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DOI
10.4233/uuid:265ecd81-4b57-4697-bd0d-60a7ec35aa8a

Publication date
2018

Document Version
Final published version

Citation (APA)
Saeedi, H. (2018). *Network-Level Analysis of the Market and Performance of Intermodal Freight Transport*. [Dissertation (TU Delft), Delft University of Technology]. TRAIL Research School. https://doi.org/10.4233/uuid:265ecd81-4b57-4697-bd0d-60a7ec35aa8a

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Delft University of Technology

Cover illustration by: Lee Torrens, W: http:// www.canva.com/

Network-Level Analysis of the Market and Performance of Intermodal Freight Transport

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus Prof.dr.ir. T.H.J.J. van der Hagen,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op donderdag 15 maart 2018 om 10.00 uur

door

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Dit proefschrift is goedgekeurd door de promotor en de copromotor.

Samenstelling van de promotiecommissie:

Rector Magnificus	voorzitter
Prof.dr. R.A. Zuidwijk	promotor
Dr. B.W. Wiegmans	copromotor

Onafhankelijke leden:

Prof. dr. L.A. Tavasszy	Technische Universiteit Delft
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TRAIL Thesis Series no. T2018/1, the Netherlands Research School TRAIL

TRAIL
P.O. Box 5017
2600 GA Delft
The Netherlands
E-mail: info@rsTRAIL.nl

ISBN: 978-90-5584-233-9

Printed in the Netherlands

“A good question is [already] half of knowledge.”

(prophet Mohammad)

Dedicated to my beloved princesses:

Reihaneh, Nika, Nava

Acknowledgments

All the stories are starting with the name of the God. Thus, I would first like to thank God for his never-ending mercy and grace, which enabled me to successfully end up this step of my life.

Whenever that I come back to any moment of these years, I remember different people who helped me in this scientific journey. I would like to take this opportunity to thank all of them for their contributions and support.

I would like to express my very great appreciation to my promotor Prof. Rob Zuidwijk for giving me the chance to work with him, and his support. Dear Rob, your inspiring, critical and beautiful mind taught me how to tackle a problem, and look at it from different aspects. I would also like to greatly appreciate my supervisor Dr. Bart Wiegmans who offered me the opportunity in joining Delft University of Technology. Dear Bart, thank you for sharing your great experience and nice ideas with me.

I would like to offer my special thanks to Dr. Behzad Behdani who joined my supervisory team in the last two years of my PhD. Dear Behzad, without your kindly support, reaching to the end of this story wouldn't have been possible. I wish you the best, and hope we could cooperate together to do good things for our country.

I would also like to thank Dr. Jafar Rezaei for his time, comments and advises in different stages of my PhD. His assistance is greatly appreciated. Also, my special thanks to Dr. Mostafa Jafari, the Faculty member of Zanjan University in Iran, for his constructive recommends.

I would like to cordially thank all colleagues and staff at the Transport and Planning Department of Delft University of Technology, and all my former colleagues in Rotterdam School of Management, Erasmus University for all cooperation and friendship, in particular, my officemates Mo, Silvia, Lin, Mahdi, Yao, Paul, Na and Harry. You supported me greatly, and were always willing to help me. We shared many great moments, and it was always my pleasure to come to the office with such lovely and engaging people.

My appreciation extends to all my Iranian friends in the Netherlands who have a great support for me and my family. Thanks for being there for us in all times and circumstance.

I would like to acknowledge my family for their enduring support of me in all stages in my life and during my doctoral work. I am grateful to my mother, my brothers and sister for their support and love. I would like to really appreciate my parents in law, my sisters in law, and my brothers in law.

During the 4^{th} year of my PhD, my father passed away. He was a great man who taught me how to live with honor, honesty and faith. He was always a source of inspiration for me and he was always proud of me and my achievements. It is sad that he is not with me to share the joy of this wonderful achievement and fruits of his overwhelming support. I wish him the mercy and grace from God, and I hope his soul rest in peace.

Last but not the least, I would like to lovely thank the woman who stood next to me during all these years. Dear Reihaneh, thanks for your support, patience and true love. You and our two beloved beautiful princesses, Nika and Nava, are the most important persons in my life and my inspiration in all I do.

Hamid SAEEDI

15 March 2018

Summary

Road transport has been the dominant modality for hinterland freight transport in the last two decades. This has resulted in congestion, air pollution and other external effects such as noise nuisance. Intermodal Freight Transport (IFT) as an alternative to road transport has been stimulated by the European Commission. In particular, there is a target of shifting more than 50% of freight being transported further than 300 km by road to IFT by 2050. However, despite all efforts, and running different programs, the market share of IFT is still quite limited. Assuming that having a competitive market, and improving the performance of the IFT service will result in higher market share for IFT service, this thesis analyzes the market structure and the performance of the IFT service at the network-level.

An IFT service comprises of different IFT chains—which themselves include different actors providing different services (i.e., pre- and end-haulage, transshipment, and main-haulage). All these IFT chains, together, form an IFT network. To improve the market share of IFT service, we need to get a better understanding of the market structure of the IFT network. This is especially important since market structure has been largely used as a descriptor of the conduct of players in the market. In the IFT domain, some research studies have analyzed separate segments of IFT market. However, due to the multistage characteristic of IFT service, the segmental analysis gives an incomplete view of the IFT market. In fact, the competition in an IFT network is between IFT chains or even between different corridors to transport goods from one "origin" to one "destination". Hence, a network-based analysis is needed. Developing a network-based model for analysis of market structure of IFT networks is the first objective in this research.

The market share of IFT service could also be limited by its low performance. Therefore, we need to have methods to evaluate the performance of a whole IFT system (or IFT chains) as well as the performance of different sub-sections in the IFT chains. In this thesis, as the second objective, we present a model to measure the efficiency of the whole IFT chains at the network level.

Based on these two objectives, we formulated the following two main research questions in this thesis:

- How can we analyze the IFT market structure at the network level?
- How can we measure the performance of an IFT chain in a network?

To analyze the market structure in an IFT network, we present a model called "Intermodal Freight Transport Market Structure (IFTMS) model". This model uses graph theory and defines distinct submarkets in an IFT network. These submarkets are represented as nodes (transshipments), links (main-haulages), and paths (corridors, and ODs). Subsequently, the model combines the market structures on IFT submarkets and extends them to the network level.

To study the market structure of real IFT networks, for example the European intermodal network, there are two main challenges. First one needs to elaborate a proper definition of the

relevant geographical transshipment submarkets. The other challenge is the availability of detailed data—especially at the chain level. To cope with these two main challenges, a methodology that is complementary to the IFTMS model is presented. This methodology applies a conservative model-based approach to define the geographic boundaries of the transshipment submarkets and creates a data set for market analysis.

In order to answer the second research question, we present a modified Network Data Envelopment Analysis (NDEA) model. The models aims at measuring the efficiency of the multi-division IFT chains with different structures (number of divisions). This model considers the concept of "value of the service" as the intermediate measure in the modeling.

The developed models and achievements of this thesis can have different policy implications: The IFTMS model could be used by antitrust authorities to investigate the anticompetitive practices in the IFT network. They can evaluate the effects of different business practices on competition and concentration in the IFT market and overall on the welfare of the society. It can also be used by business managers to examine the market implications of their business practices. The impact of policies to promote IFT in the EU or the other continents can also be evaluated using this model.

The NDEA model could be used by policy-makers to have an overall assessment of the performance of IFT systems, and determine the less efficient divisions. These results can support policy makers to determine the primary targets for performance improvement (and policy design), in order to promote IFT service.

Besides the presented models in this thesis, the application of the models to the case of EU intermodal network has resulted in some managerial insights. The analysis of EU IFT network shows that in most areas in Europe the transshipment and main-haulage submarkets are highly concentrated. Applying the efficiency model to a sample of European IFT network also suggests that - to improve the performance of the IFT network - the focus of policy-makers, in the majority of corridors, should be on improving the performance of terminals.

Samenvatting

Sinds jaar en dag is wegvervoer de dominante modaliteit voor vrachtvervoer van en naar het achterland van havens. Naast positieve effecten heeft dit ook geresulteerd in congestie, luchtvervuiling en andere externe effecten zoals geluidsoverlast. Onder andere de Europese Commissie heeft Intermodaal goederenvervoer (IFT) als alternatief voor wegvervoer gestimuleerd. De doelstelling is om in 2050 meer dan 50% van het vrachtvervoer met een afstand van 300 km of meer middels IFT te vervoeren. Ondanks alle inspanningen binnen een groot aantal programma's is het marktaandeel van IFT echter nog steeds vrij beperkt. Dit proefschrift analyseert de marktstructuur en de prestaties van de IFT-diensten op netwerkniveau, waarbij de aanname is dat het hebben van een concurrerende markt en het verbeteren van de prestaties van de IFT- diensten zal resulteren in een groter marktaandeel voor de IFT- diensten.

Een IFT-service bestaat uit verschillende IFT-ketens, die zelf uit verschillende actoren bestaan, welke vaak ook weer verschillende diensten aanbieden (d.w.z. voor- en na-transport, overslag en hoofdtransport). Al deze IFT-ketens vormen samen een IFT-netwerk. Om het marktaandeel van de IFT-service te verhogen, moeten we de marktstructuur van het IFT-netwerk beter begrijpen. Dit is vooral belangrijk omdat de marktstructuur grotendeels is gebruikt als een beschrijving van het gedrag van spelers in de markt.

In het IFT-domein hebben sommige onderzoeken de afzonderlijke marktsegmenten van de IFT-markt geanalyseerd. Vanwege het samengestelde karakter van de IFT- diensten geeft de segmentanalyse echter een onvolledig beeld van de IFT-markt. In feite is er sprake van concurrentie in een IFT-netwerk tussen IFT-ketens of zelfs tussen verschillende corridors, om de goederen van een "oorsprong" naar een "bestemming" te transporteren en mede daarom is een netwerk-gebaseerde analyse nodig. Daarom is het ontwikkelen van een netwerk-gebaseerd model voor de analyse van de marktstructuur van IFT-netwerken de eerste doelstelling van dit onderzoek. Daarnaast kan het marktaandeel van de IFT-service ook worden beperkt door te lage prestaties. Daarom zijn methoden om de prestaties van een volledig IFT-systeem (of IFT-ketens), evenals de prestaties van verschillende schakels in de IFT-ketens te kunnen evalueren, van groot belang. In dit proefschrift is het tweede doel het ontwikkelen van een model om de efficiëntie van de hele IFT-ketens op netwerkniveau te kunnen meten. Op basis van deze twee doelstellingen formuleren we de volgende twee hoofdonderzoeksvragen in dit proefschrift:

• Hoe kunnen we de IFT-marktstructuur op netwerkniveau analyseren?

• Hoe kunnen we de prestaties van een IFT-keten in een netwerk meten?

Om de marktstructuur in een IFT-netwerk te kunnen analyseren, presenteren we een model met de naam "Intermodaal model voor goederenvervoersmarktstructuur (IFTMS)". Dit model maakt gebruik van 'grafen theorie', en definieert verschillende deelmarkten in een IFT-

netwerk. Deze sub-markten worden weergegeven als knooppunten (‘overslag’), verbindingen (‘hoofdtransport’) en paden (corridors en OD paren). Vervolgens combineert het model de marktstructuren op IFT- deelmarkten en breidt deze uit naar het netwerkniveau. Om de marktstructuur van echte IFT-netwerken te kunnen bestuderen, bijvoorbeeld het Europese intermodale netwerk, zijn er twee belangrijke uitdagingen: 1) de definitie van de relevante geografische overslag markten, 2) de beschikbaarheid van gedetailleerde gegevens, vooral op het niveau van de keten. Om deze twee hoofduitdagingen het hoofd te bieden, wordt een methodologie gepresenteerd die complementair is aan het IFTMS-model. De methodologie past een conservatieve, op modellen gebaseerde aanpak toe om de geografische grenzen van de overslag deelmarkten te definiëren en een dataset voor de marktanalyse te creëren.

Om de tweede onderzoeksvraag te beantwoorden, presenteren we een aangepast ‘Network Data Envelopment Analysis’ (NDEA) -model. Dit aangepaste model is gericht op het meten van de efficiëntie van IFT-ketens met meerdere divisies met verschillende structuren (aantal divisies). Dit model beschouwt het concept " waarde van en dienst " als de tussenstap in de modellering.

De ontwikkelde modellen en geanalyseerde prestaties in dit proefschrift kunnen verschillende beleidsimplicaties hebben: Het IFTMS-model kan door mededingingsautoriteiten worden gebruikt om de concurrentiegedragingen in het IFT-netwerk te onderzoeken. Ze kunnen de effecten van verschillende bedrijfsstrategieën op concurrentie en concentratie op de IFT-markt evalueren. Het kan ook door bedrijfsmanagers worden gebruikt om de marktimplicatie van hun bedrijfsstrategieën te onderzoeken. De impact van beleid ter bevordering van IFT in de EU of op andere continenten kan ook met behulp van dit model worden geëvalueerd. Het NDEA-model zou door beleidsmakers kunnen worden gebruikt om een algehele beoordeling van de prestaties van IFT-systemen te maken en om de minder efficiënte divisies te bepalen. Deze resultaten kunnen beleidsmakers ondersteunen bij het bepalen van de primaire doelen voor prestatieverbetering (en beleidsontwerp) om verbeterde IFT-services te promoten. Naast de ontwikkelde modellen in dit proefschrift heeft de toepassing van deze modellen op het intermodale EU-netwerk geleid tot enkele managementinzichten. Uit de analyse van het EU IFT-netwerk blijkt dat in de meeste gebieden in Europa de overslag- en hoofdtransport-deelmarkten sterk geconcentreerd zijn. Het toepassen van het efficiëntiemodel op een voorbeeld van een Europees IFT-netwerk suggereert ook dat - om de prestaties van het IFT-netwerk te verbeteren - de aandacht van beleidsmakers, in de meeste corridors, zou moeten liggen op het verbeteren van de prestaties van terminals.

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Chapter 1

Introduction

Global freight transport has grown steadily in the last two decades (Gudmundsson, Hall, Marsden, & Zietsman, 2016). Because road transport has been the dominant modality for hinterland transport, this growth has resulted in congestion and other external effects such as emissions and noise nuisance (Macharis & Bontekoning, 2004; Blauwens, Baere, & Voorde, 2016). Intermodal Freight Transport (IFT) is believed to provide an attractive alternative to road transport (Kim & Van Wee, 2011). In particular, the European Commission has initiated a considerable number of research programs that are designed to stimulate IFT (European Commission, 2001; Votano, Parham, & Hall, 2004). In 2011, the European Commission set a target of shifting 30% of freight being transported further than 300 km by road to other modes of transport such as rail or waterway transport by 2030, and more than 50% by 2050. After considerable investments where approximately €28 billion has been allocated to funding of rail projects between 2007 and 2013, and priority giving to shifting freight from road to IFT, the results show a gap between planned and achieved EU intermodal performance (EU Report, 2016). As a consequence, the market share of the IFT service is still limited. A further understanding of the market environment of IFT services deployed on networks, and its performance at the network level, may help to understand and improve its competitive position. Therefore, in this thesis, the market structure and performance of IFT service from the network perspective will be analyzed.

1.1. Problem Definition

In general, no commonly accepted definition of Intermodal Freight Transport (IFT) exists. Each research uses a definition that reflects the scope of the research leading to different definitions. For example based on EU definition the intermodal freight transport is the movement of goods in one and the same loading unit or vehicle by successive modes of transport without handling of the goods themselves when changing modes (European Commission, 2001). Bontekoning et al. (2004) has reviewed different definitions of intermodal transport applied in the literature. Considering those definitions, in this thesis the IFT service is defined as: “A technical, legal, commercial, and management framework for moving goods door-to-door in containers or trailers using more than one mode of transport under a single rate”.

To improve the market share of IFT service, we need to have an understanding of the market structure of the IFT network. This is especially important since market structure has been largely used as a descriptor of the conduct of players in the market (Carlton & Perloff, 1999). Also, market analysis and measuring the market concentration are common elements in studies by industrial organization economists, and are applied frequently in the formulation of antitrust and regulatory laws that address the competitive behavior of companies (Carlton & Perloff, 1999). In the IFT domain, some research studies have analyzed separate segments of IFT market. For example, the market for transshipment service or the market for main-haulage service (see, e.g., Wiegmans et al. (1999), Makitalo (2010), Lam et al. (2007), Sys (2009), and Merikas et al. (2014)). However, due to the multistage characteristic of IFT service, the segmental analysis gives an incomplete view of the IFT market. In fact, because of the nature of service, the competition in an IFT network is between IFT chains or even between different corridors to transport the cargo from one “origin” to one “destination”; therefore, a network-based analysis is needed. Developing a network-based model for analysis of market structure of IFT networks is the first objective in this research.

The limited market share of IFT service could be caused by its (low) performance as well (Carlton & Perloff, 1999). Especially, we need to have a general understanding of the performance of a whole IFT system (or IFT chains) and its divisions, i.e., Transshipment and Transportation. Despite the importance of performance measurement, studies on the efficiency measurement of IFT chains are quite limited, and most of the attention has been paid to the tradeoff or cooperation among the chain members, rather than the efficiency of the chain (Yang, Wu, Liang, Bi, & Wu, 2009). There are some studies which have evaluated the performance of separate segments (divisions) of IFT network e.g., Hilmola (2007), Cantos et al. (1999), Notteboom et al. (2000), and Cullinane & Wang (2007). None of the previous works on efficiency measurement considered IFT as a multi-division transport chain and calculate its efficiency at the network level. Having such a model could help us to measure the performance of different IFT chains and its divisions in the network, and investigate the source of inefficiency in IFT chains.

1.2. Research Scope

An IFT chain consists of different divisions or segments, i.e., pre- and end-haulage, main-haulage transportation, and also transshipment segments – between each two consecutive transportation activities. Different operators are active to deliver a door-to-door freight transport service to the final customer. The main-haulage transportation division could include three modes: short sea shipping (SSS), rail, and inland water way (IWW). Each of these modes is further divided into liquid/dry bulk and trailer/containerized freight segments.

Many researchers and organizations (e.g., EU transport in Figures (2017), and Janic (2007)) just focus on certain segments of the respective transport modes in the IFT network. In this thesis, the focus is on the trailers or containerized rail and IWW freight transport segments as being or representing the IFT network.

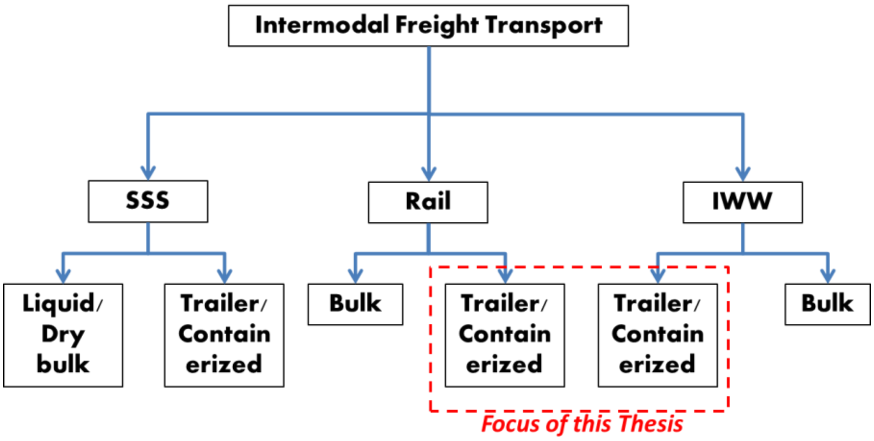

Figure 1.1. Intermodal Freight Transport Segments

1.3. Research Objectives

This thesis aims at analyzing the market and performance of IFT service at the network level. The first objective of this research is developing a model to analyze the market structure of IFT network. This model, which is called IFTMS model, is developed, using graph theory concepts to present a network-based analysis of the IFT market (Chapter 2).

Applying the IFTMS model to the real freight transport networks is the second objective. There are two main challenges in applying the model. First is the definition of the relevant geographical transshipment submarkets. The other one is the availability of detailed data, especially at the chain level. To overcome these challenges A Four-Step Methodology which is complementary to the IFTMS model is developed in chapter 3.

Having an insight about the current literature on freight transport performance measurement is the next objective. Systematic Review of the literature about the performance measurement of freight transport network could be useful to find the gap in this domain. In chapter 4, after presenting the performance analysis concepts, and different methodologies of performance measurement, a systematic literature review is done.

The last objective of this research is measuring the performance of the IFT chains in the network level. There are two main challenges to do that. The first challenge is the existence of different IFT chains with different structures (number of divisions). The second challenge is defining a relevant intermediate service that connects the various divisions of an IFT chain. Taking into account these challenges, in chapter 5, a modified network DEA model is developed.

1.4. Research Questions

In order to achieve the main objectives, the thesis provides answers to the following research questions in two main categories, i.e., market structure analysis, and performance measurement.

1.4.1. Market Structure Analysis:

- How can we analyze the IFT market structure at the network level? (Chapter 2). To answer this question we should address these questions:
    - How can we identify different IFT submarkets in a freight transport network?
    - How can we measure the concentration of these submarkets in a consistent way?
    - How can we measure the impact of anticompetitive practices on the market structure of the IFT network?

- How can we apply the IFTMS model (Developed in Chapter 2) to measure the market concentration of real freight networks, e.g. European freight transport network? (Chapter 3). To answer this question we should address these questions:
    - How can we define the relevant geographical transshipment submarkets in an IFT network?
    - How can we deal with limited data, in applying IFTMS model to the real cases?
    - How can we assign the total capacity of a transport operator to its services in the network?
    - How can we assign the flow of containers on trailers to different corridors of a freight network in accordance to the IFTMS data requirements?
    - What is the market structure of the European IFT network?

1.4.2. Performance measurement:

- What are the main methods of performance measurement applied to the freight transport domain? (Chapter 4)

- How can we measure the performance of an intermodal freight transport chain in a network? (Chapter 5). To answer this question we should address these questions:
    - How can we define a suitable intermediate service between different divisions of an IFT chain?
    - How can we measure the efficiency of IFT chains with different structures (number of divisions)?

1.5. Methodological Contributions

The main contributions of the thesis in accordance with the main research questions in two main categories are:

1.5.1. Developing a methodology to analyze the market structure of IFT service in network level:

The analysis of market structure of IFT service can be challenging, primarily due to the multistage characteristic of the presented service. The analysis can be conducted on different levels: a segmental view in which the market concentration for different submarkets (e.g., the transshipment submarket) is analyzed, or a chain perspective in which the competition between different IFT chains in one corridor is studied. At the same time, multiple corridors are potentially competing in the transportation of goods between an origin and a destination.

To distinguish these submarkets inside an IFT network, and make a consistent relation between the structures of these submarkets, we develop an Intermodal Freight Transport Market Structure (IFTMS) model. This model combines the market structures on IFT submarkets and extends them to the network level. IFTMS uses graph theory and defines distinct submarkets in an IFT network. These submarkets are represented as nodes (transshipments), links (main-haulages), and paths (corridors, and ODs). The IFT market is continuously evolving as a result of different regulatory policies and business practices adopted by different IFT operators. These business practices might be restrained by antitrust authorities if they harm the consumer welfare by reducing the competition level in the market. The IFTMS model can also be used to measure the side effects of such business practices e.g., mergers and acquisitions.

To perform market structure analysis of a real IFT network, e.g., the European intermodal network, there are two main challenges. First is the definition of the relevant geographical transshipment submarkets. The other challenge is the availability of detailed data—especially at the chain and corridor levels. To cope with these two main challenges, a methodology that is complementary to the IFTMS model is presented in the third chapter. This methodology consists of four different steps which uses a model-based approach —based on fair allocation algorithms— to make the existing high-level data more detailed toward node, link, and corridor data, and to characterize the submarkets in the IFT network. This methodology is especially useful in cases where only aggregated or incomplete data are available. It presents a comprehensive and consistent picture of all flows in different corridors of an IFT network. Applying this methodology we generate a capacitated EU IFT network.

1.5.2. Presenting a model to measure the performance of IFT service in network level:

A systematic literature review about the performance measurement in freight transportation systems has not been carried out yet. In some cases, the performance of a segment of the freight transport has been reviewed, but none of the papers reviewed considered IFT as a multi-division transport chain and calculated its efficiency using NDEA approach. In chapter 4 a systematic literature review is presented. This literature review is useful for the scholars who would like to conduct new research in the domain.

In chapter 5, we introduce a modified Network DEA model to measure the efficiency of the IFT chains with different structures (number of divisions), and their respective divisions. The application of this model to the IFT chains involves two main challenges. The first challenge is to identify the number of divisions, because in an IFT network, we may have different IFT chains with different structures, where the number of sequential transshipment and transportation activities vary. The second challenge is defining a relevant intermediate service that connects the various divisions in an IFT chain. Both challenges are discussed in the thesis, and the original formulation is extended to cope with these challenges. The model developed in this chapter is applied to a sample of the European IFT network as an illustrative case to show how the model can be applied to the real case and what the expected results would look like. Applying this model, we can find the less efficient IFT chains, and at the same time, we can find the respective less efficient division(s) which is (are) explaining the total inefficiency of the chain.

Figure 1.2 shows the structure of the thesis and the contributions of different chapters in accordance to the main research questions.

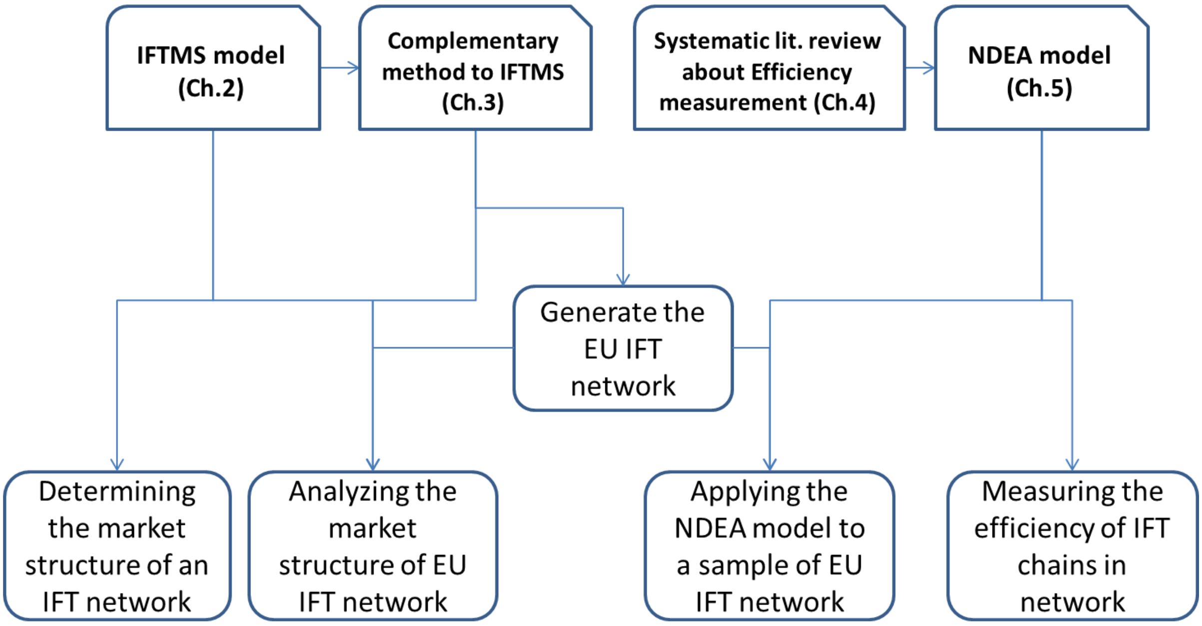

Figure 1.2. The Structure of the Thesis and Contributions of Different Chapters

1.6. Outline of the Thesis

The rest of this thesis is structured as follows. In **chapter 2**, a model to analyze the IFT services at the networks level is presented. First, a number of submarkets that correspond to the services provided, i.e. pre-haulage, end-haulage, transshipment, and main-haulage are distinguished. Then, using a graph theory concept, a flow optimization model is incorporated to assign the capacities on links, nodes, and paths to the IFT network services in a consistent way. Next, the concentration indices—like CR or HHI—for these IFT submarkets are calculated. This chapter has been published in: Saeedi H., Wiegmans, Behdani, and Zuidwijk, "*Analyzing competition in intermodal freight transport networks: The market implication of business consolidation strategies*," Research in Transportation Business and Management, vol. 23, pp. 12–20, Jun. 2017.

In **chapter 3**, the market structure of the European freight network is analyzed. There are challenges in applying the IFTMS to real freight transport networks. To cope with these challenges, a methodology that is complementary to the IFTMS model is presented in this chapter. This methodology applies a conservative model-based approach to define the geographic boundaries of the transshipment submarkets, and creates a data set for market analysis. This methodology is especially useful in cases where only aggregated or incomplete data are available. This chapter has been published in: Saeedi H., Wiegmans, Behdani, and Zuidwijk, "*European intermodal freight transport network: Market structure analysis*," Journal of Transportation Geography, vol. 60, pp. 141–154, Apr. 2017.

Chapter 4 gives an extensive overview and discussion about the literature on the performance measurement of freight transport systems. This includes both methodological studies as well as applications to the freight transportation domain. To improve the performance, it is necessary to be able to measure the performance of a freight transport system. Despite its importance, a systematic literature review about the performance measurement in freight transportation systems has not been carried out yet. In this chapter, after presenting the performance analysis concepts, the basic methodologies are explained. Next, the scientific literature is reviewed. Reviewing each paper, the main question of the paper, the variables e.g., input, output, or intermediate variables, which have been used in modeling and the main results of the paper, are presented.

In **chapter 5**, a modified network data envelopment analysis method is presented which is used to measure the performance of different intermodal freight transport chains inside a freight network. The presented model is applied to a sample of IFT chains in a European IFT network.

Finally, **chapter 6** summarizes the main findings and results of this thesis and discusses some recommendations for further research.

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Chapter 2

Analyzing the Market Structure of the Intermodal Freight Transport Networks

To cope with an intense and competitive environment, intermodal freight transport operators have increasingly adopted business practices —like horizontal and vertical business integration—which aim to reduce the operational costs, increase the profit margins, and improve their competitive position in the market. These strategies and business practices could potentially affect the competition level in the IFT market by increasing the market concentration. The impact can be on the separate submarkets (e.g., transshipment market or main-haulage market) or the whole market for IFT services at the network level. To investigate the impact of these business practices on the market structure of IFT networks, we present a model to analyze the market structure of IFT submarkets and extend the results to the network level. Using this multi-level market analysis model, we can evaluate the decisions made by firms and the market outcomes that result. The application of the presented model is also illustrated using a numerical example. The numerical example shows, for instance, that the impact of a merger, as a business practice, on the competition level in an IFT market —and its submarkets— depends on the merger type (horizontal and vertical). Furthermore, different indicators that "represent" market structure and competition might react differently to a merger in an IFT network.

This chapter is an edited version of the article:

Saeedi, H., Wiegmans, B., Behdani, B., & Zuidwijk, R. A, "*Analyzing competition in intermodal freight transport networks: The market implication of business consolidation strategies*," Research in Transportation Business and Management, vol. 23, pp. 12–20, Jun. 2017.

2.1. Introduction

Global freight transport has grown steadily in the last two decades (Gudmundsson, Hall, Marsden, & Zietsman, 2016). Because road transport has been the dominant modality for hinterland transport, this growth has resulted in congestion and other external effects such as emissions and noise nuisance (Macharis & Bontekoning, 2004). Intermodal freight transport (IFT) involving rail and inland waterways as the main transport links is believed to provide an attractive alternative to road transport (Kim & Van Wee, 2011). In particular, the European Commission has initiated a considerable number of research programs that are designed to stimulate IFT (Commission of the European communities (2001), Votano et al. (2004)). Also, growing attention has been paid to develop new practices for the design, planning, and execution of IFT and its performance (Bontekoning et al., 2004). Many IFT operators have increasingly adopted business practices to improve their competitive position in the market by reducing the operational costs and increasing the profit margins. Some of these IFT business practices, for example, mergers and acquisitions and other horizontal and vertical business integrations, could lead to market structure changes and decrease the competition level in the IFT network. Antitrust authorities may scrutinize and limit such practices because they could harm consumer welfare (Mazzeo & McDevitt, 2014). Antitrust authorities evaluate the decisions made by firms, based on the expected market structure outcomes.

The analysis of market structure and concertation measures for IFT service can be done at several different levels. First, the analysis can be performed for separate segments (e.g., the market for transshipment operators or the market for main-haulage operators). Some literature has analyzed specific segments of IFT markets; see for example Sys (2009), Wiegmans (1999), Makitalo (2010), Merikas et. al (2013). However, due to the multistage characteristic of IFT services, the segmental analysis gives an incomplete view of the IFT market. Moreover, none of these papers has explicitly studied the impact of business practices on the IFT market structure. To fill these gaps, we present a model that analyses IFT services at the network level, and we refer to it as the Intermodal freight transport market structure (IFTMS) model.

First, we distinguish a number of submarkets that correspond to the services provided: pre-haulage, end-haulage, transshipment, main-haulage, and so on. Second, the IFTMS model incorporates a flow optimization model to assign the capacities on links, nodes, and paths to the IFT network services in a consistent way. Next, the concentration indices—like CR or HHI (OECD, 1990)—for these IFT submarkets are calculated. The Concentration Ratio Index (CR_x) is the sum of the market shares of the x largest players, and the HHI is the sum of the squares of the market shares of all players in that market. In this manner, the model helps analyze the IFT market at the network level. We can also measure the impact of anticompetitive practices on the market structure of the IFT network.

This chapter is structured as follows. Section 2 concerns the literature review, and Section 3 introduces the IFTMS model to analyze the market structure of the IFT network. In Section 4, we apply our model to an illustrative example case to measure the impact of horizontal and vertical integration on market structure and competition level of the IFT network and its submarkets. Finally, the last section presents the conclusions and management implications and indicates further research directions.

2.2. Literature Review

2.2.1. Intermodal Freight Transport Market Structure Analysis

Intermodal freight transport (IFT) is defined as "unitized freight transport by at least two transport modes" (Commission of the European communities, 2001). In the IFT market, different actors (pre- and end-haulage operators, main-haulage operators, terminal operators, and intermodal operator) are active in their respective submarkets (see Figure 2.1) to deliver door to door continental transport service. The IFT market encompasses all actors operating in all submarkets.

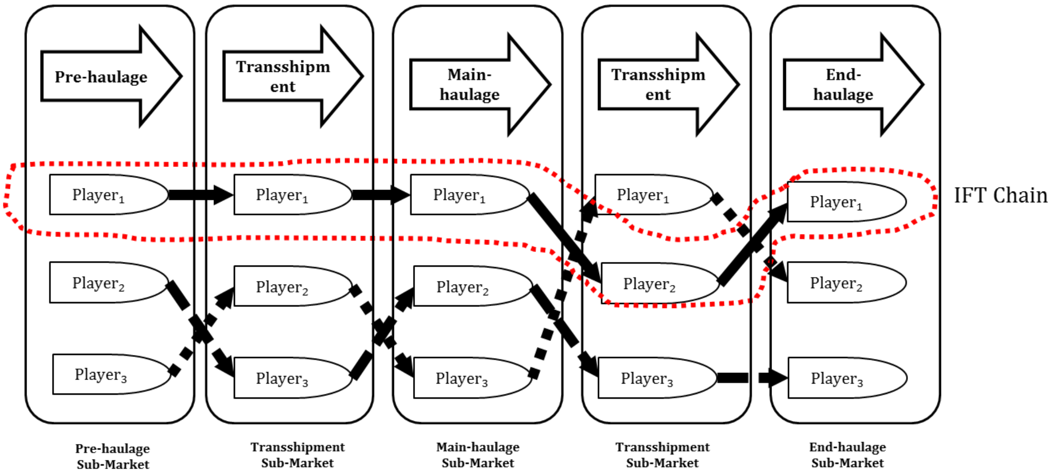

Figure 2.1. Different actors inside a corridor of an IFT network
Source: adapted from Chandrashekar and Schary (1999).

In the competition literature, the term “relevant market” is used to describe areas where competition takes place (Sys, 2009). This relevance lies in both the product or service and the geographic dimensions. In market theories, there are traditionally four main categories of market structure: perfect competition, monopolistic competition, oligopoly, and monopoly (Carlton, D. & Perloff, J., 1999). Sometimes, the oligopoly market is divided into subcategories. For example, Shepherd (1999) categorized oligopoly into loose oligopoly, tight oligopoly, super tight oligopoly, and dominant player oligopoly. Ultimately, the structure of a market will be determined based on the degree of market concentration. Only a few scientific papers have contributed to the structural analysis of (parts of) the IFT market. For example, Wiegmans et al. (1999) analyzed the IFT market in the EU qualitatively based on an extended version of Porter’s model of the competitive forces to identify the stakeholders in the terminal market and find the potential for economic benefits. Makitalo (2010) investigated the Finnish rail industry market by using Delphi techniques and revealed the largest market entry barriers. According to Macharis and Bontekoning (2004), most papers analyze only selected parts of IFT, but there is no paper that analyzes business practices in the whole IFT market. In several other research studies (e.g., Crainic et al. (1990), Jourquin & Demilie (1999), Southworth & Peterson (2000), Janic (2007), Wiegmans et al. (2007), Wiegmans (2005)), parts of the IFT network are modeled and optimized. In the supply chain literature, competition between supply chains is defined (see e.g., Zhang (2006), Zhang & Jie (2011)). Rice and Hoppe (2001) show that supply chain competition does not have a unique definition. They have undertaken a Delphi study among supply chain experts from industry and academia to find different interpretations of the concept of competition among supply chains. The findings reveal that supply chain versus supply chain is not the only existing form of competition, and the methods that companies use to compete are complicated. They categorized the findings in three different categories: actual competition between supply chains, competition in supply network capabilities, and competition in supply chain capabilities led by the master channel (the company that is most powerful on a supply network). Our focus is on the first category as actual competition among IFT chains. Another interesting work about competition among supply chains is the paper by Antai (2011). He has developed a conceptual model for competition among supply chains using the ecological niche approach. In his approach, the source of the competition is the overlap in the resources that are used by different supply chains. Then, by presenting indices and measures, such as niche breadth and niche overlap, he defines the index of competition among two supply chains. “Niche breadth” is a set of different resources that a supply chain uses, and “niche overlap” is an index that shows the degree of overlap between the niche breadth of two different supply chains. The idea concerning the source of competition is further elaborated when we analyze concentration inside the transshipment (node) and main-haulage (link) submarkets.

