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Evaluation and Modelling of Short Haul Intermodal Transport Systems

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ABSTRACT

The most significant development for intermodal transports was the birth of the shipping container, which in 1956 started a revolutionary movement for global business referred to as containerization (Levinson, 2006). Regarding the sub-sequential inland movements of standardized unit loads, conventional intermodal rail freight transport systems have proved themselves competitive and able to offer cost-leadership on long distances and in endpoint relations between two nodes. Several studies within intermodal transports have made contributions in finding the minimum distance, the "break-even" distance, which an intermodal door-to-door shipment can compete with unimodal road. The results for European conditions are found in the range 300-800 km, shown in for example Williams & Hoel (1998); Nelldal et al. (2008) and Kim & Van Wee (2011). Movements of unit loads below this "break-even" distance are defined as short haul in this thesis. Note that this break-even distance is influenced by regional and local conditions, thus the definition of short hauls differs in an international context. The main aim of this doctoral thesis has been to analyse under which conditions a short haul transport system with the railway as a base can be considered a feasible solution. This has been conducted within the framework of two research projects.

In the main research project of this thesis; REGCOMB (Regional Combined Transport System – A system study in the greater Stockholm-Mälaren region), the feasibility is evaluated in a bi-sectional manner; first a quantitative assessment is carried out where costs and CO_2 emission are estimated for a set of transport alternatives in the greater Stockholm region, Sweden. The project involves a case study of a shipper's distribution of daily consumables in the Stockholm-Mälaren region. The case study evaluates the concept of an *intermodal liner train*, which differs from other conventional rail freight systems, as it similar to a passenger train makes stops along the route for loading and unloading. Due to the stops made at intermediate stations it enables the coverage of a larger market area. For regional and urban flows, the concept has the potential of reducing drayage on road to and from intermodal terminals; and to make intermodal rail freight services also competitive on short hauls.

The quantitative assessment has been accomplished by the development of a cost model, *Intermodal Transport Cost Model (ITCM).* The results of the case study show that the most critical parameters for the efficiency of intermodal rail freight services on short hauls are the train's loading space utilization and the transshipment. Time and cost spent for transshipment at terminals restrict the competitiveness of intermodal services on shorter distances as these parameters are not proportional to transported distance but rather to the utilization rate of resources. Hence, the concept *of cost-efficient small scale (CESS) terminals* is introduced and evaluated in this study. Although, the results of the case study indicate that the evaluated transshipment technologies are closing the gap to unimodal road haulage regarding costs, it is essential that also the transport quality is ensured, in particular regarding reliability and punctuality, which is why demonstration projects are recommended as these aspects require operational testing. This is particularly crucial regarding novel transshipment technology. Unreliable and complicated transshipment procedures increase the disturbance sensitivity of the whole transport chain. As for emissions, all evaluated intermodal transport chains contribute to a significant decrease in CO_2 emissions compared to unimodal road.

Second, a qualitative assessment of the socio-technical system is carried out regarding stakeholders' perspectives and requirements; based on the participative research i.e. experts involved in in-depth interviews, workshops and a survey. The system must satisfy broader policy objectives of local authorities and commercial corporate interests in order to be adopted. Albeit interest for regional short haul intermodal transport is shown by individual public officials as for instance expressed in our workshops; the political will from local authorities in the region must be more consolidated and concretized for the system to become a feasible solution for shippers. The business model that represents the conceptual idea of the study is identified as 'the local cooperation model', where the intermodal transport service is organized by several local actors along a transport route, commonly in cooperation with local authorities. The stakeholders include shippers, operators, infrastructure owners and local authorities. This model is considered challenging in the sense that it is difficult to agree on an appropriate division of responsibilities and revenues among the partners and that there is no clear channel leader. Maintaining a partnership of core partners is important for the business model to be successful.

Regions where cost-leadership coincides with a strong will from local authorities to implement regulations in the freight transport market that promote intermodal transports have created a foundation for implementing short haul intermodal rail freight services. Two operational examples are presented in this thesis; the E&S system in Japan and the Innovatrain system in Switzerland.

In the minor research project of the thesis; BIOSUN (Sustainable Intermodal Supply Systems for Biofuel and Bulk Freight), an evaluation is carried out regarding rail-based multimodal transportation of wood biofuels. In essence, it is the factors affecting rail transportation of biofuel and the inherent capability of the rail mode that are addressed. The qualitative evaluation consists of STEEP analysis for the external factors influencing the transport system and sustainability analysis for the internal factors. These methods are complemented by a quantitative analysis of the niche market and modelling of a case study. A main conclusion from the qualitative analysis within the BIOSUN project is that rail transportation of biofuel faces a number challenges that in many cases are related to a relatively high volume requirements and operational inflexibility. The main drivers for it are commonly associated with economies of scale and the relatively low environmental impact. The case study offered an opportunity to model a rail-based multimodal transport chain for the supply of a heating plant in Gothenburg, Sweden. The results of the case study show that the break-even distance is considerably lower for biofuel transport chains than for other commodities; 180-250 km, which is mainly due to the requirement of road-road transshipment as well as the fact that intermodal terminals can be combined with wood processing facilities.

