

Total Costs = Fixed Facility Costs + Variable Shipping Costs

$$Min \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} x_{ij}$$

Constraints:

All established floating container terminals (FCTs) have only a capacity of Ki

All spoke port markets should be satisfied.

Opening an FCT is an all-or-nothing decision.

The transshipment quantity should be non-negative.

$$\sum_{i=1}^{n} \text{Xij} = \text{Dj for } j = 1,2,3 \ldots\ldots\ldots\ldots\ldots m \qquad (1)$$

$$\sum_{j=1}^{m} \text{Xij} \leq \text{KiYi} \quad for\ i = 1,2,3 \ldots\ldots.. n \qquad (2)$$

$$y_i \in \{0,1\}\ for\ i = 1, \ldots\ldots, n \qquad (3)$$

$$x_{ij} \geq 0\ for\ i = 1, \ldots.., n\ for\ j = 1, \ldots\ldots, m \qquad (4)$$

3.4 Data collection

Data collection is collecting and evaluating information or data from multiple sources to find answers to research problems, answer questions, evaluate outcomes, and forecast trends and probabilities. It is an essential phase in all research, analysis, and decision-making types, including that done in the social sciences, business, and healthcare. Researchers must identify the data types, sources, and methods used during data collection and determine the purpose of data collection.

Data can be divided into qualitative and quantitative types (Jain, 2024). Research must rely on primary and secondary data sources to analyze, organize information, and contribute to scientific knowledge. Primary data is obtained initially and is newly documented, while secondary data relies on existing sources. Collecting primary data means obtaining information directly from the source through surveys, questionnaires, interviews, observations, and experiments. Data collected from secondary sources is information already collected by someone else and is readily available for use by other researchers. Secondary data sources include existing literature, government and institutional reports, historical and public records, and statistics (Stewart, 2024).

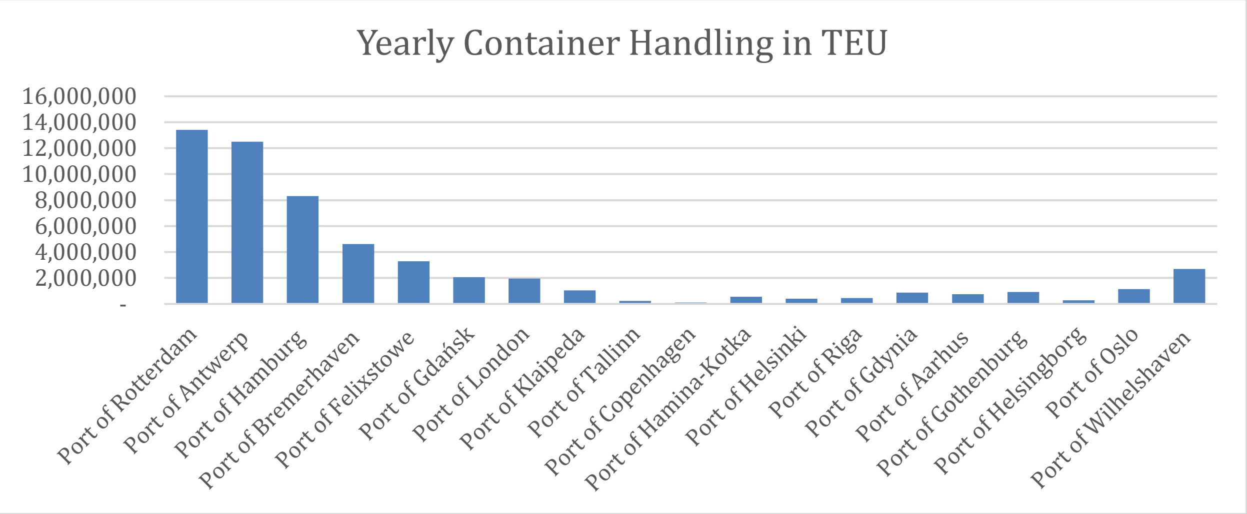
3.5 Steps in data collection

As our research includes descriptive and predictive approaches, we must collect substantial data to understand the research area and gap and answer the research question. We heavily depended on secondary data to conduct our research. Academic databases, such as Lund University's library database LUBSearch and Google Scholar, aided the search for data. Keywords such as maritime shipping, container port, offshore port, location, transshipment hub, sustainability, and triple bottom line were used. Data was gathered from peer-reviewed articles, books, and reports of international organizations such as the EU, IMO, and UN. The data from previous research by other researchers, including qualitative and quantitative information, eventually resulted in a literature review, creating a frame for this study and highlighting several different insights within the maritime shipping industry, especially within floating container ports, floating technologies, location, container hubs, benefits of floating hubs and sustainability. Through the literature review, we got insights regarding the social benefits of FCTs, which can contribute to achieving sustainability, and this helped us partially answer our research question.

We collected quantitative data to plug into our facility location model for our predictive research. Narrowing down the area of research, we decided to concentrate only on container ports of the North and the Baltic Seas. At this stage, the data collection was concentrated on port capacity, expressed as the annual throughput of containers in TEU. Port-specific data were collected from the port authorities ' websites, websites such as Maritime Analytica and Wikipedia, and websites of different international organizations. Based on container throughput, we selected and ranked nineteen ports (see “Appendix A”). Ten ports with high capacity were selected for probable locations for FCTs/hubs (supply ports) to cater to the demand of their respective adjacent ports and nine other smaller ports, which we termed spoke ports (demand ports) in our facility location model.

Figure 3

Major North and Baltic Sea Ports’ Yearly Capacity/Throughput

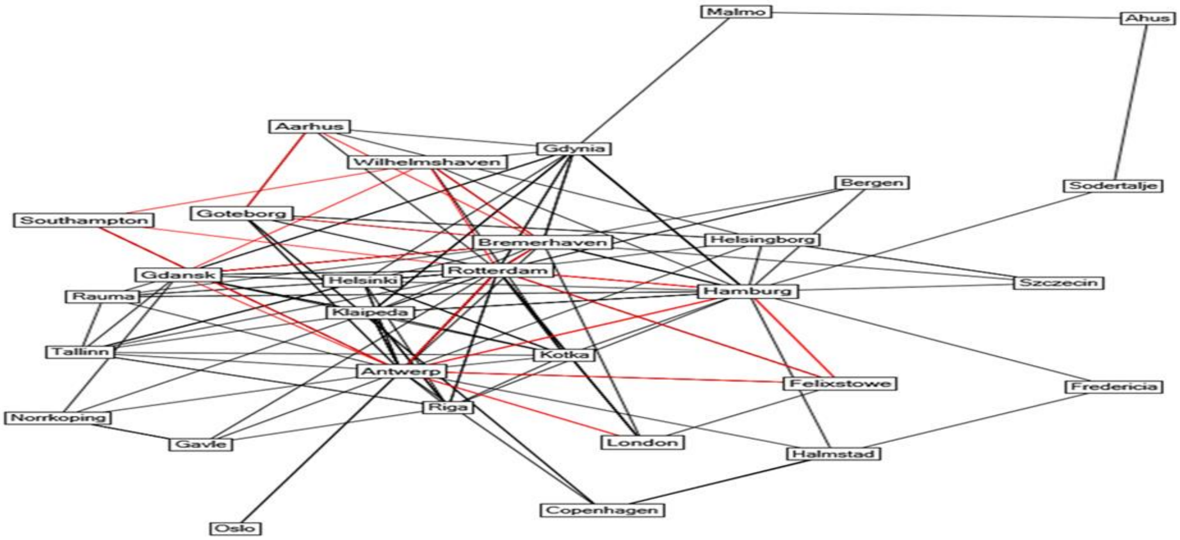


We further delved into the information regarding container traffic routes, ULCVs navigating through these routes, the capacity of these ULCVs in terms of TEU, and feeder services from large posts to small ports. Vessels' call statistics and traffic information (see “Appendix D”) were obtained from the Alphaliner website, provided by one of our thesis supervisors, Martin Svanberg, who works for RISE Research Institutes of Sweden, as we did not have access to the Alphaliner website. Based on vessels' call statistics and traffic information, we found that there is a direct call from Far-East Asia to Europe in the ports of Bremerhaven, Gdansk, Rotterdam, Goteborg, Aarhus, Wilhelmshaven, Felixstowe, Hamburg, Antwerp, Port of London.

We developed a network diagram (Figure 4) of the sea routes based on the Ultra Large Container Vehicle (ULCV) traffic from Far-East Asia to the Northern and Baltic Sea (Appendix D) with the help of NodeXL, which is a network analysis and visualization tool. We considered offshore locations near large ports with direct calls to be the probable locations of FCTs (supply ports). We denoted these locations as BRH, GDK, ROM, GTB, ARH, WSV, FLT, HBG, ATP, and POL based on their nearest direct call port and small ports without direct calls as spoke ports (demand ports). These network diagrams accompanied our selection of hubs and spokes based on container throughput. It is important to remember that an FCT will cater to the demand of the spoke ports, but it may also serve the nearest hubs.

Figure: 4

The Existing Network Diagram of Ports in North and Baltic Sea Based on Traffic Information



After considering probable locations for FCTs/hub ports and spoke ports and developing a mathematical model based on FLP to find optimum locations for FCTs at a minimum total cost, we needed to plug in the monthly demand of each spoke port (demand ports) and monthly capacity of each FCTs/hubs, fixed facility costs of FCTs and variable shipping cost (From different hubs to different spoke ports) in Excel to solve our mathematical model. To find optimum solutions from mathematical models with the help of an Excel solver, we had to make some assumptions and do some calculations to plug into Excel. We developed seven scenarios based on our assumptions regarding monthly capacity and monthly demand of hub and spoke ports. We also needed to develop a distance matrix (see “Appendix B”) and a variable shipping cost matrix (see “Appendix C”).

3.6 Assumptions

3.6.1 Size and speed of ships

The Ultra Large Container Vessels (ULCVs) speed ranges from 16 knots to 24 knots. These are some of the largest ships in the world, with a TEU capacity of over 14,501. The largest ships in this category can carry up to 24,000 TEU units. Ships change speed based on geographical factors, weather conditions, ocean currents, and routes. The average speed of a vessel to calculate shipping time depends on many factors. Ships do not travel at maximum speed. Most ships cruise the oceans at a sustainable speed (How Fast Does a Cargo Ship Go?, 2023). While calculating distances, it was assumed that ULCVs travel at an average speed of 19 knots between continents from Asia to Europe.

Feeder vessels are smaller freight ships transporting cargo between minor and significant ports, collecting containers from smaller ports and transporting them to transshipment hubs for further shipment. Feeder vessel size varies between 300 TEU and 3000 TEU in capacity ("What Are Feeder Vessels? Best Guide [+How to Book Slots]," 2023). It was also assumed that feeder vessels in our proposed networks would have an average capacity of 1000 TEU and an average speed of 14 knots in the North and Baltic Seas. Speed and travel time have an inverse relationship. The higher the speed, the higher the fuel consumption and fuel costs. Within Emission Control Areas (ECA), where fuel is considerably more costly, ships are bound to lower speed, which results in longer sailing time, less fuel consumption, and less greenhouse gas emissions (Fagerholt et al., 2015; Svindland, 2018).

3.6.2 Variable shipping costs

The trip duration from the FCTs to the spoke port is calculated based on a one-way trip from the FCTs to the spoke ports. The total transshipment cost of feeder vessels is considered the variable shipping costs in our model. Transshipment costs include fuel and personnel costs of feeder vessels. The personnel costs depend on the crew size and assumed salaries for skilled navigation personnel. According to Assbrock et al. (2020), the personnel cost per day is assumed to be € 2310/day, and the hourly personnel cost is € 96 per hour (2310/24, Considering 24 operational hours per day). The fuel cost of a feeder vessel with a capacity of 734 TEU is € 500/Hour. As a result, the fuel cost of a feeder vessel with 1000 TEU capacity is assumed to be € 681/Hour (500/734*1000). The total transshipment cost (personnel and fuel) for a feeder vessel with 1000 TEU capacity is € 777/Hour (96+681) (Assbrock et al., 2020).

A distance matrix (see “Appendix B”) of 10 probable locations of floating hub ports (supply ports) and 19 spoke ports (demand ports) of the North Sea and Baltic Sea is created based on hours needed for a one-way voyage at 14 knots for 1000 TEU feeder vessels. The distance matrix (See “Appendix B”) was calculated with the help of https://sea-distances.org/.The Variable shipping Cost matrix (see “Appendix C”) was calculated by multiplying the distance between a hub and a spoke port in terms of hours and hourly transshipment cost, which is € 777/Hour. For Example, the total variable shipping cost of transhipping 1000 TEU container from FCT/Hub in Rotterdam to spoke port in Helsingborg is = €42*777= €32634 based on the hourly distance between these two ports (see “Appendix C”).

3.6.3 Fixed facility cost

Fixed annual operating cost was considered fixed facility cost for FCTs. Depreciation cost was excluded for simplicity as fixed facility cost will not affect the locations of the hub ports as fixed costs are the same regardless of the location, as it is a floating port. It will be towed to the hub locations decided by the facility location model. Information regarding the fixed facility cost was provided by Sea Technology to the researchers of this study (see “Appendix E”). Sea Technology’s floating container terminals estimated annual fixed facility cost includes fuel costs, crewing costs, maintenance costs, other expenses, communication costs and insurance costs which is $95 Million (STFT Income and Cost, 2022). Estimated Annual Operating cost in Euro = $95Million*0.895512(Last ten years historical average exchange rate) (OFX, 2022) = € 85,073,640. Monthly Fixed facility cost = (€ 85,073,640/12) = € 7,089,470. In this research, the monthly fixed facility cost of € 7,089,470 was plugged into Excel to generate results from our mathematical model.

3.6.4 Monthly Capacity of FCTs/hubs in TEU

Port capacity measures the maximum throughput in tons, TEU, or other units a port and its terminals can handle over a given period. This maximum can be set by physical constraints or economic conditions where the marginal cost of additional throughput is prohibitive (Bureau of Transportation Statistics, 2017). Seven scenarios/strategies were assumed for the monthly capacity of FCTs. It was assumed that these FCT's capacity is physically constrained. It is expected that the main ports of Bremerhaven, Gdansk, Rotterdam, Goteborg, Aarhus, Wilhelmshaven, Felixstowe, Hamburg, Antwerp, and Port of London will be able to outsource some of the container handling activity to nearby FCTs to reduce congestion. FCTs can handle any container ships, but only the ULCVs (Having a capacity of 14501 TEU container handling and more) were considered to allocate monthly capacity to probable FCTs as they will act as transshipment hubs. It is also estimated that spoke ports will not handle ULCVs. Though ULCVs visited some other European and Russian ports as well, the capacity was allocated to the European ports of the Northern Sea and Baltic Sea only because of the intention to serve the spoke/demand ports of this region only.

In two of the scenarios (Scenario 1 and Scenario 3), it was assumed that different FCTs located in BRH, GDK, ROM, GTB, ARH, WSV, FLT, HBG, ATP, and POL locations will have different monthly capacity based on the need of their nearest existing ports. FCTs will at least be able to cater to all the ULCVs from Far-East Asia as their nearest existing main ports have direct calls from Far-East Asia. The total monthly capacity of these FCTs (see "Appendix G") in 1000 TEUs was assumed with the help of ULCV traffic data (see "Appendix D") and historical container handling capacity (see "Appendix A", "Appendix F") of their nearest ports. As ULCV routing data provided information regarding the average weekly capacity of ULCVs coming from China, we multiplied it by four to get a monthly estimation of ULCV capacity, which we used to allocate FCTs' monthly capacity (see "Appendix F"). As the monthly capacity of each ULCV traveling through this route was distributed to probable FCTs using the ratio of the historical container handling capacity of these FCTs' respective nearby existing ports to calculate the container handling capacity of these respective FCTs, the monthly capacity of each FCTs varied in scenario 1 and scenario 3(see "Appendix H," "Appendix I"). FCT near Rotterdam will have 439,000 TEU in monthly capacity, while FCT near Goteborg will have 3000 TEU in monthly capacity (see "Appendix F," "Appendix G"). These monthly capacities were included in the facility location model to obtain a Solver solution of optimal location/ locations (see "Appendix H," "Appendix I").

The second (see “Appendix J”) and fourth (see “Appendix K”) scenarios assumed that all FCTs would be constructed with a monthly fixed container handling capacity of 1000,000 TEU. In the fifth scenario (see “Appendix L”), it was assumed that all FCTs would be constructed with a monthly fixed container handling capacity of 450,000 TEU. Similarly, in the sixth (see “Appendix M”) and seventh (see “Appendix N”) scenarios, it was assumed that the FCTs would be constructed with a fixed container handling capacity of 417,000 TEU and 700,000 TEU, respectively, per month.

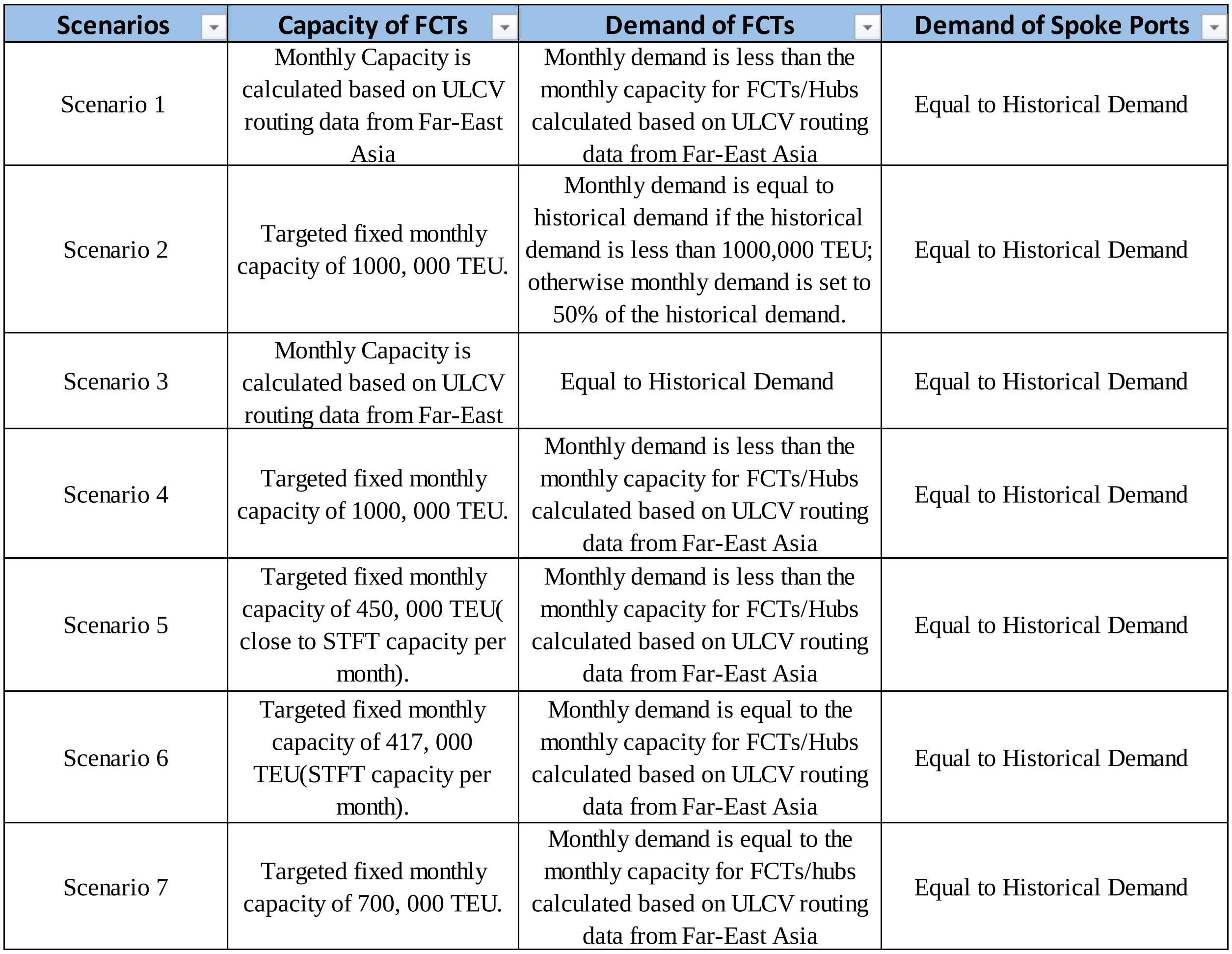
3.6.5 Monthly demand of FCTs/Hubs and spoke ports

Port demand can be measured in different ways, depending on the perspective. The most common measurements refer to cargo and shipping traffic handled within a specified period. The relationship between port capacity and port traffic demand is crucial. Increasing port capacity only sometimes leads to a proportional increase in port traffic. As port traffic approaches maximum efficient throughput, port user costs increase significantly, which can lead to decreased or stagnant traffic. Optimizing and expanding port facilities can reduce waiting times. Port overcapacity occurs when expanding a port does not stimulate increased demand, resulting in higher average port costs that harm the port's competitiveness (Notteboom et al., 2022; Yap, 2020).