Market concentration refers to the extent to which a certain number of producers or service providers represent certain shares of economic activity expressed in terms of, for example, volume (i.e., the throughput of different players) (OECD, 1990). Other indicators such as capacity, revenue, added value, capital cost, or other financial or nonfinancial indices can also be used to calculate the degree of concentration in the IFT market (Scherer, 1980). In this chapter, we use the volume of different players as the indicator. There are many indices to measure the degree of concentration, such as the Gini Index, the Concentration Ratio Index, the Herfindahl-Hirschman Index, and the Entropy Index. The most often used ones are the Concentration Ratio Index (CR) and the Herfindahl-Hirschman Index (HHI) (US Department of Justice and the Federal Trade Commission, 2010). Typically, the concentration index is calculated for the four largest players (CR_4). The main disadvantage is that two markets with the same high CR_4 levels may have a structural difference because one market may have few players, whereas the other may have many players. The HHI is defined as:

$$HHI = \sum_{i=1}^{n} (s_i)^2 * 10000 \quad (1)$$

where the market shares ($\mathrm{s_i}$) satisfy $\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{s_i} = 1$. To simplify the reading, it is multiplied by 10,000. The main disadvantage of HHI is that it shows little sensitivity to the entrance of small players into the market (Shepherd, 1999). Because of shortcomings of separate measures, it is common to employ multiple indicators in market structure analysis. Sys (2009) studied whether the container liner shipping industry as a unimodal freight transport system is an oligopolistic market. She used concentration indices and based on the degree of concentration, made judgments about the market structure. Merikas et al. (2013) investigated the change in the structure of the tanker shipping market and its impact on freight rates by applying the CR index and the HHI index. They found that market concentration has increased since 1993. Similar to Sys (2009), in this chapter we use the concentration indices for market analysis, but the calculations are extended from separate submarkets to IFT networks.

2.2.2. Intermodal Freight Transport Business Strategies

Business integration practices may aim to reduce cost and risks or to realize scale economies (Sudarsanam, 2003). Furthermore, they may lead to value optimization, improved service levels, visibility, and customer satisfaction (Mason et al., 2007). Both horizontal and vertical business integrations can take several forms ranging from light to heavy. Subcontracting (supplier relation) is a light form of business integration and aimed at the short term. Stronger forms of business integration might be strategic alliances or joint ventures. The heaviest form of business integration is a merger or acquisition.

IFT business strategies and their effects on the structure of the IFT market is a subject not often discussed in scientific literature. This is remarkable, considering the large importance given by IFT business managers and policy makers, and taking into account the large number of IFT practices initiated by different decision makers at different levels (i.e., governmental policy makers and business managers) all over the world. In a recent research into competition and horizontal integration in maritime freight transport, Alvarez-San Jaime et al. (2013a) found that the benefits of a merger depend on the size of the scale economies and on the differentiation of services. In another research, Alvarez-San Jaime et al. (2013b) found that vertical integration in maritime freight transport (shipping and terminals) leads to (1) continuing routing of cargo through the open terminal and (2) keeping terminals nonexclusive. Despite the limited amount of research in this domain, there have been several practical cases in recent years in which adopting some business practices has potentially led to change in the market structure. Three interesting cases that have been restricted by the Dutch antitrust authority are (1) takeover of TNT by UPS, (2) handling barges at ECT, and (3) coordinated barge transport between a number of inland terminals in Brabant and the port of Rotterdam. An interesting case in the transportation sector—in terms of antitrust competition policy—is the failed takeover of TNT by UPS. EU antitrust authorities said the deal would most likely lead to overconcentration in the sector, which saw UPS offering to sell parts of the company's small-packages and airline business in return, but that was not enough ("Planned UPS-TNT Express merger fails to materialize | Business | DW.COM | 14.01.2013," n.d.). In terms of business competitors operating on a European scale, this would indeed lead to just a small number of remaining competitors. However, on the national scale, for example, many more operators are still competing in these markets. Another example is the recent check, by the EU, of quay loading and unloading procedures for barges at the quays of ECT ("ECT: indeed ACM research into handling inland | The Binnenvaartkrant," n.d.). It is investigated whether barges belonging to the Extended Gate Service (EGS) of ECT are treated more favorably than non-EGS barges. Another example is the cooperation of a number of inland container terminals in Brabant that organize their inland waterway transport to and from Rotterdam together ("Van Berkel Group," n.d.). Especially this case could be analyzed from three different perspectives: (1) horizontal business integration between nodes (the inland terminals), (2) horizontal integration between different links (inland waterway transport to and from Rotterdam), (3) vertical integration between nodes and links (terminals and inland waterway transport).

2.3. Measuring Market Concentration on IFT Networks: IFTMS Model

In this section, we present a model using graph theory that decomposes the IFT network into distinct submarkets and assigns the capacities to the IFT network. The results are next used to calculate the concentration indices for different submarkets. In previous studies, for example, Crainic (2000), IFT services (pre- and end-haulage, transshipment, and main-haulage) have been modeled using graphs. A graph consists of nodes (terminals executing transshipment) and links (transport processes) where nodes are connected by links. This chapter takes a slightly different stance. We consider each transshipment submarket, which includes multiple terminals, as a node in the model. The main-haulage transport between two nodes is provided via a link that represents a main-haulage submarket. This submarket may include rail or inland waterway transport operators. On the network market level, corridors are defined as sequences of nodes and links from origin to destination. Different combinations of operators inside these nodes and links are considered as IFT chains (Figure 2.2). In reality, these IFT chains are organized by intermodal transport operators who integrate transshipment and transport operations. Certain origins and destinations can often be connected via multiple corridors. This means that in the network level—based on competing entities—we have two different types of submarkets: (1) the corridor submarket (competition between IFT chains) and (2) the origin-destination submarket (competition between corridors).

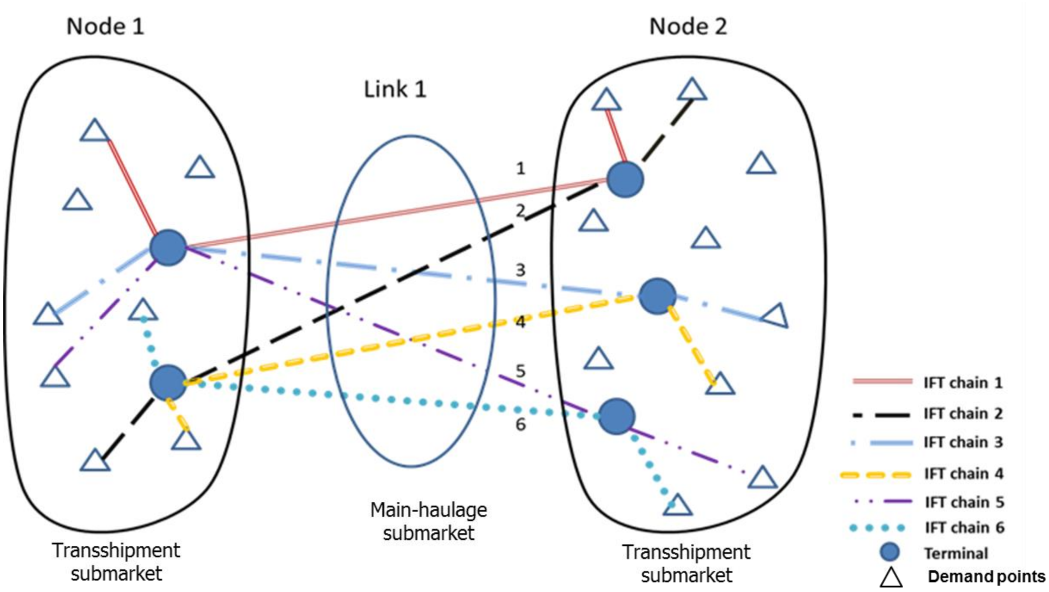

Figure 2.2. Different Submarkets inside an IFT network

By representing IFT processes (transshipment, main haulage, and logistics) with graph theory concepts (node, link, and network), we connect different submarkets on the IFT network. To assess market concentration we need to have the volume (throughput) of each player (e.g., a main-haulage operator) in different submarkets. For this purpose, we use a network flow model, which is discussed in the following section.

2.3.1. Network Flow Assignment

The flow assignment in a network with certain capacities for nodes and links can be done in various ways (Ford & Fulkerson, 2010). We will do it in a proportional and consistent way by applying a proportional fairness algorithm (Bertsekas & Gallager, 1992); that is, the amount of flow allocated to competing operators will be proportional to the capacities of these operators. In particular, we will allocate flow in such a way that assigning more flow to a corridor increases the total utility of the network more than assigning to any other corridor (Bertsekas & Gallager, 1992). We now formalize.

The network is given by graph $G = (N, A)$ with node set N and link set A. The flow f_a on link a ∈ A does not exceed link capacity, that is, $0 \leq f_a \leq c_a$. For any node $n \in N$, the flow is also assumed to respect capacity, so $0 \leq f_n \leq c_n$ for $n \in N$.

For any corridor $\pi \epsilon \prod$ that originates from o and is destined to d, we may establish a flow f_π through the corridor. By abuse of notation, we write $a \in \pi$ or $n \in \pi$ whenever the link a or the node n is part of the corridor π. Define the link-corridor (and similarly, node-corridor) incidence matrix as follows: let $\delta_{a\pi} = 1$ whenever $a \in \pi$ and $\delta_{a\pi} = 0$ otherwise. The flows f_π satisfy $f_a = \sum_\pi \delta_{a\pi} f_\pi$ and $f_n = \sum_\pi \delta_{n\pi} f_\pi$. In case the incidence matrices have ranks equal to the number of corridors, which is the case when the corridors all connect the same OD-pair, then the corridor flows can also be constructed from the link (or node) flows by applying the right inverse of the link-corridor (node-corridor) incidence matrix.

The total flow of the network is the summation of the flows through all corridors, that is, $|f| = \sum_{\pi \epsilon \prod} f_\pi$. Alternatively, the flow size equals the total outflow from the origin and the total inflow to the destination, that is, $|f| = f_o = f_d$. A corridor π has capacity $c_\pi = min\{c_a, c_n | a \in \pi, n \in \pi\}$.

The allocation of the total flow $|f|$ to corridors is proportionally fair when (Bertsekas & Gallager, 1992):

$$Max \prod_{\pi \epsilon \prod} f_\pi \tag{2}$$

$$\sum_{\pi} \delta_{n\pi} f_\pi \leq c_n \tag{3}$$

$$\sum_{\pi} \delta_{a\pi} f_\pi \leq c_a \tag{4}$$

$$f_\pi \leq c_\pi \ , \forall \pi \epsilon \prod \tag{5}$$

Hence, we maximize the product of the corridor flows, subject to three constraints. Equations (3) and (4) constrain the summation of the flows of the corridors using node n or link a to be less than or equal to the capacity of that respective node or link. Equation (5) forces that the assigned flows to the corridors are not more than the available capacity of the corridors.
We argue that in this manner, the flow will be allocated to all corridors (see Equation 2), and our allocation mechanism does not introduce market concentration artifacts as the flow is rationed proportional to available capacities. This will allow us to study market concentration as it emerges from the structure of the capacitated network.

2.3.2. Market Concentration Based on Flow Allocation to Different Businesses

The node (transshipment) submarket M_n has a flow size f_n and total capacity c_n. Each node has P_n players with the capacities c_n^k, where $k \in P_n$ are transshipment operators in the node. By definition, the flow of the player k inside node n is $f_n^k \coloneqq f_n . c_n^k / c_n$. Similarly, for the link submarket M_a, we get $f_a^l \coloneqq f_n \, c_a^l / c_a$ for main-haulage operators (rail and barge operators) $l \epsilon P_a$, and P_a is the set of all players in the link (main-haulage) submarket. Business operators in the OD-pair submarket M_{od} are identified with corridors, so the allocation of total flow to these businesses is equal to the allocation of flow to corridors, which we have previously discussed. A corridor π is associated with a sequence of nodes $(n_1, \dots, n_{m+1})$ and links $(a_1, \dots, a_m)$, where $a_j = (n_j, n_{j+1})$. A chain (p) within this corridor is associated with a service that uses capacities of certain operators inside nodes and links. If operators $k_i \epsilon P_{n_i}$ $(k_i \epsilon k, P_{n_i} \epsilon \, P_n)$ for $i = 1, \dots, m+1$, and $l_j \epsilon P_{a_i}$ $(l_j \epsilon l, P_{a_i} \epsilon \, P_a)$ for $j = 1, \dots, m$ provide capacity to chain p (and we write p$\epsilon\pi$), then the chain is given by $(c_{n_i}^{k_i}, c_{a_j}^{l_j})$.
We define the p_o as a chain with the least capacity inside the corridor π – i.e., a chain consist of players which have minimum capacity inside nodes and links:

$$p_o \coloneqq \left\{ (c_{n_i}^{k_{io}}, c_{a_j}^{l_{jo}}) \middle| \ c_{n_i}^{k_{io}} = \min\left\{ c_{n_i}^{k_i} \right\}, c_{a_j}^{l_{jo}} = \min\left\{ c_{a_j}^{l_j} \right\}, i = 1, \dots, m+1, j = 1, \dots, m \right\} \tag{6}$$

Then considering this least capacity chain (p_o), we assign a weight to different chains, by dividing the capacity of the players in nodes and links to the capacity of the players inside least capacity chain (p_o), and then make a summation on these numbers.

$$w_p \coloneqq \left\{ \sum_i \frac{c_{n_i}^{k_i}}{c_{n_i}^{k_{io}}} + \sum_j \frac{c_{a_j}^{l_j}}{c_{a_j}^{l_{jo}}} \ , \qquad p \in \pi \right\} \tag{7}$$

We allocate flow proportional to the weights, and we set the flow of the chain p in the corridor π as follows:

$$f_\pi^p := \frac{w_p}{\sum w_p} . c_\pi \tag{8}$$

Additional submarkets can be defined for those nodes and links that are bottlenecks in the corridors. These corridors effectively compete for capacity on those nodes and links. B denotes the set of bottlenecks in the network with respect to the flow f, that is,

$$B := \{n \epsilon N | f_n = c_n\} \cup \{a \epsilon A | f_a = c_a\} \tag{9}$$

We have for aϵA that $c_a = f_a = \sum_\pi \delta_{a\pi} f_\pi$ and for nϵN that $c_n = f_n = \sum_\pi \delta_{n\pi} f_\pi$. The allocation of link a (or node n) capacity to the corridor π is given by f_π.

2.4. Analyzing The Effect of Business Integrations on IFT Market Structure: Model Application

To illustrate our IFTMS model, and assess the impact of different types of business integration on competition and market concentration of IFT network, an analysis has been made of relatively heavy business integration in a simplified IFT network with one origin and one destination.

2.4.1. Introduction: Simplified Network and Assumptions

Basic services offered by different businesses in an IFT network are pre- and end haulage, transshipment, and main haulage. These businesses may be aggregated to offer more comprehensive transport services from origins to destinations, which are shipper locations, sea terminals, or inland terminals. In this chapter, we limit the scope of the model, and we make a number of simplifying assumptions regarding market organization because the market structure of the IFT network as explored in this chapter is already quite complicated under these assumptions and limitations. We discuss more complex situations in further research opportunities in the concluding section of our chapter.

First, we discuss our simplified network and its nodes, links, corridors, origin, and destination (see also Figure 2.3). The network consists of one origin and destination. In the network, we distinguish five nodes (O, A, B, C, and D). We also distinguish seven links (OA, OB, OC, AD, AB, BD, and CD). In the figure, also four corridors (OAD, OABD, OBD, and OCD) can be seen.

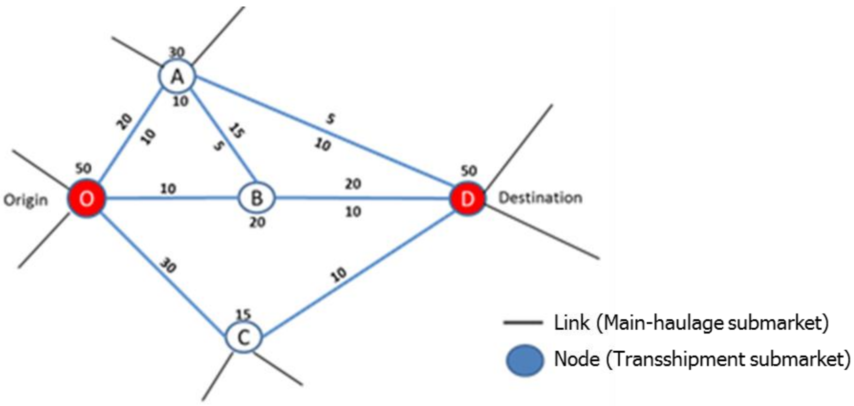

Figure 2.3. Conceptual Transport Network (capacity of each operator in nodes and links is in ‘000 TEU)

Given the large number of variables, the example is a relatively simple network that is expected to be further enlarged in future research. There are a number of important assumptions in the chapter that are now consecutively discussed:
A simple business model is assumed. This means that each business operator (terminal operator, main-haulage operator, and intermodal operator) provides a single service. This implies that two different types of services, such as transshipment and main-haulage services, or main-haulage services on two different transport routes, are not offered by a single business operator. These results in our assessment of market concentration being conservative in the sense that we tend to underestimate the level of concentration in markets;

In our model, we consider areas in which a number of transshipment operators compete for intermodal transport unit (ITU) orders that originate from consigners or that are destined to consignees. We shall identify such an area (transshipment submarket) with a node in the network. In this case, we disregard the competition for pre- and end haulage, that is, the transportation between customers and the terminals within the area.

All operators are assumed to offer homogeneous services. In the case of IFT, the main-haulage between terminals is done by high-capacity transport modes such as barge and train. An important simplifying assumption is that the transport services using these modes all compete as perfect substitutes.

Each node corresponds with a transshipment submarket in which terminal operators compete while offering transshipment services and a link corresponds with a main-haulage submarket in which carriers compete while offering transport services.

The market share of the different operators is measured by their throughput, which is assigned proportional to their capacity. The capacity of each link and node is the summation of the capacity of different business operators belonging to that node or link.
Differences between the transit times of respective corridors inside the OD pair submarket are not taken into account in this chapter (but will be in future research).
Unimodal truck transport is not considered in this chapter (but will be in future research).
The volume of transshipment of the respective terminal operators in a node (transshipment submarket) is representing their respective market shares. The freight volumes (flow) of transport operators on a certain link depict their respective market shares on that link (main-haulage submarket). The flows of organized IFT chains in a certain corridor represent the market shares in that corridor submarket. In intermodal freight transport, not all flows for all nodes and links are known. Therefore, we use capacities as a proxy. In the next sections, we apply the IFTMS model to measure market concentration in submarkets of the IFT network. We also measure the change in the market concentration indices resulting in anticompetitive horizontal and vertical merger practices in a simplified IFT network.

2.4.2. Horizontal Business Integration: Node and Link Concentration

In this section, the situation where two operators inside the same IFT submarket decide to merge, or one of them acquires the other, is analyzed (further referred to as merger). By means of an example, it is investigated how the degree of concentration inside different IFT submarkets will be affected, and it is shown how competition authorities could benefit from the model to investigate the consequences of a merger on competition and market concentration.

“Horizontal merger” means that two organizations in the same business merge. In our case, this implies that different operators’ inside links or nodes merge with each other: for example, two different terminal operators in the same transshipment submarket (node) or two rail operators in the same main-haulage submarket (link) merge. In our example, we assume that the two rail operators inside link OA merge. How will the market concentration change inside different submarkets of the IFT network? This merger will affect the concentration inside the OA link (main-haulage submarket). Now, inside the OA link, only one rail operator exists. The OA link belongs to the OAD and OABD corridors, so the merger also affects the concentration inside these two corridor submarkets. The merger reduces the number of IFT chains inside the OAD corridor from 8 to 4 and inside OABD corridor from 16 to 8. The other two corridors, OBD and OCD, are not affected. Also as a general result, the optimal flow set and the capacity of the network do not change directly because the optimal solution is related to the capacities of the links and nodes, regardless of their distributions between different operators inside links and nodes. However, after a merger, companies often realize efficiency gains, and in this respect, the merged rail company might reduce capacity, and as a consequence, the optimal flow set might change. The changing number of IFT chains inside the OAD and OABD corridors also has an effect on the concentration inside the OD pair submarket.

Table 2.1 shows the concentration indices inside link OA, and corridors OAD and OABD, before and after the merger. In link OA, the concentration in terms of the CR Index increases by about 50% and in terms of the HHI increases by about 80%, which shows a high increase in concentration. Similarly, in the corridor OAD, a merger leads to a more concentrated market. In this corridor, the concentration in terms of the CR index increases by more than 75% and, in terms of the HHI, increases by 100%. In addition, in the OABD corridor, we see the same development. Concentration increases by at least 87% (CR index) and 100% (HHI), leading to a more concentrated market. However, in the OD pair submarket, there is no change in the concentration in terms of the $CR1$, $CR2$, and $CR3$ indices, and only a small change in terms of the $CR4$ index and the HHI, because the three largest IFT chains, which exist inside corridors OBD and OCD, are not affected by the merger inside link OA, and the capacities of these three chains are very high compared with the rest.

TABLE 2.1. Concentration indices Before and After the Horizontal Merger

Related Submarkets	Concentration indices	Values	
		Before	After
Link OA	CR1	67%	100%
	HHI	5578	10000
Corridor OAD *	CR1	16%	31%
	CR2	30%	58%
	CR3	45%	81%
	CR4	57%	100%
	HHI	1288	2576
Corridor OABD	CR1	8%	16%
	CR2	16%	30%
	CR3	23%	43%
	CR4	30%	57%
	HHI	638	1280
O-D pair	CR1	22%	22%
	CR2	35%	35%
	CR3	47%	47%
	CR4	52%	57%
	HHI	805	837

** For an explanation, as a concrete example, of how for instance the CR1 is calculated for corridor OAD, see **Appendix 2A**.*

The results of the numerical example indicate that concentration degrees on certain links and nodes could already be high and probably might increase further due to a merger on a certain link or node. This suggests that horizontal mergers in a certain submarket could earlier be regarded as a deal breaker by antitrust authorities rather than vertical mergers. Next, concentration degrees in corridors might increase considerably due to a horizontal merger in a certain corridor submarket; however, network concentration degrees might still not be regarded as too high. Thus, a merger on a certain link or node does not need to have a large impact on network concentration degrees. If the analysis is lifted to the European level of package delivery, the acquisition of TNT by FedEx results in a reduction of the number of competitors from five to four, leading to a $CR4$ of 100%. However, national business competitors might also play roles, although not operating on the European level. Furthermore, concentration indices on OD pair and or corridor submarkets might depict different consequences of this merger.

2.4.3. Vertical Business Integration: Network Concentration

“Vertical merger” (or acquisition) means that different operators in different IFT submarkets merge. Suppose that a rail operator (capacity 10,000 TEUs) in link OA of our example decides to merge with a terminal operator (capacity 30,000 TEUs) in node A. What is the consequence of this merger on the degree of concentration inside the different IFT submarkets? There are two different possible situations, depending on the type of merger which we call “restricted” merger and “flexible” merger. In a restricted merger, the two operators that merge are restricted to work with each other, and the extra capacity of the one that has more capacity could be sold to other operators in a competitive way. In a flexible merger, we have two different situations based on which operator is flexible. In the situation, the operator with the higher capacity (restricted company) dedicates part of its capacity to the merged operator, whereas the operator with the lower capacity (flexible company) is not restricted to the dedicated capacity of the higher capacity operator (Flexible-L, Restricted-H). This means that it could still use the capacity of the other business operators. In the other situation (Flexible-H, Restricted-L), the business operator with lower capacity (restricted company) works only with the operator with higher capacity, but the business operator with higher capacity (flexible company) does not dedicate any capacity to the lower capacity operator but only gives it the priority to use its capacity.

In the restricted merger, the number of IFT chains is reduced, whereas, in the flexible merger, the number of IFT chains is equal to the number of IFT chains before the merger, if the operator with the higher capacity is restricted (Flexible-L, Restricted-H). In the situation that only the business operator with the lower capacity is restricted (Flexible-H, Restricted-L), the number of IFT chains is reduced, which could have a larger effect on the concentration degree.

The degree of concentration inside different IFT submarkets that are affected by the merger is shown in Table 2.2. As can be seen, if the merger is a flexible merger in which the lower-capacity operator is flexible (the rail operator in our example), the concentration change will be marginal in corridors and O-D pair, because the number of IFT chains is fixed, whereas their flows distribute a little more smoothly.

If it is a restricted merger or a flexible merger in which the higher capacity operator is flexible, the increase in the concentration indices is almost the same. In corridor OAD, concentration will be increased between 25% and 27% in terms of CR indices, and about 33% in terms of the HHI, which leads to a tight oligopoly market. In the corridor OABD, the concentration will be increased around 29% in terms of the CR indices and 33% in terms of the HHI, but it is still a loose oligopoly market. Like the horizontal merger, in the OD pair submarket, concentration in terms of the $CR1$, $CR2$, and $CR3$ indices does not change, and in terms of the $CR4$ and the HHI, there is a small increase because the three largest chains are inside the corridors OBD and OCD, which are not affected by the merger.

Results from the numerical example indicate that a vertical merger might have a lower impact on the concentration indices in corridors than horizontal mergers.

However, if we analyze the examples of EGS Rotterdam and the inland terminals in Brabant, it shows that in the end, it is also important how many competitors remain. In the case of EGS, one terminal operator has been said to provide advantageous handling conditions to barges operating in their EGS network over other barges. So although the other barges, in theory, do have alternative terminals in the port of Rotterdam to have their containers handled and also a sufficient number of competing barges is present, the actual behavior of ECT and its EGS network puts the other barges at a disadvantage because, in practice, they must have their containers handled at ECT. This means that vertical integration (IWW and terminal) does not need to have an effect on the concentration. However, it does have an impact when exclusiveness is introduced. In the case of the Brabant inland terminals cooperating to bundle inland waterway transport to and from Rotterdam, the competition on the inland waterway link Rotterdam Brabant is reduced, although there might be still enough competition on that particular inland waterway link. Furthermore, also rail and truck transport remain as transport options.

TABLE 2.2. Concentration indices Before and After the Vertical Merger

Related submarkets	Concentration indices	Values						
		Before	After			increase		
			Restricted	Flexible -H Restricted-L	Flexible-L Restricted-H	Restricted	Flexible-H Restricted-L	Flexible-L Restricted-H
Corridor OAD	CR1	16%	21%	20%	16%	28%	24%	-0.45%
	CR2	30%	39%	39%	30%	27%	28%	-1.19%
	CR3	44%	56%	56%	44%	26%	26.00%	-1.46%
	CR4	57%	72%	73%	56%	26%	27%	-2.04%
	HHI	1274	1702	1703	1280	34%	34%	0.50%
Corridor OABD	CR1	8%	11%	10%	8%	30%	27%	-0.21%
	CR2	16%	20%	20%	16%	29%	30%	-0.54%
	CR3	23%	30%	30%	23%	29%	29%	-0.66%
	CR4	30%	39%	39%	30%	29%	29%	-0.91%
	HHI	641	851	851	639	38%	33%	-0.23%
O-D pair	CR1	22%	22%	22%	22%	0.0%	0.0%	0.00%
	CR2	35%	35%	35%	35%	0.0%	0.0%	0.00%
	CR3	47%	47%	47%	47%	0.0%	0.0%	0.00%
	CR4	52%	53%	54%	52%	2%	4%	-3.10%
	HHI	805	868	869	804	8%	8%	-0.10%

2.5. CONCLUSIONS AND FUTURE RESEARCH

The IFT market is continuously evolving as a result of different regulatory policies and business practices adopted by different IFT operators. Although some business practices—like vertical integration and acquisition—potentially improve the IFT service and the profit margin for some players, they might also influence the market structure and competition in the IFT network. Therefore, antitrust authorities proactively evaluate the decisions made by firms and the market outcomes that result. In a more reactive way, the antitrust authorities respond to complaints from transport market stakeholders. In both cases, a business practice might be restrained by antitrust authorities if it harms the consumer welfare by reducing the competition level in the market.

The analysis of the market structure of IFT service can be challenging though, primarily due to the multistage characteristic of the presented service. To investigate the impact of anticompetitive business practices on the market structure of IFT networks, we present a model—which is called IFTMS—in this research. This model combines the market structures of IFT submarkets and extends them to the network level. IFTMS uses graph theory and defines distinct submarkets in an IFT network. These submarkets are represented as nodes (transshipments), links (main-haulages), and paths (corridors, and ODs). Each corridor has multiple IFT chains that include a sequence of nodes and links from an origin to a destination. The IFT chains in a corridor are organized by different competing intermodal operators to deliver an integrated IFT service to the final customer. As distinctive submarkets inside IFT network are defined, IFTMS applies a flow optimization model to assign the capacities to the IFT network players. Next, the concentration indices—like CR or HHI—for these IFT submarkets are calculated, and the market structure can be analyzed.

To illustrate the model, we studied an intermodal freight transport network. The application of IFTMS to this network helps us analyze the impact of business integration on the market concentration in the IFT market and its submarkets. In this case, the influence depends on the type of business integration (horizontal and vertical). Furthermore, the model indicates that mergers in the same submarket (horizontal) have larger impacts on market concentration in the broader market (e.g., corridors) than mergers in different submarkets (vertical). The findings of this model need to be interpreted in a conservative way in light of the methodological limitations and assumptions. These assumptions, i.e., simple business models for different operators, fair flow distribution in the network, or considering the barge and rail operators in a same main-haulage submarket, lead to a lower bound of market concentration in the IFT network.

The model developed in this chapter could be used by antitrust authorities to investigate the anticompetitive practices in the IFT network. They can evaluate the effects of different business practices on competition and concentration in the IFT market and overall on the welfare of the society. It can also be used by business managers to examine the market implication of their business practices. The impact of anticompetitive business practices on the market structure of the IFT network depends on the chosen level of analysis. Next, different indicators that “represent” market structure and competition might react differently to the business integration.

The market structure of intermodal freight transport network as explored in this chapter was already quite complicated under the assumptions made. Several possibilities for more complex situations are suitable for further research. First, more complex business models can be introduced such as more operators per submarket, different service offerings in different submarkets by the same business operator, different competitive powers per business operator, and the inclusion of other types of business integration. Second, the presented network model can be extended by introducing, for example, pre- and end-haulage and using other flow allocation methods. We can also make a differentiation between operators in different markets, considering the time and cost elements, in extending the IFTMS model.

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Appendix 2A- Calculating the Concentration Indices for Corridor OAD

In this annex, we show how the concentration indices i.e., CR and HHI are calculated for the Corridor OAD.

Table 2A.1. Capacity Assignment to Different IFT Chains inside the Corridor OAD

No.	$c_{n_1}^{k_1}$	$c_{a_1}^{l_1}$	$c_{n_2}^{k_2}$	$c_{a_2}^{l_2}$	$c_{n_3}^{k_3}$	$\frac{c_{n_1}^{k_i}}{c_{n_1}^{k_{io}}}$	$\frac{c_{a_1}^{l_j}}{c_{a_1}^{l_{jo}}}$	$\frac{c_{n_2}^{k_i}}{c_{n_2}^{k_{io}}}$	$\frac{c_{a_2}^{l_j}}{c_{a_2}^{l_{jo}}}$	$\frac{c_{n_3}^{k_i}}{c_{n_3}^{k_{io}}}$	w_p	$f_{\pi}^{p}(s_i)$	CR	HHI
1	50	20	30	10	50	1	2	3	2	1	9	16%	16%	0.03
2	50	20	30	5	50	1	2	3	1	1	8	14%	30%	0.02
3	50	10	30	10	50	1	1	3	2	1	8	14%	45%	0.02
4	50	20	10	10	50	1	2	1	2	1	7	13%	57%	0.02
5	50	10	30	5	50	1	1	3	1	1	7	13%	-	0.02
6	50	20	10	5	50	1	2	1	1	1	6	11%	-	0.01
7	50	10	10	10	50	1	1	1	2	1	6	11%	-	0.01
8	**50**	**10**	**10**	**5**	**50**	1	1	1	1	1	5	9%	-	0.01
														1288.27

In the corridor OAD, we have 3 nodes and 2 links. Considering different players inside each of these nodes and links, we have 8 (=1*2*2*2*1) possible IFT chains. We use the weighted average capacity method and assume that all the players in different nodes and links in each IFT chain have the same weight. This means that the weight coefficient of players in each node or link is 0.2 because each IFT chain in the corridor OAD has in total 5 elements (3 players in the nodes and 2 players on the links). We assign a weight of 1 to the IFT chain with the least available capacity (0.2+0.2+0.2+0.2+0.2). IFT chain with the least available capacity is the chain which is composed of operators with the least available capacity on the different links and in the nodes. In this example, the IFT chain which is composed of operators with capacities (50-10-10-5-50) is the least available capacity chain (the last IFT chain in Table 2A.1). For the other IFT chains, we divide the capacities of different operators on the different links and in their nodes to the capacity of the operators in the least powerful chain, and then summarize the results based on the weights of the links or nodes of the corresponding chain in order to arrive to the weight of the chain. As you can see in the table, first the weight of different IFT chains is computed, and, based on these weights and the assigned capacity of the corridor (it is calculated in the O-D pair level), the capacity of the different chains is calculated. After that, we can easily measure the CR and HHI indices having the capacity of each IFT chain.

Chapter 3

European Intermodal Freight Transport Network: Market Structure Analysis

The analysis of market structure and concentration measures for the Intermodal Freight Transport (IFT) market is important to avoid market failure and to find the areas for policy making to promote IFT market share. This analysis can be performed for separate segments, for example, the market for transshipment service or the market for main-haulage service. However, due to the multistage characteristic of IFT service, the segmental analysis gives an incomplete view of the IFT market at the network level. In the previous chapter, we present the Intermodal Freight Transport Market Structure (IFTMS) model to conduct a network-based study of the IFTMS in which distinctive actors (i.e., pre/post haulage operators, terminals, rail/barge operators, transport chains, and corridors) are competing at different levels inside distinctive markets to deliver an integrated IFT service. There are two main challenges in the application of IFTMS model in real cases, for example, the European IFT network. First, the definition of the geographical and spatial border of the transshipment market areas is needed to determine which actors are potentially competing for a specific service demand. The second challenge is the lack of disaggregated data and the consistency of existing data in nodes (i.e., the transshipment areas) and links (i.e., the rail and barge operators). To cope with these challenges, we develop a four-step methodology in which a model-based approach is used to define the geographic boundaries of the transshipment submarkets and provide detailed and consistent data for market analysis. We also apply the IFTMS model to study the market structure of European intermodal network. Our analysis shows that the majority of transshipment markets, as well as main-haulage markets, are highly concentrated markets. The corridor markets – which include the IFT chains- are unconcentrated markets. Furthermore, the majority of corridors in the European Union are inside highly concentrated origin-destination markets.

This chapter is an edited version of the article:

Saeedi, H., Wiegmans, B., Behdani, B., & Zuidwijk, R. A, "*European intermodal freight transport network: Market structure analysis*," Journal of Transport Geography, vol. 60, pp. 141–154, Apr. 2017.

3.1. Introduction

One of the main concerns of antitrust authorities and policy makers in the field of freight transport is the market concentration and competition level inside the IFT market (Gómez-Ibáñez & Rus, 2006). An IFT market comprises of different IFT chains—which themselves include different actors providing different services (i.e., pre- and end-haulage, transshipment, and main-haulage). All these IFT chains, together, form an IFT network. Anticompetitive behavior of the IFT operators (e.g., vertical or horizontal integration) could increase the market concentration, and potentially reduce the welfare of the customers (Motta, 2004). In fact, antitrust authorities may scrutinize and limit such business practices because they could harm the competition level in the IFT market (Mazzeo & McDevitt, 2014). Accordingly, an economic analysis of the concentration and the market structure is needed.

The analysis of the market structure and concentration measures for IFT service can be done at several different levels. First, the analysis can be performed for separate segments, for example, the market for transshipment service or the market for main-haulage service (see, e.g., Wiegmans et al., 1999; Makitalo 2010; Lam et al., 2007; Sys, 2009; and Merikas et al., 2014). However, due to the multistage characteristic of IFT service, the segmental analysis gives an incomplete view of the IFT market. In other words, the competition is between IFT chains or even between different corridors to transport the cargo from one "origin" to one "destination"; therefore, a network-based analysis is needed. To analyze the market structure for IFT service, the Intermodal Freight Transport Market Structure (IFTMS) model was developed in the previous chapter. IFTMS uses graph theory and defines distinct submarkets in an IFT network. These submarkets are represented as nodes (transshipments), links (main-haulages), and paths (corridors, and O-Ds) in the model. Each "corridor" may have multiple IFT chains that include a sequence of nodes and links from an origin to a destination. The IFT chains in a corridor are organized by different forwarders to deliver an integrated IFT service to the final customer. As distinctive submarkets inside an IFT network are defined, IFTMS applies a flow optimization model to assign the flow to the IFT network corridors, and then to the respective chains, links, and nodes. Next, the concentration indices— like concentration ratio (CR) or Herfindahl-Hirschman Index (HHI) (OECD, 1990)—for these IFT submarkets are calculated.

To study the IFT market structure at the network level, for example, the European intermodal network, there are two main challenges. First is the definition of the relevant geographical transshipment submarkets. Defining which inland terminals are potentially competing for a specific service demand (and therefore, form a transshipment submarket for that demand area) is an important step when determining whether a market is a competitive market or not. The other challenge is the availability of detailed data—especially at the chain level. Although the primary data about the transshipment and main-haulage submarkets are available, the assignment of the capacity of each transport operator to different routes is difficult—if not impossible—to attain. Furthermore, for many corridors, the available data is fragmented, incomplete, and sometimes inconsistent. To cope with these two main challenges, a methodology that is complementary to the IFTMS model is presented in this chapter. This methodology applies a conservative model-based approach to define the geographic boundaries of the transshipment submarkets and creates a data set for market analysis. The scientific contributions of this chapter are twofold. First, we present a methodology to define the different IFT submarkets in terms of the geographical and spatial aspects, the players, and their respective market shares. For this purpose, a four-step methodology has been developed. Each step uses a model-based approach to characterize a submarket in the IFT network. This methodology is especially useful in cases where only aggregated or incomplete data are available. Lack of detailed data can be caused by limited resources, distinctive and detached obligations for data gathering by legislative organizations, and confidentiality issues (Tavasszy & de Jong, 2014). Second, we apply the presented methodology to analyze the European IFT market at the network level.

The remainder of the chapter is organized as follows. Section 2 presents the methodology. In Section 3 the application of this methodology and the IFTMS model to the EU IFT network is presented. Conclusions and further research directions are given in Section 4.

3.2. Market Analysis Literature

IFT is defined as "unitized freight transport by at least two transport modes" (Comission, 2001). In the IFT market, different operators (pre- and end-haulage operators, main-haulage operators, terminal operators, and forwarders) are active and compete with each other in different submarkets (see Figure 3.1). The IFT market encompasses all actors operating in all submarkets.