Keywords: Short haul intermodal rail, Transport systems, Transshipment, Stakeholder analysis, Logistics, Evaluation and Modelling

SAMMANFATTNING

Den mest betydande händelsen för utvecklingen av intermodala godstransporter var uppkomsten av containern 1956, vilket startade en revolutionär rörelse kallad containerisering och som la grunden för globaliseringen (Levinson, 2006). När det gäller landstransporter av standardiserade enhetslaster har konventionella intermodala transporter baserad järnväg visat sig konkurrenskraftiga på långa avstånd och i förbindelserna mellan två noder. Flera studier har bidragit till att hitta det minsta avståndet, brytpunktsavståndet, där kostnaden för en intermodal transportkedja motsvarar densamma som för direkt vägtransport. Resultaten för europeiska förhållanden återfinns i storleksordningen 300-800 km, som visas i till exempel Williams & Hoel (1998); Nelldal et al. (2008) och Kim & Van Wee (2011). Transporter av enhetslaster under denna brytpunkt definieras i denna avhandling som kortväga transporter. Observera att detta avstånd påverkas av regionala och lokala förhållanden, alltså skiljer det sig i ett internationellt sammanhang. Huvudsyftet med denna avhandling har varit att utvärdera under vilka förutsättningar ett intermodalt transportsystem med järnvägen som bas kan betraktas som en möjlig lösning för godstransporter på korta avstånd. Utvärderingen har genomförts inom ramen för två forskningsprojekt.

Avhandlingens huvudsakliga forskningsprojekt är REGCOMB (Regionala kombitransporter - En systemstudie i Mälardalsregionen), där huvudsyftet har varit att analysera under vilka förutsättningar som ett regionalt kombitransportsystem kan etableras i Mälardalen. Den kvantitativa metodiken för utvärderingen baseras på att modellera kostnader och CO_2-utsläpp för en uppsättning transportalternativ i regionen. Projektet omfattar en fallstudie av en grossists distribution av dagligvaror i Mälardalsregionen. Fallstudien utvärderar konceptet *intermodalt linjetåg*, vilket skiljer sig från konventionella godstransportsystem på järnväg då det likt ett passagerartåg gör stopp för lastning och lossning på mellanliggande stationer. På grund av dessa stopp möjliggörs en större marknadstäckning. För regionala och urbana flöden har konceptet potential att minska matartransporter på väg till och från kombiterminaler och att göra intermodala godstransporter på järnväg mer konkurrenskraftiga på korta avstånd.

Den kvantitativa utvärderingen har åstadkommits genom att utveckla en kostnadsmodell, ”*Intermodal Transport Cost Model (ITCM)*”. Resultaten av fallstudien visar att de mest kritiska parametrarna är att tågets lastutrymme utnyttjas optimalt och att omlastningen sker effektivt. Tid och kostnad som spenderas för omlastning av enhetslaster begränsar konkurrenskraften för intermodala transporter på korta sträckor då dessa inte är proportionerliga med det transporterade avståndet utan med tid och utnyttjandegraden av resurser på kombiterminaer. Därför introduceras och utvärderas i denna studie konceptet småskaliga och kostnadseffektiva kombiterminaler *”cost-efficient small scale (CESS) terminals”.* Resultaten av fallstudien visar att de utvärderade omlastningsteknikerna bidrar till att minska klyftan mellan intermodala transporter och direkta vägtransporter avseende transportkostnad samt till en betydande minskning av CO_2-utsläpp. Det är dock viktigt att även transportkvaliteten garanteras, i synnerhet när det gäller pålitlighet och punktlighet. Demonstrationsprojekt rekommenderas då dessa aspekter kräver operationella tester. Detta är särskilt viktigt när det gäller ny omlastningsteknik. Opålitliga och komplicerade omlastningsförfaranden ökar störningskänsligheten i hela den intermodala transportkedjan.

Även en kvalitativ utvärdering har utförts för det socio-tekniska systemet avseende intressenternas perspektiv och behov; baserad på experter som har deltagit i workshops, djupintervjuer och en enkätundersökning. Systemet måste uppfylla myndigheters bredare politiska mål och företagens kommersiella intressen för att kunna etableras. Den ”lokala samarbetsmodellen" är den affärsmodell som bäst representerar den konceptuella idén med projektet. I modellen organiseras transporttjänsten av flera lokala aktörer längs en transportväg, vanligen i samarbete med lokala myndigheter. Intressenterna omfattar varuägare, operatörer, infrastrukturägare och lokala myndigheter. Denna modell anses vara utmanande i den meningen att det är svårt att komma överens om lämplig ansvarsfördelning och intäkter mellan parterna samt att det inte finns någon tydlig ledare. Därför är ett gott samarbete mellan ett antal kärnpartner en förutsättning för att affärsmodellen ska lyckas.