Different monthly demand scenarios for FCTs were assumed to match the FCTs' monthly capacity in all seven scenarios. In all seven scenarios, the monthly demand of spoke ports is set to their monthly historical demand of 1000 TEU. These demands were plugged into Excel (see "Appendix H," "Appendix I," "Appendix J," "Appendix K," "Appendix L," "Appendix M," "Appendix N").

Table 1:

Capacity and Demand of FCTs and Demand of Spoke Ports in Seven Assumed Scenarios



Scenarios	Capacity of FCTs	Demand of FCTs	Demand of Spoke Ports
Scenario 1	Monthly Capacity is calculated based on ULCV routing data from Far-East Asia	Monthly demand is less than the monthly capacity for FCTs/Hubs calculated based on ULCV routing data from Far-East Asia	Equal to Historical Demand
Scenario 2	Targeted fixed monthly capacity of 1000, 000 TEU.	Monthly demand is equal to historical demand if the historical demand is less than 1000,000 TEU; otherwise monthly demand is set to 50% of the historical demand.	Equal to Historical Demand
Scenario 3	Monthly Capacity is calculated based on ULCV routing data from Far-East	Equal to Historical Demand	Equal to Historical Demand
Scenario 4	Targeted fixed monthly capacity of 1000, 000 TEU.	Monthly demand is less than the monthly capacity for FCTs/Hubs calculated based on ULCV routing data from Far-East Asia	Equal to Historical Demand
Scenario 5	Targeted fixed monthly capacity of 450, 000 TEU(close to STFT capacity per month).	Monthly demand is less than the monthly capacity for FCTs/Hubs calculated based on ULCV routing data from Far-East Asia	Equal to Historical Demand
Scenario 6	Targeted fixed monthly capacity of 417, 000 TEU(STFT capacity per month).	Monthly demand is equal to the monthly capacity for FCTs/Hubs calculated based on ULCV routing data from Far-East Asia	Equal to Historical Demand
Scenario 7	Targeted fixed monthly capacity of 700, 000 TEU.	Monthly demand is equal to the monthly capacity for FCTs/hubs calculated based on ULCV routing data from Far-East Asia	Equal to Historical Demand

For example, in the first scenario, the monthly demand of the FCTs is set to a lesser amount than the monthly capacity of the FCTs. For example, from the routing data of the ULCVs (see "Appendix G"), the BRH floating container port should have a monthly capacity of 31,000 TEU. The monthly demand for the BRH hub is assumed to be 30,000 TEU (see "Appendix H"). Similarly, all the other monthly demands for all the other FCTs were plugged into Excel (see "Appendix H"). In the second scenario, the monthly demand of FCTs is set to half of that port's historical demand if the historical demand of that port is more than 1,000,000 TEU; otherwise, the monthly demand is set equal to historical demand. For example, the monthly demand for ROM Hub is assumed to be 559,000 TEU as the historical demand for Rotterdam port is 1117,000 TEU, more than the targeted fixed monthly capacity of 1000,000 TEU (see "Appendix J"). In this manner, all the other monthly demands for FCTs were allocated and plugged into Excel with assumptions made in Table 1 for all the other scenarios (see "Appendix I," "Appendix K," "Appendix L," "Appendix M," "Appendix N").

3.7 Validity and reliability

Quantitative research is a systematic investigation process, primarily using numerical techniques (statistical, mathematical, or computational) to test hypothetical generalizations (AskanAcademic.com, 2019). Validity in quantitative research refers to the issue of whether an indicator (or set of indicators) is devised to gauge and measure that concept (Bryman, 2016). We tried to understand the benefits of FCTs in achieving sustainability through TBL. Our mathematical model tried to minimize total cost by serving selected spoke ports with a minimum number of hubs. As cost reduction results in profit maximization, the cost of Euro-gauged economic benefits is concluded as it indicates the minimum cost of maintaining the FCT network. We also calculated carbon emission reduction in terms of tons. This measurement also shows that our findings were able to capture environmental benefits. However, we could not gauge the social benefits of integrating FCT into the network. Internal validity estimates the degree to which conclusions about causal relationships can be made based on the research design (AskanAcademic.com, 2019). As the findings of this research draw some causal relationship between total cost, number of FCTs, and capacity of FCTs, we can conclude that our research has internal validity. External validity is the extent to which the results of a study can be generalized to other populations, settings, or situations; the results of this study have external validity as similar general findings can be obtained if the study was conducted considering other seas, regions, or networks.

Reliability refers to the consistency of the measurements or the degree to which an instrument measures the same with every use under the same conditions. Reliability is usually estimated using internal consistency – the relationship/correlation between test results or instruments (AskanAcademic.com, 2019). In this research, we, as researchers, were diligent in using the same unit of cost (Euro), capacity (TEU), and time (Monthly) to maintain the reliability of our findings. Moreover, we first operated the model with 25 spoke ports. However, to enhance the accuracy of results, we limited spoke ports to 19 ports as Excel Solver failed to generate results when many variables were involved. In our mathematical model, the number of FCT locations, the minimum total costs of maintaining the network, and the locations of FCTs will always depend on the variable shipping cost, fixed facility cost, the monthly capacity of different FCTs/Hubs, and the monthly demand of different hub and spoke ports in the network. As a result, our findings are reliable.

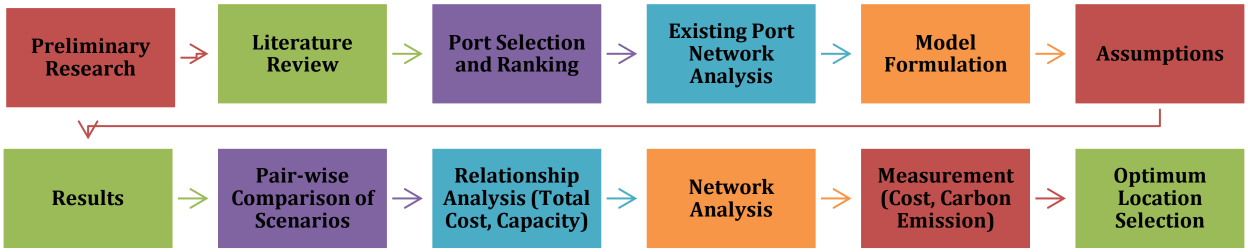
3.8 Data Analysis Techniques

In this research, we heavily depended on external websites for quantitative data, which we needed for measurement and assumptions. We used these websites to create a distance matrix in terms of hours, to know the currency conversion rate between USD and Euro, to calculate carbon emission in a particular voyage with feeder ships of different sizes, to measure transshipment cost reduction per voyage, to know the price of different sustainable fuels, to measure fuel consumption based on ship size and ship speed. In this research, we took help from previous research to estimate transshipment cost/hour through feeder vessels.

To analyze data, we mainly depended on Excel and Excel Solver. In this research, after generating results from the Excel solver, we measured whether transshipment cost reduction and carbon emission reduction from our proposed network exist. To measure these economic and environmental benefits, we depended on external websites for data, which we further analyzed through Excel. Our charts, graphs, and table composition helped us further analyze the results. We also developed network diagrams for five different optimum results for five scenarios with visualization tools such as NodeXL and the supply chain optimization app Log-hub, which further aided our analysis. To further generalize our findings, we made a pairwise comparison of scenarios to understand relationships among total cost, Total Cost/TEU, monthly capacity of FCTs, number of optimum FCTs, location of FCTs, and capacity utilization and distribution of different FCTs. The steps of this research are summarized as a workflow.

Figure 5

The simplified workflow of this research to find sustainability through optimal FCT Location



3.9 Ethical considerations

In order to perform ethical research, researchers must respect each participant's privacy and guarantee that participant information is kept private. Additionally, people must be able to choose whether or not to participate in the study, and participation must be entirely voluntary. Researchers must protect participants' health and well-being throughout the research process by not hurting them. Furthermore, the study must remain impartial and disclose potential conflicts of interest or prejudices (Bryman, 2016, p. 136).

Despite not having any actual respondents involved in this research, these principles have guided the authors through the research. To ensure the proper handling and protection of data, specifically, the data received from RI.SE, a non-disclosure agreement (NDA) between the authors and RI.SE were constructed and signed. The NDA guarantees the proper and safe treatment of data throughout the study project and its eventual transfer to RI.SE. The additional RI.SE data utilized in this study was obtained from openly accessible websites. Overall, the authors handled the gathered data carefully to guarantee integrity and prevent exploitation or dishonesty. The writers have adhered to ethical norms in their research method by being open and honest about their data sources throughout the project and adequately citing all quotes.

3.10 Methodological limitations

The facility location model is an optimization model that helps us minimize total cost and number of locations, transportation cost, increase capacity utilization, etc. As a result, this model helps us find locations that enable businesses to serve customers at minimum cost. However, the quantitative model sometimes identifies locations with high initial costs, ecological impact, and regulatory issues as optimum locations. The optimum locations should be complemented with qualitative research. Moreover, FLM cannot optimize if there are a large number of variables involved in the model. In this quantitative research, though we could somewhat predict and measure the economic and environmental sustainability dimensions of integrating FCTs in the shipping network, this quantitative model failed to capture the social dimension of sustainability.

4. Results

In the seven assumed monthly demand and monthly capacity scenarios, seven different optimum solutions were derived through Excel solver for the facility location problem, which was used to determine the optimum locations and minimum total cost for FCT networks, including both the fixed facility cost and variable shipping cost.

Table 2

Total cost of FCTs, Number of Optimum Locations, and Placement of Optimum Locations in Seven Assumed Scenarios

Scenario/Strategy	**Number of Optimal Location**	**Optimal Locations**	**Total Cost of the Floating Container Terminals (Fixed Facility cost + Variable Shipping Cost)**
Scenario 1	10	No optimal location, one hub should be constructed in all selected locations such as Bremerhaven (BRH), Gdansk (GDK), Rotterdam (ROM), Goteborg (GTB), Aarhus (ARH), Wilhelmshaven (WSV), Felixstowe (FLT), Hamburg (HBG), Antwerp (ATP), Port of London (POL).	€ 86,774,139.31
Scenario 2	**4**	**Close to Gdansk (GDK), Rotterdam (ROM), Antwerp (ATP) and Hamburg (HBG)**	**€ 49,666,548**
Scenario 3	10	No optimal location, one hub should be constructed in all selected locations such as Bremerhaven (BRH), Gdansk (GDK), Rotterdam (ROM), Goteborg (GTB), Aarhus (ARH), Wilhelmshaven (WSV), Felixstowe (FLT), Hamburg (HBG), Antwerp (ATP), Port of London (POL).	€ 89,466,327
Scenario 4	**2**	**Close to Gdansk (GDK), Rotterdam (ROM).**	**€ 27,186,807**
Scenario 5	**3**	**Close to Gdansk (GDK), Rotterdam (ROM), and Antwerp (ATP).**	**€ 33,094,515**
Scenario 6	**4**	**Close to Gdansk (GDK), Rotterdam (ROM), Antwerp (ATP) and Hamburg (HBG)**	**€ 37,430,352**
Scenario 7	**2**	**Close to Rotterdam (ROM)and Hamburg (HBG)**	**€ 31,583,850**

Figure 6

The Number of FCTs Needed to be Constructed in Seven Different Scenarios

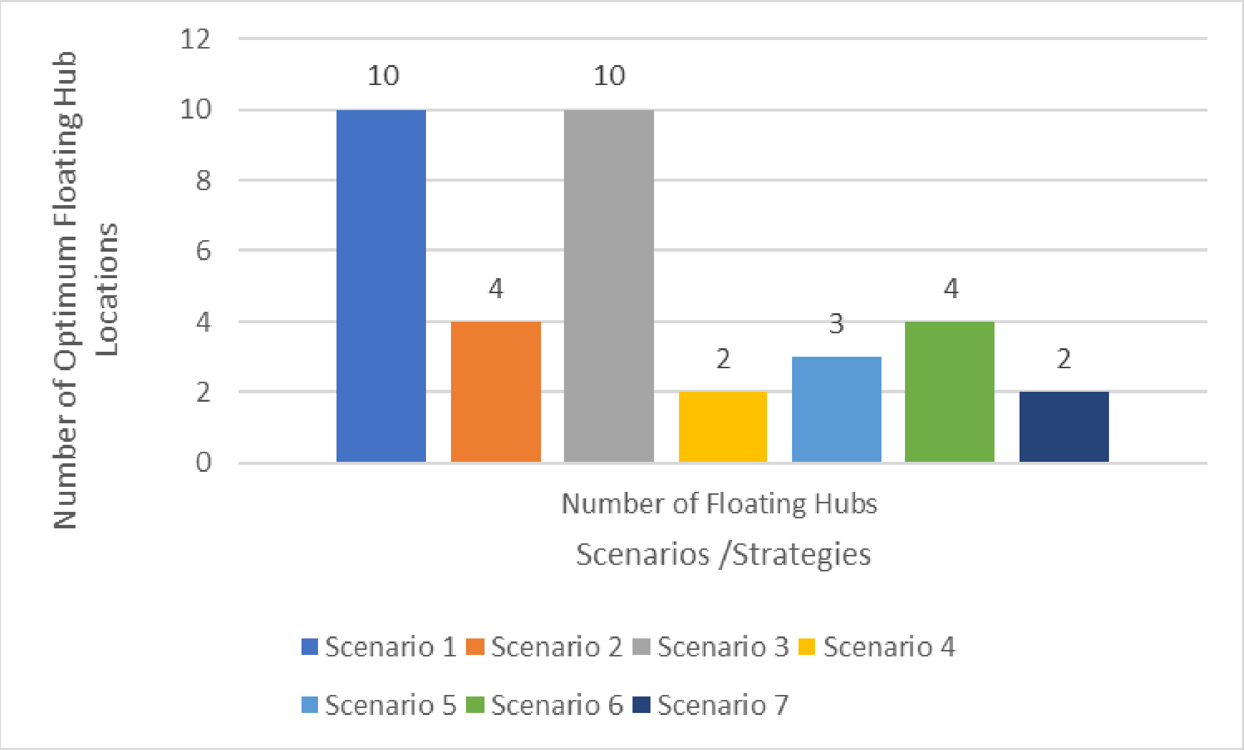
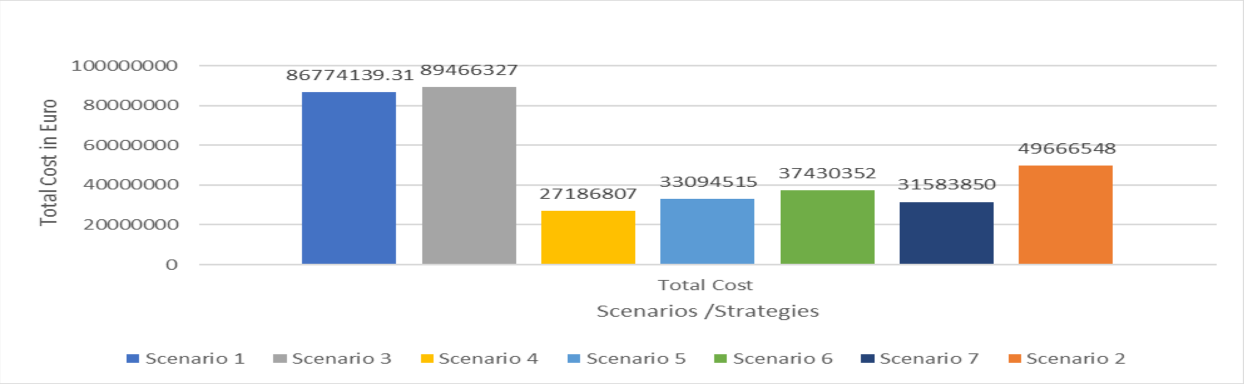


Figure 7

The Total Cost for Maintaining a Network of FCTs in Seven Different Scenarios



5. Data Screening

5.1 Scenario Analysis

Seven different scenarios were assumed based on the different monthly capacities of FCTS, monthly demand of FCTs, and spoke ports. From Excel Solver, seven different network configurations were obtained to integrate FCTs as hubs to serve the spoke ports optimally.