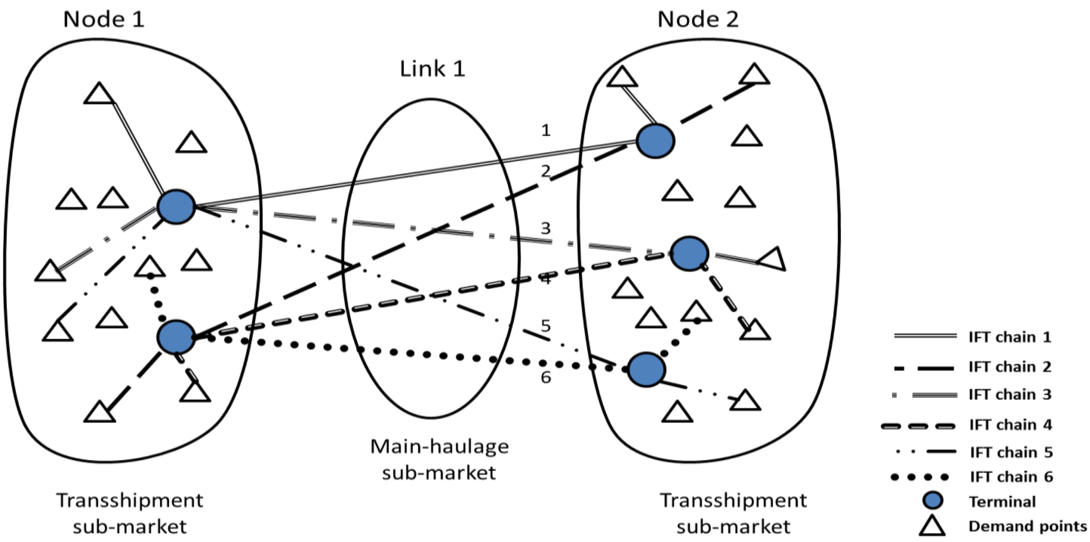

Figure 3.1. Spatial Distribution of Different Submarkets Inside a Corridor of IFT Network (Saeedi et al., 2017)**.**

We introduce these submarkets that emerge in the IFT market by means of an example. Suppose that a shipper wants to transfer containers from the Rotterdam area in the Netherlands to the Verona area in Italy. There are many forwarders/LSPs/ intermodal operators (further referred to as forwarders) that can arrange for transport and handling. These actors arrange different pre-haulage, transshipment, main-haulage, and end-haulage services, to be able to deliver integrated IFT services to the shippers. The forwarder could hire one of the many truck companies to transit containers from the shipper's location to one of the terminals in the Rotterdam area. These truck companies compete for forwarders' demands, so we have a market where there are demand and supply for trucking services (pre-haulage sub-market). Furthermore, in the Rotterdam area the forwarder needs transshipment services and different terminals in the area; for example, the Rail Service Center (RSC), or ECT Delta, deliver such a service. Therefore, in the Rotterdam area we have a market where there are demand and supply for transshipment services (transshipment submarket). Then, there are different corridors that could be chosen by a forwarder to transport the containers from a terminal in Rotterdam area to a terminal in the Verona area. The forwarder could use any corridor that is competitive (in terms of cost and quality), and directly (or indirectly) connects a particular terminal in the Rotterdam area to a particular terminal in the Verona area. The forwarder could choose the corridor that connects the Rotterdam area to the Verona area through terminals in the Koln area in Germany, whereas other corridors could pass through terminals in Munchen or Nurnberg. These different corridors, which all connect the Rotterdam area to Verona area, make an O-D submarket. When choosing one of the corridors from the O-D submarket, the forwarder is faced with the choice of different rail and barge operators (also called main-haulage) that are active inside the corridors as well as with different terminal operators in the intermediate transshipment areas. If the forwarder chooses the indirect corridor (including handling at that terminal) via Munchen, he or she could choose between IMS or TX Logistik rail companies, for example, to transport the containers from the Rotterdam area to the Munchen area. Here, we could define a main-haulage submarket between the Rotterdam area and Munchen area. Next, he or she could choose between different terminals in the Munchen area: DUSS-Reim, or Munchen-Laim terminals. So in the Munchen area, like the Rotterdam area, we could define a transshipment submarket. From a terminal in Munchen to a terminal in Verona, for example, the Quadrante Terminal, he or she could decide between the intermodal rail operators CEMAT or Kombiverkehr, which are active inside this main-haulage submarket. We can also define a transshipment submarket in the Verona area. Finally, the end-haulage toward the consignee could also be done by a large number of truck companies inside the end-haulage submarket. The structure of each of the aforementioned submarkets can be investigated to understand the competition level or design policies to avoid anti-competitive behavior. In market theories, there are four basic types of market structures: perfect competition, monopolistic competition, oligopoly, and monopoly (Dennis W. Carlton; Jeffrey M. Perloff, 1999). The oligopoly market can be divided into subcategories. For example, Shepherd (1999) categorized oligopoly into loose oligopoly, tight oligopoly, super tight oligopoly, and dominant player oligopoly. There are a few scientific papers have contributed to the structural analysis of the IFT market. However, according to Macharis and Bontekoning (2004), most papers analyze only selected parts of the IFT market. For example, Wiegmans et al. (1999) analyzed the IFT market in the EU qualitatively based on an extended version of Porter’s model of the competitive forces to identify the stakeholders in the terminal market. Makitalo (2010) investigated the Finnish rail industry market, and revealed the largest market entry barriers. In several other research studies (e.g., Crainic et al., 1990; Jourquin et al., 1999; Southworth & Peterson, 2000; Janic, 2007; Wiegmans et al., 2007, and Wiegmans, 2005), parts of the IFT network are modeled and optimized. However, there is no paper that analyzes the whole IFT market at the network level.

The main determinant of market structure is market concentration. Market concentration refers to the extent to which a certain number of producers or service providers represent certain shares of economic activity expressed in terms of throughput, for example (OECD, 1990). Indicators such as throughput, revenue, added value, capital cost, or other financial or nonfinancial indices can be used to calculate the degree of concentration in the IFT market (Scherer, 1980). In this chapter, due to data availability reasons, we use the throughput of different players as indicators. There are many indices to measure the degree of concentration in the market. The most often used indicators are CR and HHI (US Department of Justice and the Federal Trade Commission, 2010). The CR_x is the sum of the market shares of the x largest players. Typically, the CR_x is calculated for the four largest players (CR_4). The main disadvantage is that two markets with the same high CR_4 levels may have a structural difference because one market may have few players, whereas the other may have many players.

The HHI is the sum of the squares of the market shares of all players in that market and, to simplify the reading, is multiplied by 10,000. It is defined as:

$$\text{HHI} = \sum_{i=1}^{n}(s_i)^2 * 10000 \quad (1)$$

where the market shares (s_i) satisfy $\sum_{i=1}^{n} s_i = 1$. The main disadvantage of HHI is that it shows little sensitivity to the entrance of small players into the market (Shepherd, 1999). Although the concentration indices cannot capture the dynamics of the market structure, they are still useful measures. Merikas et al. (2013) and Sys (2009) have applied market concentration indices to the transport markets. Merikas et al. (2013) investigated the change in the structure of the tanker shipping market and its impact on freight rates by applying the CR index and the HHI index. They found that market concentration has increased since 1993. Sys (2009) studied whether the container liner shipping sector as a unimodal freight transport system is an oligopolistic market. She used concentration indices, and based on the degree of concentration, she made judgments about the market structure. In addition to Sys (2009), this chapter uses concentration indices as a tool, but the calculations are extended from submarkets to IFT networks.

TABLE 3.1. Defining Market Types Based on the Shepherd (1999)

Condition	Market Type
$CR_4 < 25\%$	Not-oligopoly
25%<CR4<60% and HHI<1000	Loose-oligopoly
CR4>60% and HHI>1800	Tight-oligopoly
CR2>80% or CR3>90%	Super-tight-oligopoly
40%<CR1<99%	Dominant-player Oligopoly
CR1=100	Monopoly

To measure the concentration inside different submarkets, we use the CR_x (for $x = 1,2,3,4$), and the HHI indices. According to Shepherd (Shepherd, 1999), we can determine the market type based on the CR_x and HHI (Table 3.1). The U.S. Department of Justice convention (US Department of Justice and the Federal Trade Commission, 2010) also suggests the ranges for the HHI index to categorize the market concentration (Table 3.2).

TABLE 3.2. Different Market Types Based on the U.S. Department of Justice (US DJ FTC, 2010)

Condition	Market Type
HHI<1500	Un-concentrated
1500<HHI<2500	Moderately-concentrated
HHI>2500	Highly-concentrated

3.3. Methodology to Analyze the IFT Network Market

The presented methodology consists of four different methods that we apply to the different IFT submarkets to define the submarkets in terms of the players and their respective market shares.

3.3.1. The Method of Analyzing Transshipment Submarkets

In the literature, the term relevant market describes the areas where competition takes place (Sys, 2009). This relevancy lies in both the product and service similarity and the geographical dimensions. The existence of substantial shipments between two areas indicates the geographic substitution of flows and implies that two areas belong to the same market (shipment pattern analysis) (American Bar Association. Section of Antitrust Law., 2012). For example, Elzinga and Hogarty (1998) have presented shipment tests that are widely used to assess the competitive effects of a merger. The second method is price correlation analysis, in which the prices of two different suppliers are highly correlated; these two suppliers are considered in the same market. The application of price correlation analysis can be found in Shrieves (1978), Horowitz (1981), Stigler and Sherwin (1985), and Spiller and Huang (2986). Another alternative that is frequently used in freight transport literature—especially to define the market area of a specific terminal—is transport cost (Niérat, 1997). Assessing the transport cost is an alternative to the shipment pattern analysis (Niels et al., 2011). Transport cost could even be included in the price correlation analysis and hypothetical monopolist test, e.g., SSNIP (small but significant and non-transitory increase in price) test, which is used by antitrust authorities. If the transport cost between two areas is more than 5 to 10 percent of the prevailing prices, a monopolist in one area could enforce a SSNIP by 5 to 10 percent without attracting supply from the other area (Niels et al., 2011). The method for analyzing transshipment submarkets in this chapter is based on transport cost. The central concept in this method is the IFT break-even distance, which is defined as the distance in which the total cost of intermodal transport is equal to the costs of truck-only transport (Niérat, 1997). This concept is used in different studies (e.g., Janic, 2007 & 2008; Kim & Van Wee, 2011; Kreutzberger, 2008; and Niérat, 1997) to compare the unimodal truck transport and the IFT transport. Nierat (1997) has initially used the IFT break-even distance for rail-haul intermodal transport to define the market area of a terminal. According to his spatial analysis, the terminal market area is part of a family of Descartes's ovals. Limbourg and Jourquin (2010) have argued that if pre- and post-haulage are too costly compared to the truck-only transport, the terminal market area is an ellipse. They also argue that, if a terminal provides services in the different directions, i.e. multiple destinations, the transshipments volumes can increase, creating economies of scale and thus lower transshipment costs. In such a case, the market area in each direction will be enlarged. Using this argument and taking into account different directions of the destinations, we can conclude that the shape of the terminal market can be considered as a circle around a terminal. In other words, although in the market analysis for one destination, the terminal is not necessarily located in the center, in the case of multiple destinations, the market area can be considered as a circle for which the terminal is located in the center. Kim and Van Wee (2011) used a simulation method to find the relative importance of influencing factors on IFT break-even distance. They have considered the terminal market area either as a circle or an ellipse. Their findings show that changing the shape of the market from an ellipse to a circle does not have a significant influence on the market analysis. To define the transshipment submarkets in this chapter, we consider a circle-shaped market area for a terminal. We also assume that the total intermodal transport demand in an area is concentrated in a demand point, and the terminals in nearby areas around this demand point are supplying homogenous services. With these assumptions, we define the transshipment submarkets from the customer (demand) perspective. In our definition, a transshipment submarket is an area around the demand point in which different terminals are competing with one another to supply the transshipment service to this demand point. These terminals offering intermodal transport services which is competitive compared to unimodal-truck transport.

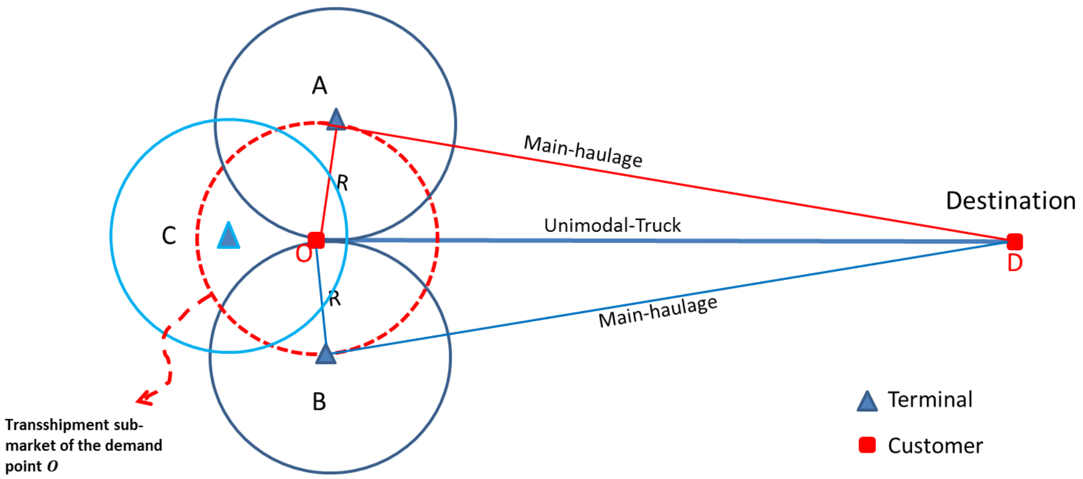

Figure 3.2. Conceptual Transshipment Submarket Around the Demand

Let's assume that we have the transport service need from origin, O, to destination, D. To define the transshipment submarket for Demand Point O, we consider two terminals, A and B. As shown in Figure 3.2, to transport goods from Point O to Point D, two options can be considered. The first is to send the products directly by road from O to D. The second option is using intermodal transport to send the products by truck to one of the two terminals, A or B, and then by rail (or barge) to the final destination, D. The market area theory implies that using the intermodal transport from Terminal A is feasible if the point O is inside the circle-shaped market area of Terminal A. It might also be possible to use Terminal B to send the product from O to D by an intermodal service because Point O is inside the market area of Terminal B as well. In general, all the overlapped points of the market areas of Terminal A and B could use either Terminal A or B to send the products to the destination, Point D. In an extreme case, the market areas of Terminals A and B may overlap in only one point, O. If we assume that the distance of Terminals A and B are small enough compared to the main-haulage distance, and they supply the homogenous service, the radii of the both market areas of Terminal A and B are the same (R). "Homogenous services" are services of different suppliers that are perceived as identical by the customers (Wiegmans, 2014). In other words, a terminal presents a service that has similar characteristics -e.g., similar service level, and reliability- as services from other competing terminals in the region. To a shipper or forwarder, this means that he or she can replace a service from Terminal A with one from Terminal B. In drawing a circle with the Radius R around Point O, Terminals A and B are on the border of this circle. This circle is considered as the transshipment market area for the demand point, O, and all terminals inside this area (e.g., Terminal C) are market players (i.e., potential competitors to offer transshipment service to the demand point, O). The IFT break-even distance literature can give indications to estimate the radius of this transshipment submarket. Depending on different factors (e.g., main-haulage distance), different estimates for the drayage distance are presented (Kim & Van Wee, 2011). For instance, Janic (2007 & 2008) argues that the drayage distance (collection/distribution distance by road, as he calls it) is 50 to 75 kilometers (km) in Europe, where the total transport distance is between 650 and 1050 km. Kim and Van Wee (2011) considered 50 km in their work as the drayage distance, assuming the main-haulage of 500 km.

Following the works of Janic (2007 & 2008), in Section 4, we consider the terminal market areas in the EU network as the circle-shaped areas where the radii are 70 km. This is followed by the assumption that inside the EU IFT network, the distance between the origins and destinations is in the range of 650 to 1,050 km. We also perform a sensitivity analysis for the radii of 90 and 50 km.

3.3.2. The Method of Analyzing Main-Haulage Submarkets

To analyze the main-haulage submarket, we assume that main-haulage operators working between two transshipment submarkets form a homogeneous market (Saeedi et al., 2017). With homogenous, we imply that in this market, the transport services (i.e., barge and rail) of different suppliers are perceived as identical by the customers (Wiegmans, 2014). To calculate the concentration, we need the capacity of the different operators inside the main-haulage submarket. Often only the aggregate capacity of the main-haulage operators and their respective active routes are available, and the distribution of the capacity over different routes is lacking for analysis. To find the fair distribution of the capacity of each main-haulage operator in different routes, we apply the proportional fairness algorithm (Bertsekas & Gallager, 1992) in this chapter. Proportional fairness considers the transfer of utility between two routes as fair if the increase in operator utility by assigning more capacity to one route is more than the decrease in its utility because of the lower assignment to the other route (Bertsimas et al., 2011). We assume that the capacity deployment among the routes considering their respective lengths (the Euclidian distance between origin-destinations) is a fair way for capacity distribution. It should be noted that applying the fairness algorithm is a conservative way to assign the capacities to the different routes. The main-haulage submarkets could be potentially more concentrated in reality.

The IFT network is given by a graph $\mathrm{G} = (\mathrm{N}, \mathrm{A})$, with node set N and link set A. Each transport operator o works along a set of routes $\mathrm{R_o}$ ($\mathrm{R_o} = \{\mathrm{R_o^k}, \mathrm{k} = 1, \dots, \mathrm{k_o}\}$). A Route is the path of each transport operator and consists of sequential nodes and links inside the IFT network. Based on the fair distribution model (Bertsekas & Gallager, 1992), the operator needs to assign its capacity, $\widetilde{\mathrm{C_o}}$, to these routes in a way that the following expression is maximized under a set of constraints:

$$Max \prod_{R_o^k \epsilon R_o} C(R_o^k) \qquad (2)$$

Here $C(R_o^k)$ is the dynamic capacity (in TEU/yr) of the operator O deployed during a year on route R_o^k.

As a first constraint, the dynamic capacity deployed by operator O along all routes in $TEU.Km/yr$ must not exceed its total fleet capacity:

$$\sum_{k=1}^{k_o} C\big(R_o^{k_o}\big).\,l\big(R_o^{k_o}\ \big) \le \widetilde{C_o}\ ,\ \forall o \qquad (3)$$

The length of the route $l(R_o^k\ )$ is given by:

$$l(R_o^k\ ) = \sum_{i,j\epsilon R_o^k} L_{ij}\ , \qquad (4)$$

where L_{ij} is the length of the link (i,j). The parameter $\widetilde{C_o}$ is defined as:

$$\widetilde{C_o}\ =\ C_o * {V_o}^m\ * T_o\ , \qquad (5)$$

which implies that the total fleet capacity of the operator O in terms of $TEU.Km/yr$ is equal to the capacity of the operator in TEU (C_o) multiplied by the velocity of the mode that the operator uses (${V_o}^m$) and the operating time of that mode (T_o).

The capacity of each link in $TEU.km$ is the summation of the capacity of different routes of different operators that use that link:

$$C_{ij} = \sum_{o \epsilon O} \sum_{k=1}^{k_o} C(R_o^k).\delta_{ij,o}^k \quad ,\forall (i,j) \in A \quad , \tag{6}$$

where $\delta_{ij,o}^k$ is a binary variable and is 1 if the link (i,j) is inside the route R_o^k.
Finally, the summation of the capacity of different routes using a certain node is limited by the capacity of that node:

$$\sum_{o \epsilon O} \sum_{k=1}^{k_o} C(R_o^k).\delta_{i,o}^k \leq C(i) \quad ,\forall i \in N \quad , \tag{7}$$

in which $\delta_{i,o}^k$ is a binary variable. It is equal to one if node i is inside the route $R_o^{k_o}$.
As shown in Equation 7, a parameter in defining the capacity of the main-haulage markets (links) is the capacity of the transshipment submarkets (nodes), $C(i)$, which forces the consistency of the data in these two submarkets.

3.3.3. The Method of Analyzing Corridor Submarkets

Different IFT chains, which are organized by different forwarders, are competing in a corridor submarket. To measure the concentration in this submarket, we should specify the capacity of these IFT chains. The throughput of an IFT chain is in proportion to its "available" capacity, which is the minimum capacity of the terminal and main-haulage operators in that chain (Saeedi et al., 2017). The formulation of this method is as follows:

$$\frac{f(x_{i,c})}{C(x_{i,c})} = \frac{f(x_{j,c})}{C(x_{j,c})}, \quad \forall i,j : x_{i,c}, x_{j,c} \epsilon x_c \tag{8}$$

$x_{i,c}$ represents the IFT chain i in corridor c, and x_c is the set of all chains along corridor c. $C(x_{i,c})$ and $f(x_{i,c})$ are available capacity and the throughput of IFT chain i.
Indeed, the summation of the throughput of the IFT chains should be equal to the throughput of the corridor:

$$\sum_{x_{i,c} \epsilon x_c} f(x_{i,c}) = f(x_c) \tag{9}$$

where $f(x_c)$ is the throughput of a corridor for which the calculation is presented in the next section.

3.3.4. The Method of Analyzing O-D Pair Submarkets

In the O-D pairs submarkets, there is competition between corridors in one level and the respective IFT chains in the other level (Saeedi et al., 2017). To measure the concentration in these submarkets, we need the market share of different corridors. In principle, the "available capacity" of a corridor is the minimum capacity of its submarkets (Saeedi et al., 2017). However, because of the overlaps in the transshipment submarkets (nodes) or main-haulage submarkets (links) inside the IFT network, the throughput might be less than the "available capacity" (Saeedi et al., 2017). To measure the throughput, we apply the fairness algorithm for flow distribution in the corridors of a network (Bertsekas & Gallager, 1992). The model is as follows:

$$\text{Max} \prod_{x_c \epsilon X} f(x_c) \tag{10}$$

Here, x_c is a corridor, and $f(x_c)$ is its flow. X is the set of all corridors. The summation of the flows of the corridors using node i should be less than or equal to the capacity of that node:

$$\sum_{x_c:\,(i) \epsilon x_c} f(x_c) \leq C(i) \tag{11}$$

and the summation of the flows of the corridors using the link (i, j) should be less than or equal to the capacity of that link:

$$\sum_{x_c:(i,j) \epsilon x_c} f(x_c) \leq C(i, j) \tag{12}$$

$$f(x_c) \leq C(x_c) \;\; , \forall c \epsilon C \tag{13}$$

Equations 11 and 12 ensure that the flow of a corridor is consistent with the capacity of the transshipment and the main-haulage submarkets in that corridor. Equation 13 confirms that the flow of each corridor is not more than its capacity.

3.4. European IFT Network Market: Analysis and Findings

In this section, we apply the IFTMS model to the EU IFT network. First, the data and underlying assumptions are described. Next, the results are presented and discussed.

3.4.1. Data Description

The majority of the IFT services in the EU are provided through 34 areas (International Union of Railways, 2004). These areas incorporate about 85 percent of the total IFT demand (Figure 3.3). The data for different IFT submarkets is presented in the following.

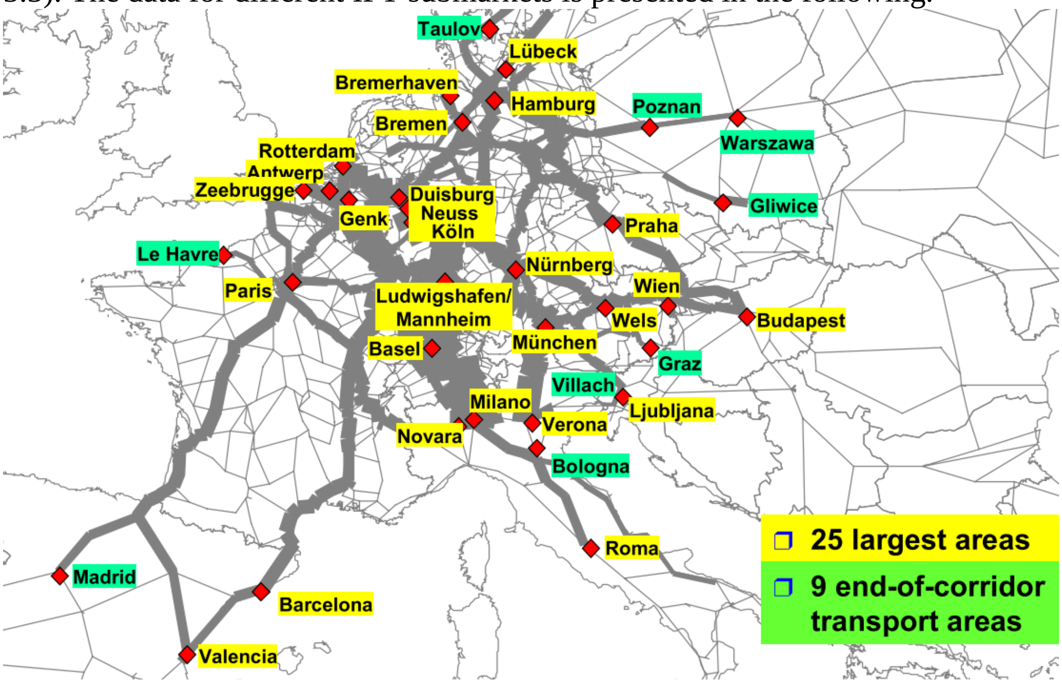

Figure 3.3. EU IFT network (International Union of Railways, 2004).

Transshipment Submarket

For the transshipment submarkets, the data are gathered from the Inland-links Web site ("Inland links website," n.d.). For each region, the Inland-links web site provides a list of the existing inland terminals and their respective capacities. In cases when we did not find the capacity data, we gathered capacity data from other sources such as the intermodal terminals Web site ("Intermodal Terminals Website," n.d.), the home page of terminals, or e-mail contact with the terminal operators (Table 3.3).

We made the following assumptions in data gathering and analysis:

- As mentioned in Section 2.1., a circle-shaped area with the radius of 70 km is considered to define the relevant transshipment submarket. For two demand points (i.e., the Hamburg and Bremen area) no inland terminal exists within 70 km. Thus we have considered the maritime terminals and included their excess capacities in the calculations. Here it could be argued that in these areas, because of the existing of the maritime terminals and their excess capacities, which can be assigned to the continental transport, there is no inland terminal in the nearby areas.
- To calculate the distance between each demand area to different inland terminals in that area, we have used the Inland-links Web site ("Inland links website," n.d.). This Web site enables the calculation of the distance between the center of the demand area and the terminal.

Main-Haulage Submarket

The capacity data of the different rail and barge operators are gathered from the Intermodal Yearbook (Gützkow, 2010). The routes where rail and barge operators are working are based on the Intermodal-links Web site ("Intermodal links website," n.d.). Furthermore, to assign the fleet of each operator to different routes (in Equation 5), we consider the velocity of the mode m (i.e., the parameter $V_o{}^m$) to be equal to $18\ \text{km/hour}$—as the average speed of the rail operators in the EU (EU Report, 2016)—and the operating time of mode m (i.e., the parameter $T_o{}^m$) to be $2{,}000\ \text{hours / year}$ (based on $40\,\frac{\text{hours}}{\text{week}} * 50\ \text{week/year}$). Table 3.3 shows the list of the data types and sources.

Corridor Submarket

The data for IFT chains competing in each corridor are formed based on the information of main-haulage and terminal operators as mentioned before.

TABLE 3.3. The Data Types and Sources for Different IFT Submarkets Analysis

IFT Sub-markets	Data type	Source
Transshipment Submarket	▪ The list of the inland Terminals in each region (a) ▪ Terminals Capacities (a), (b), (c),(d)	▪ "Inland links website," n.d. ▪ "Intermodal links website," n.d. ▪ Home pages of terminals ▪ Email contact with the terminal operators
Main-haulage Submarket	▪ Available connections between areas (e) ▪ Total capacity of main-haulage operators (f) ▪ Respective routes of each operator (e)	▪ "Intermodal links website," n.d. ▪ Intermodal Yearbook (Gützkow, 2010)
Corridor Submarket	▪ Existing corridors between origins and destinations (g)	▪ "Intermodal links website," n.d.
O-D pair Submarket	▪ The list of the main IFT demand areas in the network (h)	▪ "IFT infrastructure in EU" Report (International Union of Railways, 2004)

O-D pair Submarket

The data for origins and destinations is based on the presented information in (International Union of Railways, 2004). Sixty-nine corridors are considered based on existing data in the Intermodal-links Web site ("Intermodal links website," n.d.). The list of these corridors can be found in Appendix 3C.

The summary of the necessary data for different submarkets is presented in Table 3.3. For different submarkets, different data types are needed, and different sources are used for these data types. Based on the aforementioned data and assumptions, the application of the IFTMS model to the EU IFT network is presented in the following subsections.

3.4.2. Analysis of the Transshipment Submarkets

For transshipment market analysis, the terminals within 70 km are selected, and their market shares are determined based on their throughput. The throughput of a terminal is calculated based on the flow of the corridor to which that terminal belongs. This flow is determined based on Equations 10–13 and is dependent on the capacity of that terminal. As a sensitivity analysis, these calculations are replicated for inland terminals within 90 km and 50 km.

The concentration measures of different transshipment market areas are presented in Table 3.4. In each transshipment submarket, terminals are market players. The majority of markets are highly concentrated with a dominant-player or a tight-oligopoly type. As shown in Figure 3.4, the transshipment submarkets in the northern EU are relatively less concentrated than in central and southern areas. It should be noted that in this analysis, we presumed that the terminals in nearby areas around the IFT demand points are delivering substitutable and competitive service. In practice, however, a service of a terminal cannot always be substituted by another one due to operational reasons, railway access, or intermodal operators supply policies and cooperative agreements (International Union of Railways, 2004). This heterogeneity, therefore, could lead to more concentration in the transshipment submarkets.

TABLE 3.4. Structure of Transshipment Submarkets in the EU

Market Area	CR1	CR2	CR3	CR4	HHI	Shepherd	U.S. Department of Justice Convention
Antwerp	15%	30%	39%	47%	846	Loose Oligopoly	Unconcentrated
Bremen	100%	-	-	-	10,000	Monopoly	Highly Concentrated
Budapest	59%	100%	-	-	5,179	Dominant player	Highly Concentrated
Duisburg	20%	32%	43%	52%	979	Loose Oligopoly	Unconcentrated
Genk	33%	51%	66%	73%	1,815	Tight oligopoly	Moderately concentrated
Hamburg	34%	64%	86%	93%	2,598	Super-tight-oligopoly	Moderately concentrated
Ludwigshafen	27%	46%	65%	78%	1,752	Tight oligopoly	Moderately concentrated
Milano	52%	75%	86%	93%	3,431	Dominant-player	Highly Concentrated
Munchen	76%	89%	96%	100%	6,027	Dominant-player	Highly Concentrated
Nurnberg	92%	100%	-	-	8,587	Dominant player	Highly Concentrated
Paris	84%	94%	97%	100%	7,158	Dominant-player	Highly Concentrated
Praha	65%	84%	99%	100%	4,816	Dominant-player	Highly Concentrated
Rotterdam	12%	24%	35%	44%	746	Loose Oligopoly	Unconcentrated
Verona	71%	100%	-	-	5,856	Dominant player	Highly concentrated
Wels	67%	100%	100%	-	5,549	Dominant player	Highly Concentrated
Wien	70%	100%	-	-	5,840	Dominant player	Highly Concentrated
Zeebrugge	73%	92%	98%	100%	5,714	Dominant player	Highly Concentrated

The results of our sensitivity analysis—by increasing the radii of 70 km to 90 km—is presented in Appendix 3A. The market structure is not sensitive to increases in the radius in cases; only in Zeebrugge is the change in market structure significant (from Dominant player to Tight oligopoly). In other cases, the influence of an increase in radius is marginal. In addition, we did sensitivity analysis for the 50 km radii (Appendix 3A). Our findings show the decrease of the radii has little impact on the market structures.

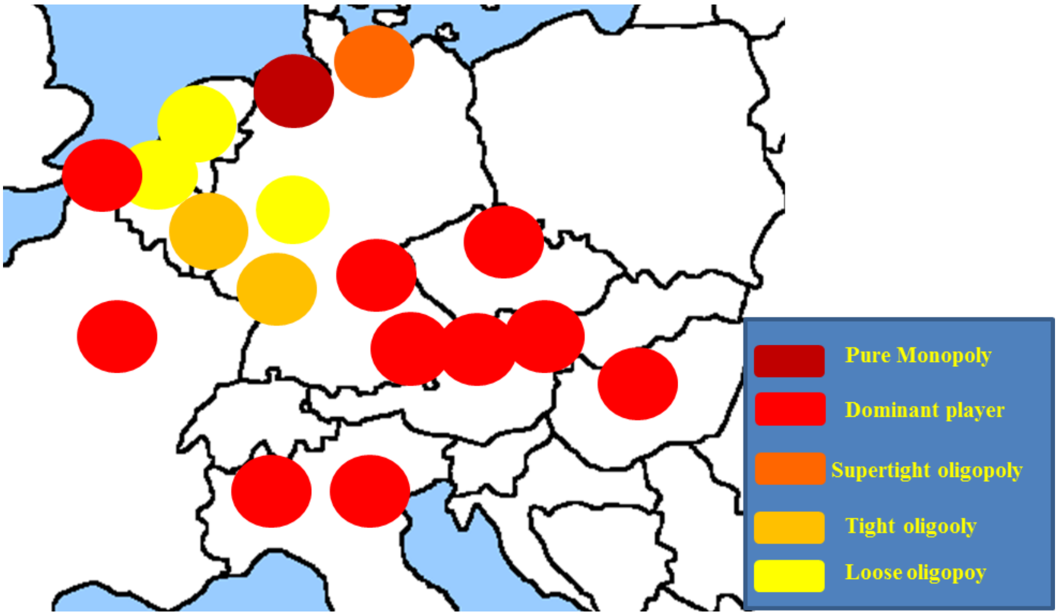

Figure 3.4. Geographical Distribution of the Transshipment Submarkets with Different Market Structures in the EU

When we look at the whole IFT network, another type of competition is happening inside the transshipment submarkets (nodes) that are bottlenecks. This competition is between corridors, which include these nodes. A bottleneck node is a node for which the throughput is equal to the available capacity (Saeedi et al., 2017). In other words, there is no excess capacity in this transshipment node, and all corridors using that node are basically competing for the available capacity (Saeedi et al., 2017). The analysis of the results shows no bottleneck node in the EU IFT network.

3.4.3. Analysis of the Main-haulage Submarkets

To calculate the main-haulage submarkets concentration, we applied the model presented in Section 3.2. To solve the mathematical model, we used the AIMMS optimization package ("AIMMS software," n.d.). The results show the distribution of the capacity of each transport operator in different routes. The concentration measures of different main-haulage submarkets are presented in Appendix 3B. Based on the results, we can conclude that the main-haulage submarkets in the EU are highly concentrated (see Figure 3.5). Considering the conservative nature of our methodology in terms of market concentration, in reality, the main-haulage submarkets in the EU are even more concentrated than what we measured here.

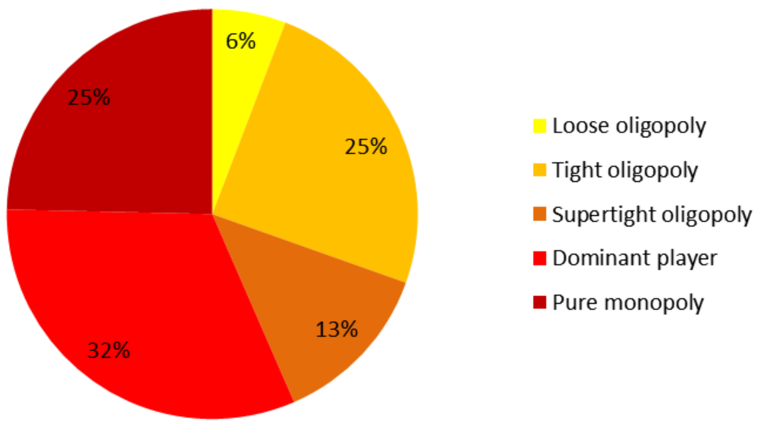

Figure 3.5. Types of The Main-haulage Submarkets in the EU

Similar to the transshipment submarket, another type of the competition occurs among corridors that include the bottleneck links (main-haulage submarkets). These corridors are competing for the capacity of those bottleneck links (Saeedi et al., 2017). Our calculations show that in the EU IFT network, there is no bottleneck link.

3.4.4. Analysis of the Corridor Submarkets

Inside the corridor submarkets, the IFT chains are the market players. Two parameters are important in the concentration degree inside the corridors: first, the number of segments inside each IFT chain, and second, the number of players inside each segment. In two corridors we have seven segments (four transshipment and three main-haulage submarkets), 18 corridors have three segments (two transshipment and one main-haulage submarkets), and the rest have five segments (see Appendix 3C). In most of the corridor submarkets, the number of IFT chains is more than 100, and only in two submarkets is the competition between less than 20 IFT chains. Because in the majority of corridors there are too many IFT chains—with the almost uniform distribution of the throughput—these corridors are unconcentrated markets. Only in the Zeebrugge-Paris corridor, we see high concentration. This corridor is a tight oligopoly and a highly concentrated submarket.

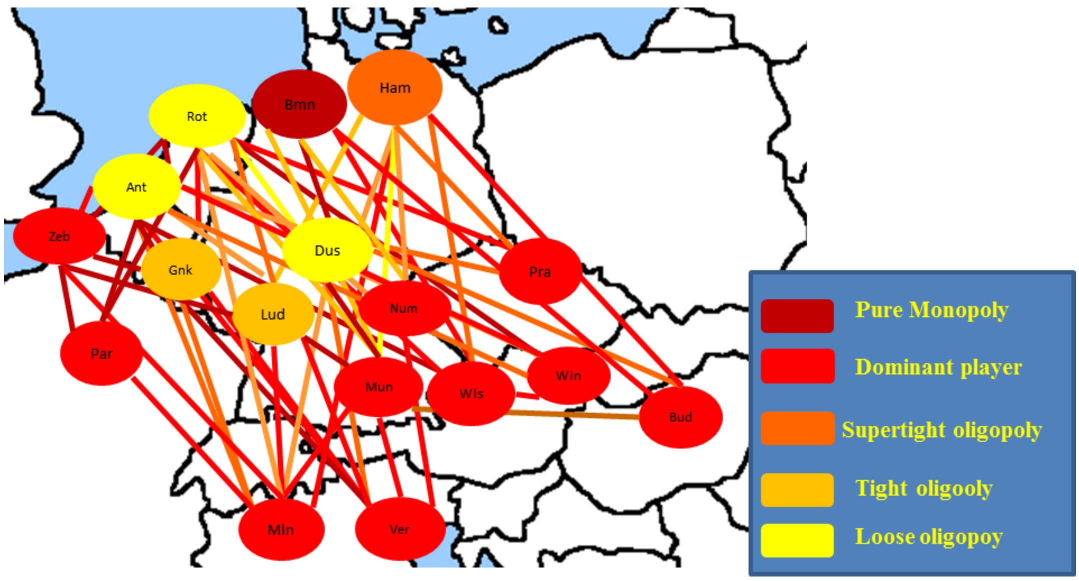

Figure 3.6. The Geographical Distribution of the Different Transshipment and Main-haulage submarkets inside the EU Network

Figure 3.6 shows the concentration of different sub-markets in different corridors for the EU IFT network. As can be seen in this figure, in the majority of corridors, the transshipment submarkets are the most concentrated submarkets. From a policy-making point of view, this implies that the transshipment submarkets (which include the terminals) have the priority for intervention and capacity extension investments. Figure 3.6 also shows the structure of transshipment and main-haulage submarkets in different areas in the EU that can be a basis for regional policy making.