Regioner där intermodala transporter är konkurrenskraftiga avseende kostnad och där myndigheter utformar ett regelverk för godstransportmarknaden som främjar intermodala transporter - har skapat en grund för etableringen av intermodala godstransportsystem på järnväg på korta avstånd. Två operationella exempel på intermodala järnvägstransporter på korta avstånd som för närvarande är i drift presenteras i denna avhandling; ”Effective & Speedy”-systemet i Japan och Innovatrain-systemet i Schweiz.

I det andra och mindre forskningsprojektet i denna avhandling; BIOSUN (Hållbara intermodala transportsystem för biobränsle och bulkvaror) har en utvärdering genomförts avseende järnvägsbaserade transporter av trä och flis som används som biobränsle för värmeverk. I huvudsak är det de faktorer som påverkar järnvägstransporter av biobränsle och den inneboende förmågan hos järnvägen som behandlas. Den kvalitativa utvärderingen består av STEEP-analys för de externa faktorer som påverkar transportsystemet och en hållbarhetsanalys genomförs för de interna faktorerna. Dessa metoder kompletteras kvantitativt genom modellering av en fallstudie. Slutsatsen från den kvalitativa analysen är att järnvägstransporter av biobränsle står inför en rad utmaningar som i många fall är relaterade till en relativt hög volymkrav och låg flexibilitet. Å andra sidan är de huvudsakliga drivkrafterna förknippade med stordriftsfördelar och den relativt låga miljöpåverkan. Resultaten av fallstudien visar att brytpunksavståndet är betydligt lägre för transportkedjor av biobränslen än för andra varor; 180-250 km. Detta beror främst beror på den interna omlastning som krävs vägtranporter samt att intermodala terminaler kan kombineras med anläggningar för bearbetning av trä och skogsprodukter.

Nyckelord: Kortväga intermodala järnvägstransporter, Transportsystem, Omlastning, Intressentanalys, Logistik, Utvärdering och Modellering

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I am also very much grateful to my parents, two sisters and grandmother for their love and support. Thank you for assisting and encouraging me to pursue my dreams. Last but not least, to my wonderful son, Sam, thank you for motivating me and making every second spent with you a joy.

Behzad Kordnejad

2016-03-25

LIST OF PUBLICATIONS

This thesis is based upon the following five papers. The papers are appended in full in the second part of the thesis and have previously been published in scientific journals or conference proceedings. Behzad Kordnejad is the sole author of all papers except for paper V, where he is the main author with contributions from supervisor Professor Sebastiaan Meijer.

- Paper I: "Intermodal liner freight trains – opportunities and limitations", (2011), Proceedings of the 16th International Conference of Hong Kong Society for Transportation Studies, Hong Kong, China
- Paper II: "Intermodal Transport Chains and Competitiveness for Combined Transport", (2012), The 4th Annual TRANSLOG 2012 Conference, Burlington, Ontario, Canada
- Paper III: "Intermodal Transport Cost Model and Intermodal Distribution in Urban Freight", (2014), *Procedia - Social and Behavioral Sciences*, Volume 125, p. 358–372
- Paper IV: "Stakeholder Analysis in Intermodal Urban Freight Transport", (2016), *Transportation Research Procedia*, Volume 12, p. 750–764
- Paper V: "Evaluation of Rail-based Multimodal Transportation of Biofuels", (2015), *The* 6th International Conference on Railway Operations Modelling and Analysis, Tokyo, Japan

Related publications not included in the thesis:

- 2016, “Capacity4Rail - Deliverable 2.3.5 Operational costs of newly designed terminals: business cases and cost-benefit analyses”
- 2015, “Capacity4Rail - Deliverable 2.3.2 Measurements in Intermodal transport chains”
- 2015, “Capacity4Rail - Deliverable 2.3.1 Co-modal transshipments and terminals”
- 2016, “A Sustainability Analysis for Wood Biofuel Transport”, TBP 2016
- 2015, “Sustainable Intermodal Biofuel Transport”, ISBN 978-91-7246-336-3, BAS Publishing, Gothenburg, Sweden
- 2015, “Sustainable development in ICT-futures”, Submitted to Routledge TBP 2016
- 2013, “Regional Intermodal Transport Systems – Analysis and Case Study in the Stockholm- Mälaren Region”, Licentiate Thesis. TRITA-TSC-LIC 13-005, KTH Royal Institute of Technology, Stockholm, Sweden
- 2012, "Market for regional intermodal traffic in the Stockholm-Mälaren region”, (”Marknad för regional kombitrafik i Mälardalen”), Kordnejad, B., Working paper KTH.