Table 3

A Snapshot of Seven Different Assumed Network Scenarios in Terms of Total Cost of FCTs, Capacity per Hub, Total Cost/TEU

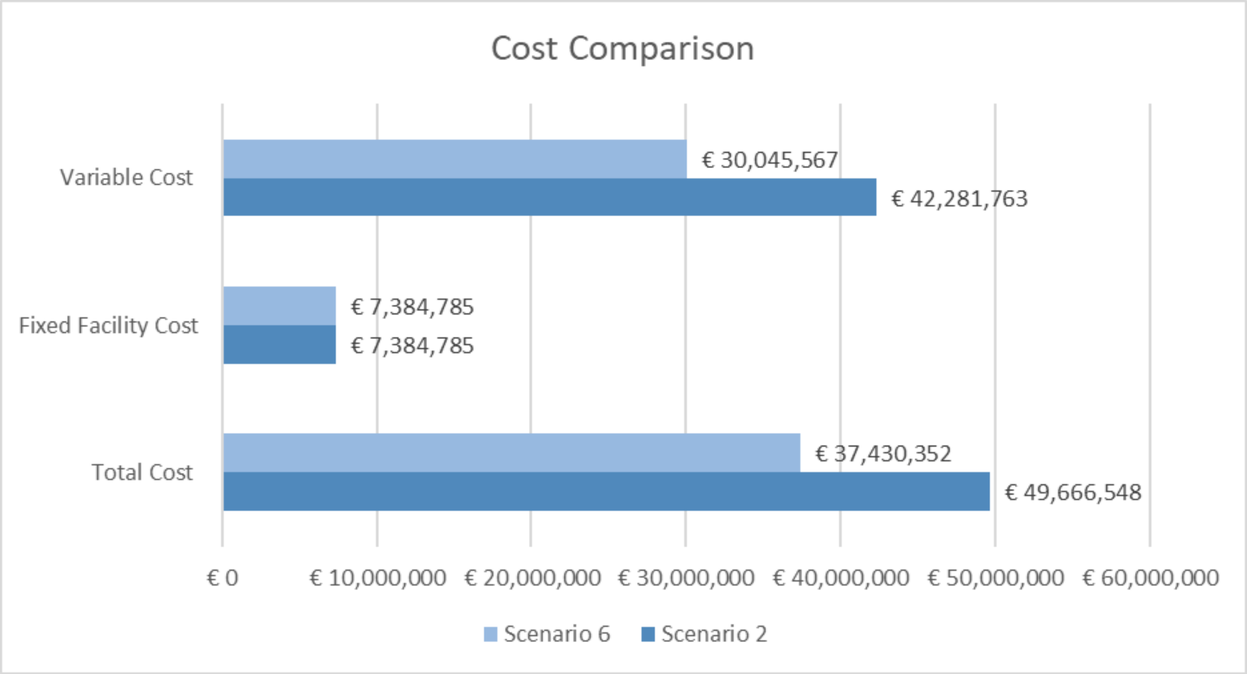
Scenario	Number of Optimal Location	Optimal Locations	Total Cost of the Floating Container Terminals (Fixed Facility cost + Variable Shipping Cost)	Fixed Facility Cost (Construction Cost of Floating Port)	Variable Shipping Cost	Total capacity (In 1000 TEU)	Capacity Per FCT/Hub (In 1000 TEU)	Total Cost / TEU (€)
Scenario 1 (Network A)	10	No optimal location, one hub should be constructed in all selected locations such as Bremerhaven (BRH), Gdansk (GDK), Rotterdam (ROM), Goteborg (GTB), Aarhus (ARH), Wilhelmshaven (WSV), Felixstowe (FLT), Hamburg (HBG), Antwerp (ATP), Port of London (POL).	€ 86,774,139.31	€ 7,384,785	79,389,354.31	951	95	91.25
Scenario 2(Network B)	**4**	**Close to Gdansk (GDK), Rotterdam (ROM), Antwerp (ATP) and Hamburg (HBG)**	**€ 49,666,548**	**7384785**	**42,281,763.00**	**4000**	**1000**	**12.42**
Scenario 3 (Network C)	10	No optimal location, one hub should be constructed in all selected locations such as Bremerhaven (BRH), Gdansk (GDK), Rotterdam (ROM), Goteborg (GTB), Aarhus (ARH), Wilhelmshaven (WSV), Felixstowe (FLT), Hamburg (HBG), Antwerp (ATP), Port of London (POL).	€ 89,466,327	7384785	82,081,542.00	951	95	94.08
Scenario 4(Network D)	**2**	**Close to Gdansk (GDK), Rotterdam (ROM).**	**€ 27,186,807**	**7384785**	**19,802,022.00**	**2000**	**1000**	**13.59**
Scenario 5 (Network E)	**3**	**Close to Gdansk (GDK), Rotterdam (ROM), and Antwerp (ATP).**	**€ 33,094,515**	**7384785**	**25,709,730.00**	**1350**	**450**	**24.51**
Scenario 6 (Network F)	**4**	**Close to Gdansk (GDK), Rotterdam (ROM), Antwerp (ATP) and Hamburg (HBG)**	**€ 37,430,352**	**7384785**	**30,045,567.00**	**1668**	**417**	**22.44**
Scenario 7 (Network G)	**2**	**Close to Rotterdam (ROM)and Hamburg (HBG)**	**€ 31,583,850**	**7384785**	**24,199,065.00**	**1400**	**700**	**22.56**

5.1.1 Cost Comparison between Scenario 2 (Network B) and Scenario 6 (Network F)

As shown in Table 3, a comparison between scenario 2 and scenario 6 reveals that both strategies suggest the construction of four FCTs close to Gdansk, Rotterdam, Antwerp, and Hamburg. The total cost for Scenario 2 is higher than the total cost of Scenario 6, though fixed facility cost is the same for both scenarios. The higher total cost in scenario 2 is due to its higher variable compared to the variable cost of scenario 6. Though the total cost is lower in scenario 6 than in scenario 2, the total cost/TEU is higher in scenario 6 (€22.44) than in scenario 2(€12.42). The total cost/ TEU in Scenario 2 is about 44.7 % lower than in Scenario 6.

Figure 8

Graph Comparing Cost Comparisons between Scenario2 and Scenario 6



In scenario 2, the monthly capacity per FCT and the total monthly capacity for FCTs are also high. Though the model predicts the construction of FCTs in the exact locations in both scenario 2 and scenario 6, the € 12,236,196 difference (€ 42,281,763- € 30,045,567) in the variable cost is due to the different capacity and capacity allocation to different hub locations ("Figure 8"). This also explains the lower total cost/TEU in scenario 2, as in this scenario, more TEU containers are handled due to higher overall capacity, which results in a lower total cost/ container—the increase in capacity results in a decrease in Total Cost/ TEU.

As shown in Table 4 and Table 5, in scenario 2, most of the demand for spoke and hub ports is catered by FCTs in ROM and HBG. These two hubs are being utilized at total capacity to fulfill monthly demands. As opposed to that, in scenario 6, the majority of the monthly demands of the hub and spoke ports would be fulfilled by the FCTs located in location ROM and ATP as these FCTs will have higher utilization rates. In scenario 2, the total capacity utilization of FCTs is higher than in scenario 6. Though higher capacity utilization did not reduce total cost for scenario 2, it reduced Total Cost/TEU in scenario 2 compared to scenario 6. The higher the capacity utilization, the lower the Total cost/TEU.

Table 4

Capacity Utilization of FCTs in Scenario 2(Network B)

Supply Port (Scenario 2/Network B)	Sum of Transshipment in Each Location (In 1000 TEU)	Capacity (In 1000 TEU)	Capacity Utilization (%)	Monthly Excess Capacity (%)
GDK Floating Container Terminal (Close to Gdansk)	737	1000	74	26
ROM Floating Container Terminal (Close to Rotterdam)	1000	1000	100	0
HBG Floating Container Terminal (Close to Hamburg)	1000	1000	100	0
ATP Floating Container Terminal (Close to Antwerp)	820	1000	82	18

Table 5

Capacity of FCTs in Utilization Scenario 6 (Network F)

Supply Port (Scenario 6/ Network F)	Sum of Transshipment in Each Location (In 1000 TEU)	Monthly Capacity (In 1000 TEU)	Monthly Capacity Utilization (%)	Monthly Excess Capacity (%)
GDK Floating Container Terminal (Close to Gdansk)	314	417	75	25
ROM Floating Container Terminal (Close to Rotterdam)	417	417	100	0
HBG Floating Container Terminal (Close to Hamburg)	304	417	73	27
ATP Floating Container Terminal (Close to Antwerp)	343	417	82	18

As in scenario 2, the monthly capacity per hub is 583,000 TEU (1000,000-417,000) TEU more than the monthly capacity of scenario 6; the total cost is also higher. The monthly capacity in scenario 2 (1000,000 TEU) is around 140% higher compared to the monthly capacity of scenario

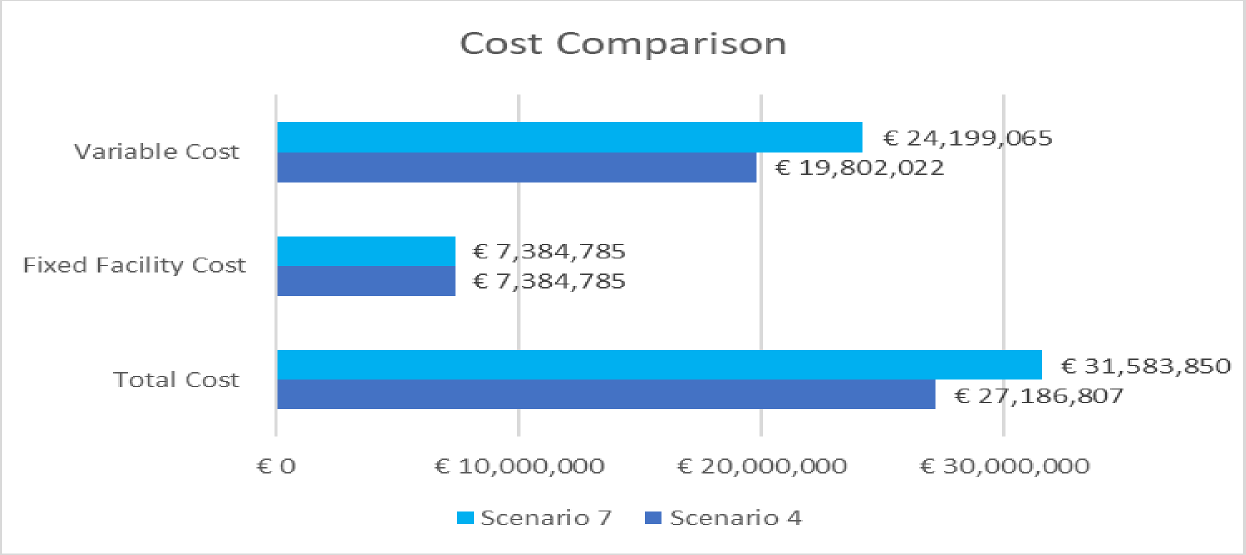
6 (417,000 TEU). The total cost of scenario 2 is around 33% higher than the total cost of scenario 6. The percentage increase in total cost is much lower than the percentage increase in total capacity.

5.1.2 Cost Comparison Between Scenario 4 (Network D) and Scenario 7 (Network G)

Referring to Table 3, a comparison between scenario 4 and scenario 7 reveals that both scenarios suggest the construction of two FCTs/hubs. The optimum location for constructing FCTs in Scenario 4 is close to Gdansk and Rotterdam, whereas the optimum location for FCTs in Scenario 7 is close to Rotterdam and Hamburg. The total cost for scenario 4 is lower than the total cost of scenario 7. As the fixed facility cost is the same for both scenarios, the higher total cost in scenario 7 is due to the higher variable cost in scenario 7 compared to the variable cost of scenario 4 ("Figure 9"). In scenario 4, the monthly capacity per FCT (1000,000 TEU) and the total monthly capacity (2000,000 TEU) for FCTs are also higher compared to the monthly capacity per FCT (700,000 TEU) and total monthly capacity (1400,000 TEU) in scenario 7. The total cost/ TEU is also lower in scenario 4 (€13.59) compared to scenario 7 (€22.56) due to the higher overall capacity of scenario 4.

Figure 9

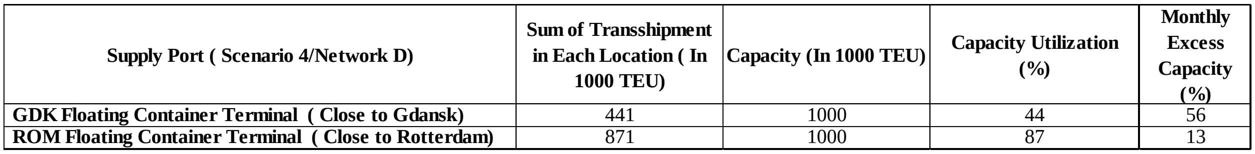
Graph Comparing Cost Comparisons between Scenario 4 and Scenario 7



Referring to Table 6, in scenario 4, most of the monthly demand from spoke and hub ports will be catered by the ROM FCT/hub. Network D will have a high overall excess capacity.

Table 6

Capacity Utilization of FCTs in Scenario 4 (Network D)

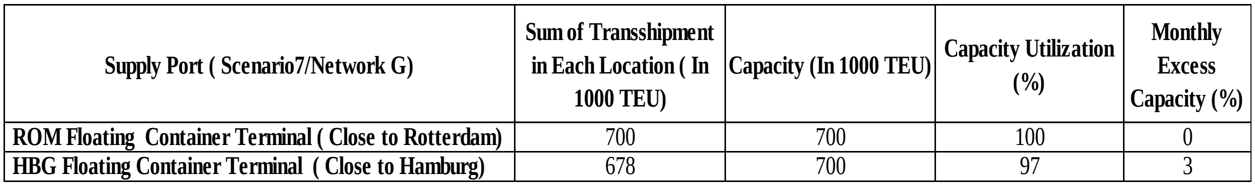


Supply Port (Scenario 4/Network D)	Sum of Transshipment in Each Location (In 1000 TEU)	Capacity (In 1000 TEU)	Capacity Utilization (%)	Monthly Excess Capacity (%)
GDK Floating Container Terminal (Close to Gdansk)	441	1000	44	56
ROM Floating Container Terminal (Close to Rotterdam)	871	1000	87	13

Similar to scenario 4, in scenario 7, the ROM FCT/hub would fulfill most of the monthly demands of the hub and spoke ports. Moreover, the ROM FCT will be fully utilized to its monthly capacity. In network G, there would be a negligent amount of excess capacity (“Table 7”).

Table 7

Capacity Utilization of FCTs in Scenario 7 (Network G)



Supply Port (Scenario7/Network G)	Sum of Transshipment in Each Location (In 1000 TEU)	Capacity (In 1000 TEU)	Capacity Utilization (%)	Monthly Excess Capacity (%)
ROM Floating Container Terminal (Close to Rotterdam)	700	700	100	0
HBG Floating Container Terminal (Close to Hamburg)	678	700	97	3

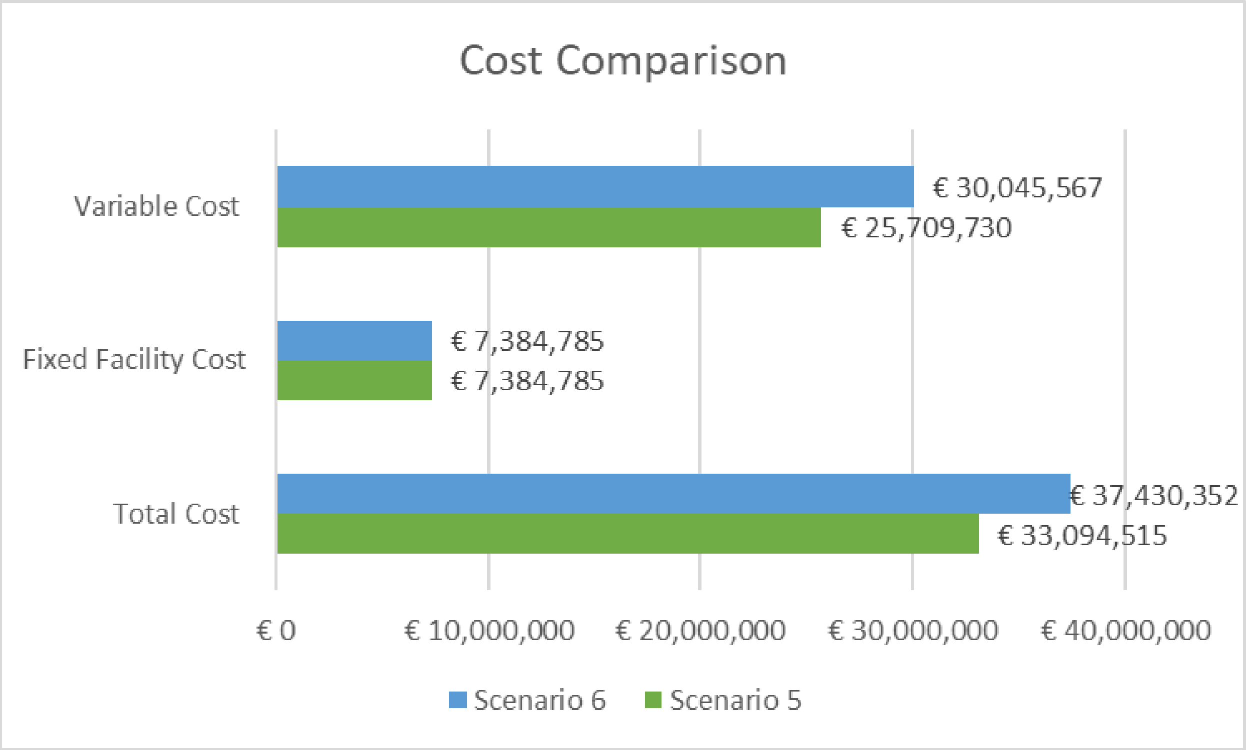
As in scenario 4, the monthly capacity per hub is 300,000 TEU (1000,000-700,000) TEU more than the monthly capacity per hub of scenario 7. The total monthly capacity in the case of scenario 4 (2000,000 TEU) is around 43% higher compared to the total monthly capacity of scenario 7 (1400 000 TEU). Whereas the total cost of scenario 4 (€ 27,186,807) is around 14 % lower than the total cost of scenario 7(€ 31,583,850). The total cost/ TEU is also around 40% lower in scenario 4 than in scenario 7. The total cost decreased while the capacity increased. Though scenario 4 has higher excess capacity than scenario 7, the total cost and total cost/TEU in scenario 4 decreased due to the higher capacity of scenario 4. Scenario 4 has a higher excess capacity than Scenario 7. However, higher excess capacity in scenario 4 did not result in higher total cost.

5.1.3 Cost Comparison between Scenario 5 (Network E) and Scenario 6 (Network F)

Referring to Table 3, a comparison between Scenario 5 and Scenario 6 reveals that Scenario 5 has a lower total cost than Scenario 6. This lower total cost in scenario 5 results from fewer optimum locations for FCTs than in scenario 6.

Figure 10

Graph Comparing Cost Comparisons between Scenario 5 and Scenario 6



A smaller number of FCTs is needed in scenario 5 as the capacity per FCT is higher in scenario 5 than in scenario 6. The monthly capacity per hub in scenario 6 was assumed based on STFT’s monthly capacity. The 33,000 TEU (450,000TEU-417,000TEU) monthly capacity increase per hub in scenario 5 compared to scenario 6 results in fewer FCTs needed to be built and lower total cost. However, it increases Total Cost/TEU by 9%. As capacity per FCT/hub increases, the number of FCTs needed decreases, and total cost decreases.

In scenario 5, most of the demand for spoke and hub ports is being catered by the floating ports ROM as the FCT located in ROM is being utilized fully to its capacity. The monthly capacity utilization is very high and excess capacity is low in scenario 5 (“Table 8”).

Table 8

Capacity Utilization of FCTs in Scenario 5 (Network E)

Supply Port (Scenario 5/Network E)	**Sum of Transshipment in Each Location (In 1000 TEU)**	**Monthly Capacity (In 1000 TEU)**	**Monthly Capacity Utilization (%)**	**Monthly Excess Capacity (%)**
GDK Floating Container Terminal (Close to Gdansk)	441	450	98	2
ROM Floating Container Terminal (Close to Rotterdam)	450	450	100	0
ATP Floating Container Terminal (Close to Antwerp)	421	450	94	6

In scenario 6, the FCT located close to ROM will cater to most of the monthly demands of the hub and spoke ports as it will be fully utilized. Network F has a higher monthly excess capacity than Network E (“Table 5”). Scenario 5 will ensure lower total cost, fewer hubs, higher monthly capacities per hub, and higher capacity utilization in the network compared to scenario 6. Scenario 6 will generate a higher monthly total capacity and lower Total Cost/TEU despite needing one more hub and higher total costs. However, scenario 6 has higher excess capacity in Network F compared to scenario 5 (“Table 3”, “Table 5”, “Table 8”). It can be concluded that the higher the number of FCTs needed, the higher the total cost and the higher the excess capacity.

5.2 Relationship Analysis

5.2.1 The Relationship between Cost and Capacity

We plotted the monthly capacity per FCT/Hub on the X-axis and the total cost on the graph's Y-axis (“Figure 11”). A downward-sloping straight line has been formed. Moreover, the total capacity (in 1000 TEUs) and the Total Cost/TEU relationship have also been visualized (“Figure 12”). Though consideration of more scenarios would have given a more precise understanding, it can be generalized that cost and capacity have an inverse relationship in most cases.