It should be noted that the results of this analysis underestimate the concentration degree inside the corridor submarkets because cooperation between different terminal operators and main-haulage operators in different submarkets to construct IFT chains is not always possible. For example, some rail operators are active in the directions that have access only to certain terminals in some transshipment submarkets. We have not considered these restrictions in our analysis here, but further research can be conducted to address this. Therefore, in general, the corridor submarkets might be more concentrated than what we found here.

3.4.5. Analysis of the O-D Pair Submarkets

Given the capacities of the links and nodes from the transshipment and main-haulage submarket analysis, the nonlinear optimization model presented in Section 2.4 is solved to study the concentration of the O-D pair submarkets at the corridor level. The results of modeling are presented in Appendix 3D and Figure 3.7. The majority of the O-D pair submarkets are highly concentrated. The results also show that none of the O-D pair submarkets are un-concentrated markets. For the majority of O-D pairs, there is only one corridor or a dominant one as the market player. In other words, only one main corridor is actively serving that O-D pair intermodal transport service.

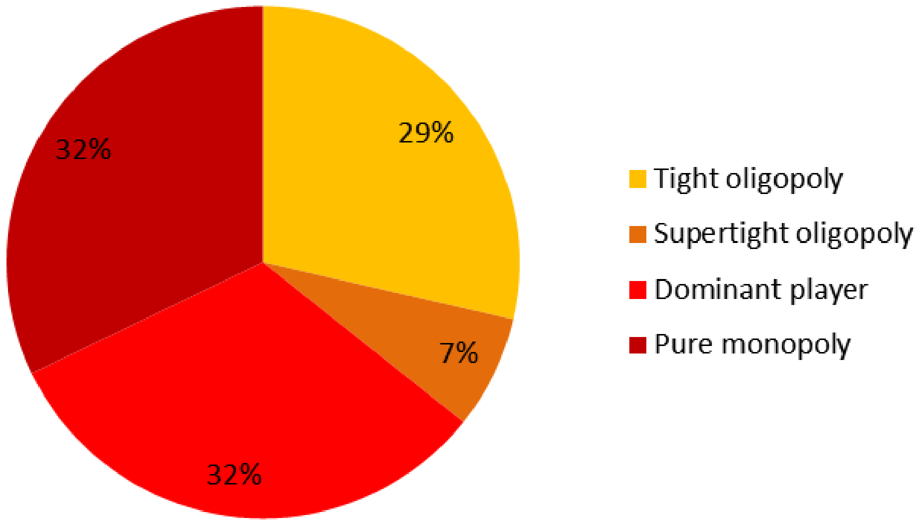

Figure 3.7. Different Types of the O-D Pair Submarkets in the EU (Corridors as Market Players)

Table 3.5 shows the market types based on the different origins and destinations of the EU IFT network. The market types of different O-D pair submarkets shows that the O-D pair submarkets originating from Bremen are the most concentrated markets between O-D pair submarkets in the EU IFT network. In addition, the Budapest area is the destination for the most concentrated O-D pair submarkets. On the other hand, the Bremen and Budapest transshipment submarkets are not the most concentrated ones compared to the transshipment submarkets in other EU IFT networks. This clearly implies that we cannot approximate the concentration of the corridor submarkets of specific origin and destination areas, but only look into the market concentration of the origin or destination area.

TABLE 3.5. Market Structure of the O-D Pair Submarkets Based on Different Origins and Destinations (Competition between Corridors)

Destinations / Origins	Praha	Paris	Budapest	Verona	Milan	Wien
Hamburg	Dominant-player	Pure-monopoly	Dominant-player	Tight-oligopoly	Supertight-oligopoly	Dominant-player
Bremen	Pure-monopoly	-	Pure-monopoly	Dominant-player	Dominant-player	Pure-monopoly
Rotterdam	Dominant-player	Pure-monopoly	Pure-monopoly	Tight-oligopoly	Supertight-oligopoly	Tight-oligopoly
Antwerp	Pure-monopoly	Dominant-player	Pure-monopoly	Tight-oligopoly	Tight-oligopoly	Tight-oligopoly
Zeebrugge	Pure-monopoly	Dominant-player	-	Tight-oligopoly	Tight-oligopoly	Dominant-player

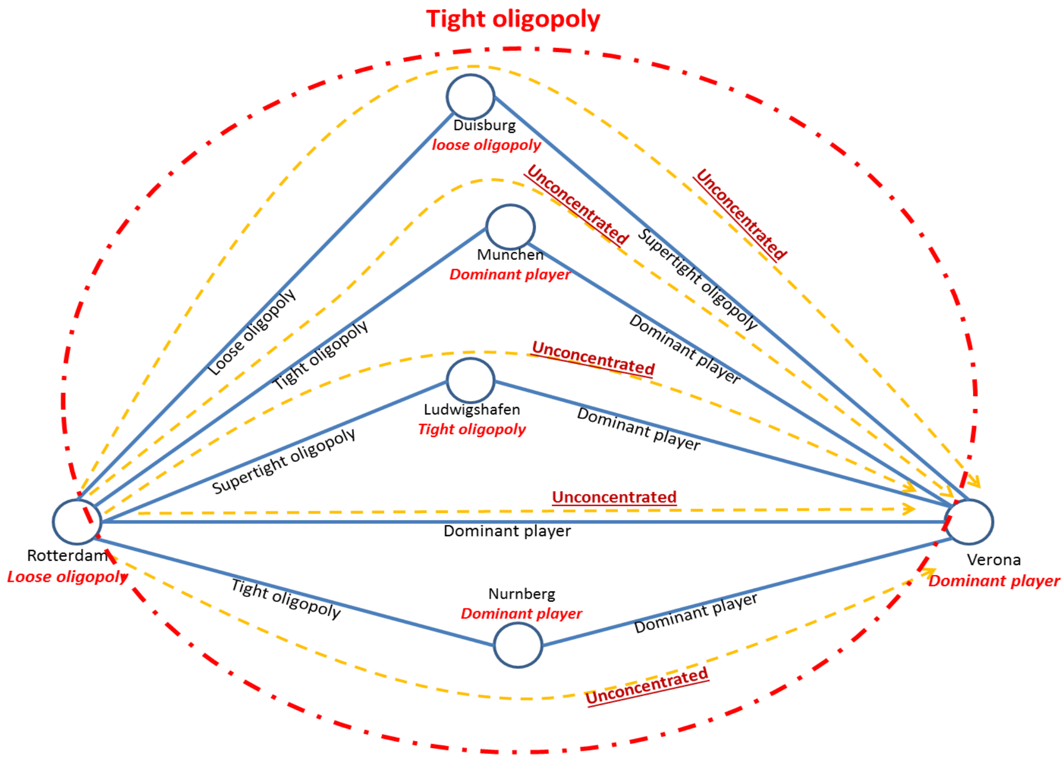

Figure 3.8. Different Levels of Competition Inside a Sample O-D of the EU IFT Network

Figure 3.8 illustrates the multilevel nature of market analysis for the EU IFT network. As can be seen, for the subnetwork originating from Rotterdam to Verona, the O-D pair submarket—as the most aggregate level of analysis—indicates the competition between different corridors that form a tight-oligopoly market. The corridor submarkets (e.g., the Rotterdam-Munchen-Verona corridor) are unconcentrated. At the segmental level, the transshipment submarket in Rotterdam is a tight oligopoly, whereas it is a dominant player in Munchen and Verona. The main-haulage submarket between Rotterdam and Munchen is a tight oligopoly, and between Munchen and Verona is a dominant player market. A main implication of these findings is that in policy making for IFT services, we should clearly define the focus of analysis because different levels of the market analysis result in different market structures.

3.5. Conclusion and Policy Implications

This chapter has addressed the subject of competition and market structure in the IFT market. The analysis of market structure is vital for policy makers who aim to promote competition in the IFT market and increase social economic welfare. Antitrust authorities can benefit from the findings and the presented methodology in this research. In both cases, a main challenge is defining the geographical market, for example, for terminals that are competing inside a transshipment submarket. Furthermore, analyzing the IFT market can be challenging due to multistage characteristics of IFT services. The analysis can be conducted on different levels. We can have a segmental view in which the market concertation for different submarkets (e.g., the transshipment submarket) is analyzed. We can also have a chain perspective in which the competition between different IFT chains in one corridor is studied. At the same time, multiple corridors are potentially competing in the transportation of goods between an origin and a destination. The IFTMS model—as presented in chapter 2—helps conduct such a multilevel market analysis. However, the difficulties in applying this model to a case like the European IFT market are the definition of the boundaries of the transshipment markets and the availability of detailed data, especially at the chain level. To cope with these challenges, a methodology that is complementary to the IFTMS model was presented in this chapter. This methodology applies a model-based approach—based on fair allocation algorithms—to make the existing high-level data more detailed toward node, link, and corridor data. It should be emphasized that using fair allocation algorithms gives a conservative estimation of market concentration, and the market structure can be more concentrated in reality. Also, the assumptions in defining the relevant geographical transshipment submarkets —that is, the demand for IFT service is concentrated in one demand point and the operators provide homogenous services—provide a conservative measure of concentrations in transshipment submarkets. The policy implication of this is that the presented methodology gives a "lower bound" of actual concentration for different submarkets. In other words, if the results of applying the presented methodology imply a high concentration in one submarket or in one region—that are possible options for policy making and interventions—the actual concentration would be higher than the estimated value.

In this chapter, we also applied this methodology to give a picture of the market structure of the European IFT network. The analysis of EU IFT network shows that in most areas the transshipment and main-haulage submarkets are highly concentrated. The majority of corridor submarkets are unconcentrated, and O-D pair submarkets are highly concentrated at the corridor level and unconcentrated at the chain level. As already mentioned, the findings of this study need to be interpreted in a conservative way in light of the methodological limitations and assumptions. These assumptions, lead to a lower bound of market concentration in the EU IFT network. Even this lower bound implies a high level of concentration in transshipment, main-haulage, and O-D pair submarkets, which implies that highly concentrated submarkets exist in the EU IFT network in reality.

In general, this research may have several important implications for policymakers and practitioners. First, this research presents a stepwise methodology for policy-makers, and antitrust authorities to study the market structure of the IFT network (and the potential impacts of anticompetitive business practices like merger and acquisition on the IFT market structure). The model can be used by companies and practitioners to study the potential market implications of their business practices as well. The results of the model's application to EU IFT network provides insight into the market structure and the submarkets with higher priority in terms of competition policy making. Finally, the impact of policies to promote IFT in the EU or the other continents can be evaluated using this model.

One of the main advantages of the presented methodology is the ability to evaluate the IFT market structure in cases when the detailed data is not available. The presented model-based approach also leads to a comprehensive and consistent picture of all flows in different corridors of an IFT network. This approach can be applied in other cases in the transport domain in which sample data need to be constructed from existing aggregate data. Such an application can be a direction for future research in this work. Analyzing the dynamics of market structures in the IFT sector and its evolution over time is another area of interest for future research. The impact of policies to promote IFT in the EU can be studied in such a dynamic market structure analysis. In the higher level of analysis, the competition between the IFT corridors and unimodal-truck transport between different O-D pairs can also be measured by assigning the total freight flows to the freight transport networks.

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Appendix 3A– Sensitivity Analysis of Transshipment Sub-Market

Market Area	Market Type With Fixed Radius 70km		Market Type After Increasing The Radius To 90km	
	Shepherd	U.S. department of justice convention	Shepherd	U.S. department of justice convention
Antwerp	Loose Oligopoly	Unconcentrated	Loose Oligopoly	Unconcentrated
Bremen	Monopoly	Highly Concentrated	Monopoly	Highly Concentrated
Budapest	Dominant player	Highly Concentrated	Dominant player	Highly Concentrated
Duisburg	Loose Oligopoly	Unconcentrated	Loose Oligopoly	Unconcentrated
Genk	Tight oligopoly	Moderately concentrated	Loose Oligopoly	Unconcentrated
Hamburg	Super-tight-oligopoly	Moderately concentrated	Super-tight-oligopoly	Moderately concentrated
Ludwigshafen	Tight oligopoly	Moderately concentrated	Loose Oligopoly	Unconcentrated
Milano	Dominant-player	Highly Concentrated	Dominant-player	Highly Concentrated
Munchen	Dominant-player	Highly Concentrated	Dominant-player	Highly Concentrated
Nurnberg	Dominant player	Highly Concentrated	Dominant player	Highly Concentrated
Paris	Dominant-player	Highly Concentrated	Dominant-player	Highly Concentrated
Praha	Dominant-player	Highly Concentrated	Dominant-player	Highly Concentrated
Rotterdam	Loose Oligopoly	Unconcentrated	Loose Oligopoly	Unconcentrated
Verona	Dominant player	Highly concentrated	Dominant player	Highly concentrated
Wels	Dominant player	Highly Concentrated	Dominant player	Highly Concentrated
Wien	Dominant player	Highly Concentrated	Dominant player	Highly Concentrated
Zeebrugge	Dominant player	Highly Concentrated	Tight oligopoly	Moderately concentrated

Market Area	Market Type With Fixed Radius 70km		Market Type After Increasing The Radius To 50km	
	Shepherd	U.S. department of justice convention	Shepherd	U.S. department of justice convention
Antwerp	Loose Oligopoly	Unconcentrated	Loose Oligopoly	Moderately Concentrated
Bremen	Monopoly	Highly Concentrated	Monopoly	Highly Concentrated
Budapest	Dominant player	Highly Concentrated	Dominant player	Highly Concentrated

Market Area	**Market Type With Fixed Radius 70km**		**Market Type After Increasing The Radius To 50km**	
Duisburg	Loose Oligopoly	Unconcentrated	Tight oligopoly	Moderately Concentrated
Genk	Tight oligopoly	Moderately concentrated	Tight oligopoly	Highly Concentrated
Hamburg	Super-tight-oligopoly	Moderately concentrated	Super-tight-oligopoly	Moderately concentrated
Ludwigshafen	Tight oligopoly	Moderately concentrated	Tight Oligopoly	Moderately Concentrated
Milano	Dominant-player	Highly Concentrated	Dominant-player	Highly Concentrated
Munchen	Dominant-player	Highly Concentrated	Dominant player	Highly Concentrated
Nurnberg	Dominant player	Highly Concentrated	Monopoly	Highly Concentrated
Paris	Dominant-player	Highly Concentrated	Dominant-player	Highly Concentrated
Praha	Dominant-player	Highly Concentrated	Dominant-player	Highly Concentrated
Rotterdam	Loose Oligopoly	Unconcentrated	Loose Oligopoly	Unconcentrated
Verona	Dominant player	Highly concentrated	Monopoly	Highly Concentrated
Wels	Dominant player	Highly Concentrated	Dominant player	Highly Concentrated
Wien	Dominant player	Highly Concentrated	Dominant player	Highly Concentrated
Zeebrugge	Dominant player	Highly Concentrated	Dominant player	Highly Concentrated

Appendix 3B - Different Structure of Main-haulage Sub-Markets in the EU

No.	Main-haulage Sub-market	CR1	CR2	CR3	CR4	HHI
1	Hamburg-Ludwigshafen	12.7%	25.5%	37.7%	49.7%	1,148
2	Hamburg-Munchen	23.2%	37.6%	51.6%	64.8%	1,531
3	Hamburg-Wels	46.1%	76.9%	100.0%	-	3,608
4	Hamburg-Budapest	62.0%	100.0%	-	-	5,291
5	Hamburg-Verona	34.6%	58.8%	82.3%	100.0%	2,649
6	Hamburg-Milan	55.4%	100.0%	-	-	5,058
7	Hamburg-Wien	31.7%	59.2%	82.1%	100.0%	2,605
8	Hamburg-Bremen	52.0%	100.0%	-	-	5,007
9	Hamburg-Duisburg	24.0%	48.0%	70.0%	91.0%	2,169
10	Hamburg-Praha	29.0%	55.0%	80.0%	100.0%	2,541
11	Hamburg-Nurnberg	25.2%	48.8%	62.9%	76.7%	1,853
12	Bremen-Ludwigshafen	18.7%	36.9%	53.9%	68.7%	1,560
13	Bremen-Munchen	27.9%	50.7%	69.3%	84.9%	2,115
14	Bremen-Wels	66.8%	100.0%	-	-	5,565
15	Bremen-Budapest	62.1%	100.0%	-	-	5,291
16	Bremen-Wien	36.5%	64.7%	85.5%	100.0%	2,770
17	Bremen-Duisburg	100.0%	-	-	-	10,000
18	Bremen-Praha	69.5%	100.0%	-	-	5,758
19	Bremen-Nurnberg	20.3%	39.9%	57.3%	72.8%	1,709
20	Rotterdam-Ludwigshafen	38.4%	60.2%	96.6%	100.0%	3,284
21	Rotterdam-Paris	100.0%	-	-	-	10,000
22	Rotterdam-Munchen	44.5%	69.0%	84.9%	100.0%	3,062
23	Rotterdam-Wels	66.8%	100.0%	-	-	5,565
24	Rotterdam-Verona	55.0%	100.0%	-	-	5,051
25	Rotterdam-Milan	64.4%	75.9%	85.8%	93.8%	4,476
26	Rotterdam-Wien	100.0%	-	-	-	10,000
27	Rotterdam-Antwerp	100.0%	-	-	-	10,000
28	Rotterdam-Zeebrugge	100.0%	-	-	-	10,000
29	Rotterdam-Genk	64.0%	100.0%	-	-	5,376
30	Rotterdam-Duisburg	14.8%	28.4%	42.0%	55.7%	1,182
31	Rotterdam-Praha	100.0%	-	-	-	10,000
32	Rotterdam-Nurnberg	37.4%	63.2%	81.9%	100.0%	2,742
33	Antwerp-Ludwigshafen	18.9%	66.8%	80.4%	98.3%	3,159
34	Antwerp-Paris	100.0%	-	-	-	10,000
35	Antwerp-Wels	100.0%	-	-	-	10,000
36	Antwerp-Verona	55.0%	100.0%	-	-	5,051
37	Antwerp-Milan	38.0%	64.6%	84.9%	100.0%	2,792
38	Antwerp-Wien	62.3%	88.3%	100.0%	-	4,699
39	Antwerp-Zeebrugge	50.0%	100.0%	-	-	5,000
40	Antwerp-Genk	100.0%	-	-	-	10,000
41	Antwerp-Duisburg	12.0%	24.2%	45.6%	55.6%	1,765
42	Zeebrugge-Ludwigshafen	100.0%	-	-	-	10,000
43	Zeebrugge-Paris	100.0%	-	-	-	10,000
44	Zeebrugge-Milan	58.8%	100.0%	-	-	5,156
45	Zeebrugge-Genk	100.0%	-	-	-	10,000
46	Zeebrugge-Duisburg	61.0%	100.0%	-	-	5,241
47	Genk-Verona	100.0%	-	-	-	10,000
48	Genk-Milan	62.3%	88.3%	100.0%	-	3,696
49	Genk-Antwerp	100.0%	-	-	-	10,000
50	Duisburg-Hamburg	24.3%	45.3%	67.0%	91.3%	2,169

No.	Main-haulage Sub-market	CR1	CR2	CR3	CR4	HHI
51	Duisburg-Ludwigshafen	33.4%	57.4%	100.0%	-	3,507
52	Duisburg-Munchen	100.0%	-	-	-	10,000
53	Duisburg-Wels	54.2%	100.0%	-	-	5,035
54	Duisburg-Budapest	37.6%	70.6%	100.0%	-	3,367
55	Duisburg-Verona	42.5%	80.9%	100.0%	-	3,644
56	Duisburg-Milan	23.0%	44.9%	61.7%	77.9%	1,800
57	Duisburg-Wien	23.9%	47.0%	67.8%	86.8%	2,073
58	Duisburg-Praha	47.7%	83.7%	100.0%	-	3,836
59	Nurnberg-Munchen	93.1%	100.0%	-	-	8,712
60	Nurnberg-Verona	51.3%	100.0%	-	-	5,003
61	Ludwigshafen-Munchen	100.0%	-	-	-	10,000
62	Ludwigshafen-Wels	53.0%	100.0%	-	-	5,018
63	Ludwigshafen-Verona	52.5%	100.0%	-	-	5,013
64	Ludwigshafen-Milan	57.5%	100.0%	-	-	5,113
65	Paris-Milan	68.1%	100.0%	-	-	5,655
66	Munchen-Budapest	100.0%	-	-	-	10,000
67	Munchen-Verona	51.0%	100.0%	-	-	5,002
68	Munchen-Milan	51.0%	100.0%	-	-	5,003
69	Wels-Wien	59.0%	100.0%	-	-	5,161

Appendix 3C – Number Of IFT Chains In Different Corridor Sub-Markets

No.	Corridor	No. of IFT chains in the corridor
1	Rotterdam-Koln - Milano	61,200
2	Rotterdam-Koln-Wels-Wien	40800
3	Antwerp-Koln-Milano	38,556
4	Rotterdam-Koln-Praha	20400
5	Rotterdam-Koln -Wien	17,000
6	Rotterdam-Ludwigshafen-Wels-Wien	11520
7	Antwerp-Koln-Wien	10710
8	Rotterdam-Koln-Budapest	10,200
9	Rotterdam-Koln-Verona	10,200
10	Antwerp-Koln-Budapest	6426
11	Hamburg-Ludwigshafen-Milano	5184
12	Bremen-Koln-Milano	3060
13	Rotterdam-Genk-Milano	2880
14	Antwerp-Rotterdam-Milano	2700
15	Antwerp-Ludwigshafen-Verona	2160
16	Rotterdam-Ludwigshafen-Verona	1920
17	Hamburg-Ludwigshafen-Verona	1728
18	Hamburg-Koln-Praha	1632
19	Bremen-Munchen-Milano	1440
20	Antwerp-Genk-Milano	1296
21	Antwerp-Milano-Paris	1296
22	Hamburg-Munchen-Milano	1152
23	Zeebrugge-Antwerp-Milano	864
24	Hamburg-Koln-Budapest	816
25	Rotterdam-Munchen-Verona	640
26	Zeebrugge-Rotterdam-Milano	600
27	Bremen-Munchen-Verona	400
28	Hamburg-Munchen-Verona	384
29	Antwerp-Rotterdam-Verona	360
30	Antwerp-Rotterdam-Praha	360
31	Rotterdam-Nurnberg-Verona	320
32	Rotterdam-Genk-Verona	320
33	Rotterdam-Milano	300
34	Hamburg-Milano-Paris	288
35	Zeebrugge-Genk-Milano	288
36	Zeebrugge-Ludwigshafen-Milano	288
37	Bremen-Nurnberg-Verona	240
38	Rotterdam-Wels-Wien	240
39	Zeebrugge-Antwerp-Wien	216
40	Antwerp-Milano	216
41	Antwerp-Rotterdam-Wien	180
42	Hamburg-Nurnberg-Verona	160
43	Hamburg-Wels-Wien	144
44	Antwerp-Genk-Verona	144
45	Zeebrugge-Antwerp-Verona	144
46	Zeebrugge-Milano-Paris	144
47	Bremen-Wels-Wien	120
48	Antwerp-Wels-Wien	108
49	Zeebrugge-Ludwigshafen-Verona	96
50	Zeebrugge-Rotterdam-Praha	80

No.	Corridor	No. of IFT chains in the corridor
51	Zeebrugge-Rotterdam-Verona	80
52	Antwerp-Wien	54
53	Hamburg-Praha	48
54	Hamburg-Milano	48
55	Zeebrugge-Rotterdam-Wien	40
56	Bremen-Praha	40
57	Rotterdam-Praha	40
58	Rotterdam-Verona	40
59	Antwerp-Verona	36
60	Hamburg-Wien	32
61	Hamburg-Verona	32
62	Zeebrugge-Genk-Verona	32
63	Rotterdam-Paris	30
64	Antwerp-Paris	27
65	Zeebrugge-Milano	24
66	Rotterdam-Wien	20
67	Bremen-Budapest	20
68	Hamburg-Budapest	16
69	Zeebrugge-Paris	6

Appendix 3D- The Results of O-D Pair Sub-Markets Analysis

		Indices	**Destinations**					
			Praha	**Paris**	**Budapest**	**Verona**	**Milano**	**Wien**
Origins	**Hamburg**	*CR1*	50%	100%	50%	25%	33%	50%
		CR2	100%	-	100%	50%	67%	100%
		CR3	-	-	-	75%	100%	-
		CR4	-	-	-	100%	-	-
		HHI	5,000	10,000	5,000	2,500	3,333	5,000
	Bremen	*CR1*	100%		100%	82%	50%	100%
		CR2	-		-	100%	100%	-
		CR3	-	-	-	-	-	-
		CR4	-		-	-	-	-
		HHI	10,000		10,000	7,049	5,000	10,000
	Rotterdam	*CR1*	50%	100%	100%	17%	33%	33%
		CR2	100%	-	-	33%	67%	67%
		CR3	-	-	-	50%	100%	100%
		CR4	-	-	-	67%		
		HHI	5,000	10,000	10,000	1,667	3,333	3,333
	Antwerp	*CR1*	100%	50%	100%	25%	50%	17%
		CR2	-	100%	-	50%	100%	33%
		CR3	-	-	-	75%	-	50%
		CR4	-	-	-	100%	-	100%
		HHI	10,000	5,000	10,000	2,500	5,000	3,333
	Zeebrugge	*CR1*	100%	86%		20%	42%	50%
		CR2	-	100%		41%	56%	100%
		CR3	-	-	-	62%	71%	-
		CR4	-	-		100%	86%	-
		HHI	10,000	7,569		2,729	2,603	5,000

Appendix 3E- Reproducibility, Calibration, and Validation of the complementary method

In this appendix, we give an overview of the calibration, validation and the reproducibility of the method presented in this chapter. First, it should be notified again that the findings of this chapter need to be interpreted in a conservative way in light of the methodological limitations and assumptions. These assumptions lead to a lower bound of market concentration in the EU IFT network.

- **IFTMS model and Reproducibility**

As mentioned in the previous chapter, the IFTMS model aims to provide a mathematical method to allocate flows to nodes, links, and corridors, and to various players on the network while taking into account their capacities (Below Flowchart). The network is given by graph $G = (N, A)$ with node set N and link set A. The flow f_a on link $a \in A$ does not exceed link capacity, i.e., $0 \leq f_a \leq c_a$. For any node $n \in N$ the flow is also assumed $0 \leq f_n \leq c_n$.
For any corridor $\pi \epsilon \prod$ (path in graph G) that originates from o and is destined to d, we may establish a flow f_π through the corridor in a consistent way. A corridor (path) π is associated with a sequence of nodes $(n_1, \dots, n_{m+1})$ and links $(a_1, \dots, a_m)$ where $a_j = (n_j, n_{j+1})$. By abuse of notation, we write $a \in \pi$ or $n \in \pi$ whenever the link a or the node n is part of the corridor π. Define the link-corridor (and similarly, node-corridor) incidence matrix as follows: Let $\delta_{a\pi} = 1$ whenever $a \in \pi$ and $\delta_{a\pi} = 0$ otherwise. The flows f_π satisfy $f_a = \sum_\pi \delta_{a\pi} f_\pi$ and $f_n = \sum_\pi \delta_{n\pi} f_\pi$. The flow size is equal to the total flow through all corridors, i.e., $|f| = \sum_{\pi \epsilon \prod} f_\pi$. Alternatively, the flow size equals the total outflow from the origin and the total inflow to the destination, i.e., $|f| = f_o = f_d$. A corridor π has capacity $c_\pi = \min\{c_a, c_n | a \in \pi, n \in \pi\}$. The allocation of the total flow |f| to corridors is proportionally fair when [38]:

$$Max \prod_{\pi \epsilon \prod} f_\pi \ , \qquad \text{(a)}$$

$$\sum_\pi \delta_{n\pi} f_\pi \leq c_n \ , \qquad \text{(b)}$$

$$\sum_\pi \delta_{a\pi} f_\pi \leq c_a \ , \qquad \text{(c)}$$

$$f_\pi \leq c_\pi \ , \forall \pi \epsilon \prod \ . \qquad \text{(d)}$$

Hence, we maximize the product of the corridor flows, subject to three constraints. Equations (b) and (c) constrain the summation of the flows of the corridors using node n or link a to be less than or equal to the capacity of that respective node or link. Equation (d) forces that the assigned flows to the corridors should not be more than the capacity of the corridors. The results of the estimated flows of the European corridors running by the Lindo software are presented in Table 3E-4.
We argue that in this manner, the flow will be allocated to all corridors (see Equation a), and our allocation mechanism does not introduce market concentration artifacts as the flow is rationed proportional to available capacities. This will allow us to study market concentration as it emerges from the structure of the capacitated network.

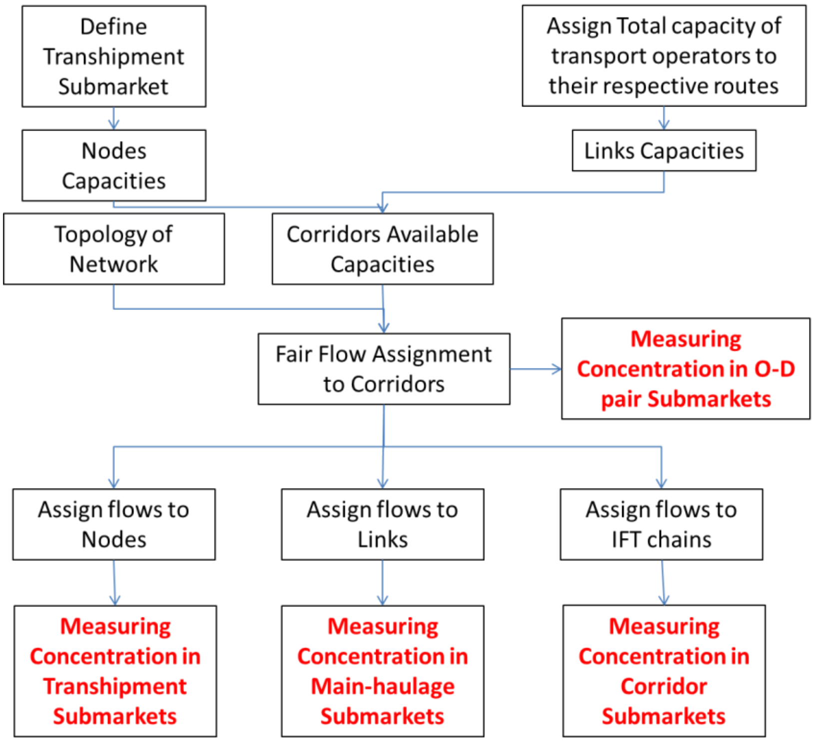

Figure 3E-1. IFTMS Model

Before assigning the flows to the corridors, we need the capacity of the different operators inside the main-haulage submarket. As explained in this chapter, often only the aggregate capacity of the main-haulage operators and their respective active routes are available, and the distribution of the capacity over different routes is lacking for analysis. To find the fair distribution of the capacity of each main-haulage operator in different routes, we apply the proportional fairness algorithm. To solve the equations presented in section 3.2.3 we used the data presented in table 3E-3 which came from the Intermodal yearbook and run the model in AIMMS software. The table 3E-5 shows the results of the software.

We now consider the situation when multiple actors have available capacity on nodes, links, and corridors, and we study the corresponding submarkets. The node (transshipment) submarket M_n has size f_n and capacities c_n^k , where $k \in P_n$ are market players in the node market. By definition $c_n = \sum_{k \in P_n} c_n^k$. The flow allocation is proportional, i.e. $f_n^k := f_n \frac{c_n^k}{c_n}$. If two nodes have overlap, the effective capacity of the terminal which is in both nodes should be calculated. It means the total capacity of that terminal should be divided between two nodes proportional to the capacity of the nodes. Similarly, for link market M_a , we get $f_a^l := f_n \frac{c_n^l}{c_n}$ for players $l \epsilon P_a$ in the link market. Players in the OD-pair market M_{od} are identified with corridors, so the allocation of total flow to players is equal to the allocation of flow to corridors, which we have discussed above. A chain (p) within this corridor is associated with a service that uses capacities of certain operators inside nodes and links. If operators $k_i \epsilon P_{n_i}$ $(k_i \epsilon k, P_{n_i} \epsilon\ P_n)$ for $i = 1, \dots, m+1$, and $l_j \epsilon P_{a_i}$ $(l_j \epsilon l, P_{a_i} \epsilon\ P_a)$ for $j = 1, \dots, m$ provide capacity to chain p (and we write pεπ), then the chain is given by $(c_{n_i}^{k_i}, c_{a_j}^{l_j})$.
We define the p_o as a chain with the least capacity inside the corridor π – i.e., a chain consist of players which have minimum capacity inside nodes and links:

$$p_o := \left\{(c_{n_i}^{k_{io}}, c_{a_j}^{l_{jo}}) \middle| \ c_{n_i}^{k_{io}} = \min\left\{ c_{n_i}^{k_i}\right\}, c_{a_j}^{l_{jo}} = \min\left\{c_{a_j}^{l_j}\right\}, i = 1, \dots, m+1, j = 1, \dots, m\right\} \qquad (e)$$

Then considering this least capacity chain (p_o), we assign a weight to different chains, by dividing the capacity of the players in nodes and links to the capacity of the players inside least capacity chain (p_o), and then make a summation on these numbers.

$$w_p := \left\{\sum_i \frac{c_{n_i}^{k_i}}{c_{n_i}^{k_{io}}} + \sum_j \frac{c_{a_j}^{l_j}}{c_{a_j}^{l_{jo}}}, \qquad p \in \pi\right\} \qquad (f)$$

We allocate flow proportional to the weights, and we set the flow of the chain p in the corridor π as follows:

$$f_\pi^p := \frac{w_p}{\sum w_p} . c_\pi \qquad (g)$$

Additional submarkets can be defined for those nodes and links that are bottlenecks in the corridors. These corridors effectively compete for capacity on those nodes and links. B denotes the set of bottlenecks in the network with respect to the flow f, that is,

$$B := \{n \epsilon N | f_n = c_n\} \cup \{a \epsilon A | f_a = c_a\} \qquad (h)$$

We have for $a \epsilon A$ that $c_a = f_a = \sum_\pi \delta_{a\pi} f_\pi$ and for $n \epsilon N$ that $c_n = f_n = \sum_\pi \delta_{n\pi} f_\pi$. The allocation of link a (or node n) capacity to the corridor π is given by f_π.
In the rest, the tables 3E-1 and 3E-2 presenting the detail data about the transshipment submarket and the capacity of different transport operators. This tables beside the rest of the information in this chapter will help the reproducibility of the model.

Table 3E-1. The capacity of the Transshipment submarkets

No.	IFT Submarket	Capacity of the Transshipment Submarket (TEU)
1	Hamburg	233,550
2	Bremen	368,550
3	Rotterdam	3,952,000
4	Antwerp	3,437,000
5	Zeebrugge	624,000
6	Genk	1,578,000
7	Koln	3,575,603
8	Praha	1,031,600
9	Nurnberg	379,000
10	Ludwigshafen	2,395,500
11	Paris	405,000
12	Munchen	473,000
13	Wels	525,418
14	Budapest	373,000
15	Verona	853,000
16	Milano	2,113,000
17	Wien	610,000

Table 3E-2. The Transport Operators in Different Routes With Their Total Capacity

No.	Transport Operator	Capacity (TEU)	Number of Routes
1	CEMAT	631,000	10
2	HUPAC	1,029,000	16
3	TX Logistik	300,000	13
4	TFG Transfracht	990,000	11
5	Shuttlewise	160,000	3
6	Samskip Van Dieren Multimodal	83,000	2

No.	Transport Operator	Capacity (TEU)	Number of Routes
7	Roland Spedition	73,000	6
8	Rail Cargo Austria	500,000	11
9	Novatrans	439,510	1
10	Neska-Intermodal	273,600	2
11	Naviland Cargo	36,000	1
12	METRANS	456,000	12
13	Mannheimer Container Terminal (MCT)	200,000	3
14	Liege Container Terminal	70,000	1
15	Kombiverkehr	1,400,000	25
16	Inter Ferry Boats	720,000	9
17	IMS	573,750	24
18	H&S Container Line	176,800	2
19	GVT Group of Logistics	195,000	1
20	Greenmodal	160,000	2
21	European Gateway Services	7,700,000	4
22	European Cargo Logistics (ECL)	187,000	3
23	Eurogate Intermodal	238,000	12
24	ERS Railways	650,000	6
25	DP World	50,000	1
26	Distri Rail	260,000	5
27	Delcatransport	50,000	1
28	Danser	416,000	4
29	CSKD Intrans	104,000	2
30	Contargo	36,000	9
31	Bohemiakombi	56,000	2
32	Binnenlandse Container Terminals Nederland	75,000	2
33	Am Zehnhoff-Söns	140,400	2
34	Alcotrans	273,600	1

Table 3E-3. The Distance Between Different Transshipment Submarkets.

	Hamburg	Bremen	Rotterdam	Antwerp	Zeebrugge	Genk	Köln	Praha	Nurnberg	Ludwigshafen	Paris	Munchen	Wels	Budapest	Verona	Milano	Wien
Hamburg	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bremen	95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rotterdam	415	330	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Antwerp	461	384	79	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zeebrugge	524	440	110	85	-	-	-	-	-	-	-	-	-	-	-	-	-
Genk	421	355	128	82	166	-	-	-	-	-	-	-	-	-	-	-	-
Köln	358	310	204	182	266	102	-	-	-	-	-	-	-	-	-	-	-
Praha	493	558	727	719	804	640	538	-	-	-	-	-	-	-	-	-	-
Nurnberg	463	487	540	513	597	431	337	251	-	-	-	-	-	-	-	-	-
Ludwigshafen	466	452	392	348	427	269	195	434	188	-	-	-	-	-	-	-	-
Paris	747	678	373	301	282	326	403	884	638	451	-	-	-	-	-	-	-
Munchen	614	637	660	620	700	540	457	300	151	273	685	-	-	-	-	-	-
Wels	663	710	800	772	854	690	597	215	260	433	864	182	-	-	-	-	-
Budapest	928	998	1156	1137	1221	1055	957	443	626	810	1245	562	381	-	-	-	-
Verona	907	918	866	807	872	738	681	577	447	488	756	304	382	658	-	-	-
Milano	902	898	793	727	783	666	628	649	467	448	634	351	480	794	148	-	-
Wien	744	807	944	923	1007	842	744	251	412	596	1035	356	174	214	513	631	-

Source: http://www.distancefromto.net/

- **Model Calibration**

To calibrate the model we should have appropriate and adequate real data that is not available in our case. We only had the capacity of different terminals and the total capacity of each transport operator. We can only claim that the assumptions we assumed to build up the models are rational assumptions. In this appendix, we have shown how the parameters of the model have been estimated by running Lindo and AIMMS software tools.