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ABBREVIATIONS

BIOSUN	Sustainable intermodal supply systems for biofuel and bulk freight
CESS terminal	Cost-efficient Small Scale terminal
CCT	CarConTrain
DC	Distribution Centre
EC	European Commission
EF	Emission Factor
EMS	European Modular System
EUR-pallet	European pallet as specified by the European Pallet Association
GHG	Greenhouse Gas
HCT	High Capacity Transports
ICT	Information and Communication Technology
ITCM	Intermodal Transport Cost Model
KPI	Key Performance Indicator
LTL	Less than truckload
OR	Operations Research
PSI	Product, Social and Institutional
REGCOMB	Regional Combined Transport System – A system study in the greater Stockholm-Mälaren region
RQ	Research Question
SB	Swap Body
SIR-C	Swedish Intermodal Research Centre
ST	Semi Trailer
STEEP	Social, Technological, Economical, Environmental and Political
SWOT	Strengths, Weaknesses, Opportunities and Threats
TBP	To be published
TEU	Twenty-foot Equivalent Unit
UL	Unit Load
UN	United Nations
VRP	Vehicle Routing Problem

Cover photograph: JR Freight's "Effective & Speedy" Tokyo, Japan in March, 2015. (Behzad Kordnejad)

1 Introduction

The main aim of this thesis has been to evaluate the feasibility of short haul intermodal rail freight transport systems. The evaluation is based on two case studies in the Swedish freight market, the primary in regards to regional urban freight in the Greater Stockholm-Mälaren region and the secondary concerning transport chains for wood biofuel. The feasibility is quantifiably evaluated with respect to costs and emissions and qualitatively regarding societal, commercial and technological components of the transport system.

1.1 Background and Literature Review

The most significant development for intermodal transports was the birth of the shipping container, which in 1956 started a revolutionary movement for global business referred to as **containerization** (Levinson, 2006). The standardized metallic cargo carrier, enabled transportation to become much more efficient than previously, which meant reduced transportation costs and that the world market became expanded and integrated, where production of goods commonly moved to places with lowest production costs. Regarding the sub-sequential inland movements of standardized unit loads; conventional intermodal rail freight transport systems have proved themselves competitive and able to offer cost-leadership on long distances and in relations between two nodes. Several studies within intermodal transports have made contributions in finding the minimum distance, the "break-even" distance; an intermodal door-to-door shipment can compete with unimodal road. The results for European conditions are found in the range 300-800 km, shown in for example Williams & Hoel (1998); Nelldal et al. (2008) and Kim & Van Wee (2011).

Movements of unit loads below this break-even distance are defined as short haul in this thesis. Road haulage is the predominant mode for these shipments due to mainly cost-leadership but also other service attributes such as accessibility and flexibility. Note that this break-even distance is influenced by regional and local conditions, thus the definition of short haul differs in an international context. The main aim of this doctoral thesis has been to analyse under which conditions a short haul transport system with the railway as a base can be considered a feasible solution from a stakeholder perspective. This has been conducted within the framework of two research projects; **REGCOMB** *(Regional Combined Transport System – A system study in the greater Stockholm-Mälaren region)* and **BIOSUN** *(Sustainable Intermodal Supply Systems for Biofuel and Bulk Freight).* The latter concerning intermodal transport chains serving wood biofuel sourced by heating plants.

The main research project of this thesis; REGCOMB considers the conditions for feasibility in the greater Stockholm-Mälaren region. The global trend of urbanization is evident and in 2007 it was estimated that the urban population worldwide became larger than the rural and in Sweden 85% of the population lived in urban areas ([UN], 2011). This has led to congestion and negative environmental impact within urban areas and the problem will most certainly continue to grow in magnitude as the urban population will increase. Estimates show that this trend is also valid in Sweden and in the region of the greater Stockholm region, also referred to as the Mälaren valley, a region consisting of metropolitan Stockholm and areas around the lake of Mälaren. The region is one of Europe's financially strongest, where a number of consumption intensive and also some production intensive cities are located in proximity to each other ([SC], 2016).

In this context, efficient urban freight transportation has emerged as essential for sustainable development of urban areas. Geographic regions are being expanded due to the fact that rapid options for transportation have expanded the range of action of people and businesses. Metropolitan regions require freight transports that are often categorized by an inflow of groceries and consumables and an outflow of waste and recycled materials that cannot always be taken care of locally. Within urban areas there are ports, terminals and storage facilities that require incoming and outgoing transport. Altogether, these shipments have led to increased congestion on the road network within urban areas, which is a contributing factor to why a shift to intermodal land transports have been advocated both in Europe and in Sweden, thus encouraging more freight to be moved from road to rail. Another contributing factor why rail freight transports have been promoted is the relatively low environmental impact. Efficient use of resources and low emissions of greenhouse gases (GHG) are factors that are in favour of the rail mode.

The notion of **transshipment** involves the shipment of goods from an origin to an intermediate destination, and from there to another destination. Transshipment of freight is a common prerequisite in order to make unimodal transports more efficient, and operationalizes in terminals or hubs where the freight is consolidated or deconsolidated. Another reason for transshipment is to change the mode of transport during the journey e.g. from rail to road (Rodrigue et al., 2009). An intermodal terminal is defined as "*a place equipped for the transshipment and storage of unit loads"* (UN, 2001). Thus in this study the terminals considered are freight nodes where there currently is a high concentration of ISO standardized **unit loads (UL)** and where there is a possibility to transfer them between different modes of transport and rail as well as between trains.