Figure 11

The Relationship between Monthly Capacity per FCT/Hub and Total Cost

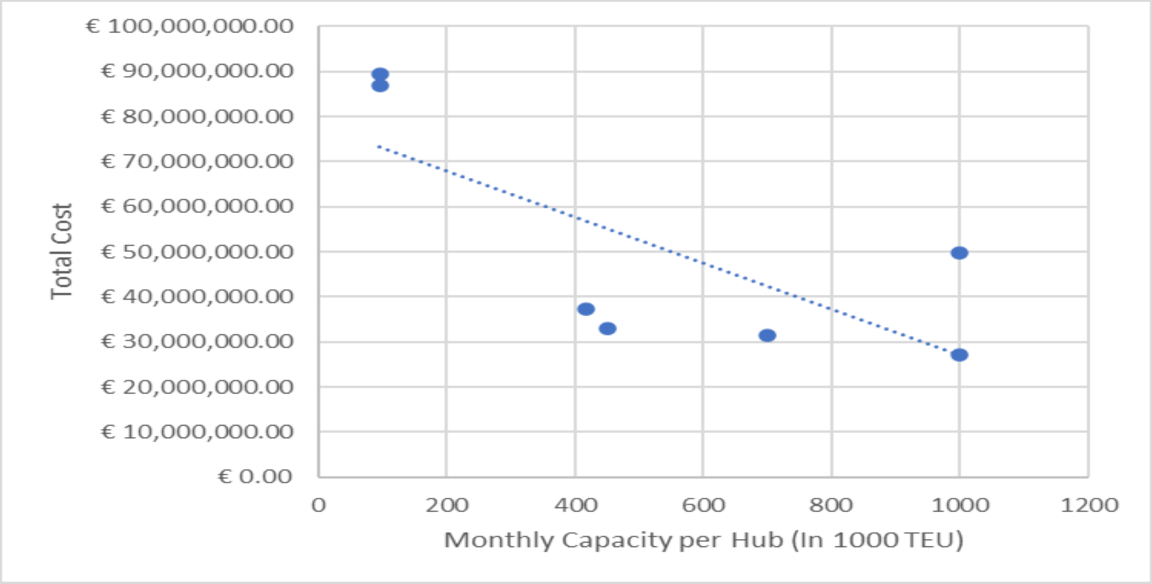
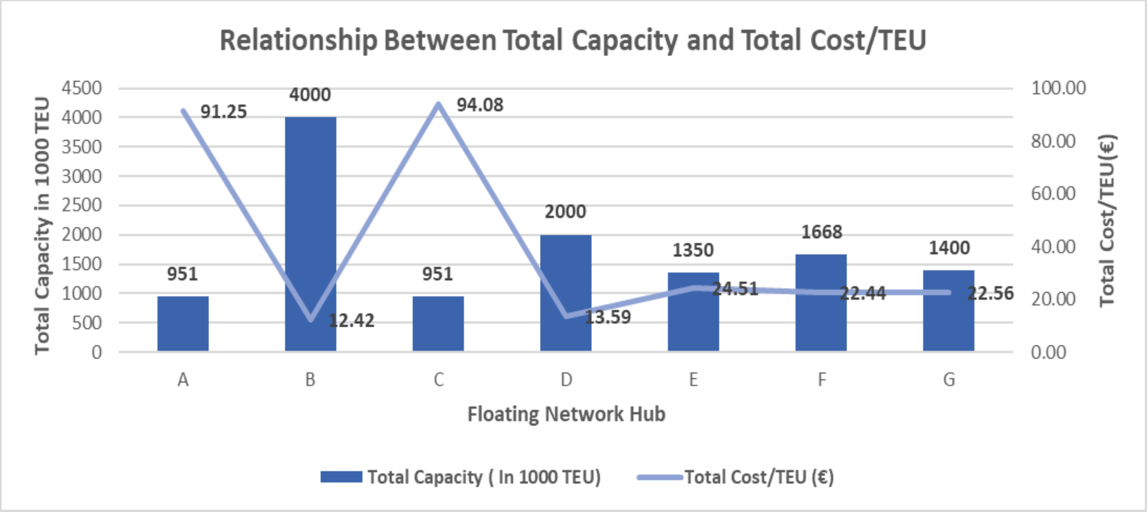


Figure 12

The Relationship between Total Cost/TEU and Total Capacity



From scenario analysis and relationship analysis between cost and capacity, it can be said that the total cost of any network depends on many factors, such as the locations of hubs, the number of FCTs/hubs needed, the monthly capacity of each FCT, and the network's total capacity. If many FCTs are needed to serve the monthly demands, the total cost will also be higher. The high number of FCTs may result in excess capacity in the network. If the total monthly capacity of each FCT and the network capacity are higher, the total cost can be higher. However, our scenario analysis has observed that the percentage increase in monthly capacity is much lower than the percentage increase in cost. Moreover, the higher the capacity utilization, the lower the Total cost/TEU. As capacity per FCT/hub increases, the number of FCTs needed decreases, and total cost decreases. An inverse relationship between cost and capacity exists due to economies of scale.

5. 3 Network Analysis

Two major Swedish container ports, Goteborg and Helsingborg, were considered to find optimum locations for the North Sea and Baltic Sea shipping network. Goteborg was a candidate location for constructing FCTs. Helsingborg was considered a spoke port. However, in our seven scenarios, Goteborg was not selected as a probable FCT location by any of the solutions predicted by Excel Solver. Both Goteborg and Helsingborg, in all the seven assumed networks, were being served by the same FCTs in all probable networks. We initially considered two proposed networks with the lowest total costs for our network analysis, Scenario 4 (Network D) and Scenario 7(Network G). In Network D, it was predicted that the floating container terminal GDK, located near Gdansk, could serve the port of Goteborg (“Figure 13”). In Network G, Excel Solver predicted that the floating container terminal HBG, located near Hamburg, could serve the port of Goteborg (“Figure 14”).

In this research, these two alternative networks measured the transshipment cost reduction and carbon reduction. ULCV from Dalian (China) will transport containers to Goteborg port through feeder services from FCTs instead of directly calling. First, we measured how much costs could be reduced through this ULCV combined with feeder service instead of direct calls to Goteborg. Cost savings were also calculated for Network D, where FCT is in GDK, and Network G, where FCT is in HBG. We measured the carbon emission reduction by selecting the network that has already reduced costs to select the most economically and environmentally sustainable network for Swedish ports.

Figure 13

Floating Container Terminal Network D

Figure 14

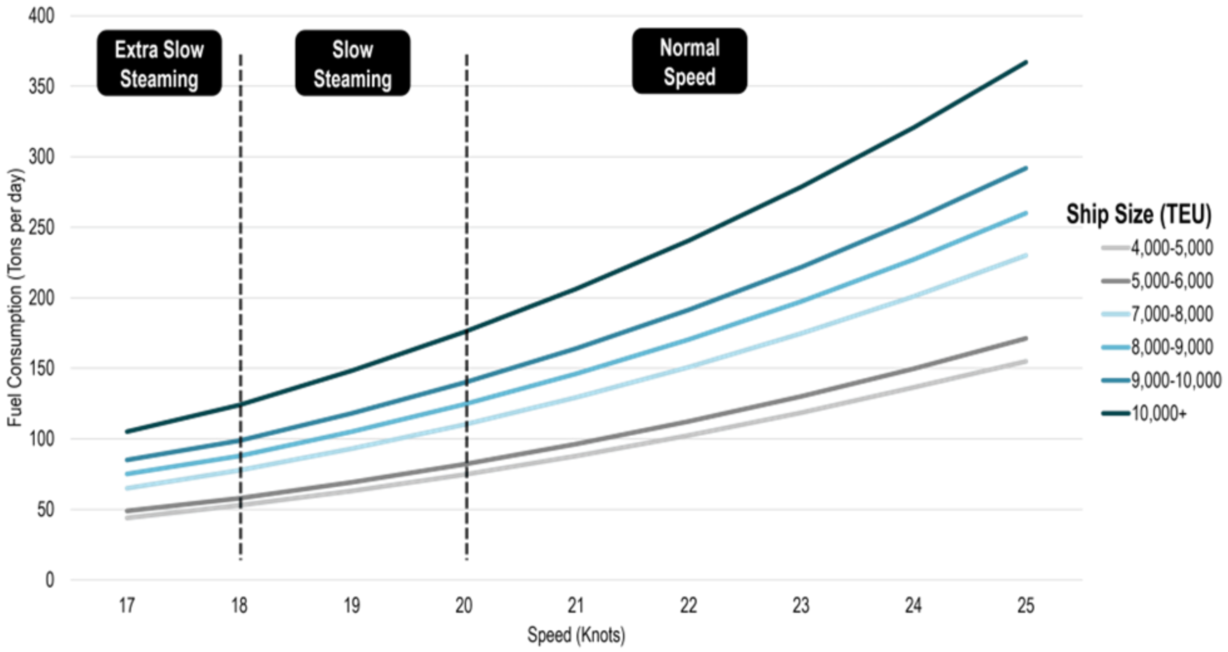
Floating Container Terminal Network G

5.4 The Measurement of Cost Reduction for Integrating FCTs

To discuss cost savings from the presence of a floating hub, it is essential to consider that containership fuel consumption significantly depends on ship size and speed, increasing exponentially above 14 knots. For instance, an 8,000 TEU ship consumes about 225 tons of fuel daily at 24 knots but only 150 tons at 21 knots, marking a 33% reduction. Shipping lines prefer slower speeds to save fuel but must balance this with longer transit times and potentially more ships to maintain port call frequency. There are four speed classes: Normal (20-25 knots), Slow Streaming (18-20 knots), Extra Slow Streaming (15-18 knots), and Minimal Cost (12-15 knots). Slow streaming is the dominant operational speed for more than 50% of global container ships. Extra slow streaming can be applied for short-distance routes (Rodrigue, 2024).

Figure 15

Fuel Consumption by Containership Size and Speed



Note: Fuel Consumption by Containership Size and Speed(adapted) (Notteboom & Cariou, 2009).

HBG floating container port (Close to Hamburg port) can be used as a hub to meet the monthly demand of Gothenburg port, as HBG port containers can be transhipped to and from Gothenburg through feeder services. The ULCV (AE-5/Albatross) traveling from Dalian (China) to Gothenburg (Sweden), having a capacity of 19,577 TEU, is considered to calculate the fuel consumption.

As the ship size is more than 10,000 TEU, the fuel consumption per day at 19 knots speed would be 150 tons, which means 7.5 tons (150/20) per hour, considering the ship operates 20 hours per day. The Fuel Consumption per hour is 7.5 * 0.907184 = 6.8 Metric Ton (1 ton = .907184 Metric Ton) (see, ‘’Appendix O’’) (*Tons to Metric Tonnes | Convert T to Mt Online - (XConvert*, n.d.).
Only fuel cost has been considered when simplifying the transshipment/transportation cost.
Transshipment/Transportation cost = Hours traveled * Fuel Consumption per Hour * Fuel Price per Metric Ton.

Transshipment/transportation costs would vary based on the route taken to travel and the type of fuel the ULCVs and feeders use. The shortest travel time is 24 days and 21 hours through the Suez Canal, while the ULCV travels at 19-knot. Before IMO 2020, High Sulphur Fuel Oil (HSFO) was standard due to its low cost. However, new regulations require Very Low Sulphur fuel oil (VLSFO) or marine gas (MGO) to meet emission standards (Casey, 2024; *SEA-DISTANCES.ORG - Distances*, n.d.).

5.4.1 Transportation Cost from Dalian to Gothenburg before HBG Floating Container Terminal Integration in Network G

Without the FCT in HBG when the ULCV travels from Dalian to Gothenburg via the Suez Canal with VLSFO, the transportation cost would be = Hours Travelled* Fuel Consumption per Hour in Metric Tons * Fuel Price Per Metric Ton.
Transportation Cost = 24 days 21 hours * 6.8 Metric Tons * $624.50 (*World Bunker Prices*, n.d.).
Transportation Cost = (24 *24+ 21) * 6.8 Metric Ton * € 574.59 (*1 USD to EUR - US Dollars to Euros Exchange Rate*, n.d.)
Transportation Cost = 597 Hours* 6.8 Metric Ton * € 574.59 = €2332605.564 = **€ 2,332,606.** The total transportation cost from Dalian to Goteborg with ULCV traveling with VLSFO at 19 Knot speed will be € 2,332,606 if no floating terminal exists (see “Appendix O”).

5.4.2 Transportation Cost from Dalian to Gothenburg after HBG Floating Container Terminal Integration in Network G

With floating container Terminal HBG, the same containers can be transhipped with ULCV and feeder vessels. First, the ULCV (Albatross) traveling at a 19-knot speed using VLSFO can travel from Dalian to the HBG hub via the Suez Canal. If the ship is carrying 19577 TEU containers per week, out of this 19577 TEU, 653 TEU (19577/30) containers have the probability of being transhipped to Gothenburg port through feeder service according to the container capacity allocation, keeping the ports' historical capacity in mind (see “Appendix D,” “Appendix F,” “Appendix G”).

The daily fuel consumption for a 5000 TEU feeder traveling at an 18-knot speed would be 50 tons (“Figure 16”). When the size of the ship is more than 10000 TEU at 18-knot speed, fuel consumption is 100 tons per day. As the size of the ship decreases by 50%, fuel consumption decreases by 50%. A 5000 TEU capacity container ship traveling at 17-knot will consume 48 tons of Fuel daily (See “Figure 16”). To tranship containers from HBG port to Gothenburg, a 1000 TEU feeder vessel can ship 653 TEU containers out of 19577 TEU containers coming to Europe. As the size of the ship decreased by 80% (From 5000 TEU to 1000 TEU), the fuel consumption can be reduced to at least 50%. As a 5000 TEU ship consumes 48 Ton per day, it is assumed that a 1000 TEU feeder will consume 24 Ton fuel per day, which means 1.2 (24/20) Tons or 1.1 Metric Tons of fuel per hour considering a 20-hour travel time in a day (see “Appendix O”).

Transportation Cost with ULCV from Dalian to HBG Port (At 19-knot speed) = Hours Travelled* Fuel Consumption per Hour in Metric Tons * Fuel Price Per Metric Ton.
Transportation Cost from Dalian to HBG Floating Port (Through ULCV) = (24 days 11 hours) * 6.8 Metric Ton per Hour * € 574.59= (587 * 6.8* € 574.59) =€ 2,293,533.
Transshipment Cost via feeder container ship from HBG Floating port to Goteborg (At 17-Knot Speed) = Hours Travelled* Fuel Consumption per Hour in Metric Tons * Fuel Price Per Metric Ton. Transshipment Cost (with feeder from HBG Floating port to Goteborg) = (19*1.2*€ 574.59) = € 13101.

The Total cost of transshipment from Dalian to Goteborg with both ULCV and Feeder in the presence of HBG Floating terminal/port would be = (€ 2,293,533+€ 13101) = **€2,306634**(see “Appendix O”).

5.4.3 The Cost Reduction from Dalian to Goteborg for Integrating the HBG Hub in the Network G

It is found that with the presence of floating hub HBG (Close to Hamburg) when ULCV travels from Dalian to HBG port and feeder service from HBG to Gothenburg port, it reduces overall transshipment cost by € 25,971 (€2,332,606 -€ 2,306,634). The overall transshipment cost is reduced by 1% for transporting containers from Dalian to Goteborg with the HBG floating port at 17knot and 14-knot speed of the feeder vessel. For every 19577 TEU inbound in HBG Floating Hub from Dalian and 653 TEU outbound to Goteborg, the overall cost reduction is €25,971(see “Appendix O”).

Though for cost reduction of €25,971, the trip from Dalian to Gothenburg takes 9 hours extra. If the feeder ship travels from the HBG hub at a 14-knot speed, the cost reduction will be € 23,213, and the overall time needed to travel will increase by 13 hours. Total cost optimization is more visible when considering a network, not individual ports. Cost reduction is not observed in Network D when the GDK port is considered a hub for the Gothenburg port if we consider it individually as a hub but not as a network of hubs (see “Appendix O”). However, to find the most economically and environmentally sustainable solution, we dropped Network D from consideration as individual cost reduction is not observed for the Swedish ports of Goteborg and Helsingborg.

5.5 Carbon Emission Reduction after Integrating HBG Floating Container Terminal in Network G

5.5.1 Carbon Emission for Direct Call to Goteborg from Dalian through ULCV

The carbon emission for transporting containers from Dalian (China) to Goteborg port through 20,000 TEU ULCV is 21680 Tons (MSC, n.d.). The carbon emission can be further reduced by 18644.80 Tons if biofuel is used in this trip. Biofuels from methane, methanol, or fuel oils are convenient for shipping companies to reduce carbon emissions (DNV, 2023). When biofuel is used, the carbon emission becomes 3035.20 tons for a 20,000 TEU ULCV from Dalian to Goteborg Port. To determine the impact of FCTs on carbon emission, VLSFO as fuel is used to compare the carbon emission in various scenarios (MSC, n.d.).

5.5.2 Carbon Emission for Network G after integration of FCT in HBG with a combined service of ULCV and feeders of different sizes

The total carbon emission if containers are transported from Dalian to HBG Floating port (Close to Hamburg) through 20,000 TEU ULCV and from HBG floating port to 5000 TEU Panamax containership as feeder is the sum of carbon emission from Dalian to Hamburg and the carbon emission from Hamburg to Goteborg. Carbon emission from Dalian to Hamburg is 20840.00. Carbon emission from Hamburg to Gothenburg through 5000 TEU capacity feeder service is 1020 Tons. The total carbon emission from the presence of the HBG floating port near Hamburg for this entire trip is 21860 tons (20840+1020). This indicates that carbon emission does not decrease with an HBG floating port. With a floating port and feeder service from HBG port to Goteborg, the overall carbon emission increases by 180 (21860-21680) Tons (MSC, n.d.).

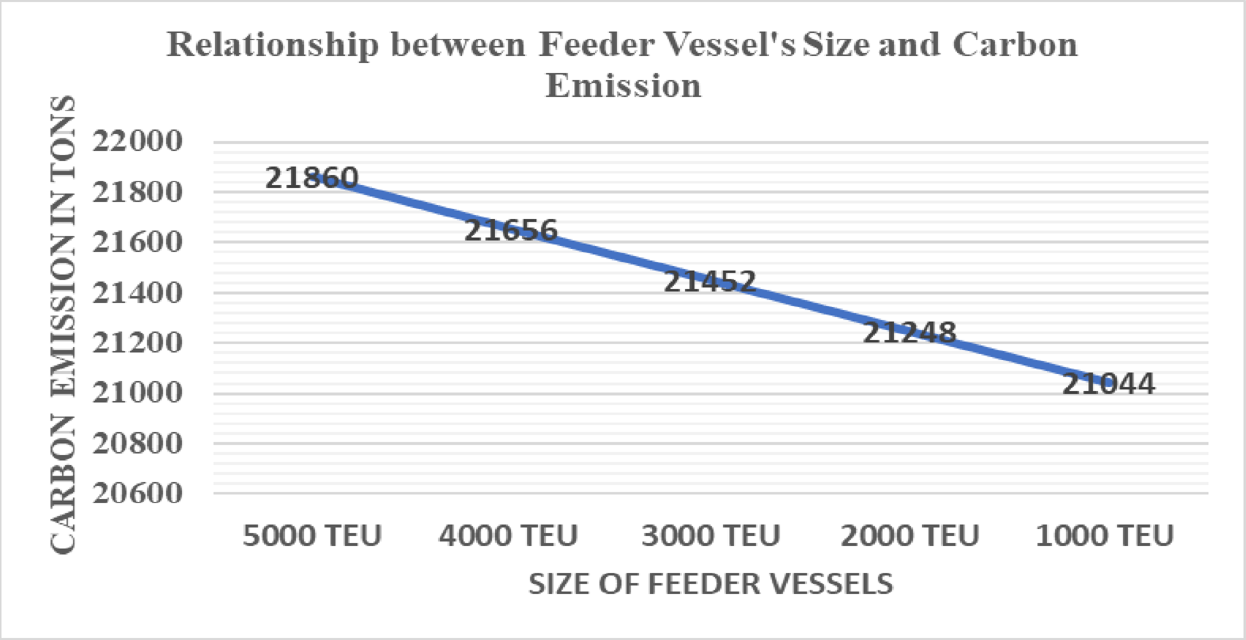
If a 4000 TEU feeder is used from HBG port to Goteborg port, the carbon emission from this trip becomes 816 Tons. The entire trip’s carbon emission (Dalian - Hamburg- Goteborg) becomes 21656 tons (20840+816). Compared to direct calls from Dalian to Goteborg, the carbon emission is reduced by 24 tons if feeder service through 4000 TEU container ships is provided from HBG port to Goteborg and 20,000 TEU ULCV is used from Dalian to HBG port. If a 3000 TEU container ship is used to tranship containers from HBG floating port to Goteborg port, the carbon emission becomes 21452 (20840+ 612) Tons. With a floating terminal in Hamburg, the carbon emission can be reduced by 228 (21680-21452) Tons. If a 2000 TEU container ship is used to provide feeder services from Hamburg to Goteborg, the overall carbon emission becomes 21248 (20840+408) Tons. Compared to direct calls through ULCV from Dalian to Gothenburg, the carbon emission can be reduced by 432 (21680-21248) Tons (MSC, n.d.).