Table 3E-4. Estimated flows of different EU corridors in the model ran by Lindo software

```
Objective value:                              690.7755
Objective bound:                              690.7755
Infeasibilities:                              0.000000
Extended solver steps:                               1
Total solver iterations:                          1315
Elapsed runtime seconds:                          0.35

Model Class:                                     PINLP

Total variables:                    69
Nonlinear variables:                69
Integer variables:                  69

Total constraints:                 100
Nonlinear constraints:               1

Total nonzeros:                    349
Nonlinear nonzeros:                 69
```

Variable	Value	Reduced Cost
X1_8	28702.00	-0.3484078E-04
X1_16_11	18010.00	-0.5552471E-04
X1_14	18010.00	-0.5552471E-04
X1_7_14	18010.00	-0.5552471E-04
X1_15	6822.000	-0.1465846E-03
X1_9_15	17985.00	-0.5560189E-04
X1_10_15	17985.00	-0.5560189E-04
X1_12_15	17985.00	-0.5560189E-04
X1_16	18010.00	-0.5552471E-04
X1_10_16	18010.00	-0.5552471E-04
X1_12_16	18010.00	-0.5552471E-04
X1_17	18004.00	-0.5554321E-04
X1_13_17	18004.00	-0.5554321E-04
X2_8	52322.00	-0.1911242E-04
X2_14	39906.00	-0.2505889E-04
X2_9_15	39881.00	-0.2507460E-04
X2_12_15	39881.00	-0.2507460E-04
X2_7_16	39906.00	-0.2505889E-04
X2_12_16	39906.00	-0.2505889E-04
X2_13_17	39900.00	-0.2506266E-04
X3_8	40829.00	-0.2449240E-04
X3_7_8	40829.00	-0.2449240E-04
X3_11	40829.00	-0.2449240E-04
X3_7_14	40829.00	-0.2449240E-04
X3_15	40804.00	-0.2450740E-04
X3_7_15	40804.00	-0.2450740E-04
X3_10_15	40804.00	-0.2450740E-04
X3_9_15	40804.00	-0.2450740E-04
X3_12_15	40804.00	-0.2450740E-04
X3_16	40829.00	-0.2449240E-04
X3_7_16	40829.00	-0.2449240E-04
X3_17	40823.00	-0.2449599E-04
X3_7_17	40829.00	-0.2449240E-04
X3_6_15	40804.00	-0.2450740E-04
X3_6_16	40829.00	-0.2449240E-04
X3_13_17	40823.00	-0.2449599E-04
X3_7_13_17	40823.00	-0.2449599E-04
X3_10_13_17	40823.00	-0.2449599E-04

```
    X4_3_8        40829.00         -0.2449240E-04
     X4_11        40829.00         -0.2449240E-04
  X4_16_11        40829.00         -0.2449240E-04
   X4_7_14        40829.00         -0.2449240E-04
     X4_15        40804.00         -0.2450740E-04
   X4_3_15        40804.00         -0.2450740E-04
  X4_10_15        40804.00         -0.2450740E-04
     X4_16        40829.00         -0.2449240E-04
   X4_3_16        40829.00         -0.2449240E-04
   X4_7_16        40829.00         -0.2449240E-04
     X4_17        40823.00         -0.2449599E-04
   X4_3_17        40823.00         -0.2449599E-04
   X4_7_17        40823.00         -0.2449599E-04
   X4_6_15        40804.00         -0.2450740E-04
   X4_6_16        40829.00         -0.2449240E-04
  X4_13_17        40823.00         -0.2449599E-04
    X5_3_8        68757.00         -0.1454397E-04
     X5_11        34804.00         -0.2873233E-04
  X5_16_11        34804.00         -0.2873233E-04
   X5_3_15        34778.00         -0.2875381E-04
   X5_4_15        34778.00         -0.2875381E-04
  X5_10_15        34778.00         -0.2875381E-04
     X5_16        34804.00         -0.2873233E-04
   X5_3_16        34804.00         -0.2873233E-04
   X5_4_16        34804.00         -0.2873233E-04
  X5_10_16        34804.00         -0.2873233E-04
   X5_3_17        34797.00         -0.2873811E-04
   X5_4_17        41059.00         -0.2435520E-04
   X5_6_15        44938.00         -0.2225288E-04
   X5_6_16        34804.00         -0.2873233E-04
```

Table 3E-5. The result of Assigning the total capacity of each transport operator to its routes

Operators/ Routes *	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
CEMAT	254,107	320,741	57,461	226,872	234,202	65,153	133,162	70,124	136,758	171,793															
HUPAC	311,167	198,623	250,708	96,999	177,335	229,419	113,139	100,490	152,574	163,223	235,149	173,019	262,385	241,097	124,816	186,367									
TX Logistik	40,662	41,545	5,751	6,634	10,201	7,018	7,901	34,653	41,578	53,408	39,297	24,683	25,951												
TFG Transfracht	12,422	6,014	6,937	7,452	8,283	38,726	7,340	9,608	37,401	25,814	27,139														
Shuttlewise	140,673	128,728	131,943																						
Samskip Van Dieren Multimodal	94,293	140,817																							

Operators/ Routes *	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Roland Spedition	78,207	90,723																							
Rail Cargo Austria	26,615	29,581	31,349	34,316	143,813	138,468	146,780	102,430	157,013																
Novatrans	271,838																								
Neska-Intermodal	325,479	583,406																							
Naviland Cargo	229,787																								
METRANS	52,710	14,474	9,748	7,008	8,083	30,078	57,016	0	16,019	8,553	9,628	12,420													
Mannheimer Container Terminal (MCT)	7,587	7,977	16,832																						
Liege Container Terminal	1,536,585																								
Kombiverkehr	135,943	68,791	22,848	12,760	19,622	42,377	126,643	83,203	73,115	74,061	71,309	-	79,977	102,732	75,589	22,249	23,947	46,701	20,505	47,479	107,834	51,803	52,750	58,666	81,420
Inter Ferry Boats	254,034	293,725	232,463	169,510	175,902	114,640	154,599	238,269	175,315																
IMS	135,539	77,982	79,675	80,618	82,141	11,029	12,722	13,666	10,921	15,189	13,460	15,153	16,096	13,352	17,619	71,346	99,931	72,869	-	-	20,444	47,338	49,768	114,290	
H&S Container Line	501,158	466,872																							
GVT Group of Logistics	367,622																								
Greenmodal	405,000	357,129																							

Operators/ Routes *	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
European Gateway Services	129,117	175,758	101,122	103,317																					
European Cargo Logistics (ECL)	10,964	3,127	7,567																						
Eurogate Intermodal	6,465	7,458	6,402	7,890	8,882	7,827	-	27,749	29,174	6,355	11,458	11,395													
ERS Railways	466,283	47,093	54,320	57,472	64,699	212,503																			
DP World	258,621																								
Distri Rail	414,743	386,368	349,724	321,349	328,986																				
Delcatransport	208,000																								
Danser	168,241	203,316	219,533	159,233	162,689	276,760	271,664	496,293																	
CSKD Intrans	227,195																								
Contargo	43,677	22,102	40,689	-	15,254	16,038	36,830	33,842																	
Bohemiakombi	41,106	149,693																							
Binnenlandse Container Terminals Nederland	416,000	225,568																							
Am Zehnhoff-Söns	466,872	501,158																							
Alcotrans	1,655,832																								

***Each route no. for each operator refer to a specific route**

- **Model Validation**

About the Validity of the model, it should be highlighted that because we did not have the real data we cannot compare the results of the model with it. The findings of application of our model to the EU IFT network about the structure of different IFT submarkets is adapted with the practitioners' impressions, and with limited works about the transshipment markets e.g., Wiegmans et al., (1999). Indeed, our model outcomes do not necessarily represent reality well, and the findings of this chapter need to be interpreted in a conservative way in light of the methodological limitations and assumptions. We claim that, with these assumptions, our model leads to a lower bound, with respect to reality, of market concentration in the EU IFT network.

Chapter 4

Performance Measurement in Freight transport systems

After analyzing the market structure of Intermodal freight transport network in chapters 2 and 3, in this chapter, we will review the literature on the performance measurement of freight transport systems from methodological and application point of view. A systematic literature review about the performance measurement in freight transportation systems has not been carried out yet. In some cases, the performance of a part of the freight transport has been reviewed, but no article reviewed the freight transport system as a whole.

This chapter is an edited version of the article:

Saeedi, H., Behdani, B., Wiegmans, B., & Zuidwijk, R. A, "*Performance Measurement in Freight Transport Systems: A Literature Review*", working paper, https://ssrn.com/abstract=3122275.

4.1. Introduction

Performance measurement is critical for the success of any transport system. It creates an understanding of a system and leads to competitive results. Comprehensive performance measurement is a fundamental tool to achieve organizational goals. Indeed, the main role of performance measurement tool is giving insights into the inefficient processes. It helps a system toward achievement of its goals and provides feedback about the success of organizational strategies. Because of these issues, performance measurement, most of the time, precedes the achievement of strategic goals (Fawcett & Cooper, 1998). There are many definitions for the efficient performance. It can be defined as "How well the resources expended are used" (Kim & Marlow, 2001). Efficient performance means, using minimum inputs when the outputs are fixed, or maximizing the outputs when the inputs are fixed (Ockwell, 2001).

Intermodal freight transport (IFT) as a sustainable and environmentally friendly solution is an interesting alternative for road transport. Policymakers e.g., the European Commission have done considerable investments to increase the market share of the IFT service. To increase the market share, the IFT service should have a better performance. In case different operators together in a freight transport network, they create an integrated IFT chain that is competitive. Such chains may result in higher efficiency and higher market share (Christopher, 2005). To have a better performance, you should first be able to measure the performance of a freight transport system. The review of the literature reveals that a systematic literature review about the performance measurement in freight transportation systems has not been carried out yet. In some cases the performance of a part of the freight transport e.g., public road transport (Jarboui et al., 2012), rail transport (Oum et al., 1999), airports (Barros & Barros, 2009), or sea-ports (Ensslin et al., 2017) has been reviewed, but none of the papers reviewed the freight transport system as a whole. In this chapter, we will review the papers that have been written in the performance measurement of freight transport systems, i.e. methodological papers, and applications to the domain. First, papers are categorized based on the method of performance analysis. Next, the papers are sub-categorized based on the domain, e.g., rail transport, public transport, port, airline, etc. Reviewing each paper, the main question of the paper, the variables e.g., input, output, or intermediate variables, which has been used in modeling, and the main results of the paper will be presented.

The current literature review will be useful for the scholars who would like to do new research in the domain. It could also be used by policy-makers to have an overall view of the performance measurement methods, and the works are done in the freight transport domain. The structure of this chapter is based on the main methods of the efficiency measurement i.e., Partial performance measurement (multiple indicators), Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA). In section 4.2, the main concepts and methodologies about efficiency measurement are explained. Section 4.3 is about the methodology of reviewing the literature. In section 4.4, papers which have used multiple performance indicators (partial efficiency measurement) will be reviewed. Section 4.5 is about the papers which have used stochastic Frontier Analysis. In section 4.6, the papers which have applied Data Envelopment Analysis (DEA) will be reviewed. In section 4.7 the papers applied Network DEA model will be reviewed. Finally, section 4.8 is the conclusion of reviewing the papers.

4.2. Performance Analysis: Concepts and Methodologies

4.2.1. Basic concepts

Two main concepts related to performance measurement are productivity and efficiency (Oum et al., 1999).

Productivity

Productivity means increased output relative to inputs. It can be compared between different firms, or within a firm over time. Different sources e.g., different efficiency levels, economies of scale, or different network characteristics could lead to different productivity levels (Oum et al., 1999).

Technical Efficiency

In Economic theory three types of efficiency are distinguished: Technical, allocative, and cost efficiency (C. Yu, 2016). Scoring a firm performance by comparing it relative to the best practice, shows the technical efficiency level of a firm (C. Yu, 2016). Allocative efficiency is selecting a certain set of inputs to produce a specified set of outputs in the minimum cost. The cost efficiency is the alignment of these two (Assaf & Josiassen, 2012). Standard models can be used to measure the technical efficiency, but productivity is typically estimated in a temporal context using panel data (Graham, 2008).

4.2.2. Basic methodologies

Stochastic Frontier Analysis (SFA)

Stochastic Frontier Analysis (SFA) is a parametric approach, which is used to measure the efficiency of an industry given its input and output data. SFA assumes a priori production/ cost function of the usual regression form and a distribution type of two error items. The first item is symmetric and captures statistical error. It usually has a normal distribution with zero mean. The second item represents technical inefficiency of firms (Lin, 2005). It mostly has a truncated normal distribution with zero mean. Before running the stochastic frontier model, the functional form of the production/ cost function must be chosen in advance. Two kinds of functional forms are mostly used in the SFA literature to model production/ cost function: Cobb-Douglas, and Translog function (Coelli et al., 2005). It is also possible to consider other statistical distributions, e.g., exponential or gamma distribution for inefficiency term. To solve the SFA models, generally, the maximum likelihood estimator is used, but also other methods such as the Bayesian framework, or corrected ordinary least squares (COLS) could also be used (Coelli et al., 2005). A Cobb-Douglas stochastic frontier of production function model of a firm is:

$$\ln \mathrm{q_i} = \beta_0 + \beta_\mathrm{i} \ln \mathrm{x_i} + \mathrm{v_i} - \mathrm{u_i} \tag{1}$$

Where q_i and x_i represent the output and input of the ith firm respectively. v_i is the statistical error, and u_i is a non-negative random variable associated with technical inefficiency.

Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a typical non-parametric approach which is usually used to evaluate the efficiency of a number of firms. It evaluates the efficiency of a firm relative to an average or representative firms (Anderson, 2003). DEA can be easily applied in several different cases and situations. It has also been extended theoretically which has increased its

flexibility, and applicability (Wang & Song, 2003). DEA is assessing the efficiency of an individual firm. This firm is the main unit of analysis and is defined as the Decision Making Unit (DMU). DEA can be used to measure the efficiency of a firm by comparing it with other similar firms. In fact, this similarity of both the inputs and outputs is a fundamental assumption in DEA efficiency measurement.
DEA does not require any assumption about the functional form. It measures the performance of a DMU relative to other DMUs. Each DMU is compared against a convex combination of the other DMUs which are on the frontier (Charnes et al., 1994). A DEA model could be applied in the three-step process (Golany & Roll, 1989):

A) Definition and selection of DMUs in the analysis. In a DEA analysis, all DMUs should perform similar activities with the same technology. It means they should have the same inputs and outputs.
B) Determination of input and output variables. These variables will be used in assessing the efficiency of selected DMUs. (In the Network DEA, intermediate variables should also be determined. Intermediate variable is a variable which is the output of a division in a chain and the input of the other division)
C) Application of the DEA models, and analyzing the results.

After selecting DMUs, It is necessary to choose an appropriate DEA model. This process has two aspects; the first aspect is related to the returns-to-scale assumption, and the other one is related to the model orientation. When the production technology has a constant returns-to-scale, the CCR-Model must be used, and when variable returns-to-scale exists the BCC-Model is suitable. The orientation of the model depends on the aim of the analysis. This aim may have Administrative or Policy aspect. From the administrative perspective, reducing the costs is more important, so they often prefer input-oriented models. Occasionally, inputs are fixed in the short run, and in some case, are financed by taxpayers. The policy-makers, in general, looking for maximum outputs, so the output-oriented models are more suitable for them (Stough, 2015). In the following, we will present an input-oriented model. Suppose we have n DMUs where each DMU_j, $j = 1,2, \dots, n$, uses m different inputs x_{ij} $(i = 1,2, \dots, m)$ to produce the same s outputs y_{rj} $(r = 1,2, \dots, s)$ in different amounts. The input-oriented variable return to scale DEA model (also called the BCC-model) to calculate the technical efficiency of DMU_0 can be formulated as a linear programming (Banker et al., 1984):

$$\mathrm{Min}_{\theta,\gamma}\ \theta \tag{2}$$

$s.t.$

$$\sum_{j=1}^{n} \gamma_j x_{ij} \leq \theta x_{io}\ , \quad i = 1, \dots, m \tag{3}$$

$$\sum_{j=1}^{n} \gamma_j y_{rj} \geq y_{ro}\ , \quad r = 1, \dots, s \tag{4}$$

$$\gamma_j \geq 0 \tag{5}$$

$$\sum \gamma_j = 1 \tag{6}$$

Where X_0 and Y_0 are the inputs and outputs of DMU_0, the vector γ describes the components of other units. X and Y are Input and output matrices and θ is efficiency measure. In other words, a firm is technically efficient when input usage (costs) cannot be decreased without decreasing the output (Anderson et al., 2002). Equation (6) ensures that the economies of scale is taken into account when comparing different DMUs with different sizes (Cooper et al., 2007).

Therefore, the basic assumption in the BCC model is that the increase in the inputs does not result in a proportional increase in the output (or there is variable return to scale). On the contrary, in the constant return to scale model (CCR-model), the increase in the inputs will result in a proportional increase in the output. Therefore the point with the highest return to scale (i.e. point B in Figure.4.1) is the reference point for the efficiency measurement.

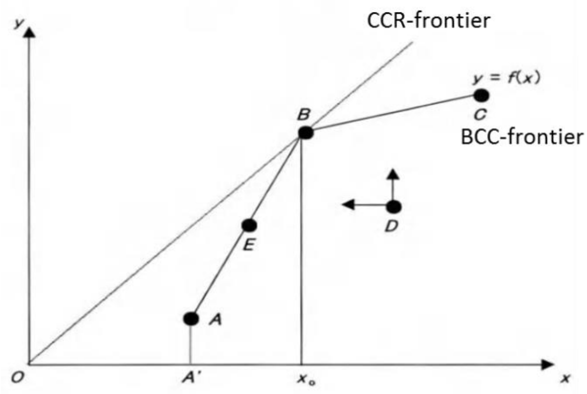

Figure 4.1. Piecewise best-practice production frontier

Now consider a simple numerical example where we have five DMUs (manufacturing companies). All the DMUs have the same profit of $ 3,000 with a different combination of cost and response time.

TABLE 4.1 . Numerical example data

DMU	cost (1000$)	Response time (week)	Profit (1000$)
1	1	5	3
2	2	2	3
3	4	1	3
4	6	1	3
5	4	4	3

The piecewise linear frontier of these DMUs is presented in Figure 4.2. Running simple DEA model we can find that DMUs 1, 2, 3, and 4 are on the frontier. However, as can be seen in Figure 4.2, DMU4 can still reduce its total cost by $ 200 to reach DMU3. This input reduction is called input slack, and DMU4 is called weakly efficient. In fact, both input and output slacks may exist in the set (Zhu, 2003).

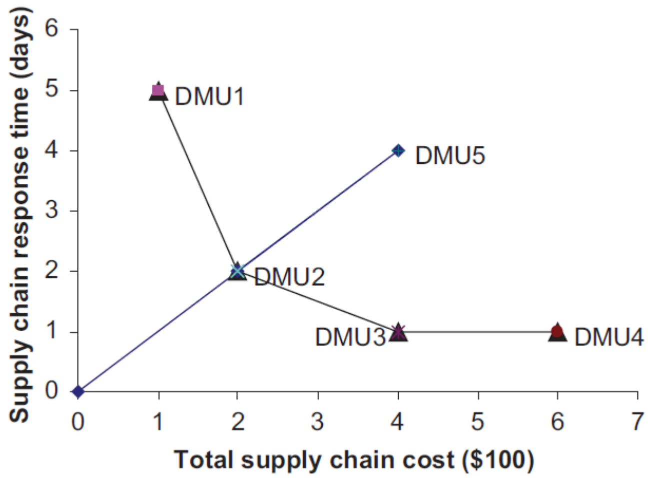

Figure 4.2. Different 5 DMUs' production technology

CCR- and BCC-DEA models do not take into account the existence of these input and output slacks. To capture these drawbacks effectively another type of the DEA models were developed which are called slacks-based models (SBM). SBM deals with the input excesses, or output shortfalls and gives a scalar measure ranging from 0 to 1 that includes all of the inefficiencies. The input-oriented SBM can be formulated as below(Cooper et al., 2007):

$$\min \rho = 1 - \frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{io} \tag{7}$$

$s.t.$

$$\sum_{j=1}^{n} \gamma_j x_{ij} + s_i^- = x_{io} \quad , \quad i = 1, \dots, m \tag{8}$$

$$\sum_{j=1}^{n} \gamma_j y_{rj} - s_r^+ = y_{ro} \ , \ r = 1, \dots, s \tag{9}$$

Where s_i^- and s_r^+ are input and output slacks respectively.
One of the developments in DEA models is about techniques which are post DEA analysis to fully rank all the DMUs. In the next sub-sections this direction of development in DEA modeling will be described:

Bootstrapped DEA

The main drawback of the DEA model is that it is a deterministic model which estimated coefficients don't have statistical properties, so it is impossible to make any statistical inference or establish hypothesis contrasts from it (Jorge & Suarez, 2003). To overcome this disadvantage, Simar & Wilson (2000) and (1998)), Hall & Simar (2009), Simar (2007) developed a stochastic version of DEA measures that improve the performance of the standard DEA measures in the presence of noise. These models which are called Bootstrapped Data envelopment (BDEA) models have been applied in the transport domain as well.

Post- DEA Analysis

The basic DEA divides the DMUs into two sets, efficient and inefficient ones (Mehrabian & Jahanshahloo, 1999). Mostly decision-makers -to improve the evaluation of the DMUs- are interested in a complete ranking. In order to rank all the DMUs, other approaches are required. Over the last two decades, many papers have been published in the DEA context, which have developed new methods to fully rank the DMUs (Mehrabian et al., 1999). These methods are considered as post-DEA analyses since they only add value to the standard DEA models not replacing it. Jiang et al.(2011) present a new method to calculate the efficiency with some developments in DEA model. In their paper, after defining the strongly efficient and inefficient frontiers concepts, different models are presented to calculate different distances between DMUs and frontiers. Jahanshahloo and Afzalinejad (2006) suggest a full-inefficient frontier ranking method and compared all DMUs against it. He uses his model to make a distinction between efficient DMUs. Adler et al (2002) have divided post-DEA analysis methods into 6 categories. In the following we will review these categories:

Cross-efficiency ranking methods

The cross-efficiency method computes the efficiency of each DMU several times, using the multiplications (weights) reached by the different linear combination of DMUs. The existence of different optimal multiplications creates considerable practical limitations to use the cross-efficiency method (Adler et al., 2002). Some researchers, e.g., Doyle and Green (1994), Cook and Zhu (2014) tried to expand the standard cross-efficiency model to obtain unique results.

Super-efficiency ranking methods

In super-efficiency methods to create a reference set, the DMU which its efficiency is evaluated not considered in the set. Thus, for extreme efficient units, the efficiency score shall be greater than one. Super efficiency methods have some problems. For example, they can give extremely high efficiency scores to some DMUs, which could lead to an infeasible solution (Adler et al., 2002). Some papers, e.g., Sueyoshi and Toshiyuki (1999), and Mehrabian et al.(1999) did some revisions in the approach to ensure feasibility.

Benchmark ranking method

In this method, the Efficient DMUs are ranked based on their importance as a benchmark for the other DMUs (Jahanshahloo & Afzalinejad, 2006).

The other Post-DEA methods are ranking with multivariate statistics in the DEA context, the ranking of inefficient decision-making units, and DEA and multi-criteria decision-making methods. In recent years, this problem is still an interesting issue for researchers in the DEA modeling domain. These developed post-DEA analyses aid DEA models to be implemented more by increasing their discrimination power to fully rank all the DMUs.

Network DEA

Traditional data envelopment analysis (DEA) because of the existence of the intermediate products/ services connecting different divisions of a chain could not be used directly for measuring the performance of a chain and its members. On the other words, they cannot capture the impact of division-specific inefficiencies on the overall efficiency of a chain (Tone & Tsutsui, 2009). Intermediate product/ service is a product/ service which is the output of a division of the chain and at the same time the input of the next division. Traditional DEA models only consider input and output variables. It means they behave a multidivisional chain as a black-box and will miss all the intermediate measures. This could result in misleading efficiency levels (Tone & Tsutsui, 2009).

Assume a two-division transport chain (Figure 4.3), where X_A and Y_A are the input and output vectors of the operator A. Y_A is also an input vector of the operator B, beside the X_B vector. Y_B is the operator B's output vector. Suppose there are n such transport chains.

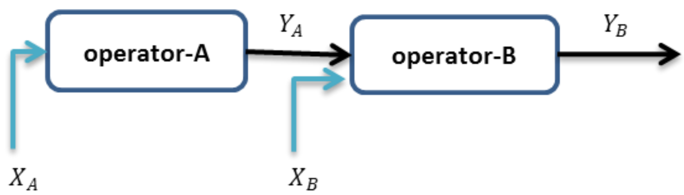

Figure 4.3. Two-division Transport Chain

The radial input-oriented Network DEA efficiency of the transport chain is measured as:

$$\text{Min } w_A\theta_A{}^{*} + w_B\theta_B{}^{*} \tag{10}$$

$$\sum_j \gamma_j x_{ij}^A \le \theta_A x_{io}^A \quad i = 1,2, \ \dots, \ m \tag{11}$$

$$\sum_j \gamma_j y_{rj}^A \ge y_{ro}^A \quad , r = 1,2, \ \dots, \ s \tag{12}$$

$$\sum_j \delta_j y_{ij}^A \le y_{io}^A \quad , i = 1,2, \ \dots, \ m \tag{13}$$

$$\sum_j \delta_j x_{ij}^B \le \theta_B x_{io}^B \quad , i = 1,2, \ \dots, \ m \tag{14}$$

$$\sum_j \delta_j y_{rj}^B \ge y_{ro}^B \quad , r = 1,2, \ \dots, \ s \tag{15}$$

Where, w_A and w_B are the weights (e.g., the cost share) of operators A and B, θ_A is the efficiency measure of operators A, and θ_B is the efficiency measure of operators B, and the vectors γ and δ describe the components of other operators in other transport chains respectively.
Tone and Tsutsui (2009) extend the slacks concepts in Network DEA models and developed a slacks-based network DEA model. This model from one side like simple SBM models deals with the input excesses, or output shortfalls, and from the other side, like Network DEA models, deals with intermediate products formally.

Route-based NDEA
In practice, different transport operators (e.g., different shipping companies or airlines) may operate in different routes. Some of the routes can be efficient, and on some of them inefficient. Thus, a company-level analysis may lead to a different operational benchmark. To avoid such a heterogeneity, Some studies have used the specific type of the NDEA models which is called "Route-based NDEA" to evaluate the performance of transport operators (Yu & Chen, 2016).

Dynamic NDEA
Dynamic network DEA (DNDEA) measures the efficiencies of a system and its internal processes by capturing multi-period activities, dealing with carry-overs that connect two consecutive periods (Tone & Tsutsui, 2017).

4.3. Literature Review Methodology

For this chapter, we used the review methodology as presented by Van Wee and Banister (2016).

4.3.1. Paper selection criteria

We conducted a literature search using the Scopus database. The following keywords were used to find scientific papers: “performance”, “efficiency” “productivity”, “data envelopment analysis”, and “stochastic frontier analysis”. By using “Freight transport*”, “railway”, “inland waterway”, “port”, “maritime”, and “short sea shipping” keywords, we insured that the results are within the freight transportation domain. Because the number of the papers was limited, we extended the search by searching the papers in the “airport”, “airlines”, and “public transport” domains. The literature about the airport and airlines was chosen because part of the freight is transported by air service. We also reviewed the public transport literature, because characteristics of public transport networks have similarities with the rail freight transport networks. The search was limited to papers published between 2000-2017. Then we excluded all conference papers, books, reviews, notes, and chapter books. All the papers were then scanned to exclude the irrelevant articles. Further sources were identified by searching reference lists, called the “backward snowballing” strategy (Wee & Banister, 2016). Figure 4.4 shows the scheme of the paper selection.

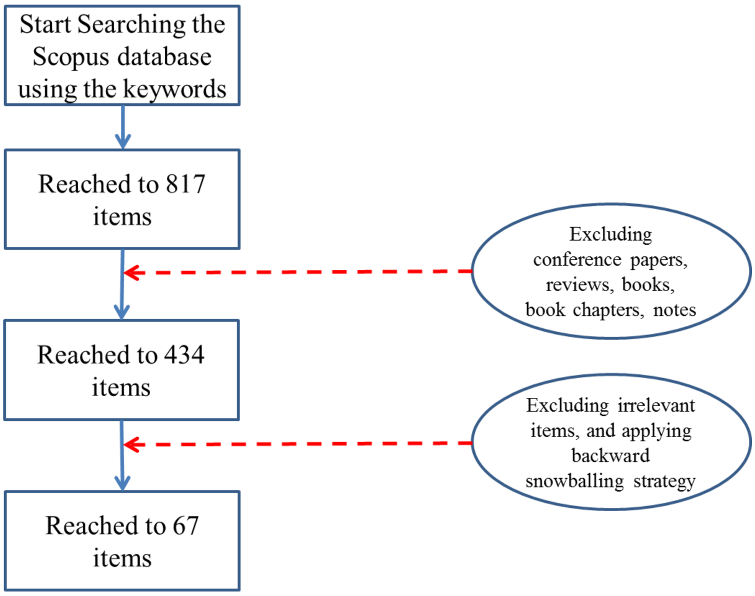

Figure 4.4. Paper selection Scheme

4.3.2. Paper classification and analysis

In this chapter, we use different criteria to classify the papers. First, they are categorized based on the adopted approach to measure efficiency. Then, they are clustered on the basis of the application in different domains, input/ output variables, year of publication, the period that the investigation has done, the functional form (for papers used stochastic frontier analysis), and the main findings.

4.4. Partial performance measurement (Multiple Indicators)

The simple and straightforward approach to measure the efficiency is the use of multiple performance indicators (partial performance measures). Isoraite (2005) developed a step-wise approach to define meaningful transport indicators. He believes that the performance indicators should be defined from a top-down strategic perspective. He also mentions the disadvantage of multiple indicators.

4.4.1. Railway systems

Wiegmans and Donders (2007) measure the efficiency of large rail operators in EU by defining partial efficiency indicators and comparing with the best practice benchmarks. Some of the performance indicators they used are tons/employee, sales/employee, employees/locomotive, sales/ton, and sales/ton-km. Hilmola (2007) studied the efficiency of European railways using 8 different partial efficiency indices. He has compared the results of partial efficiency analysis with the results of DEA model. Oum et al.(1999) present a list of indicators for rail efficiency measurement.

4.4.2. Inland waterways

Caris et al. (2011) analyzed alternative bundling strategies for container barge transport in the port of Antwerp. They used average and maximum waiting times, and average turnaround time at the port of Antwerp as performance indicators of the barge transport.

4.4.3. Ports & Terminals

Cullinane & Wang (2005) using a list of performance indicators suggested by UNCTAD in 1976 to measure the performance of the ports. These indicators are in two categories: Financial indicators, e.g., labor expenditure, and Operational indicators e.g., waiting time, service time, and tons per ship-hour in port. Tongzon (2006) introduced a quantitative approach to classify and compare the ports based on the principal component analysis. He decreased the number of quantitative measures and presented six measures to classify and compare the ports. There are other works which have presented or measured the port performance by using partial multiple performance indicators, e.g., Fourgeaud (2000), Ensslin et al.(2017), and Bichou (2013).

4.4.4. Maritime transport

Valdez Banda et al. (2016) identified 53 key performance indicators for monitoring and reviewing the functioning of maritime safety management systems.

4.4.5. Public Transport

Devaraj et al. (2016) measured the performance of bus services of Bangalore metropolitan considering different operational and financial indicators. The indicators are Vehicle utilization, Fleet utilization, Staff per schedule, Staff productivity, Breakdown rate, Accident rate, Fuel efficiency, Total revenue, Total earnings, and Total cost. These indicators are benchmarked by considering the best performing units as the target. They also compare the results of this partial efficiency measures with DEA model.

4.4.6. Airports

Bezerra and Gomes (2016) reviewed the literature on the performance measurements of the airports. He has prepared a list of the indicators used in the literature in different dimensions, i.e., Service quality, Safety, Security, Commercial, Economic/ financial, Environmental, Social, and Competitiveness.

4.4.7. Airlines

Dincer et al. (2017) evaluate the performance of the European airlines, using a balanced scorecard perspective. In their multi-criteria approach, they use different indicators. Their findings show that airline with the largest profit and the highest number of passengers and flights has the better performance.

TABLE 4.2 . Papers used multiple performance indicators to measure the efficiency

No	paper	Performance Indicators	Area	Period
Railway systems				
1	Wiegmans et al., (2007)	▪ Tons/employee ▪ Sales/employee ▪ Employees/locomotive ▪ Sales/ton ▪ Sales/ton-km	EU	-
2	Hilmola (2007)	▪ Ton-km/ wagons ▪ Ton-km/ staff ▪ Ton-km/ locomotives ▪ Ton-km/ tracks (km) ▪ Tons/ wagons ▪ Tons/ staff ▪ Tons/ locomotives ▪ Tons/ tracks (km)	EU	1980-2003
Ports & Terminals				
3	Fourgeaud (2000)	▪ Average cargo dwelling time ▪ Average waiting time of a trailer ▪ Ratio loaded vs. unloaded containers ▪ Unproductive moves, i.e., the handling of all the containers that do not have to be unloaded but have to be moved ▪ Level of automation of the gantry-cranes ▪ Average weight of containers ▪ Commercial constraints	-	-
4	Tongzon (2006)	▪ Total throughput ▪ Number of commercial ship visits ▪ Vessel size and cargo exchange ▪ Nature and role of the port ▪ Port functions ▪ Infrastructure provided	worldwide	1991
5	Bichou (2013)	▪ Operating ratio ▪ Operating surplus ▪ Return on investment (ROI) ▪ Return on assets (ROA) ▪ Return on equity (ROE) ▪ Capital and labor expenditures per handled ship or cargo unit ▪ Berth occupancy per cargo-ton ▪ Handling revenues per cargo-ton	-	-

Maritime transport				
6	Valdez Banda et al. (2016)	▪ Number of reviews to the safety and environmental policy in a year ▪ Percentage of the assigned personnel per shift, available to perform safety operations ▪ How many ships must be assigned to a person working full time with ISM matters ▪ Percentage of the safety programmers performed in a year (plan vs. real) ▪ Number of fires reported in a year (complete fleet) ▪ Etc.,	-	-
Public Transport				
7	Devaraj et al. (2016)	▪ Vehicle utilization ▪ Fleet utilization ▪ Staff per schedule ▪ Staff productivity ▪ Breakdown rate ▪ Accident rate ▪ Fuel efficiency ▪ Total revenue ▪ Total earnings ▪ Total cost	Bangalore metropolitan	2011-2012
Airports				
8	Bezerra and Gomes (2016)	▪ Air traffic movements; ▪ Passengers; ▪ Cargo; ▪ Workload unit; ▪ Aeronautical revenue; ▪ Operating revenue; ▪ Number of employees; ▪ Labor cost; ▪ Operating cost ▪ Waiting times ▪ Processing times ▪ Accidents; ▪ Number of reported security breaches ▪ Parking turnover rate, ▪ Cash flow ▪ Number of destinations (non-stop); ▪ etc.	worldwide	1970-2015

Airlines				
9	Dincer et al. (2017)	▪ Profit per Customer ▪ The Number of Passengers/Number of Seats ▪ Increasing Customer Retention and Loyalty ▪ ROE ▪ ROA ▪ Growth in Profit Debt Ratio ▪ Current Ratio Flying on Time ▪ Sales Performance ▪ Number of Accidents ▪ Flights/Number of Employees ▪ Number of Flights/Number of Fleets ▪ Number of Passengers/Number of Employees ▪ Staff Turnover Rate (Number of Employees) ▪ Increase in Number of Planes ▪ Profit per Employee	EU	-

The main disadvantage of partial performance (multiple indicators) analysis is difficulty to evaluate the performance improvement, in the cases when some indicators show improvement, and the rest not (Lu & Wang, 2017). To overcome this problem, Total Performance analysis was developed, which is defined as a measure of total output per unit of the input (Windle & Dresner, 1992). For example, Talley(1994) presents an overall performance indicator to measure the performance of the ports. This indicator which is a weighted summation of multiple performance indicators is useful when changes in these indicators have opposite effects on port performance. The most commonly used models to do total performance analysis are Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA) which are described in the following sections. In the next two sections, the application of these models to the freight transport domain will be reviewed.

4.5. Stochastic Frontier Analysis (SFA)

The SFA model has been vastly applied in the transport domain to measure the efficiency of different transportation systems. In the following, we will review this literature. It should be noted that we did not find any paper applying SFA in the Inland waterways sub-domain.

4.5.1. Railway systems

Cheristopoulos & Tsionas (2001), based on the SFA, identify the sources of inefficiency and provide guidelines to improve the efficiency of the European railways. He used McFadden flexible functional form to represent the cost structure of railway systems in ten countries of the European Union for the period 1969-1992. In his model, total traffic units is the output, and interest and depreciation costs, Capital prices, number of employees, Labor costs, and energy cost are input explanatory variables. He concluded that Greece, Portugal, and Italy should use capital resources in railways more efficiently. Portugal and Denmark railway systems are both energy inefficient. However, efficient use of labor is a major problem in Portugal. De Jorge & Suarez (2003) Based on 19 European railway companies data, measured the efficiency of European railways during 1965-1998, using stochastic frontier Analysis. They used two different functional forms: factor requirement and quadratic production functions. In their model, which consider freight and passenger transport, passengers and line lengths (km) are outputs, and labor cost, electrification percentage, and percentage of lengths of double lines as inputs. Sànchez and Villarroya (2000) measured the levels of efficiency of 15 European railway companies between 1970-1990, by estimating the stochastic cost frontier function. In their paper, operation costs including labor cost, energy cost, material cost, purchases, and external services are considered as independent (input) variables and passenger train-km and freight train-km as outputs. Their findings show that companies with a greater degree of financial and management independence are more cost efficient. Lan & Lin (2006) examine 39 worldwide railway systems over eight years (1995–2002) to measure their technical inefficiency, using a stochastic input distance function. In their paper, inputs are number of passenger cars, number of freight cars, and number of employees, while outputs of production step are passenger train-kilometers and freight train-kilometers. They used these outputs as inputs for the consumption step. The consumption-step outputs contain passenger-kilometers and ton-kilometers. Their findings show that railways' inefficiency is negatively influenced by GDP, the percentage of electrified lines, and line density. They also found that, in general, the railways in West Europe are more efficient than those in East Europe and Non-European regions. Other works e.g., Gathon and Perelman (1999), and Coelli and Perelman (1996) have also used SFA model to measure the efficiency of European Railways.