Figure 1 illustrates the scope of terms and transshipment terminal typologies in multi- and unimodal operations. The term **Multimodal transport** is the most general term when referring to the carriage of goods by at least two modes. The notion of **intermodal transport** involves the movement of goods in the shape of ISO standardized unit loads i.e. containers, semi-trailers **(ST)** and swap-bodies **(SB)** that are transferred between at least two modes - without handling the goods themselves. The UL's are illustrated by Figure 12. The term **combined transport** is the most specific definition, as it is a type of intermodal transport where *"the major part of the journey is by rail, inland waterways or sea and any initial and/or final legs carried out by road are as short as possible*" (Ibid).

A further notion is **co-modality,** which refers to a use of different modes on their own and in combination - in order to obtain an optimal and sustainable utilization of resources. The term introduces an approach for not opposing transport modes against each other, but rather to find an optimum utilization of the various transport modes and their capabilities.

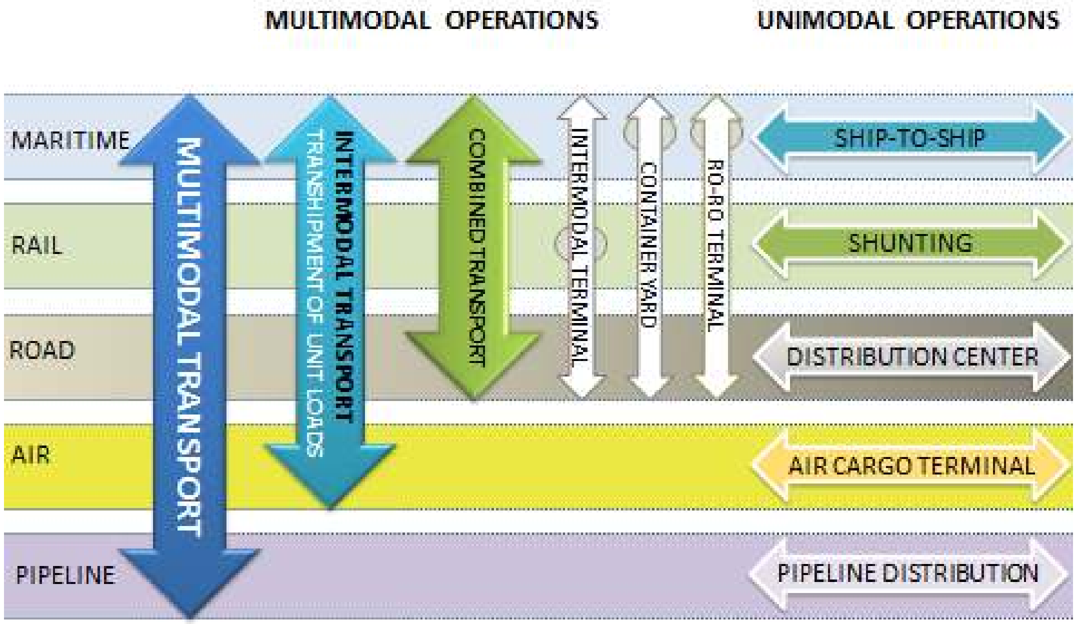


Figure 1. Scope of terms and transshipment terminal typologies in multi- and unimodal operations.

Figure 1 also illustrates the main terminal typologies for intermodal transshipment; hinterland or port terminals (Notteboom & Rodrigue, 2009). Hinterland, or inland, intermodal terminals enable transshipment of UL's between rail and road; rail is commonly the focal mode of that terminal typology - represented by the grey circle in Figure 1. Albeit barges used in inland water ways could also be connected to land modes in an inland intermodal terminal. RO-RO (roll-on roll-off) terminals for ST's and container yards constitute port-hinterland terminals enabling transshipment between sea and rail or road.

The break-even distance between an intermodal transport chain and unimodal road is best described by a schematic illustration of the relation between cost and distance as represented by Figure 2, which is based on similar figures found in e.g. (UN, 2009), Kim & Van Wee (2011) and ([AG], 2016).