Similarly, if a 1000 TEU container ship is used to provide feeder services from Hamburg to Goteborg, the overall carbon emission becomes 21044 (20840+204) Tons. Compared to direct calls through ULCV from Dalian to Gothenburg, the carbon emission can be reduced by 636

(21680-21044) Tons if 1000 TEU container ships are used to provide feeder service from HBG floating port to Goteborg. It indicates that carbon emission is reduced due to the size of the container ships used in feeder services. It is not reduced simply by deploying floating terminals. The smaller the containership used for feeder services from Hamburg to Goteborg, the lesser the carbon emission. Further carbon emission is possible using biofuel in ULCVs and feeder vessels (MSC, n.d.).

Figure 16

The relationship between Feeder Vessels' Size and Carbon Emission



6 Discussion

6.1 Summary of Findings

This section summarizes the findings and answers the research question: How can Floating Container Terminals (FCTs) benefit the maritime shipping industry and contribute to sustainability?

This analysis considered seven scenarios/strategies based on varying monthly demands and capacities to determine the minimum total cost. These scenarios resulted in seven network configurations (Network A to G). After considering seven different pairs of monthly capacity and monthly demand, seven different total costs were found, reflecting the varying number and location of FCTs needed to cover the North Sea and the Baltic Sea.

It is observed that the higher the number of FCTs required to cater to this region, the higher the total cost. Two networks requiring the same number of hubs to serve the targeted areas may differ in total cost due to varying optimum locations, resulting in different variable costs, assuming a constant fixed facility cost per FCT. The difference in variable cost between the two networks with the same number of optimal FCT locations is due to varied distances from different FCTs and spoke ports, as fuel consumption depends on these distances. Additionally, while comparing two networks with the same number of optimal FCT (hub) locations and different total costs, the monthly capacity of each FCT and capacity utilization/excess capacity should also be considered.

An inverse relationship exists between the total cost and monthly capacity per hub. In most networks, as the capacity per FCT increases, the total cost and Total cost/TEU decreases. The monthly capacity per FCT increase results in a decrease in the number of floating hubs needed. This eventually results in a decrease in total cost. In a few other proposed networks, as the total monthly capacity per FCT increases, the total cost increases but at a lower percentage than the monthly capacity increase.

Higher monthly capacity utilization per FCT reduces idle/excess capacity, total costs, and the number of FCTs required in the network to serve the desired region. The allocation of the total monthly capacity of FCTs to different spoke ports also determines the total cost. The closer the spoke ports are to the FCTs/hubs, the higher the percentage of a hub's monthly capacity the nearest spoke port uses, reducing the overall cost. Considering the total cost, Total Cost/TEU, monthly capacity, capacity allocation to spoke ports, capacity utilization, transshipment cost reduction in the voyage, and carbon emission reduction, Scenario 7 (Network G) has proven to be the best-proposed network in this research for serving the Swedish port of Goteborg.

Transshipment cost depends on the hub's location, the container vehicle's size, and the speed at which the container ship travels. Moreover, transshipment cost also depends on the kind of fuel used in ULCVs and feeder vessels. With the presence of an FCT near Hamburg (HBG Port), if a ULCV travels from Dalian to HBG and feeder service is available from HBG to Gothenburg, the overall transshipment cost is reduced by 1% if Low Sulphur Fuel Oil (LSFO) is used in the whole journey. Though further cost reduction is possible using High Sulphur Fuel Oil (HSFO), it is not environmentally sustainable. The carbon reduction in the voyage from Dalian to Gothenburg depends on feeder services combined with ULCV and an FCT near Hamburg. A positive relation also exists between carbon emission reduction and feeder vessel size. The smaller the feeder vessels, the lower the carbon emissions.

FCTs have economic, environmental, and social benefits. FCTs reduce the total cost of shipping liners, and the benefit will be passed on to customers. Profit maximization can be attained through cost reduction. Port authorities can prioritize FCTs to avoid dredging while expanding an existing onshore port, which will reduce costs and ensure environmental compliance. With FCTs, ULCV, small feeder service, and LSFO shipping liners, port authorities and customers can comply more with environmental regulations. Moreover, the whole community benefits from less carbon emission. So, this research's findings resonate with the TBL sustainability framework, which encompasses economic, environmental, and social sustainability.

6.2 Implications

Cutting expenses and carbon emissions through FCTs as transshipment hubs provides significant advantages to several maritime sector stakeholders with noteworthy practical, theoretical, and policy implications. TBL Theory emphasizes that industries/businesses can achieve sustainability by addressing the economic, environmental, and social aspects. FCTs embody this principle by contributing to the economy, environment, and society.

6.2.1 Practical Implications

This study helps to locate optimum locations for FCTs to serve the North Sea and Baltic Sea spoke ports. In addition, this study can also help port authorities decide on the FCTs' monthly capacity in TEU and the number of FCTs based on their available financing to expand the port operations.

Apart from allocating monthly demand to FCTs as transshipment hubs, this mathematical model predicts each FCT's capacity utilization and excess capacity. This study found an inverse relationship between total cost and monthly capacity per FCT. The percent increase in monthly capacity (in thousand TEU) is higher than the percentage increase in total cost, indicating the network's cost-efficient and flexible capacity expansion by adding new FCTs upon increased demand. This study will help liners configure their shipping network optimally with the assistance of FCTs. The shipping liners can optimize their transshipment costs by choosing the closest FCT for delivering containers to spoke ports through feeder vessels.

Port authorities’ goal can be congestion reduction through monthly capacity maximization or maximum capacity utilization. FCTs with more monthly excess capacity reduce congestion and waiting time. Such benefits will be transferred to customers of the shipping lines through reduced lead time. On the contrary, the goal of some port authorities can be to maximize monthly capacity utilization and serve the current monthly market demand profitably. Port authorities intending to serve the growing monthly demand for containers may prioritize FCTs with more excess capacity/per month.

Some researchers previously determined the economic viability of FCTs as hubs (Baird & Rother, 2013; Kurt et al., 2021; Minh et al., 2023). Such studies were mainly conducted from a port authority or government's perspective. Contrarily, this research focused on optimizing the total cost of the network operation by identifying optimum locations for transshipment hubs from a ship liner's perspective, keeping the liner's intention of vertical integration in mind. In some research, the FCTs are considered environmentally friendly because of their ability to avoid environmentally sensitive sites (Flikkema & Waals, 2019; Pachakis et al., 2016). This research proves that carbon emissions can be reduced by establishing FCTs in optimal locations as transshipment hubs. This research will also help shipping liners decide the size of feeder vessels in TEU to tranship containers from FCT to spoke ports for further carbon reduction.

Further analysis of the findings showed reduced voyage costs from Dalian to Gothenburg by avoiding direct calls to Gothenburg and integrating FCT near Hamburg. Such findings emphasized the need for fewer direct calls and more transshipment operations in a shipping network, which may affect the liners' decisions while designing shipping networks. MAERSK already ended direct calls to the port of Gothenburg from Asia at a point when an investment of a total of SEK 2.8 billion was already promised in the Skandiaporten project to make the port capable of receiving ULCVs. This reconfiguration may have consequences for Swedish transport buyers, the transport industry, and the rest of the Scandinavian shipping industry (Hultén, 2024). A floating port in an optimal location with minimum total cost can solve this issue for port authorities and governments before investing a considerable amount in dredging.

Though container transport is increasing with economic development and increased globalization, very few ports have space to expand to cater to ULCVs. Increased efficiency of terminal operations by adding FCTs for port expansion will decrease transit time, ship costs (lower round voyage time), and port dues (as part of the port dues are based on the time spent in port). FCTs can provide excellent connectivity and accessibility to remote areas and develop alternative routes and gateways to continents (Notteboom, 2010; Pachakis et al., 2016, 2017). Though the port of Rotterdam expanded in the North Sea, such expansion is impossible for Hamburg, Antwerp, Constanta, Barcelona, and Gibraltar. An FCT can be the only solution as large ships navigate narrow rivers. Most ports of Tunisia and Port Klang of Malaysia are experiencing expansion challenges due to limited land. The development of FCT will imply productivity, resulting in a smooth supply chain and hinterland link (Azmi & Arof, 2022; Flikkema & Waals, 2019).

6.2.2 Theoretical Implications

This research contributes to the existing literature by providing prediction and empirical evidence. The thesis fills the gap in the research on finding optimum locations for FCTs to serve the North and Baltic Seas. Along with finding an optimum location, this thesis also minimizes the total cost of transshipment and maintaining an FCT network. This thesis calculates the transshipment cost reduction and carbon reduction due to implementing FCTs, which somewhat answers the research question. Moreover, the thesis explores the economic, environmental, and social impact of integrating FCTs in the shipping network to ensure the sustainability of the maritime shipping industry.

Previous studies (Baird & Rother, 2013; Kurt et al., 2021; Minh et al., 2023) related to FCT predicted financial viability from a profit-maximizing point of view through generating more revenue by catering maximum ULCVs and feeders for loading and unloading containers. Cost minimization is also an important strategy to maximize profit. This research mainly focuses on optimally managing a network of FCTs with minimum cost and reassures the economic viability of FCTs. Previous literature (Flikkema & Waals, 2019; Pachakis et al., 2016) related to floating platforms discuss their contribution to reduced land use, protection of natural resources such as sea bed and marine species, and produce sustainable energy. An essential contribution of this research is that it is evident from our calculation that the integration of FCTs will improve air quality as it reduces carbon emissions—this reduced carbon emission results from an optimal shipping network design that optimizes shipping routes by integrating FCTs. As ULCVs travel less distance due to the presence of FCTs, less carbon is emitted.

As no widely accepted conceptualization of maritime social sustainability exists, previous studies analyzed social sustainability, mainly considering employee-related aspects. Some studies also considered societal indicators related to mobility and transport for older and disabled people, transport infrastructure in remote areas, community development, passenger transport, and length of transport routes (Ajmal et al., 2017; Antolín-López et al., 2016; Fernandes et al., 2022; Karakasnaki et al., 2023; Shiau & Liu, 2013). This thesis could not empirically measure the social benefit of integrating FCTs into the network. However, through the literature review, we could discuss some potential social benefits of FCTs.

6.2.3 Policy Implications

There is policy implication of FCTs as floating islands should receive a flag state classification to appoint to which country the floating island belongs and, therefore, which laws apply on the island as national regulations usually do not extend to the deep ocean. There is a requirement for a regulatory framework to protect the people who will work on FCTs professionally and to protect the invested assets on FCTs. There would be interaction and intersection between cargo flow, people, and markets. As a means of external connection for the rest of the world, policies can be affected by global spatial development. Updated policies related to port fees can be implemented for FCTs. There can be tax and fee rebates for shipping lines for using green ports and sustainable fuels and increased carbon taxes for those who fail to comply. Such policies will ensure sustainability's social, environmental, and economic dimension (“Green Shipping: Mooted Carbon Tax Set to Make Waves,” 2023; M. M. B. Flikkema et al., 2021; Ng et al., 2014).

The maritime industry is under pressure to decarbonize as demand for sustainability and scrutiny is increasing from regulators, customers, partners, and the public. Meeting the targets in the IMO Revised Strategy on Reduction of GHG Emissions from ships is challenging because shifting to cleaner fuels is extremely expensive. According to the regulation, ships should hold a valid FuelEU compliance document to enter European Union waters. As a result, it would be better for shipping lines to reduce direct calls to spoke ports and operate feeder services from FCTs to be economically and environmentally sustainable as fewer routes traveled and fewer fuels will be used (“Green Shipping: Mooted Carbon Tax Set to Make Waves,” 2023; “Review of Maritime Transport 2023,” 2023).

6.2 Limitations

This research identified optimal locations and capacity for FCTs with potential cost and carbon reduction benefits. However, multiple unaddressed factors can affect the accuracy of this research that we could not address within the time and scope of work. There were many assumptions related to fuel costs, speed, labor costs, monthly demand, monthly capacity, and fixed facility costs. Actual data instead of assumptions would have generated more accurate results. The fixed facility cost is based on STFT’s cost assumptions. Other technologies for FCT may have different fixed facility costs for operation. In this research, only seven scenarios based on different monthly capacities and monthly demands have been considered. More scenarios could be developed to increase the accuracy of the findings, keeping the maritime trade growth in mind as historical data was used to make assumptions.

Moreover, while calculating travel time between two ports, no stoppages and waiting times in ports along the routes were considered for simplification. Empty and full container ships may have different travel times and fuel costs, which should have been considered. The study needs to consider the complex regulations imposed by different countries, which may impact the cost of the proposed shipping network. We depended heavily on routing data of ULCVs from Far-East Asia to find the optimum location. We only considered the route through the Suez Canal. Alternative routes such as the Panama Canal, The Cape of Good Hope, the Strait of Magellan, the

Cape of Horn, and other ULCV data should have been considered. We developed our model based on the routing of ULCVs involved in import. Our calculation did not consider the export scenario in the return voyage when the feeder service takes Swedish export items to FCTs, and ULCVs take them to Far-East Asia. While calculating carbon and transshipment cost reduction, we only considered Gothenburg port. We could not consider the effect on other ports due to lack of time.

Further cost reduction through FCT is possible by bypassing road and train transfer of containers in some short sea routes, which we could not calculate in our research time frame. Our suggested network will have two FCTs near Hamburg and Rotterdam. We could not rank our preference between these two locations as most shipping lines may not be interested in simultaneously investing in constructing FCTs in two locations. This research is solely based on quantitative data and assumptions. It would have been better if we had the time to rank our preferences based on qualitative data such as interviews with industry stakeholders and experts.

6.3 Future Research Directions

The Capacitated Facility Location model predicts the simultaneous construction of FCTs in two locations that the available funding for the project may not permit. The future research focus would combine qualitative and quantitative research techniques, such as the Analytical Hierarchy Process (AHP), to rank locations for constructing FCTs in order of preference. Future research will include input from industry experts who will help make decisions based on AHP. Moreover, overall transportation cost and carbon emission reduction in the logistic network, including road haulage, would be measured to understand the benefits of incorporating FCTs. As finding the social benefits of FCT was based only on a literature review, further focus would be given to this area.

7. Conclusion

Maritime trade has always been a significant economic engine. As 90% of global trade is conducted through sea routes, naval shipping has become more critical in this era of globalization. Ports and shipping play an impeccable role in connecting nations by sustaining international commerce and driving economic growth. As billions of tons of goods are carried and transported across borders annually, it is beyond dispute that maritime transportation ensures efficient logistics systems and empowers businesses to achieve global competitiveness. As seas cover two-thirds of the area of this planet, there are still domains where seas can contribute efficiently. Blue growth and a blue economy have become sustainable development goals to unlock the seas' immense potential. The blue economy aims for sustainable ocean use, focusing on sectors like shipping, renewable energy, and ocean-based food production. Maritime Spatial Planning (MSP) is being discussed a lot lately as a contributor to fostering efficient blue growth. Deployment of Very Large Floating Structures (VLFS) such as Floating container terminals (FCTs) is also considered a low-cost, flexible, and sustainable alternative to conventional ports.

Floating container terminals can benefit the shipping industry in many ways. These benefits can be categorized into economic, environmental, and social. These three benefits can together contribute to sustainability by achieving three bottom lines of sustainability or sustainable development. There are already recognized economic and environmental benefits of deploying FCTs. The financial benefits come from cost reduction for port expansion as the existing ports can bypass dredging costs. Port authorities can construct floating container terminals at sea at much less expense than a traditional port, which will reach breakeven and positive return earlier than a conventional port. The environmental benefits are obtained through land reclamation, marine ecology preservation, and dredging avoidance. Apart from these benefits, FCTs can contribute to sustainability with a reconfigured shipping network consisting of FCTs as hubs, which will reduce the cost of transshipment, carbon emission, and overall operational cost of the network. In our research, these benefits were highlighted and quantitively articulated with the help of the facility location model.

Maritime logistics rely on hub-and-spoke networks, where strategically placed FCTs can streamline container handling, reduce port congestion, and improve transit reliability with the lowest cost of maintaining this overall network. Finding optimum locations for deploying FCTs acting as hubs to serve the North and Baltic Sea-spoke ports with minimum total cost was the core objective of the mathematical model. Forming a mathematical model following the facility location model aided our study in optimizing locations, reducing total cost, and considering the monthly demand for container handling in mind. The predicted locations for FCTs as hubs in our proposed network will mitigate container transport costs and reduce carbon emissions. Consequently, the changed network configuration will aid in achieving economic and environmental sustainability. As sustainability does not operate in silos, economic and ecological sustainability will influence the achievement of social sustainability.

An analysis of seven configurations (Network A-Network G) based on varying demands and capacities was done to find the most efficient network for catering ULCVs from Far-East Asia to the North Sea and Baltic Sea ports. Scenario analysis finds that total costs correlate directly with the number and location of FCTs needed to cover regions like the North and Baltic Seas. Moreover, an inverse relationship between total cost and capacity has been observed. Excess capacity may contribute to increasing total costs in the network. However, the analysis shows that choosing a high-capacity strategy with substantial excess capacity ensures resilience against rising demand and maintains efficiency with minimal cost increases, thereby supporting sustainable growth. Strategically deploying an FCT in Hamburg will be the most efficient way to reduce costs and emissions for the route from Dalian to Gothenburg.

This research has practical, theoretical implications supporting more sustainable, efficient port operations while alleviating congestion and enhancing network design by integrating FCTs. FCTs can be the only sustainable solution for ports struggling with land limitations for expansion. Large shipping liners opting for vertical integration through the acquisition of ports can also benefit from this research. This study finds optimum locations for offshore container handling that are not bounded by the existence of natural islands for transshipment activity. Necessary Policy frameworks to govern FCT classification, protect workers, and incentivize green practices, such as using cleaner fuels, have been discussed in the research.

Limitations of this quantitative research include data assumptions, route simplifications, and reliance on ULCV imports. Considering trade growth and market growth in mind, it is essential to determine the maximum capacity needed by the FCTs to serve the North Sea and Baltic Sea regions. It is necessary to determine if there is a demand for new capacity, as increased capacity only sometimes translates to increased demand. Shipping liners and port authorities can use our research as a guideline to determine optimum locations for efficiently managing the network by demand and capacity scenarios known to them so that excess capacity cannot increase the cost.