4.5.2. Ports &Terminals

Cullinane & Song (2006) estimate the efficiency of 74 European container ports using SFA model. They use log-linear Cobb-Douglas as the functional form of the production function. Their findings show that size of a port or terminal is closely correlated with its efficiency. Geographical location and below average size can explain the low efficiency of the Scandinavian and Eastern European container terminals. Estache et al. (2002) apply SFA model with Cobb-Douglas and Translog production function to measure the efficiencies of Mexico container ports during 1996 to 1999. Their findings show that better managing the port infrastructure can generate short-term improvements in the average performance of the sector. Cullinane, et al. (2002) uses the SFA method to estimate the efficiency of 15 major container ports in Asia between 1989 and 1998. Their findings show that the size of a port is closely correlated with its efficiency. They also found that changing the ownership from public to the private sector could improve the efficiency. Coto-Millan et al. (2000) applied SFA to study the economic efficiency of Spanish ports using panel data of 27 Spanish ports from 1985 to 1989. They found that translog production function better represents the technology according to the data. They used the dependent variable of total cost and the independent variables of labor, capital, and intermediate consumptions. In contrast to previous findings, their findings show that larger ports were more inefficient.

4.5.3. Maritime transport

Panayides et al. (2011) examine the relative market efficiency and operating performance efficiency of 26 major international maritime firms in dry, wet and container shipping sectors using stochastic frontier analysis. Their findings show that Tanker companies are more market efficient, while container shipping firms have high efficiency but were market inefficient. Dry bulk firms were found to have the lowest market efficiency.

4.5.4. Public transport

Jarboui et al. (2013), (2014a), (2014b) have measured the technical efficiency of different public transport operators in 18 countries using Stochastic frontier analysis (SFA) method. They have used twelve years data to see which factors influence efficiency levels of these operators. They used a translog production function in which total operating costs and number of employees are independent inputs, and revenue is output. Jarboui et al. (2012) did a literature review about the public road transport efficiency between 2000-2011. Their findings show that number of employees, and operating costs are appropriate and most-used variables as inputs in the models.

4.5.5. Airports

SFA has been used to measure the efficiency of the airports as well. Oum et al.(2008) studied the effects of different ownership forms on airports' cost efficiency. They have applied stochastic frontier analysis to 109 airports around the world. Their findings show that airports owned or controlled by private firms are more efficient than those owned and/or controlled by the government. Barros & Barros (2009) studied the efficiency of 27 UK airports using latent stochastic frontier model and ranked the airports according to their cost frontier for the period 2000–2006. Their model takes into account the heterogeneity in airports. His finding shows that airports should be analyzed in relatively homogenous benchmarks. Martin et al. (2009) evaluate the efficiency of the 37 Spanish airports using stochastic SFA model. Their findings show a significant level of inefficiency in airport operations. Different distributional assumptions on the error component do not have any effect on the inefficiency level of the airports. Scotti et al. (2012) investigate how the competition between airports can affect their efficiency. Their findings show increasing the competition degree has a negative effect on Italy's airports from 2005 to 2008.

4.5.6. Airlines

Assaf and Josiassen (2012) measure the efficiency of 31 European and U.S. airlines using baysian distance frontier SFA model. Their findings show that European airlines have slightly higher efficiency than U.S. airlines. In addition, the low-cost airlines are on average more productive and efficient than full-service airlines.

TABLE 4.3 . Papers Used Stochastic Frontier Analysis (SFA) To Measure The Efficiency

No	paper	Variables	Functional form	Area	Period
Railway systems					
1	Coelli and Perelman (1996)	Inputs: ▪ Staff number ▪ Energy consumption ▪ Lines length (km) Outputs: ▪ Passenger-km ▪ Tonnes-km	Translog distance function	EU	1979- 1983
2	Gathon and Perelman (1999)	Inputs: ▪ Passenger train-km ▪ Freight train-km ▪ Length of lines ▪ Passenger and freight mean distance ▪ Passenger and freight load factor ▪ Electrification percentage Output: ▪ Labor	Factor requirement function	EU	1961-1988

3	Sanchez & Villarroya (2000)	Inputs: ▪ Labor cost ▪ Energy cost ▪ Material cost ▪ Purchases ▪ External services Outputs: ▪ Passenger train-km ▪ Freight train-km	Translog function	EU	1970-1990
4	Christopoulos et al. (2001)	Input: ▪ Interest depreciation costs ▪ Capital prices ▪ Number of employees ▪ Labor costs ▪ Energy cost Output: ▪ Total traffic units	McFadden flexible cost function	EU	1969-1992
5	Jorge & Suarez (2003)	Inputs: ▪ Labor cost ▪ Electrification percentage ▪ Percentage of lengths of double lines Outputs: ▪ Passengers ▪ Line lengths (km)	Factor requirement and quadratic production functions	EU	1965-1998
6	Lan & Lin (2006)	Inputs: ▪ Number of passenger cars ▪ Number of freight cars ▪ Number of employees Outputs ▪ Passenger train-kilometers ▪ Freight train-kilometers	Stochastic input distance function	world wide	1995–2002
Public transport					
7	Jarboui et al (2013)	Inputs: ▪ Total operating costs ▪ Number of employees Output: ▪ Revenue	Translog production function	world wide	2000- 2011
8	Jarboui et al (2014a)	Inputs: ▪ Total operating costs ▪ Number of employees Output: ▪ Revenue	Translog production function	world wide	2000- 2011
9	Jarboui et al (2014b)	Inputs: ▪ Total operating costs ▪ Number of employees Output: ▪ Revenue	Translog production function	world wide	2000- 2011
Ports &Terminals					
10	Coto-Millan et al. (2000)	Inputs: ▪ Unit employee cost ▪ Unit depreciation of quays ▪ Consumption per port activity (tons) Output: ▪ Total cost	Translog cost function	Spain	1985-1989

11	Estache et al.(2002)	Inputs: ▪ Number of workers ▪ Length of docks Output: ▪ Handling volume (tons)	Cobb-Douglas and Translog production function	Mexico	1996–1999
12	Cullinane, et al. (2002)	Inputs: ▪ Terminal quay length ▪ Terminal area in hectares ▪ Number of cargo handling equipment Output: ▪ Annual throughput (TEU)	Log-linear Cobb–Douglas production function	Asia	1989- 1998
13	Cullinane & Song (2006)	Inputs: ▪ Quay length (m) ▪ Terminal area ▪ Number of pieces of cargo handling equipment Outputs: ▪ Container throughput (TEU)	Log-linear Cobb-Douglas production function	EU	2002
Maritime transport					
14	Panayides et al. (2011)	Inputs: ▪ Inputs profits ▪ Book value of equity ▪ Total assets ▪ Number of employees ▪ Capital expenditure Output: ▪ Market value of equity ▪ Sales	Log-Log Cobb–Douglas production function	Worldwide	2008
Airports					
15	Oum et al. (2008)	Inputs: ▪ Number of employees, ▪ Non-labor variable cost, ▪ Number of runways, ▪ Terminal size Outputs: ▪ Number of passengers, ▪ Number of aircraft movements, ▪ Non-aeronautical revenue	Translog cost function	world wide	2001-2004
16	Barros and Barros (2009)	Inputs: ▪ Unit employee cost ▪ Price of capital-premises ▪ Price of capital- investment ▪ Number of passengers ▪ Aircraft movements Outputs: ▪ Operational cost	Translog cost function	UK	2000–2006

17	Martin et al (2009)	Inputs: ▪ Unit employee cost ▪ Price of capital (total cost per passenger) ▪ Price of materials (total cost per ton) Outputs: ▪ Operational cost	Translog cost function	Spain	1991–1997
18	Scotti et al.(2012)	Inputs: ▪ Maximum number of authorized flights per hour ▪ Number of aircraft parking positions ▪ Terminal surface area ▪ Number of check-in desks ▪ Number of baggage claims Outputs: ▪ Numbers of aircraft ▪ Numbers of passengers ▪ Volume of freight	Translog distance function	Italy	2005- 2008
Airlines					
19	Assaf and Josiassen (2012)	Inputs: ▪ Number of employees ▪ Number of planes ▪ Load factor Outputs: ▪ Incidental revenues ▪ Passenger service measured	Translog production function	US & EU	2001- 2008

However, SFA models have some disadvantages. In advance selection of the functional form is a big challenge. Moreover, the efficiency scores are sensitive to distributional assumptions on the error terms, and the model requires large samples to be robust (Martín et al., 2009). DEA is an approach that has been developed to overcome mentioned disadvantages of SFA model. In the next subsections, the basic model and the advanced development of the model will be presented.

4.6. Data Envelopment Analysis

Data Envelopment Analysis (DEA) and its extensions have been applied in the freight transport domain. In this section, this literature will be reviewed based on the type of the DEA model. It should be noted that we did not find any paper applying DEA in Inland waterways sub-domain.

4.6.1. Railway systems

Hilmola (2007) studied the efficiency of European railways using DEA analysis between 1980-2003. He found that those EU countries, whose companies were showing the highest efficiency levels in the 1980s, experienced an efficiency ‘collapse’ in the 1990s. The productivity of locomotives and railway tracks should be the primary target of productivity improvement in these countries. Cantos et al (1999) analyzed the evolution of productivity in the 17 European railways in the period 1970–95, using a DEA model. Their model breaks the productivity into technical change and differences in efficiency. They found that the productivity is growing in the period 1985–95 when the majority of the companies did reforms. This increase in productivity is mainly due to technical progress. Merkert et al.(2010) applied a BDEA model to a sample of 43 Swedish, German and British rail operators for the year of 2006-2007. Their findings show that transactional factors, e.g., monetary values of transaction costs, are more important in determining technical efficiency than others.

4.6.2. Ports &Terminals

Roll and Hayuth (1993), for the first time, represent a theoretical method to apply the DEA approach to the ports context. Martinez-Budria et al (1999) classified 26 Spanish ports into three groups, namely high, medium and low according to their complexity. After examining the efficiency of these ports by DEA models, the authors conclude that the ports with high complexity are more efficient. Tongzon (2001) uses DEA to analyze the efficiency of 16 international container ports, he found that, based on constant and variable returns to scale assumptions, the ports of Melbourne, Rotterdam, Yokohama, and Osaka are the most inefficient ports in the sample, mainly because of enormous slacks in their container berths, terminal area, and labor inputs. Almawsheki & Shah (2015) measured the technical efficiency of 19 container terminals in the Middle-East region using DEA model. Their findings show that the Jebel Ali, Beirut and Salalah terminals are the most efficient terminals in the region. Barros (2003) evaluates the productivity of the Portuguese seaports using DEA approach during 1990-2000. His findings show that almost all of the ports achieved improvements in technical efficiency during this period. Barros (2006) evaluates the performance of Italian seaports from 2002 to 2003 using DEA model. He concludes that the Italians seaports display relatively high efficiency. Nguyen et al. (2016) applied BDEA model to a sample of the 43 Vietnamese ports. Their findings show that the average mean of efficiency scores for Vietnamese ports is very low. Barros & Managi (2008) analyzed the efficiency of 39 Japanese seaports between 2003-2005, using BDEA model. They first apply a simple DEA model, and then in the second step, bootstrap the DEA scores with a truncated bootstrapped regression to identify efficiency sources. Their findings show the seaports which have adopted hub strategy are on average more efficient than others. Barros et al.(2010a) applied BDEA model to measure the efficiency of 23 African seaports between 2004 and 2006. The results show that Nigerian seaports are the most efficient ones.

4.6.3. Maritime transport

Panayides et al. (2011) examine the relative market efficiency and operating performance efficiency of 26 major international maritime firms in dry, wet and container shipping sectors using data envelopment analysis. Their findings show that Tanker companies are more market efficient, while container shipping firms have high efficiency but were market inefficient. Dry bulk firms were found to have the lowest market efficiency. Hilmola (2013) evaluate the performance of the short sea shipping on one of the highest volume general cargo transportation routes of Finland using data envelopment analysis. Based on their results containers could be carried efficiently either in container ships or even at currently favored RoRo or RoPax ships. Mantalis et al. (2016) have analyzed the efficiency of different Greek shippers using two different class of vessels during the 2007-2011. Their findings show that firms had a downtrend efficiency route.

4.6.4. Public transport

Sow et al. (2016) investigate the efficiencies of different 24 lines of the main public transportation company in Dakar. They first applied CRS and VRS DEA output oriented models. Then using bootstrap approach, they did stochastic bias correction. Their findings show that under both CRS and VRS assumptions, suburban lines are more efficient than the urban ones. Hirschhausen & Cullmann (2010) analyzed the 179 communal public transport bus companies in Germany (1990–2004), using BDEA model. They used number of buses, number of workers, and density as input variables, and bus-km, and seat-km as outputs. Their findings indicate that the structure of the German public bus sectors should be improved.

4.6.5. Airports

Tsui et al. (2014) using BDEA models explain the variations in New Zealand's 11 major airports efficiency between 2010 and 2012. They used two input variables, and three output variables to run slacked-based DEA model. Then, they used six explanatory variables to run a bootstrap regression. Their findings show that the number of efficient airports increased from two airports in 2010 to seven airports in 2012. They also found that four explanatory variables including the airport's hub status, operating hours, ownership, and the Rugby World Cup 2011 are meaningful variables in BDEA model.

4.6.6. Airlines

Barbot et al. (2008) used DEA model to analyze the efficiency of 49 different airlines in Europe, North America, and Australia. Their findings show that low-cost airlines are in overall more efficient than full-service airlines. They also compare the results of DEA with the TFP method. Scheraga (2004) analyzed the efficiency of the 38 airlines for 1990 and 2000.

TABLE 4.4 . Papers Used Data Envelopment Analysis (DEA) To Measure The Efficiency

No	paper	Method	Variables	Functional form	Area	Period
Railway systems						
1	Cantos et al (1999)	DEA	Inputs: ▪ Number of workers, ▪ Consumption of energy, ▪ Number of locomotives ▪ Number of passenger carriages ▪ Number of freight cars ▪ Number of kilometers of track Outputs: ▪ Passenger-km ▪ Tones-km	CCR Input-oriented	EU	1970–1995
2	Hilmola (2007)	DEA	Inputs: ▪ Number of freight wagons ▪ Total track route (kilometers) ▪ Total number of locomotives ▪ Staff Outputs: ▪ Freight-tonne-kilometers ▪ Freight-tons	CCR output-oriented	EU	1980-2003

3	Merkert et al. (2010)	Two-stage Bootstrapped DEA	Inputs: ▪ Operating cost ▪ Staff number ▪ Transaction dedicated staff outputs: ▪ Train-km Explanatory variables in the Tobit regression model: ▪ Vertical separation and type of operation ▪ Competition ▪ Monetary values of transaction costs	BCC input-oriented model	Sweden, Germany, UK	2006-2007
4	Roll and Hayuth (1993)	DEA	Inputs: ▪ Manpower ▪ Capital ▪ Cargo uniformity Outputs: ▪ Throughput ▪ Level of service: ratio of handling time to the total time ▪ Users' satisfaction ▪ Ship Calls	-	EU	-
Ports &Terminals						
5	Martinez-Budria et al. (1999)	DEA	Inputs: ▪ Labour cost ▪ Depreciation charge ▪ Other costs Outputs: ▪ Total cargo movement (ton) ▪ Revenue	BCC input-oriented	Spain	1993-1997
6	Tongzon(2001)	DEA	Inputs: ▪ Number of berths ▪ Number of cranes ▪ Number of tugs ▪ Stevedoring labor ▪ Terminal area outputs: ▪ Throughput (TEU) ▪ Ship working rate (TEU/ h)	CCR & additive input-oriented	world wide	1996-2000
7	Barros (2003)	DEA	Inputs: ▪ Number of workers ▪ Book value of the assets outputs: ▪ Ships ▪ Movement of freight ▪ Gross gauge ▪ Break-bulk cargo ▪ Containerized freight, ▪ Solid bulk ▪ Liquid bulk	BCC input-oriented	Portugal	1990-2000

8	Barros (2006)	DEA	Inputs : ▪ Number of employees ▪ Book value of assets outputs: ▪ Liquid bulk ▪ Dry bulk ▪ Number of ships ▪ Passengers ▪ Number of Containers ▪ Sales	CCR & BCC output-oriented model	Italy	2002-2003
9	Barros & Managi (2008)	Two-stage Bootstrapped DEA	Inputs : ▪ Number of personnel ▪ Number of cranes outputs: ▪ Throughput (TEU) ▪ Number of ships ▪ Tons of bulk	CCR & BCC output-oriented model	Japan	2003-2005
10	Wu & Goh (2010)	Supper-efficient DEA	Inputs: ▪ Terminal area (ha) ▪ Total quay length (m) ▪ No. of pieces of equipment (number of quayside gantries, yard gantries, and straddle carriers) outputs: ▪ No. of containers (TEU)	CCR and BCC output-oriented models	Emerging markets	2005
11	Barros et al. (2010b)	Two-stage Bootstrapped DEA	Inputs : ▪ Depths of berths ▪ Total area ▪ Number of quay cranes ▪ Number of employees outputs: ▪ Number of ships call ▪ Total tons embarked ▪ Total number of containers embarked and disembarked	BCC output-oriented model	Africa	2004-2006
12	Jiang et al. (2011)	Modified DEA	Inputs: ▪ The total area ▪ Container quay length ▪ Storage capacity outputs: ▪ Number of direct calls ▪ Container throughput	CCR & BCC non-oriented model	Asia	2008
13	Almawsheki & Shah (2015)	DEA	Inputs: ▪ Terminal area (ha) ▪ Quay length (m) ▪ Quay crane (no.) ▪ Yard equipment (no.) ▪ Maximum draft (m) outputs: ▪ Throughput (TEU)	CCR input-oriented	Middle-east	2012
14	Nguyen et al. (2016)	Two-stage Bootstrapped DEA	Inputs: ▪ Berth length ▪ Terminal areas ▪ Warehouse capacity ▪ Cargo handling equipment outputs: ▪ Throughput (TEU)	Bootstrapped CCR DEA model	Vietnam	-

Maritime transport						
15	Panayides et al. (2011)	DEA	Inputs: ▪ Inputs profits ▪ Book value of equity ▪ Total assets ▪ Number of employees ▪ Capital expenditure ▪ Output: ▪ Market value of equity ▪ Sales	CCR & BCC input-oriented	World wide	2008
16	Hilmola (2013)	DEA	Inputs: ▪ Lead time ▪ Total costs ▪ Diesel consumption ▪ CO2 emission Outputs: ▪ Transported freight (tons)	Not specified	Finlan d	-
17	Mantalis et al. (2016)	DEA	Inputs: ▪ Total Shareholders' Equity ▪ Total Assets ▪ Capital Expenditure Outputs: ▪ sales	BCC input-oriented	Greec e	2007-2011
Public transport						
18	Hirschhausen & Cullmann (2010)	Two-stage Bootstrapped DEA	Inputs: ▪ Number of buses ▪ Number of workers ▪ Density outputs: ▪ Bus-km ▪ Seat-km	CCR & BCC input-oriented model	Germ any	1990–2004
19	Sow et al. (2016)	Two-stage Bootstrapped DEA	Inputs: ▪ Fuel consumption ▪ Number of buses ▪ Line length outputs: ▪ Total traveled distance ▪ Total collected receipts ▪ Number of passengers	CCR & BCC output-oriented model	Bangl adesh	
Multimodal transport						
20	Dotoli et al. (2016)	Cross-efficient DEA	Inputs: ▪ Total cost ▪ Overall travel time ▪ Level of emissions ▪ Value of Time (VOT) ▪ Quantity of emitted noise outputs: ▪ Mortality rate per accident for each transport mode ▪ Added value of a transport mode for each hour of transport	BCC output-oriented model	EU	Not clarifi ed

Airports						
21	Adler & Berechman (2001)	Super-efficient DEA	Inputs: ▪ Airport charges ▪ Connecting time ▪ Number of passenger terminals ▪ Number of runways ▪ Distance to the nearest city center outputs: ▪ Satisfaction level	BCC input-oriented model	World wide	-
22	Bazargan & Vasigh (2003)	Super-efficient DEA	Inputs: ▪ Operating expenses ▪ Non-operating expenses ▪ Number of runways ▪ Number of gates outputs: ▪ Numbers of passengers ▪ Number of air carrier operations ▪ Number of other operations ▪ Aeronautical revenue ▪ Non-aeronautical revenue ▪ Percentage of on-time operations	CCR input-oriented model	US	1996-2000
23	Tsui et al. (2014)	Two-stage Bootstrapped DEA	Inputs: ▪ Operating expenses ▪ Number of runways ▪ Outputs: ▪ Operating revenues ▪ Air passenger movements ▪ Aircraft traffic movements Explanatory variables in the Tobit regression model: ▪ Population around the airport ▪ Airport hub status ▪ Airport operating hours ▪ Airport ownership ▪ Christchurch earthquakes ▪ Rugby World Cup 2011	VRS Slacks-based input-oriented DEA Simare-Wilson bootstrapping regression	New Zealand	2010-2012

Airlines						
24	Scheraga (2004)	Two-stage Bootstrapped DEA	Inputs: ▪ Available ton-kilometers ▪ Operating cost ▪ Non-flight assets 3 Outputs: ▪ Revenue passenger-kilometers ▪ Non-passenger revenue ton-kilometers Explanatory variables in the Tobit regression model: ▪ Average flight length, ▪ Non-flight assets as a percentage of available ton-kilometers ▪ Passenger revenues as a percentage of total revenues ▪ International passenger revenue kilometers as a percentage of total passenger revenue-kilometers ▪ The percentage of state ownership in the airline	BCC non-oriented model	World wide	1995 & 2000
25	Barbot et al. (2008)	DEA	Inputs: ▪ Labour ▪ Fleet ▪ Fuel Outputs: ▪ ASKs ▪ RPKs ▪ Revenue tonne kilometers (RTKs)	BCC input-oriented model	World wide	2005

4.7. Network Data Envelopment Analysis (NDEA)

Studies on suitable multidivisional supply/ transport chain performance measurement systems are quite limited. Most attention has been paid to the tradeoff or cooperation among the chain members, rather than the efficiency of a chain. As an independent decision maker, each chain member maximizes its own efficiency, without considering other members or the overall chain (Yang, Wu, Liang, Bi, & Wu, 2009). Liang et al. (2006) develop different DEA approaches based on non-linear programming by taking the intermediate measures into account. Yang et al. (2009), try to find the best combination of production systems belong a supply chain with an intermediate product by replacing inefficient supply components under this assumption that a unique decision maker controls all the supply chain. Golany et al. (2006) develop an efficiency measurement framework for systems composed of two subsystems who could share the resources between each other during the vertical integration in order to maximize the total efficiency of the system. Network DEA has also been applied to the freight transport domain, but they only applied multi-activity (-function) NDEA, not the multi-division NDEA. It should be noted that we did not find any paper applying NDEA in Inland waterways sub-domain.

4.7.1. Railway systems

Yu and Lin (2008) use a NDEA model that represents both production and consumption technologies. Their model is applied to 20 selected railways for the year 2002 to estimate passenger and freight efficiency simultaneously. Their findings show that freight service is resource intensive compares to the passenger service. Yu (2008) propose a new performance evaluation framework to include both the un-storable feature of transportation service and the technological differences within a group of 40 global railways in the year 2002, using DEA and multi-activity NDEA models. His findings show that transportation service characteristics have positive effects on the evaluation of performance, and NDEA can give more insight into the process-specific source of the inefficiency.

4.7.2. Ports &Terminals

Bichou (2011) applied a DEA model to capture the transformational process within the container-terminal system, and across its sub-systems. He found the existence of disproportionate performances and efficiency levels between container-terminal operating sites and sub-processes.

4.7.3. Maritime transport

Omrani and Keshavarz (2016) measure the efficiency of an international shipping company in Iran with relevant sub-processes in the period 2008–2011 using Network DEA model. Their results show that in no year the shipping company has been efficient. The maximum efficiency has been experienced in the year 2010.

4.7.4. Public transport

Sheth et al. (2007) apply network DEA to bus routes. The service along a bus route is presented by a network, and the efficiency of service provided along the bus route is assessed from providers' and customers' perspectives. They aimed to provide a tool for decision-makers to improve the performance of the network as a whole. Yu (2008) used NDEA to determine the efficiency of different multi-mode transit firms. Highway Bus (HB) service and Urban Bus (UB) service are considered as main processes. The output of the HB process is vehicles-km and the output of the UB process is the frequency of service. They use different inputs which one of them (number of mechanics) is shared between them. He found that there are different optimal scale sizes for HB and UB services in the Taipei. Chiou et al. (2012) have done an empirical study of 37 Taiwanese intercity bus companies operating on 1035 routes. In order to do that, they have developed a Route-based DEA (RDEA) model that decomposes the company-level efficiency into route-level efficiency measures, by optimizing the allocation of common inputs at the same time. Yu et al. (2016) developed a DNDEA model which consider carry-over items among periods in the model. They have applied their model to 20 bus transit firms in Taiwan for the period 2004–2012. Their finding shows that none of the bus transit firms was operationally effective.

4.7.5. Airports

Lozano et al. (2013) apply a NDEA approach to model and benchmark Spanish airport operations in 2008. Their model takes into account undesirable outputs as well. They compare the results with the simple DEA and found that NDEA has more discriminatory power. Liu (2016) evaluates the performance of 10 East Asia airport companies from 2009 to 2013 using Network Data Envelopment Analysis (NDEA). They found that non-aeronautical revenues and service quality have significant and positive influences on commercial service efficiency. Maghbouli et al.(2014) applied NDEA to measure the efficiency of the airports in Spain. In their model, they have considered two undesirable intermediate measures. They have considered both non-cooperative and cooperative game approaches to see how weak disposability assumption could influence the two-stage network.

4.7.6. Airlines

Lozano and Gutierrez (2014) present a slacks-based two-step DEA approach to assess the airlines' efficiency. They apply their model to the 16 European airlines. The findings show that only 6 airlines are totally efficient, and a few others are partially efficient. They also compare the results with those of the corresponding conventional DEA model.

Zhu (2011) presented a two-stage NDEA model by considering the internal structure of airline companies to calculate the overall and stage efficiency. In the first stage, resources such as fuel cost, benefit, and other factors are used to maintain the load factor and fleet size, which generate revenue in the second stage. He applied his model to study the performance of 21 airlines during 2007 and 2008. Freight revenue was not considered as the final output, because of the lack of data. Chiou and Chen (2006) employ a route-based DEA model to evaluate the performance of the 15 routes operated by a Taiwanese domestic airline. In their model, there are two sub-systems: production and consumption sub-systems. Omrani & Soltanzadeh (2016) measured the efficiency of 8 Iranian airlines in three periods from 2010 to 2012 using DNEA model. Their findings show that the efficiency scores calculated from the DNDEA model are larger than that calculated from the NDEA one.

TABLE 4.5 . Papers Used Network Data Envelopment Analysis (NDEA) To Measure The Efficiency

No	paper	Method	Variables	Functional form	Area	Period
Railway systems						
1	Yu & Lin (2008)	Network DEA	Inputs: ▪ Number of employees ▪ Length of lines ▪ Number of freight (passenger) cars Intermediate: ▪ Freight (passenger) train-km outputs: ▪ Ton-km ▪ Passenger-km	Input-oriented NDEA model	Worldwide	2002
2	Yu (2008)	Network DEA	Inputs: ▪ Length of line ▪ Number of passenger cars ▪ Number of freight cars ▪ Number of employees Intermediate: ▪ Passenger–train–kilometers ▪ Freight–train–kilometers associated Outputs: ▪ Ton-km ▪ Passenger-km	Input-output oriented NDEA model	Worldwide	2002
Maritime transport						
3	Omrani and Keshavarz (2016)	Network DEA	Inputs: ▪ Ship purchase cost ▪ Crew cost ▪ Costs of spare parts, provisions, insurance, etc. ▪ Costs of repairs (voyage + dry dock) ▪ Commercial container operation cost + other costs ▪ Commercial passenger operation cost + other costs	CCR output oriented NDEA	Iran	2008-2011

No	paper	Method	Variables	Functional form	Area	Period
			Intermediates: ▪ Lease + purchasing (by installments) ▪ Ship manning cost ▪ Supply of spares & provisions plus 3% overhead ▪ Total available days per year (on-hire days) ▪ Time charter to service provider (container) ▪ Time charter to service provider (passenger) ▪ No. of containers carried per year ▪ No. of passenger + cars carried per year outputs: ▪ Net income			
			Airlines			
4	Chiou and Chen (2006)	Route-based DEA (RDEA)	Inputs: ▪ Fuel cost ▪ Personnel cost ▪ Aircraft cost Intermediates: ▪ Number of flights ▪ Seat-mile outputs: ▪ Passenger-mile ▪ Embarkation passengers	CCR & BCC input-oriented NDEA	Taiwan	2001
5	Zhu (2011)	Network DEA	Inputs: ▪ Cost per available seat mile ▪ Salaries per available seat mile ▪ Wages per available seat mile ▪ Benefits per available seat mile ▪ Fuel expense per available seat mile Intermediates: ▪ Fleet size ▪ Load factor outputs: ▪ Revenue passenger miles ▪ Passenger revenue	NDEA	worldwide	2007-2008
6	Lozano and Gutierrez (2014)	Network DEA	Inputs: ▪ Fuel cost ▪ Wages ▪ Operating costs Intermediates: ▪ Available seat kilometers ▪ Available tonne kilometers outputs: ▪ Revenue passenger kilometers ▪ Revenue ton kilometers	non-oriented slacks-based NDEA	EU	2007

No	paper	Method	Variables	Functional form	Area	Period
7	Omrani & Soltanzadeh (2016)	Dynamic network DEA (DNDEA)	Inputs: ▪ Number of employees Intermediates: ▪ Available seat-kilometer ▪ Available ton-kilometer ▪ Number of scheduled flights Carry-overs: ▪ Fleet's seat outputs: ▪ Passenger-kilometer ▪ passenger ton-kilometer	CRS	Iran	2010-2012
Airport						
8	Lozano et al. (2013)	Network DEA	Inputs: ▪ Total runway area ▪ Apron capacity ▪ Number of boarding gates ▪ Number of baggage belts ▪ Number of check-in counters Aircraft Intermediates: ▪ Aircraft Traffic Movements outputs: ▪ Annual Passenger Movement ▪ Annual Cargo handled ▪ Number of Delayed Flights ▪ Accumulated Flight Delays	CCR and BCC output oriented NDEA	Spain	2008
9	Maghbouli et al. (2014)	Network DEA	Inputs: ▪ Total runway area ▪ Apron capacity ▪ Number of boarding gates ▪ Number of baggage belts ▪ Number of check-in counters Aircraft Intermediates: ▪ Aircraft Traffic Movements ▪ Number of delayed flights ▪ Accumulated flight delays outputs: ▪ Annual Passenger Movement ▪ Annual Cargo handled	BCC Network DEA & game theory approach	Spain	2008
10	Liu (2016)	Network DEA	Inputs: ▪ Runway area ▪ Staff cost ▪ Other operating costs Intermediates: ▪ Aircraft movements outputs: ▪ Passengers and cargo ▪ Operating revenues	CRS output-oriented NDEA	Asia	2009-2013

Public transport						
11	Sheth et al. (2007)	Network DEA	Inputs: ▪ Headway ▪ Service duration ▪ Costs ▪ Number of intersections ▪ Number of priority lanes Intermediates: ▪ Vehicle miles ▪ Schedule reliability ▪ Average traveling time outputs: ▪ Passenger-miles	BCC output-oriented NDEA	US-simulated data	-
12	Yu (2008)	Network DEA	Inputs: ▪ Number of drivers ▪ Number of buses in the active fleet ▪ Fuel consumption ▪ Route kilometers served Intermediates: ▪ Number of mechanics outputs: ▪ Vehicles-km ▪ Frequency of service	BCC input-oriented NDEA	Taiwan	2001
13	Chiou et al. (2012)	Route-based DEA (RDEA)	Shared Inputs: ▪ Fuel cost ▪ Number of employees ▪ Number of buses outputs: ▪ Operating revenue ▪ Passenger-km	CCR & BCC input-oriented NDEA	Taiwan	2005
14	Yu et al. (2016)	Dynamic network DEA	Inputs: ▪ Number of drivers ▪ The number of vehicles ▪ The number of liters of fuel ▪ Number of ticket agents Shared Inputs: ▪ Number of technicians ▪ Number of management staff Intermediates: ▪ Vehicle-kms Carry-overs: ▪ Network length outputs: ▪ Passenger-kms ▪ Number of passengers ▪ Number of accidents (ACC)	CRS Resource sharing NDEA	China	2004-2012

4.8. Conclusion

To increase the market share, the IFT service should provide a good level of performance. In order to measure the performance, we first need to have a methodology and a set of performance measures for a freight transport system. The review of the literature reveals that a systematic literature review about the performance measurement in freight transportation systems has not been carried out yet. In this chapter different methods of performance measurement that are applied to the freight transport systems, i.e., partial performance measures, Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA), were reviewed. The papers are categorized based on the freight transport sub-domains, i.e., railway, inland waterway, port, maritime, and short sea shipping. Because the number of the papers was limited, we extended the search by adding the papers in the airport, airlines, and public transport domains.

Each of the performance measurement methods has some pros and cons that are summarized in Table 6. The main disadvantage of partial performance (multiple indicators) analysis is difficulty to evaluate the performance improvement, in the cases when some indicators show improvement, and the rest not (Lu & Wang, 2017). Stochastic Frontier Analysis (SFA) is a parametric approach, which is used to measure the efficiency of an industry given its input and output data. Although using a SFA model, the statistical analysis of the results is possible, assuming a priori production or cost functional form is the main challenge in SFA models. Moreover, the efficiency scores are sensitive to distributional assumptions on the error terms, and the model requires large samples to be robust (Martín et al., 2009). Data Envelopment Analysis (DEA) is a typical non-parametric approach which evaluates the efficiency of a firm or a system relative to an average or representative firms (Anderson, 2003). The main drawback of DEA model is that it is a deterministic model, and the estimated coefficients don't have statistical properties; therefore it is impossible to make any statistical inference or establish hypothesis contrasts from it (Jorge & Suarez, 2003). Moreover, the basic DEA model does not fully rank the DMUs. It cannot also consider the intermediate products/ services in evaluating the performance of the multidivisional DMUs.

To overcome different disadvantages of the standard DEA model, different extensions of the model were developed, e.g., Bootstrapped DEA which is a stochastic version of DEA, or post-DEA models which can fully rank the DMUs. The other disadvantage is this that the standard DEA models treat a multidivisional chain as a black-box, and – as a result- it misses all the intermediate measures and the trade-offs between the performance of different divisions. To overcome this disadvantage, the Network DEA models were developed. Network DEA models take into account the efficiencies of different divisions as well as the efficiency of the overall chain in a unified framework. Therefore, it helps in finding the sources of inefficiency in a chain or a multi-division system.

Comparing different performance measurement methods, and their applications, we conclude that data envelopment analysis (DEA) and its extensions are most suitable methods and have been widely applied to the freight transport domain, and related sub-domains. Network DEA has also been applied to the freight transport domain, but so far, papers have applied multi-activity (-function) NDEA with focus on the un-storable feature of transportation service, by dividing the transport service to production and consumption activities. As a result, papers have not studied the multi-division NDEA where a transport service is considered a vertical chain of different divisions. In the next chapter, we develop a modified multi-division Network DEA model to measure the efficiency of intermodal freight transport chains and their respective divisions. This model is applied to part of the European IFT network as an illustrative case.

TABLE 4.6 . Pros and cons of Different performance measures

performance measurement method	Advantage	Disadvantage
partial performance measures	▪ Simple calculation	▪ Difficulty to evaluate the performance, in the case of indicators with different signs
Stochastic Frontier Analysis (SFA)	▪ Total performance measure ▪ a parametric approach ▪ The statistical analysis of the results is possible	▪ Assuming a priori production or cost functional form ▪ Efficiency scores are sensitive to distributional assumptions on the error terms ▪ It requires large samples to be robust
Data Envelopment Analysis (DEA)	▪ Total performance measure ▪ Non-parametric approach ▪ It does not need any priori assumption about functional form ▪ I can be run by small number of samples	▪ It is a deterministic model that is impossible to make any statistical inference or establish hypothesis contrasts from it ▪ It does not fully rank the DMUs ▪ It cannot consider the intermediate products/ services in evaluating the performance of the multidivisional DMUs.

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Chapter 5

Assessing the Efficiency of Intermodal Freight Transport Chains Using a Modified Network DEA Approach

Formulating effective policies to promote intermodal freight transport (IFT) market share calls for performance measurement models that help benchmark the efficiency of transport chains, and identify the points for improvements. Despite the importance of efficiency measurement, studies on the performance measurement of IFT chains are quite limited. This chapter presents a modified network data envelopment analysis (NDEA) method to measure the performance of different intermodal freight transport chains inside a freight network. NDEA is an extension of traditional data envelopment analysis (DEA) which is used to evaluate the performance of multi-divisional systems. It has been used before in other sectors as well. The application of this method to the IFT chains, what can be seen as a sequence of divisions, involves two main challenges. The first challenge is to identify the number of divisions because, in an IFT network, we may have different IFT chains with different structures, where the number of sequential transshipment and transportation activities varies. The second challenge is defining a relevant intermediate service that connects the various divisions. Both challenges are discussed in the chapter and the original formulation is extended to cope with these challenges. We also illustrate the presented model by applying it to a sample of 10 IFT chains in a European IFT network. The results of the model are used to compare different IFT chains and also to analyze the sources of inefficiencies. Based on the observations, a general conclusion would be that in most of the IFT chains, the transshipment activities are less efficient activities in a chain, and therefore, the focus of improvement efforts in the majority of corridors should be on the terminal divisions.

This chapter is an edited version of the article:

Saeedi, H., Behdani, B., Wiegmans, B., & Zuidwijk, R. A, "*Assessing the efficiency of intermodal freight transport chains using a modified Network DEA approach*", working paper, https://ssrn.com/abstract=3122267.

5.1. Introduction

A key part of EU transport policy for the last two decades has been to promote Intermodal Freight Transport (by rail, or Inland waterways). In 2011, the European Commission set a target of shifting 30% of freight being transported further than 300 km by road to other modes of transport such as rail or waterway transport by 2030, and more than 50% by 2050. After considerable investments (approximately €28 billion to funding rail projects between 2007 and 2013), and giving priority to shifting freight from road to intermodal freight transport (IFT), the results show the failure of the EU intermodal transport to achieve a satisfactory performance (EU Report, 2016). The performance of an IFT service is attributed to two main factors: the performances of different IFT chain divisions, and the co-operation and harmony of these divisions (Yang et al., 2009). Despite the importance of efficiency measurement, studies on the performance measurement of IFT chains are quite limited, and most of the attention has been paid to the tradeoff or cooperation among the chain members, rather than the efficiency of the chain(Yang et al., 2009).