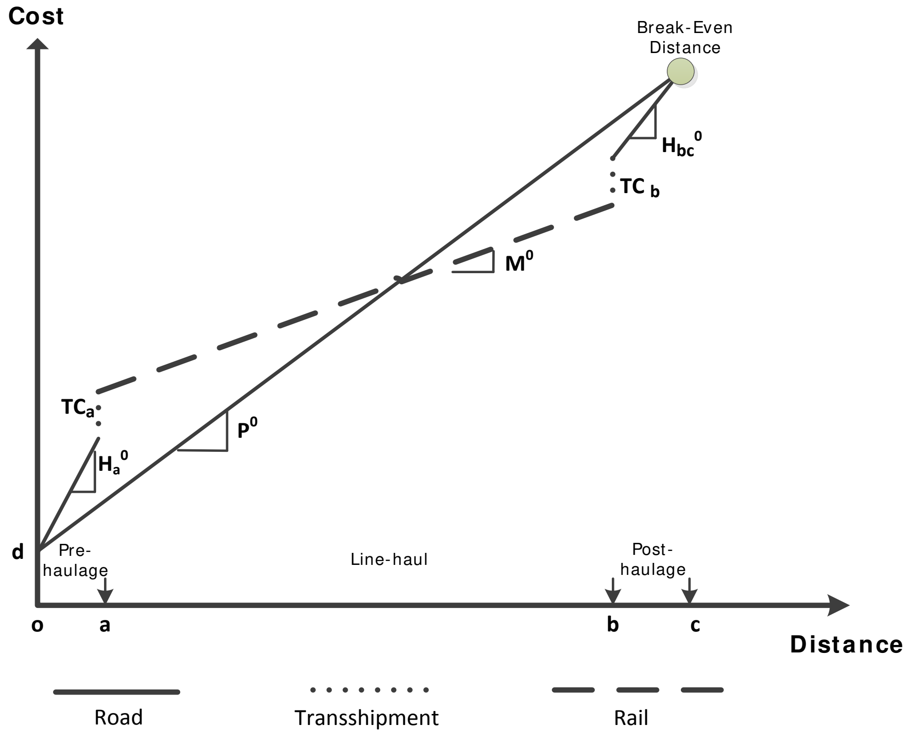


Figure 2. The cost structure of the break-even distance between a road-rail intermodal door-to-door transport chain and unimodal road.

The main cost elements in the intermodal transport chain are the following; pre- and post-haulage by road, also referred to as drayage; the line-haul which in this thesis only considers rail but could also consist of maritime transportation; as well as transshipment at terminals connecting the pre- and post-haulage by road with the line-haul by rail. Note as the transshipment cost is dependent on time and not distance, this cost component composes a larger share of the total cost as the total distance is reduced. A linear relation between cost and distance is commonly observed for unimodal road haulage. The fixed costs for road are represented by $\overline{\boldsymbol{od}}$. The running costs for rail are lower than road i.e. $\mathbf{P}^{\circ} > \mathbf{M}^{\circ}$, hence there is break-even point between intermodal rail and unimodal road for the door-to-door transport chain. Albeit the running costs are lower - the volume requirements on the other hand are obviously higher for rail in order to achieve cost-effectiveness as the capacity of the train is higher. This commonly implies lower frequencies and flexibility for rail freight services compared to road haulage. Principle strategies for making intermodal rail more competitive cost-wise towards road haulage are:

1 Reducing transshipment cost ($\sum_a^n TC$)
2 Reducing the cost for pre- and post-haulage on road (H_a^0, H_b^0)
3 Reducing rail transport cost on the line-haul (M^0)
4 Increasing costs for road haulage($\boldsymbol{od}$, P^0)

The inclinations of the angles P^0, M^0, $H_a{}^0$ and $H_b{}^0$ could be reduced as higher degree of cost-effectiveness is achieved by undertaking a range of operational measures e.g. higher degree of loading space utilization and backhauls. (AG), 2016)

Conventional rail freight is commonly competitive on long distances and in line-haul relations between two nodes. However, an intermodal liner train, as a transport system for freight differs from conventional rail freight systems, as it similar to a passenger train makes stops along the route for loading and unloading. Due to the frequent stops made at intermediate stations it enables a larger market area being covered by rail in a combined transport system. For intra- and inter-regional relations, the concept has the potential of reducing drayage by trucks to and from intermodal terminals, strategy number (2), and making rail freight competitive also over medium and short distances. Complex bundling concepts for freight e.g. hub-and-spoke or the line network, are considered to have longer average distances and times. However, this disadvantage could be compensated by the additional network links. Thus they can be competitive with unimodal road transport, at least for medium to long distances (Kreutzberger, 2008). The design of transport networks has strong implications for the performance of intermodal transshipment technologies (Woxenius, 2007).

The intermodal liner train could in theory enable rail freight transport to enter new market segments and to gain further market shares. However, as the transshipment cost in an intermodal transport chain is not proportional to the transported distance; time and cost-efficient transshipment is a prerequisite, strategy (1) (Paper I); Behrends & Flodén (2012). Transshipment is however a sensitive matter, as it is also required to be reliable and uncomplicated in order to reduce the disturbance sensitivity of the intermodal chain. Nevertheless, intermodal transport must be able to serve more transport flows, also small flows and on relatively short distances, which can be achieved through implementing higher frequencies and serving more destinations. An intermodal liner train making intermediate stops along its route could be a feasible solution for achieving this if it is operated efficiently. For rail to regain market share in urban freight it will have to achieve this despite the fact that road hauliers are market leaders; providing shippers service attributes such as cost-leadership, accessibility and flexibility. A number of studies have been conducted regarding shippers' requirements and their stated preferences. (Lundberg (2006); Bektas & Crainic (2007)) The study of Lundberg (2006) based on survey and data analysis of 99 shippers in Sweden, states the following shipper requirements regarding transportation and ranks them accordingly:

1. Cost
2. Transport time
3. Reliability
4. Punctuality
5. Flexibility
6. Frequency
7. Environmental impact

Regarding strategy (4), there are factors in favour of non-road modes transport within urban areas aside from societal factors i.e. congestion on the road network and the high environmental impact of road haulage. There are also operational restrictions based on the regulatory framework that affect road haulage in urban freight regarding e.g. vehicle size and dimensions, loading/unloading procedures and operating hours. Limited vehicle sizes within urban areas implies that unimodal road transshipment (cross-dock) is often required when entering these areas or alternatively having a low capacity from the origin node. Other situations where land modes are competing on more equal terms are maritime flows connected to land transports, as the cost of transshipment inflicts both road and rail at ports. Port hinterland intermodal services and "Dryport" concepts connecting port terminals with inland terminals through the means of rail shuttles have proved to be successful (Roso (2008); (2011); Cullinane et al. (2012)).