Future research should integrate industry feedback and account for alternative routes, exports, and additional scenarios, keeping container throughput growth in mind.

Floating Container Terminals can vastly benefit the maritime sector by effectively contributing to all the dimensions of sustainability, such as economic, environmental, and social sustainability. Integrating floating container terminals will aid economies, port authorities, and shipping lines in attaining sustainable development agendas and conventional business goals of reduced cost and enhanced profit. Moreover, the optimum location selection for placing floating container terminals can contribute to achieving sustainability through reduced fuel usage and carbon emission. With the assistance of a triple-bottom-line framework, this research assures that FCTs can significantly contribute to people's planet and prosperity.

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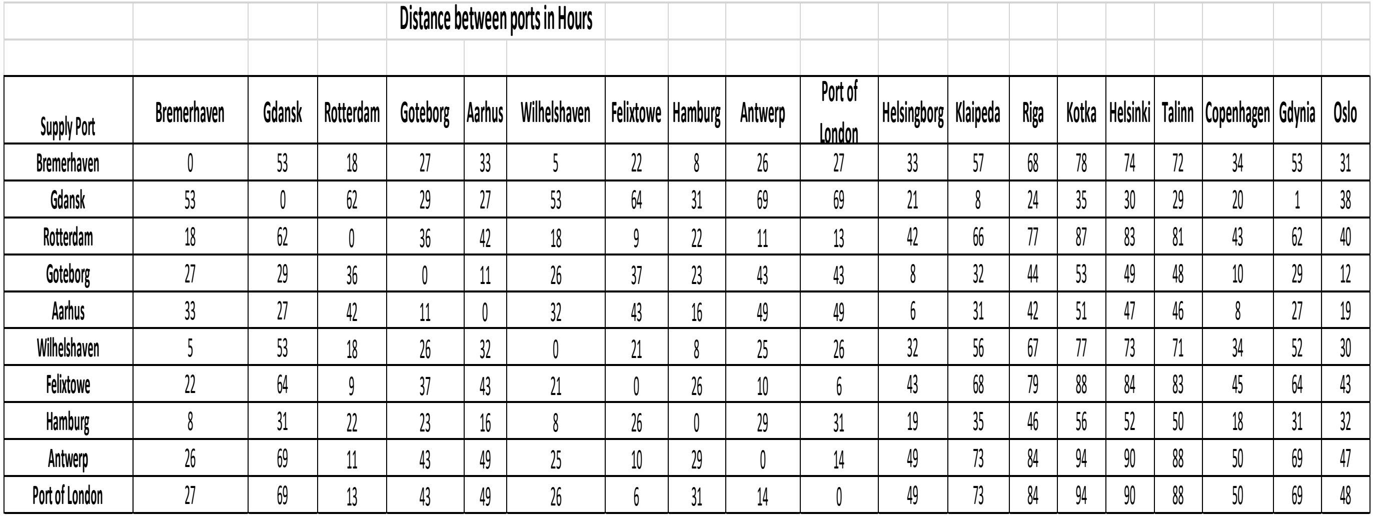
APPENDICES

Appendix A: Selected Hub and Spoke Ports in the North Sea and Baltic Sea

	Port	Country	Location	Yearly Container Handling In TEU	Monthly Container Handling in 1000TEU
1	Port of Rotterdam	Netherlands	North Sea	13,400,000	1117
2	Port of Antwerp	Belgium	North Sea	12,500,000	1042
3	Port of Hamburg	Germany	North Sea	8,300,000	692
4	Port of Bremerhaven	Germany	North Sea	4,604,000	384
5	Port of Felixstowe	United Kingdom	North Sea	3,297,000	275
6	Port of Gdańsk	Poland	Baltic Sea	2,050,000	171
7	Port of London	United Kingdom	North Sea	1,964,000	164
8	Port of Klaipeda	Lithuania	Baltic Sea	1,050,000	88
9	Port of Tallinn	Estonia	Baltic Sea	221,405	18
10	Port of Copenhagen	Denmark	Baltic Sea	102,000	9
11	Port of Hamina-Kotka	Finland	Baltic Sea	561,577	47
12	Port of Helsinki	Finland	Baltic Sea	407,995	34
13	Port of Riga	Latvia	Baltic Sea	465,391	39
14	Port of Gdynia	Poland	Baltic Sea	873,892	73
15	Port of Aarhus	Denmark	Kattegat	757,000	63
16	Port of Gothenburg	Sweden	Kattegat	914,000	76
17	Port of Helsingborg	Sweden	Kattegat	275,000	23
18	Port of Oslo	Norway	North Sea	1,152,674	96
19	Port of Wilhelshaven	Germany	North Sea	2700000	225

Appendix B: Distances between ports in hours while Feeder vessels travel at 14 knots.



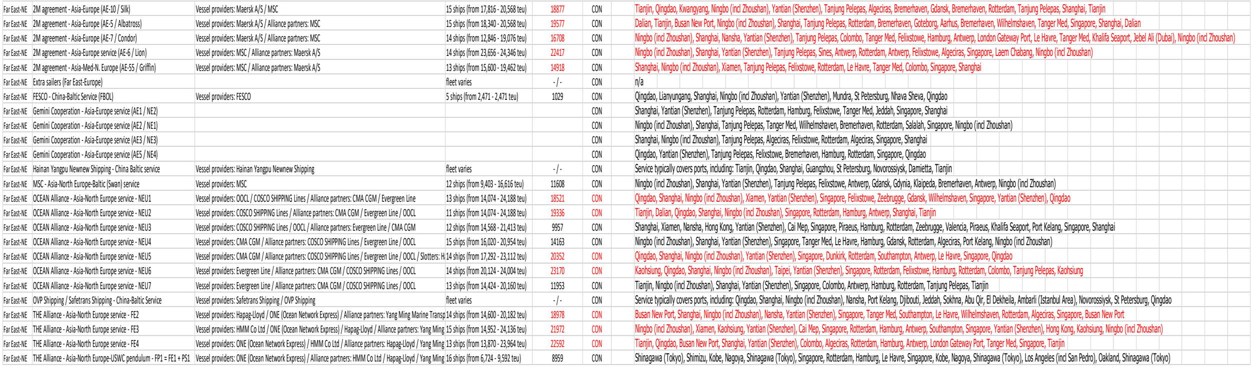
Distance between ports in Hours

Supply Port	Bremerhaven	Gdansk	Rotterdam	Goteborg	Aarhus	Wilhelshaven	Felixtowe	Hamburg	Antwerp	Port of London	Helsingborg	Klaipeda	Riga	Kotka	Helsinki	Talinn	Copenhagen	Gdynia	Oslo
Bremerhaven	0	53	18	27	33	5	22	8	26	27	33	57	68	78	74	72	34	53	31
Gdansk	53	0	62	29	27	53	64	31	69	69	21	8	24	35	30	29	20	1	38
Rotterdam	18	62	0	36	42	18	9	22	11	13	42	66	77	87	83	81	43	62	40
Goteborg	27	29	36	0	11	26	37	23	43	43	8	32	44	53	49	48	10	29	12
Aarhus	33	27	42	11	0	32	43	16	49	49	6	31	42	51	47	46	8	27	19
Wilhelshaven	5	53	18	26	32	0	21	8	25	26	32	56	67	77	73	71	34	52	30
Felixtowe	22	64	9	37	43	21	0	26	10	6	43	68	79	88	84	83	45	64	43
Hamburg	8	31	22	23	16	8	26	0	29	31	19	35	46	56	52	50	18	31	32
Antwerp	26	69	11	43	49	25	10	29	0	14	49	73	84	94	90	88	50	69	47
Port of London	27	69	13	43	49	26	6	31	14	0	49	73	84	94	90	88	50	69	48

Appendix C: Transportation cost for transshipment from probable FCTs to spoke ports.

				Operation, Personel and Transportation Cost in Euro Per 1000 Unit															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Supply Port	**Bremerhaven**	**Gdansk**	**Rotterdam**	**Goteborg**	**Aarhus**	**Wilhelshaven**	**Felixstowe**	**Hamburg**	**Antwerp**	**Port of London**	**Helsingborg**	**Klaipedia**	**Riga**	**Kotka**	**Helsinki**	**Talinn**	**Copenhagen**	**Gdynia**	**Oslo**
Bremerhaven (BRH)	0	41181	13986	20979	25641	3885	17094	6216	20202	20979	25641	44289	52836	60606	57498	55944	26418	41181	24087
Gdansk (GDK)	41181	0	48174	22533	20979	41181	49728	24087	53613	53613	16317	6216	18648	27195	23310	22533	15540	777	29526
Rotterdam (ROM)	13986	48174	0	27972	32634	13986	6993	17094	8547	10101	32634	51282	59829	67599	64491	62937	33411	48174	31080
Goteborg (GTB)	20979	22533	27972	0	8547	20202	28749	17871	33411	33411	6216	24864	34188	41181	38073	37296	7770	22533	9324
Aarhus (ARH)	25641	20979	32634	8547	0	24864	33411	12432	38073	38073	4662	24087	32634	39627	36519	35742	6216	20979	14763
Wilhelshaven (WSV)	3885	41181	13986	20202	24864	0	16317	6216	19425	20202	24864	43512	52059	59829	56721	55167	26418	40404	23310
Felixstowe (FLT)	17094	49728	6993	28749	33411	16317	0	20202	7770	4662	33411	52836	61383	68376	65268	64491	34965	49728	33411
Hamburg (HBG)	6216	24087	17094	17871	12432	6216	20202	0	22533	24087	14763	27195	35742	43512	40404	38850	13986	24087	24864
Antwerp(ATP)	20202	53613	8547	33411	38073	19425	7770	22533	0	10878	38073	56721	65268	73038	69930	68376	38850	53613	36519
Port of London(POL)	20979	53613	10101	33411	38073	20202	4662	24087	10878	0	38073	56721	65268	73038	69930	68376	38850	53613	37296

Appendix D: Routing Information of ULCV coming from Far-East Asia to Europe from Alphaliner

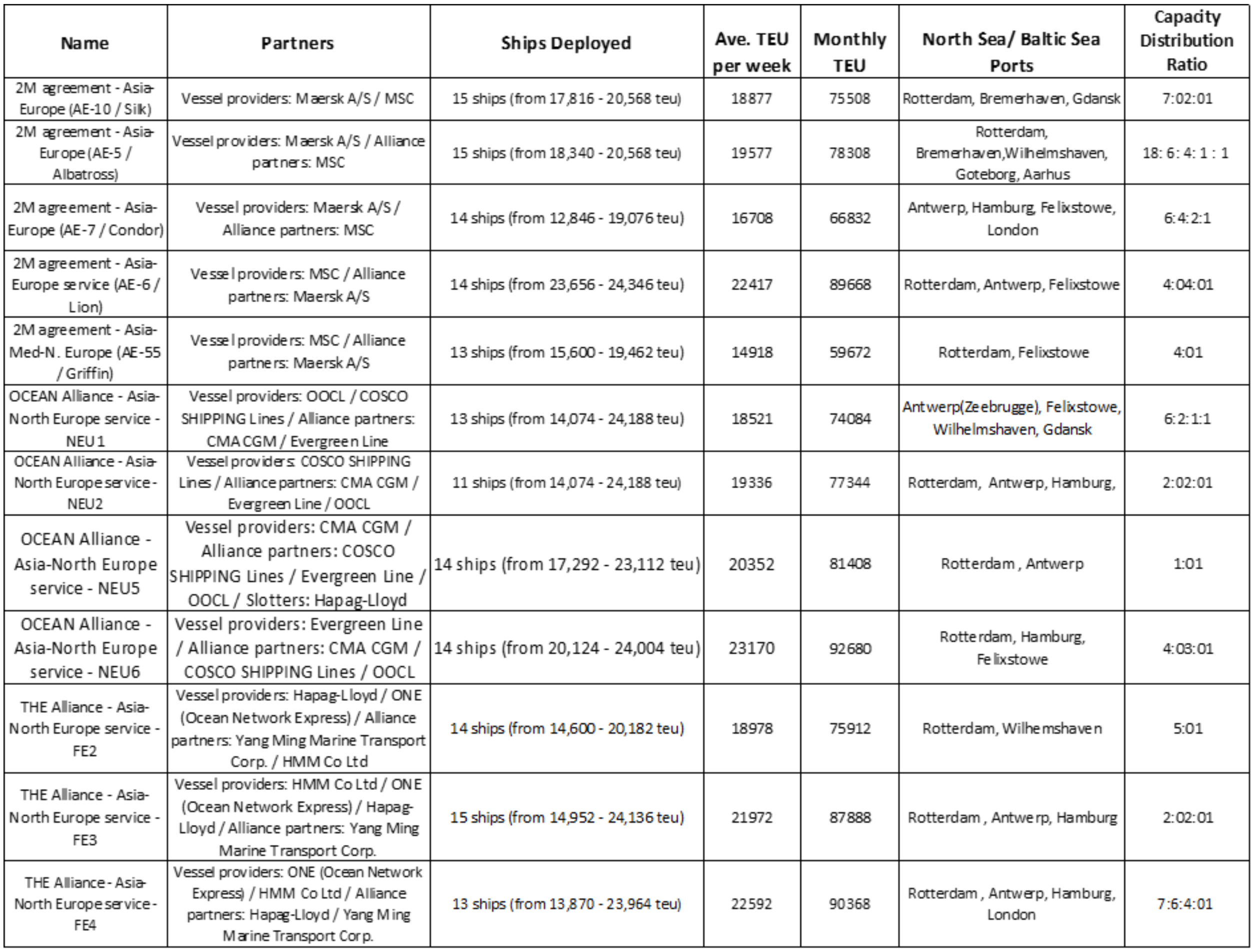


Far East-NE	2M agreement - Asia-Europe (AE-10 / Silk)	Vessel providers: Maersk A/S / MSC	15 ships (from 17,816 - 20,568 teu)	18877	CON		Tianjin, Qingdao, Kwangyang, Ningbo (incl Zhoushan), Yantian (Shenzhen), Tanjung Pelepas, Algeciras, Bremerhaven, Gdansk, Bremerhaven, Rotterdam, Tanjung Pelepas, Shanghai, Tianjin
Far East-NE	2M agreement - Asia-Europe (AE-5 / Albatross)	Vessel providers: Maersk A/S / Alliance partners: MSC	15 ships (from 18,340 - 20,568 teu)	19577	CON		Dalian, Tianjin, Busan New Port, Ningbo (incl Zhoushan), Shanghai, Tanjung Pelepas, Rotterdam, Bremerhaven, Goteborg, Aarhus, Bremerhaven, Wilhelmshaven, Tanger Med, Singapore, Shanghai, Dalian
Far East-NE	2M agreement - Asia-Europe (AE-7 / Condor)	Vessel providers: Maersk A/S / Alliance partners: MSC	14 ships (from 12,846 - 19,076 teu)	16708	CON		Ningbo (incl Zhoushan), Shanghai, Nansha, Yantian (Shenzhen), Tanjung Pelepas, Colombo, Tanger Med, Felixstowe, Hamburg, Antwerp, London Gateway Port, Le Havre, Tanger Med, Khalifa Seaport, Jebel Ali (Dubai), Ningbo (incl Zhoushan)
Far East-NE	2M agreement - Asia-Europe service (AE-6 / Lion)	Vessel providers: MSC / Alliance partners: Maersk A/S	14 ships (from 23,656 - 24,346 teu)	22417	CON		Ningbo (incl Zhoushan), Shanghai, Yantian (Shenzhen), Tanjung Pelepas, Sines, Antwerp, Rotterdam, Antwerp, Felixstowe, Algeciras, Singapore, Laem Chabang, Ningbo (incl Zhoushan)
Far East-NE	2M agreement - Asia-Med-N. Europe (AE-55 / Griffin)	Vessel providers: MSC / Alliance partners: Maersk A/S	13 ships (from 15,600 - 19,462 teu)	14918	CON		Shanghai, Ningbo (incl Zhoushan), Xiamen, Tanjung Pelepas, Felixstowe, Rotterdam, Le Havre, Tanger Med, Colombo, Singapore, Shanghai
Far East-NE	Extra sailers (Far East-Europe)		fleet varies	- / -	CON		n/a
Far East-NE	FESCO - China-Baltic Service (FBOL)	Vessel providers: FESCO	5 ships (from 2,471 - 2,471 teu)	1029	CON		Qingdao, Lianyungang, Shanghai, Ningbo (incl Zhoushan), Yantian (Shenzhen), Mundra, St Petersburg, Nhava Sheva, Qingdao
Far East-NE	Gemini Cooperation - Asia-Europe service (AE1 / NE2)				CON		Shanghai, Yantian (Shenzhen), Tanjung Pelepas, Rotterdam, Hamburg, Felixstowe, Tanger Med, Jeddah, Singapore, Shanghai
Far East-NE	Gemini Cooperation - Asia-Europe service (AE2 / NE1)				CON		Ningbo (incl Zhoushan), Shanghai, Tanjung Pelepas, Tanger Med, Wilhelmshaven, Bremerhaven, Rotterdam, Salalah, Singapore, Ningbo (incl Zhoushan)
Far East-NE	Gemini Cooperation - Asia-Europe service (AE3 / NE3)				CON		Shanghai, Ningbo (incl Zhoushan), Tanjung Pelepas, Algeciras, Felixstowe, Rotterdam, Algeciras, Singapore, Shanghai
Far East-NE	Gemini Cooperation - Asia-Europe service (AE5 / NE4)				CON		Qingdao, Yantian (Shenzhen), Tanjung Pelepas, Felixstowe, Bremerhaven, Hamburg, Rotterdam, Singapore, Qingdao
Far East-NE	Hainan Yangpu Newnew Shipping - China Baltic service	Vessel providers: Hainan Yangpu Newnew Shipping	fleet varies	- / -	CON		Service typically covers ports, including: Tianjin, Qingdao, Shanghai, Guangzhou, St Petersburg, Novorossiysk, Damietta, Tianjin
Far East-NE	MSC - Asia-North Europe-Baltic (Swan) service	Vessel providers: MSC	12 ships (from 9,403 - 16,616 teu)	11608	CON		Ningbo (incl Zhoushan), Shanghai, Yantian (Shenzhen), Tanjung Pelepas, Felixstowe, Antwerp, Gdansk, Gdynia, Klaipeda, Bremerhaven, Antwerp, Ningbo (incl Zhoushan)
Far East-NE	OCEAN Alliance - Asia-North Europe service - NEU1	Vessel providers: OOCL / COSCO SHIPPING Lines / Alliance partners: CMA CGM / Evergreen Line	13 ships (from 14,074 - 24,188 teu)	18521	CON		Qingdao, Shanghai, Ningbo (incl Zhoushan), Xiamen, Yantian (Shenzhen), Singapore, Felixstowe, Zeebrugge, Gdansk, Wilhelmshaven, Singapore, Yantian (Shenzhen), Qingdao
Far East-NE	OCEAN Alliance - Asia-North Europe service - NEU2	Vessel providers: COSCO SHIPPING Lines / Alliance partners: CMA CGM / Evergreen Line / OOCL	11 ships (from 14,074 - 24,188 teu)	19336	CON		Tianjin, Dalian, Qingdao, Shanghai, Ningbo (incl Zhoushan), Singapore, Rotterdam, Hamburg, Antwerp, Shanghai, Tianjin
Far East-NE	OCEAN Alliance - Asia-North Europe service - NEU3	Vessel providers: COSCO SHIPPING Lines / OOCL / Alliance partners: Evergreen Line / CMA CGM	12 ships (from 14,568 - 21,413 teu)	9957	CON		Shanghai, Xiamen, Nansha, Hong Kong, Yantian (Shenzhen), Cai Mep, Singapore, Piraeus, Hamburg, Rotterdam, Zeebrugge, Valencia, Piraeus, Khalifa Seaport, Port Kelang, Singapore, Shanghai
Far East-NE	OCEAN Alliance - Asia-North Europe service - NEU4	Vessel providers: CMA CGM / Alliance partners: COSCO SHIPPING Lines / Evergreen Line / OOCL	15 ships (from 16,020 - 20,954 teu)	14163	CON		Ningbo (incl Zhoushan), Shanghai, Yantian (Shenzhen), Singapore, Tanger Med, Le Havre, Hamburg, Gdansk, Rotterdam, Algeciras, Port Kelang, Ningbo (incl Zhoushan)
Far East-NE	OCEAN Alliance - Asia-North Europe service - NEU5	Vessel providers: CMA CGM / Alliance partners: COSCO SHIPPING Lines / Evergreen Line / OOCL / Slotters: H	14 ships (from 17,292 - 23,112 teu)	20352	CON		Qingdao, Shanghai, Ningbo (incl Zhoushan), Yantian (Shenzhen), Singapore, Dunkirk, Rotterdam, Southampton, Antwerp, Le Havre, Singapore, Qingdao
Far East-NE	OCEAN Alliance - Asia-North Europe service - NEU6	Vessel providers: Evergreen Line / Alliance partners: CMA CGM / COSCO SHIPPING Lines / OOCL	14 ships (from 20,124 - 24,004 teu)	23170	CON		Kaohsiung, Qingdao, Shanghai, Ningbo (incl Zhoushan), Taipei, Yantian (Shenzhen), Singapore, Rotterdam, Felixstowe, Hamburg, Rotterdam, Colombo, Tanjung Pelepas, Kaohsiung
Far East-NE	OCEAN Alliance - Asia-North Europe service - NEU7	Vessel providers: Evergreen Line / Alliance partners: CMA CGM / COSCO SHIPPING Lines / OOCL	13 ships (from 14,424 - 20,160 teu)	11953	CON		Tianjin, Ningbo (incl Zhoushan), Shanghai, Yantian (Shenzhen), Singapore, Colombo, Antwerp, Hamburg, Rotterdam, Tanjung Pelepas, Tianjin
Far East-NE	OVP Shipping / Safetrans Shipping - China-Baltic Service	Vessel providers: Safetrans Shipping / OVP Shipping	fleet varies	- / -	CON		Service typically covers ports, including: Qingdao, Shanghai, Ningbo (incl Zhoushan), Nansha, Port Kelang, Djibouti, Jeddah, Sokhna, Abu Qir, El Dekheila, Ambarli (Istanbul Area), Novorossiysk, St Petersburg, Qingdao
Far East-NE	THE Alliance - Asia-North Europe service - FE2	Vessel providers: Hapag-Lloyd / ONE (Ocean Network Express) / Alliance partners: Yang Ming Marine Transp	14 ships (from 14,600 - 20,182 teu)	18978	CON		Busan New Port, Shanghai, Ningbo (incl Zhoushan), Nansha, Yantian (Shenzhen), Singapore, Tanger Med, Southampton, Le Havre, Wilhelmshaven, Rotterdam, Algeciras, Singapore, Busan New Port
Far East-NE	THE Alliance - Asia-North Europe service - FE3	Vessel providers: HMM Co Ltd / ONE (Ocean Network Express) / Hapag-Lloyd / Alliance partners: Yang Ming	15 ships (from 14,952 - 24,136 teu)	21972	CON		Ningbo (incl Zhoushan), Xiamen, Kaohsiung, Yantian (Shenzhen), Cai Mep, Singapore, Rotterdam, Hamburg, Antwerp, Southampton, Singapore, Yantian (Shenzhen), Hong Kong, Kaohsiung, Ningbo (incl Zhoushan)
Far East-NE	THE Alliance - Asia-North Europe service - FE4	Vessel providers: ONE (Ocean Network Express) / HMM Co Ltd / Alliance partners: Hapag-Lloyd / Yang Ming	13 ships (from 13,870 - 23,964 teu)	22592	CON		Tianjin, Qingdao, Busan New Port, Shanghai, Yantian (Shenzhen), Colombo, Algeciras, Rotterdam, Hamburg, Antwerp, London Gateway Port, Tanger Med, Singapore, Tianjin
Far East-NE	THE Alliance - Asia-North Europe-USWC pendulum - FP1 = FE1 + PS1	Vessel providers: ONE (Ocean Network Express) / Alliance partners: HMM Co Ltd / Hapag-Lloyd / Yang Ming	16 ships (from 6,724 - 9,592 teu)	8959	CON		Shinagawa (Tokyo), Shimizu, Kobe, Nagoya, Shinagawa (Tokyo), Singapore, Rotterdam, Hamburg, Le Havre, Singapore, Kobe, Nagoya, Shinagawa (Tokyo), Los Angeles (incl San Pedro), Oakland, Shinagawa (Tokyo)