There are many definitions for the efficiency concept in the literature. It is generally defined as "How well the resources expended are used" (Kim & Marlow, 2001). Therefore, efficiency is either minimizing the inputs when the outputs are fixed or maximizing the outputs when the inputs are fixed (Ockwell, 2001). A well-known approach for efficiency analysis is Data Envelopment Analysis (DEA). DEA measures the efficiency of each individual observation by calculating a discrete piecewise frontier determined by the set of Pareto-efficient DMUs (Charnes et al., 1994). It does not require any assumption about the functional form. DEA measures the performance of each DMU relative to all other DMUs in the sample considering the fact that each DMU lies on or below the best-practice production frontier. Each DMU which is not on the frontier is compared against a convex combination of the DMUs on the frontier facet closest to it (Charnes et al., 1994). DEA can be applied in several different situations and has also been the subject of a number of theoretical extensions that have increased its flexibility, ease of use and applicability (Cooper et al., 2011). The traditional DEA models are focused on the efficiency evaluation of a single process. This black-box approach - in which all inputs and outputs are aggregated for the whole system- can be challenging for a system with several divisions and sub-processes (Lozano & Gutiérrez, 2014). In most real situations, the organizations may perform several functions, and can also be separated into different divisions which are connected serially. Also, the organization may include several independent divisions (e.g., a supply chain) that maximize their own efficiency, without considering other members or the overall chain (Yang et al., 2009). In such situations, some divisions could play a more important role in producing outputs through the use of intermediate outputs obtained from other divisions (Beasley, 2003). Network DEA models are models which consider these linking activities and intermediate products/ services in the model and therefore, the effect of divisional inefficiencies can be evaluated (Tone & Tsutsui, 2009). This provides greater insight into the organization and more diagnostic information of sub-processes. The results of efficiency assessment by NDEA models are also believed to be more valid as it uses more information and a more detailed level of analysis (Lozano & Gutiérrez, 2014; Tone & Tsutsui, 2009). It is shown that ignoring the internal structure of an organization may lead to different and sometimes misleading results (Tone & Tsutsui, 2009; Kao, 2014; Kao & Hwang, 2010).

In this chapter, a modified multi-division network DEA model is developed to analyze the performance of the IFT chains. This model is applied to part of the European IFT network as an illustrative case. The scientific contribution of this chapter is developing a model to measure the efficiency of the IFT chains with different structures (different number of divisions), and their respective divisions. For this purpose, we use the network DEA approach, and, in addition, introduce the value of service (value of transport service, and value of transshipment service) as the intermediate variable in modeling the IFT chains efficiency. We also apply our model to measure the efficiency of a sample of European IFT network.

In section 5.2 we review the papers applying DEA models to the transport domain. Section 5.3 is presented our methodology. In section 5.4 our methodology is applied to an illustrative case, and finally, section 5.5 is discussion and policy recommendations.

5.2. Performance Evaluation of Transport Systems

In the last two decades, there have been many applications of DEA in the transportation domain. As one of the first applications, Hilmola (2007) studied the efficiency of European railways between 1980-1999 using traditional DEA approach. The analysis showed that the productivity of locomotives and railway tracks should be the primary target of productivity improvement in these countries. Cantos et al.(1999) analyzed the evolution of productivity in the 17 European railways in the period 1970–95, using a DEA model. Their model breaks the productivity into technical change and differences in efficiency. They found that the productivity is growing in the period 1985–95 when the majority of the companies did reforms. This increase in productivity is mainly due to technical progress. Merkert et al.(2010) applied a DEA model to a sample of 43 Swedish, German and British rail operators for the year of 2006-2007. Their findings show that transactional factors, e.g., monetary values of transaction costs, are more important in determining technical efficiency than others. Martinez-Budria et al. (1999) examine the efficiency of 26 Spanish ports by DEA models, the authors conclude that the ports with high complexity are more efficient. Tongzon (2001) uses DEA to analyze the efficiency of 16 international container ports, he found that the ports of Melbourne, Rotterdam, Yokohama, and Osaka are the most inefficient ports in the sample, mainly because of enormous slacks in their container berths, terminal area, and labor inputs. Almawsheki & Shah (2015) measured the technical efficiency of 19 container terminals in the Middle-East region using DEA model. Their findings show that the Jebel Ali, Beirut and Salalah terminals are the most efficient terminals in the region. Barros (2003) evaluates the productivity of the Portuguese seaports using DEA approach during 1990-2000. His findings show that almost all of the ports achieved improvements in technical efficiency during this period. Barros (2006) evaluates the performance of Italian seaports from 2002 to 2003 using DEA model. He concludes that the Italians seaports display relatively high efficiency. DEA has also been applied to other transport sections such as maritime transport, urban transport, airports, and airlines as well. Panayides et al. (2011) examine the relative market efficiency and operating performance efficiency of 26 major international maritime firms in dry, wet and container shipping sectors using data envelopment analysis. Their findings show that Tanker companies are more market efficient, while container shipping firms have high efficiency but were market inefficient. Hirschhausen & Cullmann (2010) analyzed the 179 communal public transport bus companies in Germany (1990–2004), using Bootstrapped DEA model. Their findings indicate that the structure of the German public bus sectors should be improved. Tsui et al. (2014) using Bootstrapped DEA models explain the variations in New Zealand's 11 major airports efficiency between 2010 and 2012. They used two input variables, and three output variables to run slacked-based DEA model. Then, they used six explanatory variables to run a bootstrap regression. Their findings show that the number of efficient airports increased from two airports in 2010 to seven airports in 2012. Barbot et al.(Barbot, Costa, & Sochirca, 2008) used DEA model to analyze the efficiency of 49 different airlines in Europe, North America, and Australia. Their findings show that low-cost airlines are in overall more efficient than full-service airlines. Table 5.1 shows the technical details of different papers using DEA models.

The important remark is that all of them have compared single players with each other, not the overall transport chains. Markovits (2011) reviewed 69 papers related to DEA models applied in the transport sector to analyze the input and output data which is mostly used in these models. He found that there are 3 or 4 inputs which are mostly chosen from the areas of labor, capital, and energy such as the number of employees or the cost of labor, the price of capital, materials expenditures, and facilities. The number of outputs is mostly 1 or 2 that usually describe operational and/or fiscal characteristics such as turnover or the amount of cargo/ freight (tons) handled. His work is a good literature review for anyone who wants to work on efficiency measurement in transportation sector using DEA models. In all these applications, the efficiency measurement is focused on a transportation system with one division. The evaluation of a multi-divisional system is challenging because of the existence of the intermediate products/ services connecting different divisions, and traditional data envelopment analysis (DEA) could not be directly used to measure the performance. In order to deal with the efficiency measurement of the chains, the Network DEA models are developed that account for efficiencies of different divisions as well as the efficiency of the overall chain in a unified framework.

TABLE 5.1 . Application of DEA to Measure The Efficiency of Transport systems

No	paper	Domain	Variables	Functional form	Area	Period
1	Hilmola (Hilmola, 2007)	Railway systems	Inputs: ▪ Number of freight wagons ▪ Total track route (kilometers) ▪ Total number of locomotives ▪ Staff Outputs: ▪ Freight-tonne-kilometers ▪ Freight-tons	CCR output-oriented	EU	1980-2003
2	Cantos et al (Cantos et al., 1999)	Railway systems	Inputs: ▪ Number of workers, ▪ Consumption of energy, ▪ Number of locomotives ▪ Number of passenger carriages ▪ Number of freight cars ▪ Number of kilometers of track Outputs: ▪ Passenger-km ▪ Tones-km	CCR Input-oriented	EU	1970–1995
3	Merkert et al. (Merkert et al., 2010)	Railway systems	Inputs: ▪ Operating cost ▪ Staff number ▪ Transaction dedicated staff outputs: ▪ train-km Explanatory variables in the Tobit regression model: ▪ vertical separation and type of operation ▪ competition ▪ monetary values of transaction costs	BCC input-oriented model	Sweden, Germany, UK	2006-2007
4	Martinez-Budria et al. (Martinez-Budria et al., 1999)	Ports &Terminals	Inputs: ▪ Labour cost ▪ Depreciation charge ▪ Other costs Outputs: ▪ Total cargo movement (ton) ▪ Revenue	BCC input-oriented	Spain	1993-1997

No	paper	Domain	Variables	Functional form	Area	Period
5	Tongzon (Tongzon, 2001)	Ports &Terminals	Inputs: ▪ Number of berths ▪ Number of cranes ▪ Number of tugs ▪ Stevedoring labor ▪ Terminal area outputs: ▪ Throughput (TEU) ▪ Ship working rate (TEU/ h)	CCR & additive input-oriented	world wide	1996-2000
6	Almawsheki & Shah (Almawsheki & Shah, 2015)	Ports &Terminals	Inputs: ▪ Terminal area (ha) ▪ Quay length (m) ▪ Quay crane (no.) ▪ Yard equipment(no.) ▪ Maximum draft(m) outputs: ▪ Throughput (TEU)	CCR input-oriented	Middle-east	2012
7	Barros (C. PESTANA Barros, 2003)	Ports &Terminals	Inputs: ▪ Number of workers ▪ Book value of the assets outputs: ▪ Ships ▪ Movement of freight ▪ Gross gauge ▪ Break-bulk cargo ▪ Containerised freight, ▪ Solid bulk ▪ Liquid bulk	BCC input-oriented	Portugal	1990-2000
8	Barros (Carlos Pestana Barros, 2006)	Ports &Terminals	Inputs : ▪ Number of employees ▪ Book value of assets outputs: ▪ Liquid bulk ▪ Dry bulk ▪ Number of ships ▪ Passengers ▪ Number of Containers ▪ Sales	CCR & BCC output-oriented model	Italy	2002-2003
9	Panayides et al. (Panayides et al., 2011)	Maritime transport	Inputs: ▪ Inputs profits ▪ Book value of equity ▪ Total assets ▪ Number of employees ▪ Capital expenditure Output: ▪ Market value of equity ▪ Sales	CCR & BCC input-oriented	World wide	2008
10	Hirschhausen & Cullmann (von Hirschhausen & Cullmann, 2010)	Public transport	Inputs: ▪ Number of buses ▪ Number of workers ▪ Density outputs: ▪ Bus-km ▪ Seat-km	CCR & BCC input-oriented model	Germany	1990–2004
11	Tsui et al. (Tsui et al., 2014)	Airports	Inputs: ▪ Operating expenses ▪ Number of runways ▪ Outputs: ▪ operating revenues ▪ Air passenger movements ▪ Aircraft traffic movements Explanatory variables in the Tobit regression model: ▪ Population around the airport ▪ Airport hub status ▪ Airport operating hours ▪ Airport ownership ▪ Christchurch earthquakes ▪ Rugby World Cup 2011	VRS Slacks-based input-oriented DEA Simare-Wilson bootstrapping regression	New Zealand	2010-2012

No	paper	Domain	Variables	Functional form	Area	Period
12	Barbot et al. (Barbot et al., 2008)	Airlines	Inputs: ▪ Labor ▪ Fleet ▪ Fuel Outputs: ▪ ASKs ▪ RPKs ▪ Revenue ton kilometers (RTKs)	BCC input-oriented model	World wide	2005

Different papers e.g., Liang et al. (2006), Yang et al. (2009), and Golany et al. (2006) have developed a theoretical framework for systems composed of two or more subsystems, using Network DEA model. Halkos et al. (2014) have reviewed and classified the papers which applied two-stage network DEA models to the supply chains. They define four categories of the models -independent, connected, relational, and game theoretic NDEA- and present the formulation and main applications of them. This paper gives an overall view of the different ways to formulate NDEA and its application in different cases.
Network DEA has also been applied to the transportation domain. Lozano and Gutierrez (2014) present a slacks-based two-step DEA approach to assess the airlines' efficiency. They apply their model to the 16 European airlines, considering available seat kilometers, and available ton kilometers as intermediate parameters. They also compare the results with those of the corresponding conventional DEA model. The findings show that only 6 airlines are totally efficient, and a few others are partially efficient. Sheth et al. (2007) apply network DEA to bus routes. The service along a bus route is presented by a network, and the efficiency of service provided along the bus route is assessed from providers' and customers' perspectives. They aimed to provide a tool for decision-makers to improve the performance of the network as a whole. Yu (2008) used NDEA to determine the efficiency of different multi-mode transit firms. Highway Bus (HB) service and Urban Bus (UB) service are considered as main processes. The output of the HB process is vehicles-km and the output of the UB process is the frequency of service. They use different inputs which one of them (number of mechanics) is shared between them. They found that there are different optimal scale sizes for HB and UB services in the Taipei. Zhu et al. (2016) develop a NDEA model to measure the efficiency of the bus routes. This model provides decision support both for regulators and for producers of bus services. They also apply their model to the 39 routes in China. All of these papers, by dividing a transport service into different components, give deeper insight into their performance to the policymakers.
In practice, different transport operators (e.g., different shipping companies or airlines) may operate in different routes. Some of the routes can be efficient, and on some of them inefficient. Thus, a company-level analysis may lead to a different operational benchmark. To avoid such a heterogeneity, Some studies have used the route-based performance evaluation to evaluate the performance of transport operators (Yu & Chen, 2016). Chiou et al. (2012) have done an empirical study of 37 Taiwanese intercity bus companies operating on 1035 routes. These different routes have different lengths. In order to do that, they have developed a Route-based DEA (RDEA) model that decomposes the company-level efficiency into route-level efficiency measures, by optimizing the allocation of common inputs at the same time. Chiou and Chen (2006) employ a route-based DEA model to evaluate the performance of the domestic air routes operated by a Taiwanese domestic airline. The route lengths varied between 52-196 Miles. Similarly, in measuring the efficiency of each IFT chain, we need to consider that every single operator e.g., transport operator may belong to different chains, and accordingly, may have different performance in each of them. The list of the papers applied multi-activity (-function) NDEA models in transport domain with the respective assumed Input/ intermediate/ Output parameters have has been presented in table 4.5 in chapter 4.

None of the previous works on DEA-based efficiency measurement considered IFT as a multi-division transport chain and calculate its efficiency using NDEA approach. Therefore, this research aims to present a model based on the slacks-based network DEA (SB-NDEA) to calculate the efficiency of IFT chain and its divisions (Terminals, and Main-haulages) simultaneously by considering the value of service as the intermediate measure. Applying the SB-NDEA model, we can find the less efficient IFT chains in a freight transport network, and at the same time, we can find the respective less efficient division(s) which is (are) explaining the total inefficiency of the chain.

5.3. Methodology to evaluate the efficiency of IFT chains

On the IFT network, a sequence of transshipment and transportation activities is defined as an IFT chain (Saeedi et al., 2017a). These IFT chains are arranged by different forwarders. In this chapter, we extend a SB-NDEA model as presented by Tone and Tsutsui (Tone & Tsutsui, 2009) to measure the overall efficiency of the IFT chain as well as the divisional efficiencies. As discussed in chapter 4, the Slacks-based models avoid the weakly efficient DMUs in the set of efficient DMUs and consequently have more discriminatory power in ranking the studied DMUs.
We describe the structure of the model in section 3.1, and in sections 3.2 and 3.3 two main challenges in the application of this model for IFT domain will be discussed, added to the model.

5.3.1. Slacks-based Network DEA Model

Figure 5.1 shows a typical IFT chain, which consists of k divisions, connects an origin to a destination via transfer terminals.

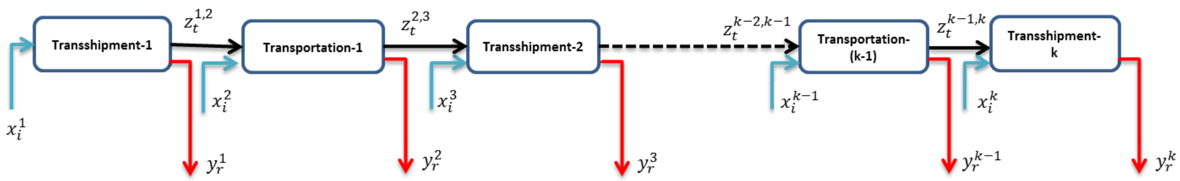


Figure 5.1. An Intermodal freight transport chain with K divisions

Tone and Tsutsui (2009) developed a Slacks-based NDEA model to deal with the intermediate measures in efficiency measurement of the multi-divisional companies. Slack-based models take into account the existence of input and output slacks and avoid weak efficient DMUs in the frontier (more detail in chapter 4). These models are useful when inputs and outputs may change non-proportionally (Tone & Tsutsui, 2009). Assuming that the transport operators are cost minimizers (Cantos & Maudos, 2001), we use input-oriented fixed link formulation of the model to calculate the efficiency of the IFT chains. The model considers n DMUs ($j = 1, \dots, n$) and each DMU consists of K divisions. m_k and r_k are the numbers of inputs and outputs of division k respectively, and $t_{k,k+1}$ is the number of intermediate product/ services between division k and $k + 1$.

$$Min_{\,s_{i,k}^{+},\,\lambda_k}\ \theta_o^* = \sum_{k=1}^{K} w_k \left[1 - \frac{1}{m_k}\left(\sum_{i=1}^{m_k} \frac{s_{i,k}^{+}}{x_{io,k}}\right)\right] \tag{1}$$

$$\sum_{j=1}^{n} \lambda_j^k . x_{i,j}^k + s_{i,k}^{+} = {x_{io}}^k \quad , i = 1, \dots, m_k \tag{2}$$

$$\sum_{j=1}^{n} \lambda_j^k . z_{t,j}^{k,k+1} = z_{to}^{k,k+1} \quad , t = 1, \dots, t_{k,k+1} \tag{3}$$

$$\sum_{j=1}^{n} \lambda_j^{k+1} . z_{t,j}^{k,k+1} = z_{to}^{k,k+1} \quad , t = 1, \dots, t_{k,k+1} \tag{4}$$

$$\sum_{j=1}^{n} \lambda_j^k . y_{r,j}^k - s_{r,k}^- = y_{ro}{}^k \quad , r = 1, \dots, r_k \tag{5}$$

Where θ_o^* is the total efficiency of the IFT chain O which is the DMU under investigation. This efficiency is the weighted summation of the efficiencies of respective divisions (k). w_k is the weight of the different divisions of the IFT chain, where $\sum_k w_k = 1$. This weight is determined corresponding to the importance of each division (Tone & Tsutsui, 2009). The observed data are X_j^k (which are the input resources to DMU j at division k), and Y_j^k (which are output products from DMU j at division k). $Z_j^{k,k+1}$ is also a vector defining the intermediate product/ service from division k to division $k+1$.

5.3.2. Comparison of different IFT chains with different structures

The first challenge in the application of NDEA in analyzing IFT network performance is to determine the number of divisions. In NDEA models the assumption is that all DMUs have the same number of divisions, and the performance of each division is measured by comparing with similar divisions in other DMUs. However, in the case of IFT network, we may have different IFT chains with the different structure, and number of divisions (number of sequential transshipment and transportation activities). To cope with this challenge, we should keep in mind that different divisions in different IFT chains perform similar activities, and can be used in building the efficiency frontier. For example, different terminals in different divisions of the IFT chains are doing similar transshipment activities, and as far as they have the same technology, their performance is comparable. We call this property of the IFT service "substitutability". In other words, because in each IFT chain we perform two typical activities (i.e., transshipment and transportation) all transshipment (transportation) activities disregard of their position in IFT chain can be put in each benchmark set. In this way, we can solve the issue of different structures and number of divisions for different IFT chains. Furthermore, increasing the number of observations in each benchmark set would increase the quality and accuracy of the efficiency estimation. Again it should be emphasized that the activities in each benchmark set should have similar technology. For the case of transportation activity, this implies using similar modality for the main-haulage. For the case of transshipment, terminals should belong to similar category (e.g., in terms of size, technology, and inputs/ outputs). For detailed categorization of terminals, we refer readers to Wiegmans and Behdani (2017).
For division i of DMU j, let's assume that $C(k)$ defines a set of activities comparable with the activity of division k. Applying the substitutability assumption, the formulation will be as follows:

$$Min_{s_{i,k}^+, \lambda_k} \theta_o^* = \sum_{k=1}^{K} w_k \left[1 - \frac{1}{m_k} \left(\sum_{i=1}^{m_k} \frac{s_{i,k}^+}{x_{io,k}} \right) \right] \tag{6}$$

$$\sum_c \lambda_c . x_i^c + s_{i,k}^+ = x_{io}{}^k \quad , i = 1, \dots, m_k \tag{7}$$

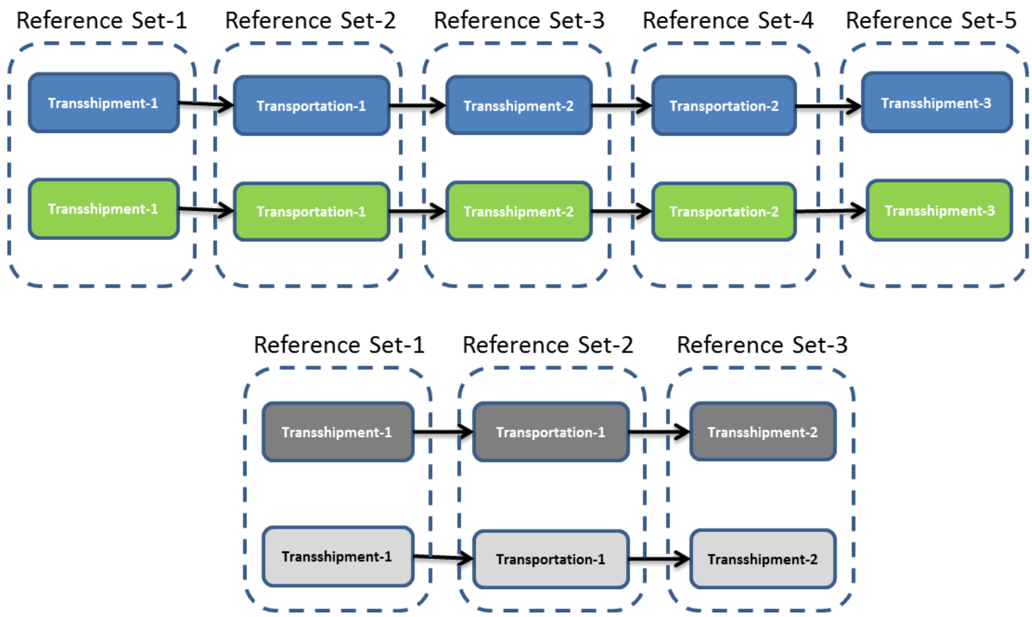
$$\sum_c \lambda_c . z_t^{c,c'} = z_{to}^{c,c'} \quad , t = 1, \dots, t_k \tag{8}$$

$$\sum_c \lambda_c . z_t^{c,c'} = z_{to}^{c,c'} \quad , t = 1, \dots, t_k \tag{9}$$

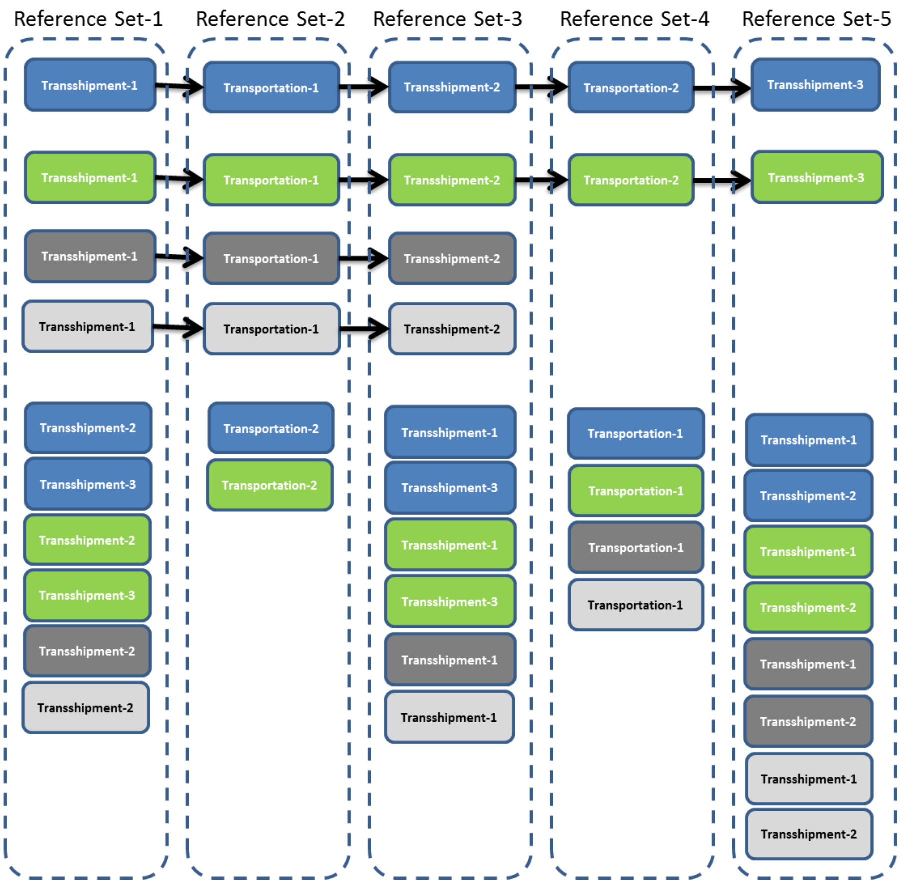
$$\sum_c \lambda_c \cdot y_r^c - s_{r,k}^- = {y_{ro}}^k \quad ,r = 1, \dots, r_k \tag{10}$$

$C'(k)$ is a set of consecutive activities for each member of $C(k)$.

To illustrate the formulation, let's assume that we have 4 IFT chains (two with 3 divisions, and two with 5 divisions). In a normal NDEA model, every two chains with the same structure should be compared with each other (two separate benchmark sets). Furthermore, the performance of each division will be compared with the same division in the other chain. In this case, each reference set includes two members (Figure 5.2a). In our presented model (equations 6-10), we can compare all chains in one benchmark set. Also, each division (i.e., transportation or transshipment activity) will be compared with other similar activities in other chains or its own chain (Figure 5.2b). In this case, the transshipment reference sets (i.e., $C(1)$, $C(3)$, and $C(5)$) will have 10 members, and transportation reference sets (i.e., $C'(2)$, and $C'(4)$) will have 6 members. In both sets, the assumption of substitutability must hold. In other words, the transshipment and transportation activities are comparable. If all transshipment (or transportation) activities are not similar, the reference sets we will have more sets with less number of members. If we assume that some of the IFT chains have only 3 divisions (two terminals, and one main-haulage operator), then the number of members will be reduced in the reference sets. The reference set for each division will be built in the same way as for 5-division chains.



(a)



(b)

Figure 5.2. NDEA Application To Illustrative Network With 4 IFT Chains

5.3.3. Intermediate service definition

The main challenge of the application of the NDEA models to transport domain, in general, and for IFT chains specifically, is defining a relevant intermediate service. For production chains, this is less of a challenge, because the tangible intermediate product can be determined between two subsequent divisions. In general, the intermediate service/ product between divisions k and $k + 1$ is the service/ product which is generated by division k, and consumed by division $k + 1$.

In the case of the IFT service, the intermediate service should fulfill some requirements. First, the intermediate service is defined between transshipment and transportation activity, and subsequently, it should be relevant as input or output of the transshipment activity, as well as the input or output of the transportation activity. It should be noted that the terms "activity" and "division" are interchangeably used in this chapter. In the literature of the freight transport, parameters like ton-km, and TEU-km are used as outputs of the freight operator to measure the efficiency (Markovits-Somogyi, 2011). These parameters cannot be used as the intermediate service in the case of the IFT chain because they cannot be interpreted as input or output of the transshipment activity. Furthermore, since each IFT chain is a sequence of transshipment and transportation activities, the intermediate service needs to be interpreted as both input and output of each activity (i.e. transshipment and main-haulage). For example, always a transshipment activity exists before and after a main-haulage activity, and for the transshipment before main-haulage, the intermediate service is the output, and for the transshipment after the main-haulage, the intermediate service is an input. An additional implication of this is that the intermediate services in different steps of the chain should be of a similar type (because always the intermediate service is defined between a transshipment operator and a transportation operator). Taking into account these characteristics of the intermediate service, the intermediate service can be estimated by the value that is created by division k in the whole process. To evaluate the value creation by division k let's consider a physical network of transshipment (nodes) and transportation (links) as shown in Figure 5.3. On an IFT network, there are different IFT chains which are arranged by forwarders on the top of this physical network. In general, IFT service creates "spatial" value and "time" value for the products. Spatial value is created by changing the location of the products, i.e. by satisfying the customers' needs to have the products on the demanded places. Time value is created by making the products available at a right time in a specific place (Kilibarda, 2013). It means that when the customer receives its product at right time and, in the right place the value of the service is created.

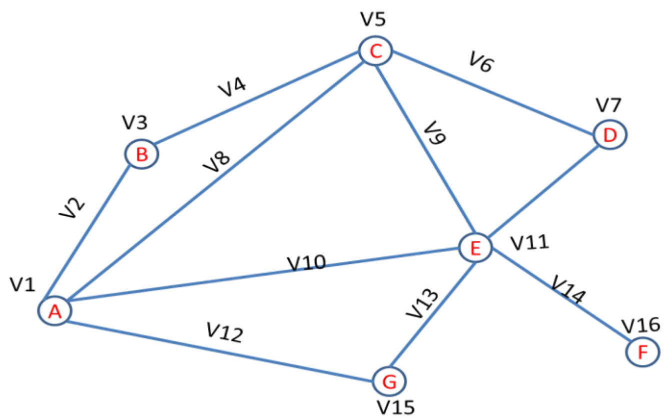


Figure 5.3. A hypothetical transport network

For transportation activity, we may observe that for a given mode of transport m, the value that is created is a function of the distance covered, and the time of transportation activity. We define this value as the value of intermodal freight transport service (VIFTS). To estimate this value, we need a theory that represents the relation between the price of service (or Freight charge), time, and distance (Massiani, 2003). A theory that is used for this purpose is "Hedonic pricing". Hedonic pricing methods reveal customers' willingness to pay for transport service and estimates their revealed preferences (Pettersen, 2013). Massiani (2003) defines the freight charge function as a bundle of characteristics such as weight, distance, and time, i.e. $P_{ij}(Q, S_{ij}, T_{ij})$. Based on the estimated freight charge function, he defines the value of time (VOT) as the derivative of freight charge with respect to transport time. Halvorsen and Pollakowski (1981) present a general functional form for hedonic pricing which is described in Appendix 5B. Using hedonic formulation, we define the VIFTS for mode i as the estimation of the freight charge using a regression model:

$$VIFTS_i = \widehat{P} \tag{31}$$

For transshipment activities, the value creation comes from the change of modality from mode i to j. This value is related to the unit price of transshipment, and the total quantity. The value of transshipment service is defined as:

$$VIFTS_{transshipment} = Q.P_{tr}{}^{i,j} \tag{32}$$

Where $P_{tr}{}^{i,j}$ is the unit price of transshipment between modes i and j.

For a transportation network, as shown in figure 5.3, equations (31) and (32) can be used to estimate the value that is created in each node and link of the network. This value is a "local" value which is based on the activity that is done on these links and nodes, irrespective of the different IFT chains that these nodes and links can belong to. For an IFT chain, the value is additive, i.e., the summation of the value of consecutive activities (Figure 5.4). In fact, each division- using certain resources- adds certain value to the existing value of the IFT service. It should be noted in the value creation of an IFT chain, we assume that there is no delay between two consecutive activities. Additionally, IFT chain fulfills the time requirements of cargo delivery at the destination.

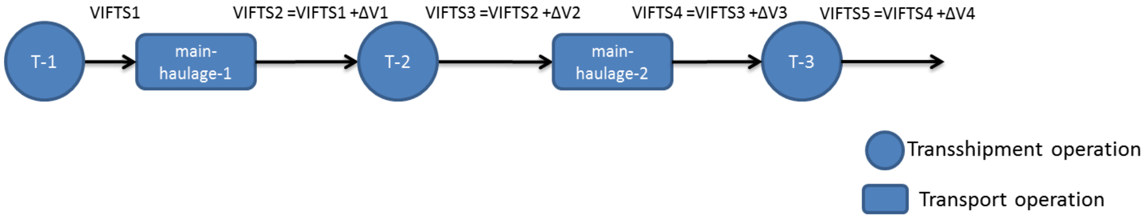


Figure 5.4. Incremental value of the service in an IFT chain

The modified model, which considers these solutions, will be applied to a sample of IFT network in the next section.

5.4. Illustrative case

5.4.1. Data and Assumptions

To illustrate we applied the presented model to a sample of 10 IFT chains in European IFT network. In these chains the transportation mode is rail. The list of selected corridors and the respective chains is shown in table 5.2 and Figure 5.5. This sampled network is part of the EU IFT network that was developed and discussed in Chapter 3.
It should be noted that – in order to reduce the complexity of the model-, for this illustrative case we have chosen the IFT chains from different corridors which have no overlaps. Only in one terminal, there is an overlap between two IFT chains. In that case, the inputs of the terminal have been divided between two IFT chains proportionally according to their flow.
We have categorized the data into 3 different categories: input data, intermediate data, and output data. The inputs for the terminals are Total terminal area (m2), Quay length (m), No. of tracks, Length of tracks (m), No. of cranes, No. of stackers. The data of the facilities of the terminals have been gathered from Inland links website and Intermodal Terminals Website. These facilities have been multiplied by the utility ratio of the terminal, to find the real resources have been used in specific IFT chain. The utility ratio is the ratio of the flow of the chain to the total capacity of the terminal. To calculate the value of transshipment service, the transshipment cost is assumed to be €40 per load (Janic, 2007) for all terminals. Indeed using average values for the parameters could decrease the discriminatory power of the model, but because of the lack of data for specific terminals, the assumed values are inevitable. For transportation operators, we have considered operating cost and external cost as inputs. Again, there is no public data available about specific transport operators, e.g., labor data and number of facilities in different routes, which perhaps influences the discriminatory power of the model.

TABLE 5.2 . Different IFT Chains In The Sampled Network

No	Corridor	*IFT chains*
1	**Rotterdam-Ludwigshafen-Verona**	*Beatrix Terminal – HUPAC - Ludwigshafen KTL - CEMAT - Verona Quadrante Europa*
2	**Hamburg – Budapest**	*Container Terminal Altenwerder (CTA) – IMS - Rail Cargo Terminal BILK*
3	**Antwerp - Milano**	*Combinant (Quay 755) – HUPAC - Busto Arsizio (Gallarate)*
4	**Bremen - Wels - Wien**	*Eurogate C.T. – IMS - Enns Hafen CTE- IMS - Wien Freudenau Hafen CCT*
5	**Zeebrugge - Rotterdam- Praha**	*PROGECO ZEEBRUGGE – Danser - Rail Service Center (RSC) – METRANS – Terminal METRANS Praha*
6	**Rotterdam-Koln-Wien**	*RCT Rotterdam - Kombiverkehr - DUSS Terminal Duisburg- HUPAC- Wien Freudenau Hafen CCT*
7	**Hamburg-Ludwigshafen-Verona**	*DUSS Billwerder - Kombiverkehr - Ludwigshafen KTL - CEMAT - Verona Quadrante Europa*
8	**Antwerp-Paris**	*VAN DOORN - Naviland Cargo - Paris Valenton*
9	**Bremen-Praha**	*Eurogate C.T. - Metrans - METRANS Praha*
10	**Zeebruge-Milan**	*PROGECO ZEEBRUGGE - HUPAC - Busto Arsizio (Gallarate)*

Source: Saeedi et al. (2017b)

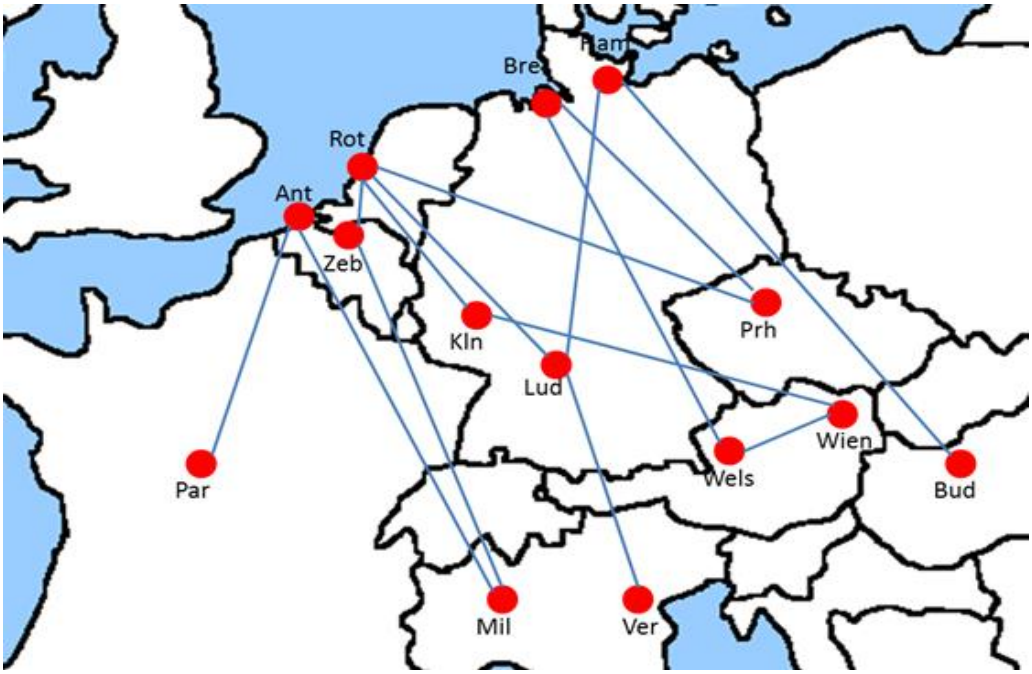


Figure 5.5. Different Corridors in the Sampled Network

Indeed, we need to emphasize that this section aims for an illustrative case to show how the model works and what results and insights it may provide. Following the work of Janic (2007), the internal-operating cost and the external-operating cost of a train are assumed:

$$C_{ot}(w,s) = €0.58\ (ws)^{0.74} \quad (33)$$

$$C_{ex}(w,s) = €0.57\ (ws)^{0.6894} \quad (34)$$

where w is the gross weight of a train, and s is the main-haulage distance. Using these equations, the annual operating cost of a transport operator is measured as:

$$TC_o(w,s,f) = C_{ot}(w,s) * f\ * u_{chain} \quad (35)$$

and the annual external cost of a transport operator is measured as:

$$TC_{ex}(w,s,f) = C_{ex,t}(w,s)\ * f * u_{chain} \quad (36)$$

Where f is the frequency of the service per year (each year is 52 week), u_{chain} is the share of the flow of specific chain in the total flow of a train.
Each train consists of 26 flatcars. The capacity of each car is 3 TEU (42.9 metric tonnes), so with an average load factor per trains (γ) which is $\gamma = 0.75$, the load per train is equal to 837 tonnes (Janic, 2007). Considering the weight of the empty train as 724 tones, the gross weight (w) of a full train is equal to 1561 tonnes. By dividing the total flow of a chain (Q) to the number of frequency of the service per year (f), the flow of the chain in each train (Q_t) will be specified. Then we can calculate u_{train} :

$$u_{chain} = \frac{Q_t}{78 * 0.75} \quad (37)$$

To estimate the VIFTS for transportation operators, we used the freight charge function as presented by Konishi et al. (2014):

$$P = 1415.15 - 1895.78T + 386.07QT + 1.48 * r^x.S.e(q,s) + 75.54 * S + 10912.3\frac{t_{ij}^N}{T} \quad (38)$$

Where r^x is average oil price, $e(q,s)$ is fuel efficiency function, and t_{ij}^N is the shortest driving time between i,j. Because the distance between origin destinations is the direct distance between them, then we assume that $T = t_{ij}^N$. The fuel efficiency $e(q,s)$ is also assumed 0.382. This function has not been estimated for the European transport network. We just use it for the illustrative case to show how the model works. In the case of using it for the real European network, the calibration and validation of the estimated function should be checked.
Finally, the total VIFTS, which is a cumulative summation of the value of different divisions, is considered as the final output of each chain in the model. Figure 4.5 shows the summary of input, intermediate and output items in different steps of an IFT chain. The detailed data are presented in Appendix 5A.