Moreover, the need of reducing greenhouse gas (GHG) emissions from transportation is evident and there is a demand for developing more sustainable transport systems. When sustainability is an objective of 'combined transport', the principle should be that the freight should be transported as far as possible with rail and then distributed by road as short distances as possible (UN, 2001). However, intermodal rail transport suffers from a number of problems that restrict its competitiveness over short and medium distances. Improvement of the cost-quality ratio of intermodal transport are also needed, due to factors such as lack of reliability, long lead times, low frequencies and limited slots in the timetable (Bontekoning & Trip (2002); Mortimer & Robinson (2004). However, it is not only certain requirements that shippers base their choice upon - the perception of the performance of the modes and services can have an even higher impact on the overall decision making process (Bektas & Crainic, 2007).

Nevertheless, there are stated above also factors in favour of short haul intermodal rail transport systems e.g. the congestion on the road network, the environmental impact of transportation and the fact that road haulage may require unimodal transshipment for cross-dock activities due restricted road vehicle dimensions in urban areas.

1.2 Research Objective

The main aim of this doctoral thesis has been to evaluate under which conditions a short haul transport system with the railway as a base can be considered a feasible solution. Albeit a holistic view have been applied for the evaluation; emphasis is on the perspectives of shippers as they are the actual decision makers regarding mode choice, based on the offerings of logistics provider and infrastructure owners.

The evaluation has been based on two research projects and case studies. First, in the main and primary project of this doctoral thesis - the research project **REGCOMB** evaluates the feasibility of creating a regional rail freight transport system regarding costs and emissions in the greater Stockholm-Mälaren region. Data from a shipper's distribution of daily consumables in the region has been used for the modelling of the case study. The research has been funded jointly by the Swedish Transport Administration through the virtual Swedish Intermodal Research Centre (SiR-C) and The KTH Railway Group.

Second, in the minor project and case study of this thesis, **BIOSUN**, an evaluation has been conducted regarding rail-based multimodal transportation of wood biofuels. In essence, it is the factors affecting rail transportation of biofuel and the inherent capability of the rail mode that are addressed. A qualitative evaluation is complemented by quantitative analysis of the market as well as a case study. Data from a heating plant has been used as input for the modelling of the case study.

The main project has also had the aim to visualize and describe terminals and freight flows in the Stockholm-Mälaren region that could potentially be included in an intermodal transport system. The critical question is under which conditions an intermodal system with the railway as a base can be competitive in a market with relatively short distances where road haulage is almost exclusively used. The project has also provided opportunities to develop a cost model as well as to incorporate models developed in parallel and previous projects.

Thus the feasibility has been quantifiably evaluated with respect to costs and emissions and qualitatively regarding societal, commercial, environmental and technological components of the transport system. Hence, intermodal transport systems for freight can be considered to be **socio-technical systems** where organizational, market-related and societal aspects as well as infrastructural and technological have to be considered in order to apply a holistic view. The following research questions and corresponding sub-questions have been addressed during the course of the thesis and applied on two separate case studies concerning short haul intermodal rail transport systems:

RQ1 What stakeholder requirements exist for short haul intermodal rail transport systems?

1. What is the interest of shippers in using the system; where are the greatest needs and how can they be combined?
2. What is the interest of service providers to supply the system?
3. What policies guide authorities that influence the system?

RQ2 How can a system be implemented in the evaluated region that is both technically efficient and cost-effective?

1. Is it possible with the existing combinations of terminals and technologies or is further development required?
2. What conditions influence the competitiveness of the system against the prevailing market prices of road hauliers?

RQ3 How can the design of the system influence the environmental sustainability in the evaluated region?

1. How can transshipment and traction technologies with low-emission propulsion systems and fuels be used?

RQ4 What are the contextual conditions for feasibility of the system?

1.3 System Characteristics

Although the main objective of the two case studies that are covered in this thesis are similar i.e. to evaluate under which conditions the socio-technical combined transport system with the railway as a base can be considered feasible; the characteristics of the two transport systems differ on several points. Table 1 illustrates the main descriptive characteristics of each transport system.

Table 1. Characteristics of the evaluated transport systems.