Appendix E: Operation Cost/Fixed Facility Cost of STFT

	(USD in Million)
Operation costs. Estimated costs preliminary basis. Per year	
MDO/Ammonia costs, 600 USD/ton, Daily consumption average = 200 tons.	40
Crewing costs, 300 men basis 2 or 3 shifts, Crews/Officers, Catering. Services.	15
Maintenance, cleaning, coatings, repairs, spare parts, diver services.	10
Consumables, provisions, lub oils.	10
Communications, crew changes, heli and speed boats transportations.	5
Insurances. Site fees. Class Certificate renewals.	15
Total operation costs per year	**95**

Appendix F: Monthly Capacity Distribution to FCTs based on ULCV Capacity and Historical Port Throughput Data

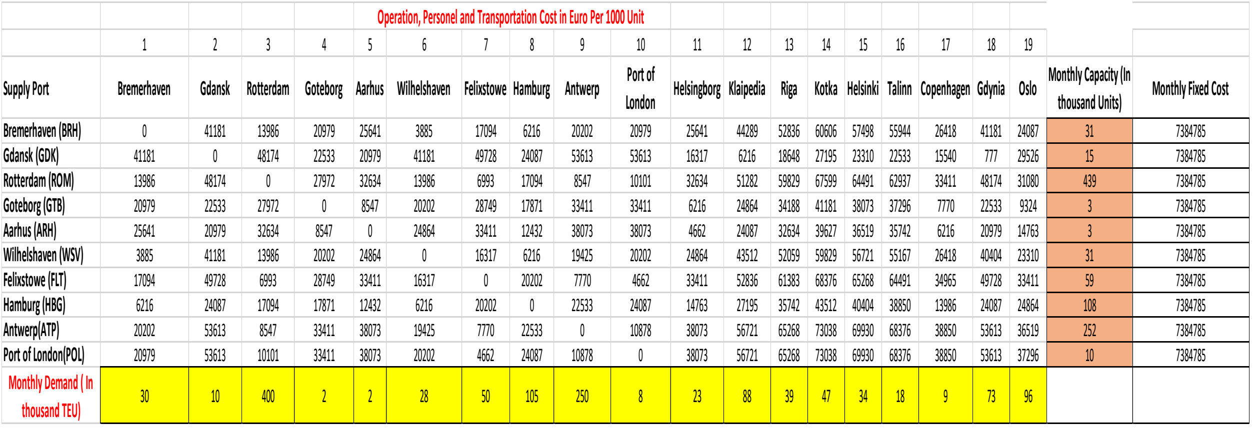


Name	Partners	Ships Deployed	Ave. TEU per week	Monthly TEU	North Sea/ Baltic Sea Ports	Capacity Distribution Ratio
2M agreement - Asia-Europe (AE-10 / Silk)	Vessel providers: Maersk A/S / MSC	15 ships (from 17,816 - 20,568 teu)	18877	75508	Rotterdam, Bremerhaven, Gdansk	7:02:01
2M agreement - Asia-Europe (AE-5 / Albatross)	Vessel providers: Maersk A/S / Alliance partners: MSC	15 ships (from 18,340 - 20,568 teu)	19577	78308	Rotterdam, Bremerhaven,Wilhelmshaven, Goteborg, Aarhus	18: 6: 4: 1 : 1
2M agreement - Asia-Europe (AE-7 / Condor)	Vessel providers: Maersk A/S / Alliance partners: MSC	14 ships (from 12,846 - 19,076 teu)	16708	66832	Antwerp, Hamburg, Felixstowe, London	6:4:2:1
2M agreement - Asia-Europe service (AE-6 / Lion)	Vessel providers: MSC / Alliance partners: Maersk A/S	14 ships (from 23,656 - 24,346 teu)	22417	89668	Rotterdam, Antwerp, Felixstowe	4:04:01
2M agreement - Asia-Med-N. Europe (AE-55 / Griffin)	Vessel providers: MSC / Alliance partners: Maersk A/S	13 ships (from 15,600 - 19,462 teu)	14918	59672	Rotterdam, Felixstowe	4:01
OCEAN Alliance - Asia-North Europe service - NEU1	Vessel providers: OOCL / COSCO SHIPPING Lines / Alliance partners: CMA CGM / Evergreen Line	13 ships (from 14,074 - 24,188 teu)	18521	74084	Antwerp(Zeebrugge), Felixstowe, Wilhelmshaven, Gdansk	6:2:1:1
OCEAN Alliance - Asia-North Europe service - NEU2	Vessel providers: COSCO SHIPPING Lines / Alliance partners: CMA CGM / Evergreen Line / OOCL	11 ships (from 14,074 - 24,188 teu)	19336	77344	Rotterdam, Antwerp, Hamburg,	2:02:01
OCEAN Alliance - Asia-North Europe service - NEU5	Vessel providers: CMA CGM / Alliance partners: COSCO SHIPPING Lines / Evergreen Line / OOCL / Slotters: Hapag-Lloyd	14 ships (from 17,292 - 23,112 teu)	20352	81408	Rotterdam , Antwerp	1:01
OCEAN Alliance - Asia-North Europe service - NEU6	Vessel providers: Evergreen Line / Alliance partners: CMA CGM / COSCO SHIPPING Lines / OOCL	14 ships (from 20,124 - 24,004 teu)	23170	92680	Rotterdam, Hamburg, Felixstowe	4:03:01
THE Alliance - Asia-North Europe service - FE2	Vessel providers: Hapag-Lloyd / ONE (Ocean Network Express) / Alliance partners: Yang Ming Marine Transport Corp. / HMM Co Ltd	14 ships (from 14,600 - 20,182 teu)	18978	75912	Rotterdam, Wilhemshaven	5:01
THE Alliance - Asia-North Europe service - FE3	Vessel providers: HMM Co Ltd / ONE (Ocean Network Express) / Hapag-Lloyd / Alliance partners: Yang Ming Marine Transport Corp.	15 ships (from 14,952 - 24,136 teu)	21972	87888	Rotterdam , Antwerp, Hamburg	2:02:01
THE Alliance - Asia-North Europe service - FE4	Vessel providers: ONE (Ocean Network Express) / HMM Co Ltd / Alliance partners: Hapag-Lloyd / Yang Ming Marine Transport Corp.	13 ships (from 13,870 - 23,964 teu)	22592	90368	Rotterdam , Antwerp, Hamburg, London	7:6:4:01

Appendix G: Monthly Allocated Capacity of FCTs in 1000 TEU

					Demand for Hub ports in TEU due to ships coming from Far-East							
North Sea/ Baltic Sea Ports	**Capacity in TEU**	**Capacity Distribution Ratio**	**Rotterdam (ROM)**	**Bremerhaven (BRH)**	**Gdansk (GDK)**	**Wilhelmshaven (WSV)**	**Goteborg (GTB)**	**Aarhus(ARH)**	**Antwerp (ATP)**	**Hamburg (HBG)**	**Felixstowe (FLT)**	**London (POL)**
Rotterdam, Bremerhaven, Gdansk	75508	7:02:01	52856	15102	7551							
Rotterdam, Bremerhaven,Wilhelmshaven, Goteborg, Aarhus,	78308	18: 6: 4: 1 : 1	46985	15662		10441	2610	2610				
Antwerp, Hamburg, Felixstowe, London	66832	6:4:2:1							30846	20564	10282	5141
Rotterdam, Antwerp, Felixstowe	89668	4:04:01	39852						39852		9963	
Rotterdam, Felixstowe	59672	4:01	47738								11934	
Antwerp(Zeebrugge), Felixstowe, Wilhelmshaven, Gdansk	74084	6:2:1:1			7408	7408			44450		14817	
Rotterdam, Antwerp, Hamburg	77344	2:02:01	30938						30938	15469		
Rotterdam , Antwerp	81408	1:01	40704						40704			
Rotterdam, Hamburg, Felixstowe	92680	4:03:01	46340							34755	11585	
Rotterdam, Wilhemshaven	75912	5:01	63260			12652						
Rotterdam , Antwerp, Hamburg	87888	2:02:01	35155						35155	17578		
Rotterdam , Antwerp, Hamburg, London	90368	7:6:4:01	35143						30123	20082		5020
Total Assigned Capacity to Ports in TEU			438970	30763	14959	30501	2610	2610	252068	108447	58581	10161
Total Assigned Monthly Capacity of Ports in 1000 TEUs			439	31	15	31	3	3	252	108	59	10

Appendix H: Monthly Capacity Assumption of FCTs and Monthly Demand Allocation of Ports in Scenario 1 (Network A)



					Operation, Personel and Transportation Cost in Euro Per 1000 Unit																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
Supply Port	Bremerhaven	Gdansk	Rotterdam	Goteborg	Aarhus	Wilhelshaven	Felixstowe	Hamburg	Antwerp	Port of London	Helsingborg	Klaipedia	Riga	Kotka	Helsinki	Talinn	Copenhagen	Gdynia	Oslo	Monthly Capacity (In thousand Units)	Monthly Fixed Cost
Bremerhaven (BRH)	0	41181	13986	20979	25641	3885	17094	6216	20202	20979	25641	44289	52836	60606	57498	55944	26418	41181	24087	31	7384785
Gdansk (GDK)	41181	0	48174	22533	20979	41181	49728	24087	53613	53613	16317	6216	18648	27195	23310	22533	15540	777	29526	15	7384785
Rotterdam (ROM)	13986	48174	0	27972	32634	13986	6993	17094	8547	10101	32634	51282	59829	67599	64491	62937	33411	48174	31080	439	7384785
Goteborg (GTB)	20979	22533	27972	0	8547	20202	28749	17871	33411	33411	6216	24864	34188	41181	38073	37296	7770	22533	9324	3	7384785
Aarhus (ARH)	25641	20979	32634	8547	0	24864	33411	12432	38073	38073	4662	24087	32634	39627	36519	35742	6216	20979	14763	3	7384785
Wilhelshaven (WSV)	3885	41181	13986	20202	24864	0	16317	6216	19425	20202	24864	43512	52059	59829	56721	55167	26418	40404	23310	31	7384785
Felixstowe (FLT)	17094	49728	6993	28749	33411	16317	0	20202	7770	4662	33411	52836	61383	68376	65268	64491	34965	49728	33411	59	7384785
Hamburg (HBG)	6216	24087	17094	17871	12432	6216	20202	0	22533	24087	14763	27195	35742	43512	40404	38850	13986	24087	24864	108	7384785
Antwerp(ATP)	20202	53613	8547	33411	38073	19425	7770	22533	0	10878	38073	56721	65268	73038	69930	68376	38850	53613	36519	252	7384785
Port of London(POL)	20979	53613	10101	33411	38073	20202	4662	24087	10878	0	38073	56721	65268	73038	69930	68376	38850	53613	37296	10	7384785
Monthly Demand (In thousand TEU)	30	10	400	2	2	28	50	105	250	8	23	88	39	47	34	18	9	73	96		

Appendix I: Monthly Capacity Assumption of FCTs and Monthly Demand Allocation of Ports in Scenario 3 (Network C)

Supply Port	Bremerhaven	Gdansk	Rotterdam	Goteborg	Aarhus	Wilhelshaven	Felixtowe	Hamburg	Antwerp	Port of London	Helsingborg	Klaipedia	Riga	Kotka	Helsinki	Talinn	Copenhagen	Gdynia	Oslo	Monthly Capacity (In thousand Units)	Monthly Fixed Cost
Bremerhaven (BRH)	0	41181	13986	20979	25641	3885	17094	6216	20202	20979	25641	44289	52836	60606	57498	55944	26418	41181	24087	31	7384785
Gdansk (GDK)	41181	0	48174	22533	20979	41181	49728	24087	53613	53613	16317	6216	18648	27195	23310	22533	15540	777	29526	15	7384785
Rotterdam (ROM)	13986	48174	0	27972	32634	13986	6993	17094	8547	10101	32634	51282	59829	67599	64491	62937	33411	48174	31080	439	7384785
Goteborg (GTB)	20979	22533	27972	0	8547	20202	28749	17871	33411	33411	6216	24864	34188	41181	38073	37296	7770	22533	9324	3	7384785
Aarhus (ARH)	25641	20979	32634	8547	0	24864	33411	12432	38073	38073	4662	24087	32634	39627	36519	35742	6216	20979	14763	3	7384785
Wilhelshaven (WSV)	3885	41181	13986	20202	24864	0	16317	6216	19425	20202	24864	43512	52059	59829	56721	55167	26418	40404	23310	31	7384785
Felixstowe (FLT)	17094	49728	6993	28749	33411	16317	0	20202	7770	4662	33411	52836	61383	68376	65268	64491	34965	49728	33411	59	7384785
Hamburg (HBG)	6216	24087	17094	17871	12432	6216	20202	0	22533	24087	14763	27195	35742	43512	40404	38850	13986	24087	24864	108	7384785
Antwerp(ATP)	20202	53613	8547	33411	38073	19425	7770	22533	0	10878	38073	56721	65268	73038	69930	68376	38850	53613	36519	252	7384785
Port of London(POL)	20979	53613	10101	33411	38073	20202	4662	24087	10878	0	38073	56721	65268	73038	69930	68376	38850	53613	37296	10	7384785
Monthly Demand (In thousand TEU)	384	171	1117	76	63	28	275	692	1042	164	23	88	39	47	34	18	9	73	96		

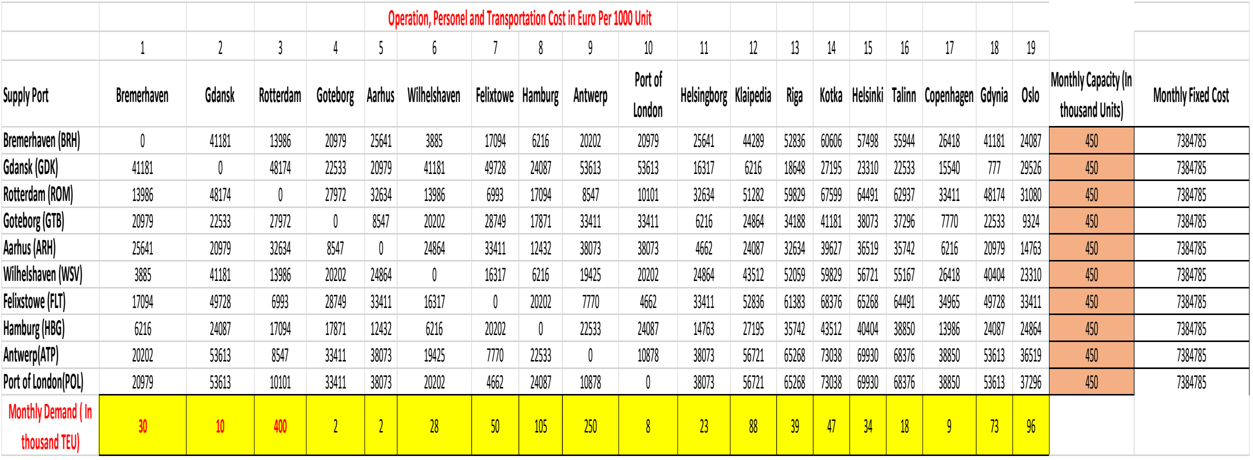
Appendix J: Monthly Capacity Assumption of FCTs and Monthly Demand Allocation of Ports in Scenario 2 (Network B)