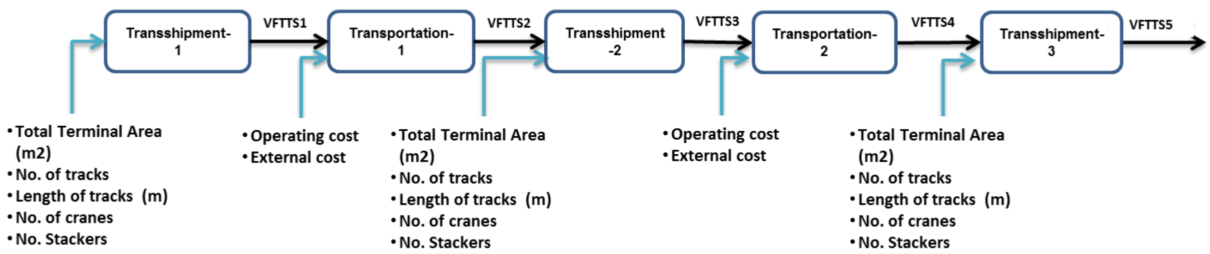


Figure 5.6. The Input Data for different divisions of the IFT chain

In the objective function of the model, we have the parameter w_i. This weight determines the importance of each division in total efficiency of the chain. In this chapter, we assume the equal weights for different divisions. We also run the model by considering the cost share as the weight for each division. Findings show that the efficiency of different divisions is not sensitive to these weights.

5.4.2. Results and Analysis

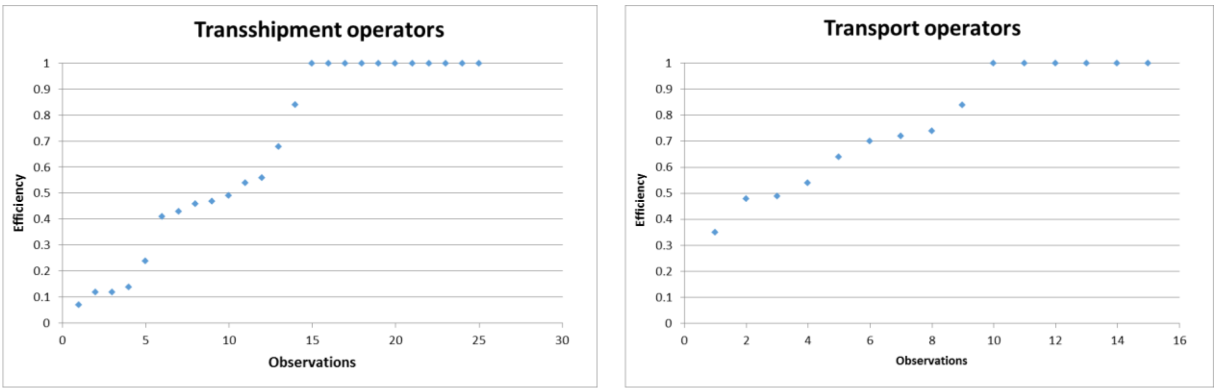
Applying the presented SB-NDEA model, the chain and division efficiency of different IFT chains are calculated. The results are presented in table 5.3. The results can be used to rank the DMUs and analyze the source of inefficiency in each chain. The IFT chain 4, 6 and 2 are relatively the most efficient ones where only the 4th chain, which belongs to the Bremen-Wels- Wien corridor, has achieved the full efficiency. The minimum relative efficiency has been experienced in 8th chain, which belongs to the Antwerp-Paris corridor. This low efficiency can be especially attributed to the first terminal in the chain (i.e. Van Doorn terminal) and improving the efficiency of this chain could be primarily achieved by improving this transshipment activity. The source of inefficiency of different divisions could be the inefficient usage of the resources to create a certain value. We call this the "division source" of inefficiency; i.e., the low performance of division is because it does not use the source inputs in an efficient way. Moreover, the inefficiency could be the result of deploying certain resources to this chain and corridor without taking into account the resource planning of other tiers in the network. In other words, the total flow of a chain is constrained by the flow of bottleneck step in that chain. This total flow defines the output of the whole chain and also the (maximum) throughput of each division in that chain. One division might have invested in extra input resources but cannot deploy those resources because of this network effect. This, that we call it the “network source” of inefficiency, will lead to low efficiency for that division. The source of inefficiency could also be related to the market structure, fiscal measures, government financial support, or technical regulation that could influence the efficiency of the operators in different markets in Europe. We call this the “environmental source” of inefficiency – since it is not because of actors in the chain or their interactions.

TABLE 5.3 . Total Efficiency of the IFT chains

No.	DMUs	Total Efficiency	T1	R1	T2	R2	T3
1	Beatrix Terminal – HUPAC - Ludwigshafen KTL - CEMAT - Verona Quadrante Europa	0.51	0.56	0.54	0.41	0.64	0.43
2	Container Terminal Altenwerder (CTA) – IMS - Rail Cargo Terminal BILK	0.82	1.00	0.48	1.00	-	-
3	Combinant– HUPAC - Busto Arsizio (Gallarate)	0.64	0.24	0.70	1.00	-	-
4	Eurogate C.T. – IMS - Enns Hafen CTE- IMS - Wien Freudenau Hafen CCT	1.00	1.00	1.00	1.00	1.00	1.00
5	PROGECO– Danser - Rail Service Center (RSC) – METRANS – Terminal METRANS Praha	0.57	0.12	0.49	1.00	0.74	0.49

No.	DMUs	Total Efficiency	T1	R1	T2	R2	T3
6	RCT Rotterdam - Kombiverkehr - DUSS Terminal Duisburg- HUPAC- Wien Freudenau Hafen CCT	0.91	1.00	1.00	0.54	1.00	1.00
7	DUSS Billwerder - Kombiverkehr - Ludwigshafen KTL - CEMAT - Verona Quadrante Europa	0.60	0.14	1.00	0.68	0.72	0.46
8	VAN DOORN - Naviland Cargo - Paris Valenton	0.47	0.07	0.35	1.00	-	-
9	Eurogate C.T. - Metrans - METRANS Praha	0.71	0.84	0.84	0.47	-	-
10	PROGECO - HUPAC - Busto Arsizio (Gallarate)	0.70	0.12	1.00	1.00	-	-

The average efficiency of all transshipment activities (i.e., 25 terminals) in the set is 0.663 and 44% of terminals operate on the efficient frontier (11 out of 25). For transportation activities (i.e., 15 main-haulage operators), the average efficiency score is 0.767 and 40% are projected on the efficient frontier. The distribution of efficiency for terminal and main-haulage operators is also shown in Figure 5.7. A general conclusion would be that the focus of improvement efforts in the majority of corridors should be on the terminal divisions. The detailed data in table 5.3 also shows that all terminals in the Bremen - Wels- Wien corridor (4th chain), i.e., Eurogate C.T., Enns Hafen CTE, and Wien Freudenau Hafen CCT terminal, and all terminals in the Hamburg – Budapest corridor (2nd chain) are performing efficient transshipment activities. Terminals in the 1st chain have low efficiency score. PROGECO Terminal belongs to two different chains in two different corridors, and in both cases, it is the least efficient terminal in the chain. Verona Quadrante terminal belongs to two different chains from different corridors, and in both cases, it has almost the same efficiency score. We can further look at the relation between the efficiency and the size of the terminals (Figure 5.8). Comparing the efficiency score of different terminals in our example shows that for a terminal to be efficient, it is sufficient to be large. It could be a sign of size economies.



(a) (b)

Figure 5.7. The Efficiency Of Different Terminals (a) and Transportation Operators (b)

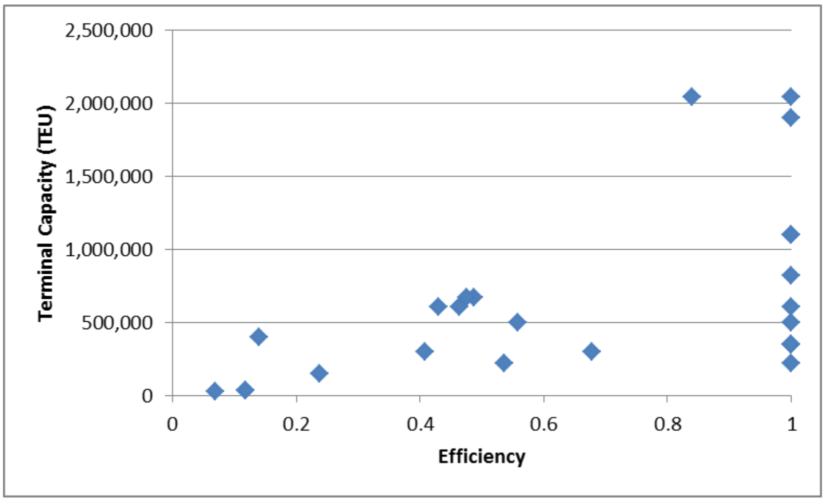


Figure 5.8. The Efficiency Of Different Terminals With Different Size

We can also examine the relation between the efficiency and length of the transportation service (Figure 5.8 and Table 5.4). Based on the sample of IFT chains in our analysis, there is no significant relation between the length of the transportation activity and the efficiency of transport operator; although it seems that the operators in the short-distance origin-destinations are more likely to be inefficient. We also observe that some transportation operators, e.g., IMS, Hupac, and Kombiverkehr have different efficiency scores in different corridors. For example, Hupac is active in four corridors. Three of these corridors are more than 700 km in which the operator is efficient. However, in one corridor, which is a short-distance connection with 182km, the operator is relatively inefficient.

TABLE 5.4 . The Efficiency Of Different Transport Operators With Different Length Of Service

(chain no., position in the chain)	Transport operator	Efficiency Score	Length (km)
R(4,1)	IMS	1.00	710
R(4,2)	IMS	1.00	174
R(6,1)	Kombiverkehr	1.00	204
R(6,2)	HUPAC	1.00	744
R(7,1)	Kombiverkehr	1.00	466
R(10,1)	HUPAC	1.00	783
R(9,1)	Metrans	0.84	558
R(5,2)	METRANS	0.74	727
R(7,2)	CEMAT	0.72	488
R(3,1)	HUPAC	0.70	727
R(1,2)	CEMAT	0.64	488
R(1,1)	HUPAC	0.54	182
R(5,1)	Danser	0.49	110
R(2,1)	IMS	0.48	928
R(8,1)	Naviland Cargo	0.35	301

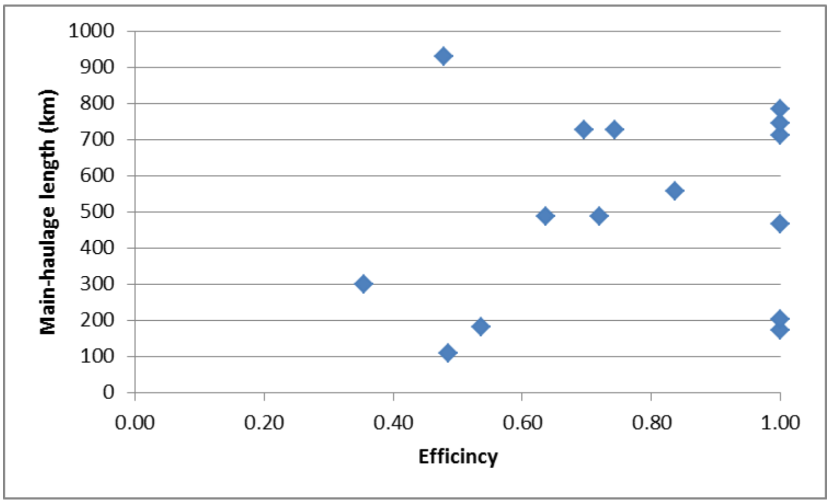


Figure 5.9. The Efficiency Of Different Transport Operators With Different Length

5.5. Concluding Remarks and Future Work

To improve the performance of IFT networks (for example, at the EU level), and suggest effective policies to promote IFT market share, we need to have an overall picture of the (less) efficient IFT chains and understand the main activities that cause the inefficiency in an IFT network. None of the previous works on DEA-based efficiency measurement considered IFT as a multi-division transport chain and calculate its efficiency. Therefore, this chapter presented a slacks-based network DEA method to measure the performance of different intermodal freight transport chains inside a freight network. The Slacks-based models avoid the weakly efficient DMUs in the set of efficient DMUs and consequently have more discriminatory power in ranking the studied DMUs. Applying this model, we can find the less efficient IFT chains, and at the same time, we can find the respective less efficient division(s) which is (are) explaining the total inefficiency of the chain. However, there are two main challenges in the application of this model for IFT domain. The first challenge is the number of divisions because, in an IFT network, we may have different IFT chains with the different structure, and number of divisions (number of sequential transshipment and transportation activities). To cope with this challenge, we discussed a revised formulation in which transshipment and transportation activities - disregard of their position in IFT chain - can be put in one benchmark set. We call this property of the IFT service “substitutability”. To do that it is necessary that different divisions in the chains, which are doing the same activity (e.g., transshipment or transportation), have the same technology. The second challenge in the application of the NDEA models to transport domain, in general, and for IFT chains specifically, is defining a relevant intermediate service. We extensively discussed the requirements for defining this intermediate service in this chapter and concluded that the value creation in the consecutive divisions of an IFT chain can be an appropriate intermediate service in this case. We called this value as the value of intermodal freight transport service (VIFTS) and discussed the formulation for measuring VIFTS for transportation and transshipment activities. Finally, to illustrate, we applied the presented model to a sample of 10 IFT chains in European IFT network. The results of the model were used to compare different IFT chains and also analyze the source of inefficiency in each chain. Looking at the results of the illustrative case, a general conclusion would be that the focus of improvement efforts in the majority of corridors should be on the terminal divisions. The results show that for a terminal to be efficient, it is sufficient to be large. Moreover, based on the sample of IFT chains in our analysis, there is no significant relation between the length of the transportation

activity and the efficiency of transport operator; although it seems that the operators in the short-distance origin-destinations are more likely to be inefficient. We also observe that some transportation operators, e.g., IMS, Hupac, and Kombiverkehr have different efficiency scores in different corridors, which means the efficiency of an operator could be different in different routes and corridors. It should be noted that because of the lack of data we have assumed average values, i.e. handling cost, or aggregate values, i.e. transport operation cost and external cost which could reduce the discriminatory power of the model.
The presented model and results can be used by policy-makers to measure the efficiency of the IFT chains and focus on the less efficient divisions, as the primary target of performance improvement, in order to promote IFT service.
Policy-makers can also investigate the source of inefficiency. As mentioned in this paper, the source of inefficiency of different divisions could be the inefficient usage of the resources to create a certain output. We call this the "divisional source" of inefficiency; i.e., the low performance of division is because it does not use the source inputs in an efficient way. Moreover, the inefficiency could be the result of deploying certain resources to a chain and corridor without taking into account the resource planning of other tiers in the network. In other words, one division might have invested in extra input resources but cannot deploy those resources because of the network effect and lack of resources by following steps of the chain. We call this the "network source" of inefficiency. The source of inefficiency could also be related to the market structure, fiscal measures, government financial support, or technical regulation that could influence different sub-markets in Europe. We call this the "environmental source" of inefficiency – since it is not because of actors in the chain or their interactions.

It is noteworthy to emphasize again that the results of the illustrated case study need to be interpreted in light of the following limitations and assumptions:

- Because of the lack of detailed data for each operator, we have considered the average handling cost for all the terminals and aggregated data i.e., the total operation cost and external cost, instead of physical inputs (e.g., labor and facilities) for transport operators.
- There was no hedonic pricing function estimated based on the European data. Developing such a function was not part of the scope of this research and for the illustrative case, we used the function presented by Konishi et al. (2014) for Japan transport network. Indeed, in our future work, as we aim to apply the model to a real case EU network, we would aim to calibrate that function for European transport network.

There are several potential interests for further research. One possibility is including resource sharing in the model to measure the efficiency of the chains or corridors with overlap in nodes or links which help more detail analysis at the network level. Applying the resource sharing it is possible to see the effect of the different IFT chains which have overlap on each other in different parts of the network, in terms of e.g., the resource usage, cooperation, and congestion. Applying the model to a real case, like European IFT network, is the other direction in our future research. Indeed, in that case, the detailed data should be used to increase the discriminatory power of the model. Taking into account the effect of the deregulation policies on the efficiency of the European IFT chains is a possible direction for the future research as well. Assigning the weight to different divisions of a chain based on their cost or market Characteristics could be another possible extension of the model.

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APPENDIX 5A- Data of Different IFT Chains

Terminal Data

No	Terminal	Capacity per annum TEU	Lot size- (m2)	Length of tracks (m)	No. of tracks	No. of cranes (RMG)	Total Stackers	VIFTS
1	Beatrix Terminal	500,000	262,000	937	3	12	7	69,600
2	Ludwigshafen KTL	300,000	130,000	4,116	7	4	4	69,600
3	Verona Quadrante Europa	603,000	360,000	9,750	15	7	8	69,600
4	Container Terminal Altenwerder	1,900,000	1,106,146	3,600	9	19	1	63,873
5	Rail Cargo Terminal BILK	220,000	223,000	750	7	2	4	63,873
6	Combinant (Quay 755)	150,000	125,000	3,100	5	3	1	301,720
7	Busto Arsizio (Gallarate)	1,100,000	242,800	7,290	11	12	2	301,720
8	Eurogate C.T.	2,040,000	1,400,000	4,590	6	4	1	386,070
9	Enns Hafen CTE	350,000	80,000	3,000	4	1	6	386,070
10	Wien Freudenau Hafen CCT	817,000	120,000	4,550	7	3	14	386,070
11	PROGECO ZEEBRUGGE	35,000	20,000	600	6	8	3	235,374
12	Rail Service Center (RSC)	350,000	240,000	750	8	4	5	235,374
13	METRANS Praha	671,200	420,000	7,400	15	5	21	235,374
14	RCT Rotterdam	500,000	170,000	190	3	1	1	32,200
15	DUSS-Terminal Duisburg	220,000	140,000	5,980	9	3	4	32,200
16	Wien Freudenau Hafen CCT	603,000	360,000	9,750	15	7	8	32,200
17	DUSS Billwerder	400,000	850,000	7,660	12	7	4	61,409
18	Ludwigshafen KTL	300,000	130,000	4,116	7	4	4	61,409
19	Verona Quadrante Europa	603,000	360,000	9,750	15	7	8	61,409
20	VAN DOORN	25,000	160,000	300	1	1	5	52,683
21	Paris Valenton	350,000	208,190	1,100	4	2	12	52,683
22	Eurogate C.T.	2,040,000	1,400,000	4,590	6	4	5	261,610
23	METRANS Praha	671,200	420,000	7,400	15	5	21	261,610
24	PROGECO ZEEBRUGGE	35,000	20,000	600	6	8	3	116,013
25	Busto Arsizio (Gallarate)	1,100,000	242,800	7,290	11	12	2	116,013

Main-haulage operators

IFT chain	Main-haulage operators	Capacity*	Frequency (per week)**	Distance (KM)***	Total Operation Cost	Total External cost	VIFTS
1st chain	HUPAC	262,385	10	182	140,428	73,106	187,720
	CEMAT	171,793	8	488	291,361	144,297	291,200
2nd chain	IMS	77,114	5	928	430,221	206,250	310,440
3rd chain	HUPAC	173,245	10	727	1,696,411	823,376	507,520
4th chain	IMS	16,096	15	710	2,092,410	1,018,132	745,680
	IMS	20,444	14	174	739,132	386,173	257,712

IFT chain	Main-haulage operators	Capacity*	Frequency (per week)**	Distance (KM)***	Total Operation Cost	Total External cost	VIFTS
5th chain	Danser	624,000	10	110	320,950	171,622	149,240
	METRANS	310,389	10	727	1,298,202	630,928	505,440
6th chain	Kombiverkehr	307,552	10	204	69,348	35,941	200,200
	HUPAC	115,845	5	744	180,663	87,700	256,620
7th chain	Kombiverkehr	27,504	10	466	243,717	121,143	351,000
	CEMAT	315,797	8	488	252,180	125,057	291,200
8th chain	Naviland Cargo	229,787	6	301	151,306	76,890	153,504
9th chain	Metrans	59,746	12	558	1,186,350	584,338	487,344
10th chain	HUPAC	160,855	10	783	675,991	327,301	536,640

* This data is coming from Intermodal Yearbook(2004) presented in chapter 3.
** From Inlandlinks website.
*** Source: http://www.distancefromto.net/

Corridors & IFT chains Flows

Corridor* / *IFT chain*	Assigned Flow (TEU)
Rotterdam-Ludwigshafen-Verona (20)	40,804
Beatrix Terminal – HUPAC - Ludwigshafen KTL - CEMAT - Verona Quadrante Europa	*1,740*
Hamburg – Budapest (68)	18,010
Container Terminal Altenwerder (CTA) – IMS - Rail Cargo Terminal BILK	*1,597*
Antwerp - Milano (43)	40,829
Combinant (Quay 755) – HUPAC - Busto Arsizio (Gallarate)	*7,543*
Bremen - Wels - Wien (33)	39,900
Eurogate C.T. – IMS - Enns Hafen CTE- IMS - Wien Freudenau Hafen CCT	*9,652*
Zeebrugge - Rotterdam- Praha (54)	68,757
PROGECO ZEEBRUGGE – Danser - Rail Service Center (RSC) – METRANS – Terminal METRANS Praha	*5,884*
Rotterdam-koln-Wien (4)	40,829
RCT Rotterdam - Kombiverkehr - DUSS Terminal Duisburg- HUPAC- Wien Freudenau Hafen CCT	*805*
Hamburg-Ludwigshafen-Verona (17)	17,985
DUSS Billwerder - Kombiverkehr - Ludwigshafen KTL - CEMAT - Verona Quadrante Europa	*1,535*
Antwerp-Paris (65)	40,829
VAN DOORN - Naviland Cargo - Paris Valenton	*1,317*
Bremen-Praha (53)	52,322
Eurogate C.T. - Metrans - METRANS Praha	*6,540*
Zeebrugge - Milan (66)	34,804
PROGECO ZEEBRUGGE - HUPAC - Busto Arsizio (Gallarate)	*2,900*

** These corridors and their respective flows are coming from the EU IFT network explained in chapter 3.*

APPENDIX 5B- Hedonic Pricing Function

Halvorsen and Pollakowski (Halvorsen & Pollakowski, 1981) present a general functional form for hedonic pricing:

$$P^{(\theta)} = \alpha_0 + \sum_{i=1}^{m} \alpha_i Z_i^{(\Delta)} + \frac{1}{2}\sum_{i=1}^{m} \sum_{j=1}^{m} \gamma_{ij} Z_i^{(\Delta)} Z_j^{(\Delta)} \qquad (5a)$$

Where P is price, the Z_i are attributes, and $P^{(\theta)}$ and $Z_i^{(\Delta)}$ are Box-Cox transformations,

$$P^{(\theta)} = \begin{cases} (P^{\theta} - 1)/\theta & ,\theta \neq 0 \\ Ln\, P & ,\theta = 0 \end{cases} \qquad (5b)$$

$$Z_i^{(\Delta)} = \begin{cases} (Z_i^{\Delta} - 1)/\Delta & ,\Delta \neq 0 \\ Ln\, Z_i & ,\Delta = 0 \end{cases} \qquad (5c)$$

Assuming different values for θ and Δ we can define different functional forms. For example, by imposing $\theta = \Delta = 1$ we have the Lin-Lin form (Halvorsen & Pollakowski, 1981):

$$P = c_0 + \sum_i c_i Z_i + \sum_i \sum_j \gamma_{ij} Z_i Z_j \qquad (5d)$$

Where:

$$c_0 = 1 + \alpha_0 - \sum_i \left(\alpha_i - \frac{1}{2} \sum_j \gamma_{ij}\right), c_i = \alpha_i - \sum_j \gamma_{ij} \qquad (5e)$$

Other useful specifications are Log-Log ($\theta = \Delta = 0$), Lin-Log ($\theta = 1, \Delta = 0$), and Log-Lin ($\theta = 0, \Delta = 1$). Considering the quality of estimates for the explanatory variables, the best fitting specification should be looked for.

Chapter 6

Conclusion and Further Research

The market and performance of IFT service at the network level has been analyzed in this thesis by developing novel models. This chapter summarizes the contributions of this thesis and discusses some important directions for future research.

6.1. Introduction

An IFT service comprises of different IFT chains—which themselves include different actors providing different services (i.e., pre- and end-haulage, transsshipment, and main-haulage). All these IFT chains, together, form an IFT network. Although different segments of IFT systems have been analyzed separately in some previous research studies, looking at the whole system and analyzing IFT chains at the network level has not received much attention. This network level analysis is especially important since efficient segments for a chain do not necessarily imply an efficient IFT chain and an IFT chain needs to work effectively as a whole. Furthermore, to provide IFT service between an origin and destination, different IFT chains are competing with each other (and not separate segments). Therefore, in this thesis, we have had two main research directions: IFT market structure analysis at the network level, and measuring the performance of the IFT operators at the network level. Accordingly, we formulated the following two main research questions in this study:

- How can we analyze the IFT market structure at the network level?
- How can we measure the performance of an IFT chain in a network?

The answers to these research questions and a set of findings throughout this thesis are presented in the following subsections. Section 6.2 is about the main scientific achievements. After discussing the findings and the policy implications in sections 6.2 and 6.3, recommendations for future research are given in section 6.4.

6.2. Main Scientific Contributions

The main scientific achievements of this thesis can be listed in two main directions: market structure analysis, and performance measurement of IFT systems at the network level.

6.2.1. Market Structure Analysis:

To analyze the market structure, we have two main contributions that have been presented in chapters 2 and 3:

- ***Developing An Intermodal Freight Transport Market Structure (IFTMS) Model:***

To analyze the market structure in an IFT network, we presented a model called "Intermodal Freight Transport Market Structure (IFTMS) model". This model uses graph theory and defines distinct submarkets in an IFT network. These submarkets are represented as nodes (transshipments), links (main-haulages), and paths (corridors, and ODs). Subsequently, the model combines the market structures on IFT submarkets and extends them to the network level. In summary, the presented model can be used:

- To consider the multistage characteristic of the IFT service in analyzing the market structure of IFT service in a network.
- To identify and distinguish a number of submarkets inside an IFT network. These submarkets are corresponding to the services, which are provided through an IFT chain: pre-haulage, end-haulage, transshipment, main-haulage, and so on.
- To incorporate a flow optimization model to assign the capacities on links, nodes, and paths of the IFT network, and measure the concentration of IFT submarkets in a consistent way.

- To analyze the effect of different IFT business strategies, e.g., merger and acquisition on the structure of the IFT market.

- ***Developing A Four-Step Methodology*** which is complementary to the IFTMS model:

To study the market structure of real IFT networks, for example, the European intermodal network, there are two main challenges. First is the definition of the relevant geographical transshipment submarkets. The other challenge is the availability of detailed data—especially at the chain level. To cope with these two main challenges, a methodology that is complementary to the IFTMS model is presented in the third chapter. This methodology applies a conservative model-based approach to define the geographic boundaries of the transshipment submarkets and creates a data set for market analysis. This methodology is used:

- To define the relevant geographical transshipment submarkets in an IFT network.
- To assign the total capacity of a transport operator to its belonged paths.
- To assign the flow to different corridors of a freight transport network.
- To measure the market structure of the European intermodal freight network.

6.2.2. Performance measurement:

To measure the performance of an IFT network, we have two main contributions, which have been presented in chapters 4 and 5:

- ***Performing a Systematic Literature Review*** about the performance measurement in freight transport systems.

We find that a systematic literature review about the performance measurement in freight transportation systems has not been carried out yet. In some cases, the performance of a part of the freight transport has been reviewed, but none of the papers reviewed the freight transport system as a whole. In the fourth chapter, we reviewed the literature on the performance measurement of freight transport systems, which includes both methodological, and application contributions to the domain.

- ***Developing A Modified Network DEA Model*:**

The performance of an IFT service is attributed to two main factors: the performances of different IFT chain divisions, and the co-operation and harmony of these divisions. Despite the importance of efficiency measurement, studies on the performance measurement of IFT chains are quite limited. In chapter 5, we develop a modified Network DEA model which:

- Measures the efficiency of the IFT chains with different structures (different number of divisions), and their respective divisions.
- Considers the concept of “value of the service” as the intermediate measure in the model.

6.3. Main Practical Findings and limitations

Besides the presented models in this thesis, the application of models to the case of EU intermodal network has resulted in some empirical insights. The main empirical findings of different chapters of the thesis show that:

Applying IFTMS model to a numerical example in chapter two indicates that concentration degrees on certain links (Main-haulage submarkets) and nodes (Transshipment submarkets) could already be high and probably might increase further due to a merger on a certain link or node. This suggests that horizontal mergers in a certain submarket could earlier be regarded as a deal breaker by antitrust authorities rather than vertical mergers. Next, concentration degrees in corridors might increase considerably due to a horizontal merger in a certain corridor submarket; however, network concentration degrees might still not be regarded as too high. Thus, a merger on a certain link (Main-haulage submarket) or node (Transshipment submarket) does not necessarily have a large impact on network concentration degrees. In the application of the model to an illustrative case, we made some assumptions, i.e., simple business models for different operators, fair flow distribution in the network, and considering the barge and rail operators in a same main-haulage submarket. All these assumptions would lead to a lower bound of market concentration in the IFT network and therefore, the results of the study should be interpreted in the light of this fact.

The analysis of EU IFT network in the third chapter shows that in most areas the transshipment and main-haulage submarkets are highly concentrated. The majority of corridor submarkets are unconcentrated, and O-D pair submarkets are highly concentrated at the corridor level and unconcentrated at the chain level. As mentioned in the chapter, the findings of this study need to be interpreted in a conservative way in light of the methodological limitations and assumptions, e.g., the demand for IFT service is concentrated in one demand point and the operators provide homogenous services, or the capacity is assigned to different corridors in a fair way. Even this lower bound implies a high level of concentration in transshipment, main-haulage, and O-D pair submarkets, which implies that highly-concentrated submarkets exist in the EU IFT network in reality.

The literature review in the fourth chapter shows that Network DEA has been applied to the freight transport domain, but all the papers only applied multi-activity (-function) NDEA which focus on un-storable feature of transportation service, by dividing the transport service to production and consumption activities, not the multi-division NDEA which assume a transport service as a vertical chain of different divisions.

The model developed in the fifth chapter is applied to a sample of European IFT network. The results of the model were used to compare different IFT chains, and also analyze the source of inefficiency in each chain. Looking at the results, a general conclusion would be that the focus of improvement efforts in the majority of corridors should be on the terminals. The results show that for a terminal to be efficient, it is sufficient to be large. Moreover, based on the sample of IFT chains in our analysis, there is no significant relation between the length of the transportation activity and the efficiency of transport operator; although it seems that the operators in the short-distance origin-destinations are more likely to be inefficient. We also observe that some transportation operators, e.g., IMS, Hupac, and Kombiverkehr have different efficiency scores in different corridors, which means the efficiency of an operator could be different in different routes and corridors – possibly because of the network influence of other actors in the chain. It should be noted that because of the lack of data we have assumed average values, i.e. handling cost, or aggregate values, i.e. transport operation cost and external cost which could reduce the discriminatory power of the model. Therefore, the results should be treated with some caution.

6.4. Policy Recommendations

The developed models and achievements of this thesis can have different policy implications:

The IFTMS model developed in the second chapter could be used by antitrust authorities to investigate the anticompetitive practices in the IFT network. They can evaluate the effects of different business practices on competition and concentration in the IFT market and overall on the welfare of the society. It can also be used by business managers to examine the market implication of their business practices. The impact of anticompetitive business practices on the market structure of the IFT network depends on the chosen level of analysis. Next, different indicators that represent the market structure and competition might react differently to the business integration.

The third chapter presents a stepwise methodology for policy-makers, and antitrust authorities to study the market structure of the IFT network. The results of the model's application to EU IFT network provide insight into the market structure and the submarkets with higher priority in terms of competition policy making. Finally, the impact of policies to promote IFT in the EU or the other continents can be evaluated using this model. As mentioned before, the presented methodology in the third chapter gives a "lower bound" of actual concentration for different IFT submarkets. In other words, if the results of applying the presented methodology imply a high concentration in one submarket or in one region—that are possible options for policy making and interventions—the actual concentration would be higher than the estimated value. The model can also be used by companies and practitioners to study the potential market implications of their business practices.

The content of the fourth chapter could be used by policy-makers to have an overall view about the performance measurement methods, and the works have been done in freight transport domain.

Policy-makers can use the presented model in chapter 5 to measure the efficiency of the IFT chains and focus on the less efficient divisions, as the primary target of performance improvement, in order to promote IFT service. A general conclusion of applying the model to a sample of European IFT network would be that the focus of policy-makers to improve the performance of the IFT network, in the majority of corridors, should be on the terminals. Policy-makers can also investigate the source of inefficiency. As mentioned in this paper, the source of inefficiency of different divisions could be the inefficient usage of the resources to create a certain output. We call this the "divisional source" of inefficiency; i.e., the low performance of division is because it does not use the source inputs in an efficient way. Moreover, the inefficiency could be the result of deploying certain resources to a chain and corridor without taking into account the resource planning of other tiers in the network. In other words, one division might have invested in extra input resources but cannot deploy those resources because of the network effect and lack of resources by following steps of the chain. We call this the "network source" of inefficiency. The source of inefficiency could also be related to the market structure, fiscal measures, government financial support, or technical regulation that could influence different sub-markets in Europe. We call this the "environmental source" of inefficiency – since it is not because of actors in the chain or their interactions.

6.5. Recommendations for Future Research

In this thesis, we developed two main models, i.e. IFTMS model for IFT market structure analysis (Chapters 2&3), and Modified NDEA model for IFT performance measurement (Chapters 4&5). These models could help policy-makers to better analyze the IFT market and developing policies to increase the market share of the IFT service. In the current setup, the IFT network developed in Chapter 3 is used as an illustrative case in Chapter 5 to show how developed NDEA model can be applied to the real case and what the expected results would look like. Considering the market structure of an operator as a parameter, which affects its performance is an interesting direction for the future research that can make a better connection between two models presented in this thesis.

In this section, a number of possible directions for future research are outlined. These directions are based on the conclusions and the reflection on those conclusions and process of this research.

Extending IFTMS Model. The market structure of intermodal freight transport network as explored in the second chapter was already quite complicated under the assumptions made. Still, to better reflect the reality of business, some possibilities for more complex situations are suggested for further research. First, more complex business models can be introduced such as more operators per submarket, different service offerings in different submarkets by the same business operator, different competitive powers per business operator, and the inclusion of other types of business integration. Second, the presented network model can be extended by introducing, for example, pre-, end-haulage, and using other flow allocation methods. We can also make a differentiation between operators in different markets, considering the time and cost elements, in extending the IFTMS model. In this research, we used the capacity of the operators to measure the market share. Using other variables e.g., revenue or sale could be a future direction for research.

Application of IFTMS model and the complementary methodology of chapter 3 to other cases: The approach presented in the third chapter can be applied in other cases in the transport domain. It is especially useful to use the model in cases for which sample data need to be constructed from existing aggregate data. Analyzing the dynamics of market structures in the IFT sector and its evolution over time is another possibility for future research. The impact of policies to promote IFT in the EU can be studied in such a dynamic market structure analysis. In the higher level of analysis, the competition between the IFT corridors and unimodal-truck transport between different O-D pairs can also be measured by assigning the total freight flows to the freight transport networks. As the next step, considering the structure of the different submarkets, the behavior and conduct of different operators can be investigated.

Extending the Modified Network-DEA model: There are several potential interests for further research. One possibility is including resource sharing in the model to measure the efficiency of the chains or corridors with overlap in nodes or links, which require a more detailed analysis at the network level. It also helps to study the effect of the different IFT chains, with overlap, on each other in different parts of the network, in terms of e.g., the resource usage, cooperation, and congestion. Applying the model to a real case, like European IFT network is another direction of future research. The application of the model in chapter 5 aimed at an illustrative case and therefore, it includes a small network with some simplifications and assumptions. Indeed, in the real case of EU network, the detailed data – e.g., the actual physical facilities or assets for terminal and transport operators - is needed to increase the discriminatory power of the model. Although gathering that detailed data for such a case is expected to be a time-consuming process, I believe this study would provide a sound basis for regulation and policymaking at the EU level – and can be potentially repeated every few years to monitor the efficiency of IFT networks and the need for re-regulation. Taking into account the effect of the new policies on the efficiency of the European IFT chains is, therefore, another possible direction for future research.

ABOUT THE AUTHOR

Hamid Saeedi was born in Tehran, Iran in 1980. He obtained his B.Sc. in Industrial Engineering (Planning and Analyzing the Systems) from Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran in 2002. Afterwards, he did his Master study in Socio-Economic Systems Engineering in Institute for Management and Planning Studies (IMPS), Tehran, Iran. He worked in Iran Khodro Company (IKCo) as an Economic researcher and market analyzer. In 2007, He joined Tarhe-No-Andishan (TNA) consulting company in Iran. In TNA, he was working on different projects as a business analyst and project manager. After working for several years in different companies, he decided to return to academia as a Ph.D. researcher. He joined the Transport and Planning Department, Delft University of Technology in April 2012. He was working on a project called “Network level analysis of market and performance of Intermodal Freight Transport”. The most interesting parts of that project have been presented in this book. From Nov. 2016 he was also involved in the SELIS (Shared European Logistics Integrated information System) project in Erasmus University Rotterdam, as a part-time senior researcher working on the concept of Synchromodal Freight Transport Systems. He is now working as a Postdoctoral researcher in Wageningen University, Operation Research and Logistics (ORL) Group.

Publications

Journal Papers:

1- **Saeedi, H.,** Wiegmans, B., Behdani, B., & Zuidwijk, R. A, "*European Intermodal Freight Transport Network :Market Structure Analysis*", Journal of Transport Geography, Vol. 60, PP. 141-154, April 2017.

2- **Saeedi, H.,** Wiegmans, B., Behdani, B., & Zuidwijk, R. A, "*Analyzing competition in intermodal freight transport networks: the market implication of business consolidation strategies*", Research in Transportation Business and Management Journal, Vol. 23, PP. 12-20, June 2017.

3- **Saeedi, H.,** Behdani, B., Wiegmans, B., & Zuidwijk, R. A, "*Performance Measurement in Freight transport systems: A Literature Review*", submitted to Transport Reviews.

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