					Operation, Personel and Transportation Cost in Euro Per 1000 Unit															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Supply Port	**Bremerhaven**	**Gdansk**	**Rotterdam**	**Goteborg**	**Aarhus**	**Wilhelshaven**	**Felixstowe**	**Hamburg**	**Antwerp**	**Port of London**	**Helsingborg**	**Klaipedia**	**Riga**	**Kotka**	**Helsinki**	**Talinn**	**Copenhagen**	**Gdynia**	**Oslo**	**Monthly Capacity (In thousand Units)**
Bremerhaven (BRH)	0	41181	13986	20979	25641	3885	17094	6216	20202	20979	25641	44289	52836	60606	57498	55944	26418	41181	24087	1000
Gdansk (GDK)	41181	0	48174	22533	20979	41181	49728	24087	53613	53613	16317	6216	18648	27195	23310	22533	15540	777	29526	1000
Rotterdam (ROM)	13986	48174	0	27972	32634	13986	6993	17094	8547	10101	32634	51282	59829	67599	64491	62937	33411	48174	31080	1000
Goteborg (GTB)	20979	22533	27972	0	8547	20202	28749	17871	33411	33411	6216	24864	34188	41181	38073	37296	7770	22533	9324	1000
Aarhus (ARH)	25641	20979	32634	8547	0	24864	33411	12432	38073	38073	4662	24087	32634	39627	36519	35742	6216	20979	14763	1000
Wilhelshaven (WSV	3885	41181	13986	20202	24864	0	16317	6216	19425	20202	24864	43512	52059	59829	56721	55167	26418	40404	23310	1000
Felixstowe (FLT)	17094	49728	6993	28749	33411	16317	0	20202	7770	4662	33411	52836	61383	68376	65268	64491	34965	49728	33411	1000
Hamburg (HBG)	6216	24087	17094	17871	12432	6216	20202	0	22533	24087	14763	27195	35742	43512	40404	38850	13986	24087	24864	1000
Antwerp(ATP)	20202	53613	8547	33411	38073	19425	7770	22533	0	10878	38073	56721	65268	73038	69930	68376	38850	53613	36519	1000
Port of London(POL	20979	53613	10101	33411	38073	20202	4662	24087	10878	0	38073	56721	65268	73038	69930	68376	38850	53613	37296	1000
Monthly Demand (In thousand TEU)	384	171	559	76	63	225	275	692	521	164	23	88	39	47	34	18	9	73	96	

Appendix K: Monthly Capacity Assumption of FCTs and Monthly Demand Allocation of Ports in Scenario 4 (Network D)

					Operation, Personel and Transportation Cost in Euro Per 1000 Unit															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
Supply Port	Bremerhaven	Gdansk	Rotterdam	Goteborg	Aarhus	Wilhelshaven	Felixstowe	Hamburg	Antwerp	Port of London	Helsingborg	Klaipedia	Riga	Kotka	Helsinki	Talinn	Copenhagen	Gdynia	Oslo	Monthly Capacity (In thousand Units)	Monthly Fixed Cost
Bremerhaven (BRH)	0	41181	13986	20979	25641	3885	17094	6216	20202	20979	25641	44289	52836	60606	57498	55944	26418	41181	24087	1000	7384785
Gdansk (GDK)	41181	0	48174	22533	20979	41181	49728	24087	53613	53613	16317	6216	18648	27195	23310	22533	15540	777	29526	1000	7384785
Rotterdam (ROM)	13986	48174	0	27972	32634	13986	6993	17094	8547	10101	32634	51282	59829	67599	64491	62937	33411	48174	31080	1000	7384785
Goteborg (GTB)	20979	22533	27972	0	8547	20202	28749	17871	33411	33411	6216	24864	34188	41181	38073	37296	7770	22533	9324	1000	7384785
Aarhus (ARH)	25641	20979	32634	8547	0	24864	33411	12432	38073	38073	4662	24087	32634	39627	36519	35742	6216	20979	14763	1000	7384785
Wilhelshaven (WSV)	3885	41181	13986	20202	24864	0	16317	6216	19425	20202	24864	43512	52059	59829	56721	55167	26418	40404	23310	1000	7384785
Felixstowe (FLT)	17094	49728	6993	28749	33411	16317	0	20202	7770	4662	33411	52836	61383	68376	65268	64491	34965	49728	33411	1000	7384785
Hamburg (HBG)	6216	24087	17094	17871	12432	6216	20202	0	22533	24087	14763	27195	35742	43512	40404	38850	13986	24087	24864	1000	7384785
Antwerp(ATP)	20202	53613	8547	33411	38073	19425	7770	22533	0	10878	38073	56721	65268	73038	69930	68376	38850	53613	36519	1000	7384785
Port of London(POL)	20979	53613	10101	33411	38073	20202	4662	24087	10878	0	38073	56721	65268	73038	69930	68376	38850	53613	37296	1000	7384785
Monthly Demand (In thousand TEU)	30	10	400	2	2	28	50	105	250	8	23	88	39	47	34	18	9	73	96		

Appendix L: Monthly Capacity Assumption of FCTs and Monthly Demand Allocation of Ports in Scenario 5 (Network E)



					Operation, Personel and Transportation Cost in Euro Per 1000 Unit																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
Supply Port	Bremerhaven	Gdansk	Rotterdam	Goteborg	Aarhus	Wilhelshaven	Felixtowe	Hamburg	Antwerp	Port of London	Helsingborg	Klaipedia	Riga	Kotka	Helsinki	Talinn	Copenhagen	Gdynia	Oslo	Monthly Capacity (In thousand Units)	Monthly Fixed Cost
Bremerhaven (BRH)	0	41181	13986	20979	25641	3885	17094	6216	20202	20979	25641	44289	52836	60606	57498	55944	26418	41181	24087	450	7384785
Gdansk (GDK)	41181	0	48174	22533	20979	41181	49728	24087	53613	53613	16317	6216	18648	27195	23310	22533	15540	777	29526	450	7384785
Rotterdam (ROM)	13986	48174	0	27972	32634	13986	6993	17094	8547	10101	32634	51282	59829	67599	64491	62937	33411	48174	31080	450	7384785
Goteborg (GTB)	20979	22533	27972	0	8547	20202	28749	17871	33411	33411	6216	24864	34188	41181	38073	37296	7770	22533	9324	450	7384785
Aarhus (ARH)	25641	20979	32634	8547	0	24864	33411	12432	38073	38073	4662	24087	32634	39627	36519	35742	6216	20979	14763	450	7384785
Wilhelshaven (WSV)	3885	41181	13986	20202	24864	0	16317	6216	19425	20202	24864	43512	52059	59829	56721	55167	26418	40404	23310	450	7384785
Felixstowe (FLT)	17094	49728	6993	28749	33411	16317	0	20202	7770	4662	33411	52836	61383	68376	65268	64491	34965	49728	33411	450	7384785
Hamburg (HBG)	6216	24087	17094	17871	12432	6216	20202	0	22533	24087	14763	27195	35742	43512	40404	38850	13986	24087	24864	450	7384785
Antwerp(ATP)	20202	53613	8547	33411	38073	19425	7770	22533	0	10878	38073	56721	65268	73038	69930	68376	38850	53613	36519	450	7384785
Port of London(POL)	20979	53613	10101	33411	38073	20202	4662	24087	10878	0	38073	56721	65268	73038	69930	68376	38850	53613	37296	450	7384785
Monthly Demand (In thousand TEU)	30	10	400	2	2	28	50	105	250	8	23	88	39	47	34	18	9	73	96		

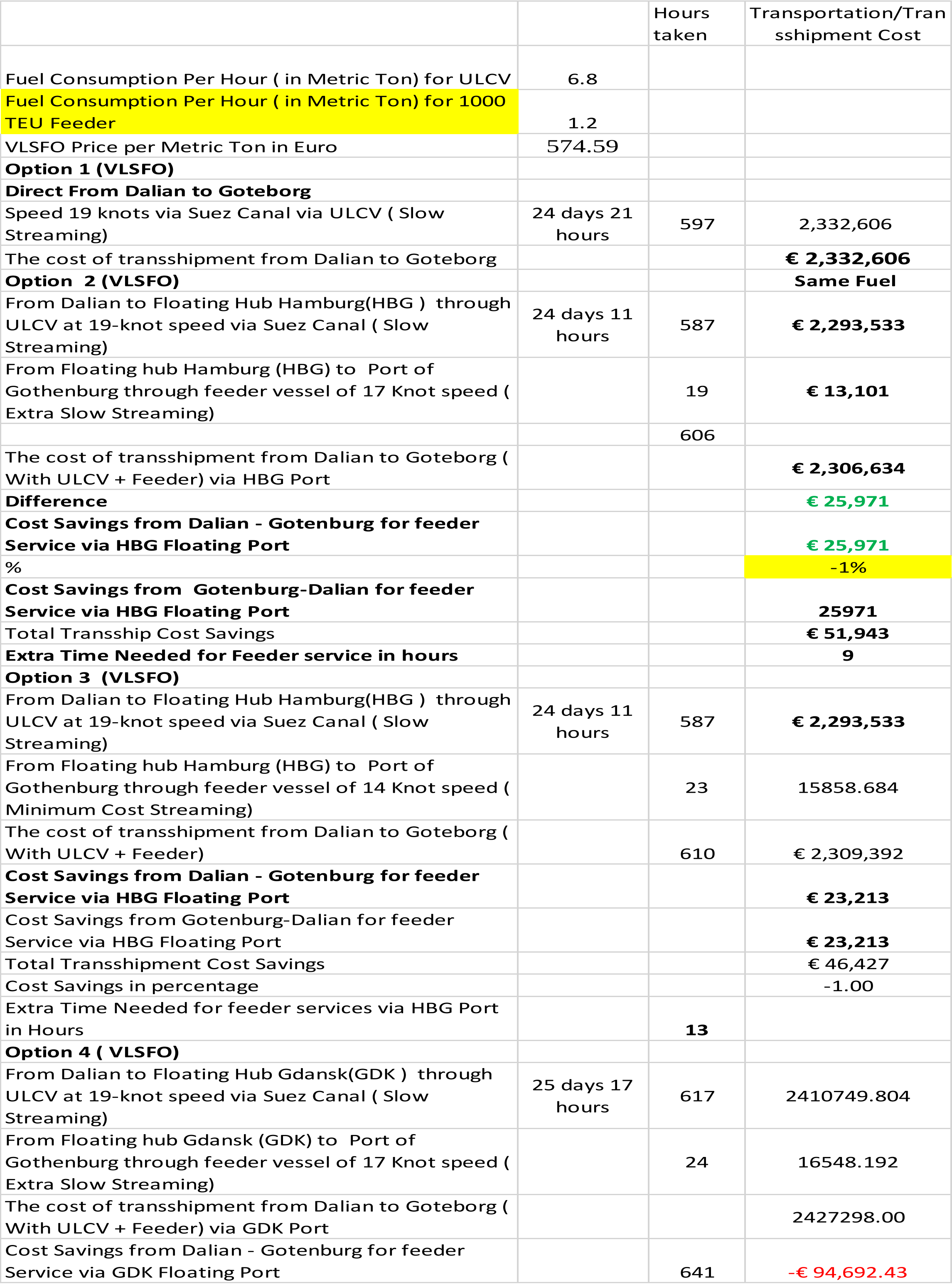
Appendix M: Monthly Capacity Assumption of FCTs and Monthly Demand Allocation of Ports in Scenario 6 (Network F)

Supply Port	Bremerhaven	Gdansk	Rotterdam	Goteborg	Aarhus	Wilhelshaven	Felixtowe	Hamburg	Antwerp	Port of London	Helsingborg	Klaipedia	Riga	Kotka	Helsinki	Talinn	Copenhagen	Gdynia	Oslo	Monthly Capacity (In thousand Units)	Monthly Fixed Cost
Bremerhaven (BRH)	0	41181	13986	20979	25641	3885	17094	6216	20202	20979	25641	44289	52836	60606	57498	55944	26418	41181	24087	417	7384785
Gdansk (GDK)	41181	0	48174	22533	20979	41181	49728	24087	53613	53613	16317	6216	18648	27195	23310	22533	15540	777	29526	417	7384785
Rotterdam (ROM)	13986	48174	0	27972	32634	13986	6993	17094	8547	10101	32634	51282	59829	67599	64491	62937	33411	48174	31080	417	7384785
Goteborg (GTB)	20979	22533	27972	0	8547	20202	28749	17871	33411	33411	6216	24864	34188	41181	38073	37296	7770	22533	9324	417	7384785
Aarhus (ARH)	25641	20979	32634	8547	0	24864	33411	12432	38073	38073	4662	24087	32634	39627	36519	35742	6216	20979	14763	417	7384785
Wilhelshaven (WSV)	3885	41181	13986	20202	24864	0	16317	6216	19425	20202	24864	43512	52059	59829	56721	55167	26418	40404	23310	417	7384785
Felixstowe (FLT)	17094	49728	6993	28749	33411	16317	0	20202	7770	4662	33411	52836	61383	68376	65268	64491	34965	49728	33411	417	7384785
Hamburg (HBG)	6216	24087	17094	17871	12432	6216	20202	0	22533	24087	14763	27195	35742	43512	40404	38850	13986	24087	24864	417	7384785
Antwerp(ATP)	20202	53613	8547	33411	38073	19425	7770	22533	0	10878	38073	56721	65268	73038	69930	68376	38850	53613	36519	417	7384785
Port of London(POL)	20979	53613	10101	33411	38073	20202	4662	24087	10878	0	38073	56721	65268	73038	69930	68376	38850	53613	37296	417	7384785
Monthly Demand (In thousand TEU)	31	15	439	3	3	31	59	108	252	10	23	88	39	47	34	18	9	73	96		

Appendix N: Monthly Capacity Assumption of FCTs and Monthly Demand Allocation of Ports in Scenario 7 (Network G)

	Operation, Personel and Transportation Cost in Euro Per 1000 Unit																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
Supply Port	Bremerhaven	Gdansk	Rotterdam	Goteborg	Aarhus	Wilhelshaven	Felixstowe	Hamburg	Antwerp	Port of London	Helsingborg	Klaipedia	Riga	Kotka	Helsinki	Talinn	Copenhagen	Gdynia	Oslo	Monthly Capacity (In thousand Units)	Monthly Fixed Cost
Bremerhaven (BRH)	0	41181	13986	20979	25641	3885	17094	6216	20202	20979	25641	44289	52836	60606	57498	55944	26418	41181	24087	700	7384785
Gdansk (GDK)	41181	0	48174	22533	20979	41181	49728	24087	53613	53613	16317	6216	18648	27195	23310	22533	15540	777	29526	700	7384785
Rotterdam (ROM)	13986	48174	0	27972	32634	13986	6993	17094	8547	10101	32634	51282	59829	67599	64491	62937	33411	48174	31080	700	7384785
Goteborg (GTB)	20979	22533	27972	0	8547	20202	28749	17871	33411	33411	6216	24864	34188	41181	38073	37296	7770	22533	9324	700	7384785
Aarhus (ARH)	25641	20979	32634	8547	0	24864	33411	12432	38073	38073	4662	24087	32634	39627	36519	35742	6216	20979	14763	700	7384785
Wilhelshaven (WSV)	3885	41181	13986	20202	24864	0	16317	6216	19425	20202	24864	43512	52059	59829	56721	55167	26418	40404	23310	700	7384785
Felixstowe (FLT)	17094	49728	6993	28749	33411	16317	0	20202	7770	4662	33411	52836	61383	68376	65268	64491	34965	49728	33411	700	7384785
Hamburg (HBG)	6216	24087	17094	17871	12432	6216	20202	0	22533	24087	14763	27195	35742	43512	40404	38850	13986	24087	24864	700	7384785
Antwerp(ATP)	20202	53613	8547	33411	38073	19425	7770	22533	0	10878	38073	56721	65268	73038	69930	68376	38850	53613	36519	700	7384785
Port of London(POL)	20979	53613	10101	33411	38073	20202	4662	24087	10878	0	38073	56721	65268	73038	69930	68376	38850	53613	37296	700	7384785
Monthly Demand (In thousand TEU)	31	15	439	3	3	31	59	108	252	10	23	88	39	47	34	18	9	73	96		

Appendix O: Cost before FCT, Cost After FCTs, and Cost Savings from FCT Integration



		Hours taken	Transportation/Transshipment Cost
Fuel Consumption Per Hour (in Metric Ton) for ULCV	6.8		
Fuel Consumption Per Hour (in Metric Ton) for 1000 TEU Feeder	1.2		
VLSFO Price per Metric Ton in Euro	574.59		
Option 1 (VLSFO)			
Direct From Dalian to Goteborg			
Speed 19 knots via Suez Canal via ULCV (Slow Streaming)	24 days 21 hours	597	2,332,606
The cost of transshipment from Dalian to Goteborg			**€ 2,332,606**
Option 2 (VLSFO)			**Same Fuel**
From Dalian to Floating Hub Hamburg(HBG) through ULCV at 19-knot speed via Suez Canal (Slow Streaming)	24 days 11 hours	587	**€ 2,293,533**
From Floating hub Hamburg (HBG) to Port of Gothenburg through feeder vessel of 17 Knot speed (Extra Slow Streaming)		19	**€ 13,101**
		606	
The cost of transshipment from Dalian to Goteborg (With ULCV + Feeder) via HBG Port			**€ 2,306,634**
Difference			**€ 25,971**
Cost Savings from Dalian - Gotenburg for feeder Service via HBG Floating Port			**€ 25,971**
%			-1%
Cost Savings from Gotenburg-Dalian for feeder Service via HBG Floating Port			**25971**
Total Transship Cost Savings			**€ 51,943**
Extra Time Needed for Feeder service in hours			**9**
Option 3 (VLSFO)			
From Dalian to Floating Hub Hamburg(HBG) through ULCV at 19-knot speed via Suez Canal (Slow Streaming)	24 days 11 hours	587	**€ 2,293,533**
From Floating hub Hamburg (HBG) to Port of Gothenburg through feeder vessel of 14 Knot speed (Minimum Cost Streaming)		23	15858.684
The cost of transshipment from Dalian to Goteborg (With ULCV + Feeder)		610	€ 2,309,392
Cost Savings from Dalian - Gotenburg for feeder Service via HBG Floating Port			**€ 23,213**
Cost Savings from Gotenburg-Dalian for feeder Service via HBG Floating Port			**€ 23,213**
Total Transshipment Cost Savings			€ 46,427
Cost Savings in percentage			-1.00
Extra Time Needed for feeder services via HBG Port in Hours		**13**	
Option 4 (VLSFO)			
From Dalian to Floating Hub Gdansk(GDK) through ULCV at 19-knot speed via Suez Canal (Slow Streaming)	25 days 17 hours	617	2410749.804
From Floating hub Gdansk (GDK) to Port of Gothenburg through feeder vessel of 17 Knot speed (Extra Slow Streaming)		24	16548.192
The cost of transshipment from Dalian to Goteborg (With ULCV + Feeder) via GDK Port			2427298.00
Cost Savings from Dalian - Gotenburg for feeder Service via GDK Floating Port		641	-€ 94,692.43