Transport system:	**Regional Combined Transport System – A case study in the greater Stockholm-Mälaren region (REGCOM)**		
Freight Typology	**Main Flow Direction**	**Operational Area**	**Evaluated Operational Concepts**
Intermodal unit loads. Perishable, fast moving consumables	Outbound distribution (To retail shops from DCs)	• Short haul (50-500km) • Within a metropolitan region (Greater Stockholm-Mälaren region)	• Intermodal liner train • Cost Efficient Small Scale Terminals (CESS) • Intermodal urban freight
Transport system:	**Sustainable intermodal supply systems for biofuel and bulk freight (Biosun)**		
Freight Typology	**Main Flow Direction**	**Operational area**	**Evaluated Operational Concepts**
Bulk. Forest residues and chips	Inbound transportation (To heating plant from forest)	• Short haul (200-700km) To a metropolitan region (Gothenburg)	• Combined terminals for transshipment and wood processing • Increased sourcing distance

The type of freight and the main flow directions differ between the case studies; where the REGCOMB project involves mainly **outbound** distribution of intermodal unit loads carrying mainly perishable, fast moving and **high value** consumables. The Biosun project on the other hand involves mainly **inbound** transportation of **low value** bulk**;** forest residues and chips as raw material for heating plants. Moreover, there are also differences in the operational area, where the area that is considered in the REGCOMB project is a large metropolitan region in Sweden, the Greater Stockholm-Mälaren region, and distances are short haul; less than 500km. Main operational concepts or measures that are evaluated are the following; intermodal liner train, Cost-Efficient Small Scale (CESS) terminals and intermodal urban freight.

The transport system considered in the Biosun operates also in short haul relations as defined in this thesis albeit on longer distances; 200-700 km, between the metropolitan region of Gothenburg and the sourcing nodes that are located in or in vicinity of forest areas. Another significant difference when evaluating the cost performance of the transport system in the Biosun project, is the fact that it not only decides the beak-even distance for mode-choice but also the distance that is economically viable for heating plants to source the raw material for their production. Hence, rail based multimodal transportation may increase heating plants sourcing range. Another main operational concept that is evaluated in the Biosun projects is combined terminals for transshipment and wood processing; transferring the pre-haulage cost to the overall logistics processes.

The problems that these systems are designed to solve are on the other hand similar. Environmental sustainability and cost-leadership are the two main problems that an efficient design of an intermodal transport system has the potential to overcome. The study of Meijer et al. (2014) identifies three generic spaces that characterize the designing process for solving a problem, embedded in a larger socio-economic-technical-cultural context. The analysis framework is used in order to illustrate the complexity of the design problems dealt with in this thesis and in a structured manner present and derive conclusions from the research that has been carried out. The spaces are the *Product, Social and Institutional (PSI)* space. The product can be either a physical artefact or a service that intends to solve the problem and the space is defined by *disciplinary complexity* i.e. number of disciplines that are required to understand and create the product; s*tructural complexity* i.e. the decomposition of the product or problem into parts and their relationships as well as k*nowledge availability* for developing products or services. The social space consists of the social unit that creates the product space in terms of specifying, creating and utilising the product. The main decisions in this space are which perspectives to include and what capabilities that are required to address the problem. The institutional space deals with the regulatory framework required for producing a product to properly address the problem. All three spaces will be dealt with throughout the thesis and the PSI analysis framework will connect the sections at the concluding chapter of the thesis.

BIOSUN has the characteristics of a conventional intermodal line or a trainload system with end point traffic connecting two terminals on each trip. Liner trains, which are in service in Japan and Switzerland, and have been tested in Sweden are also connects two end point terminals but also have intermediate terminals along the line as illustrated by Figure 3 . The traffic system in REGKOMB is a special case of a liner train, a liner loop. This cannot be found in the literature as a rail system, however it is common for distribution systems by truck in local areas. As can be seen in the figure, it is possible to reach many relations by this system, compared with a hub and spoke system with a similar line length. The system is formed as a loop because it covers a region where it is a lake in the middle so there is a natural barrier. Of course there are also disadvantages with this system, but it is interesting to evaluate if a distribution system is possible by rail and truck in combination with this loop.

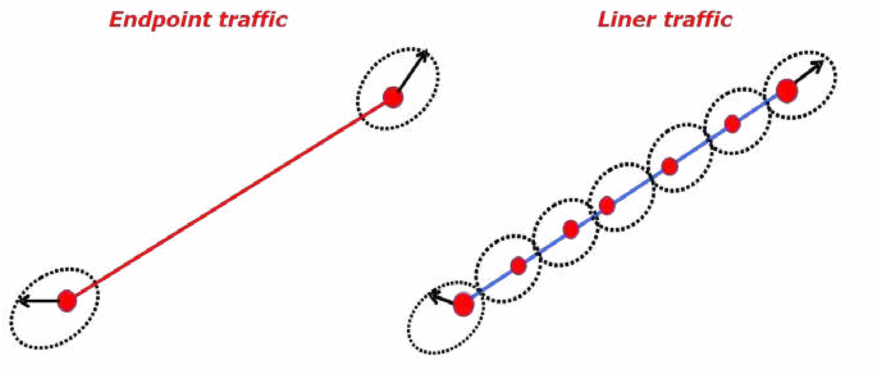


Figure 3. Endpoint and liner traffic.

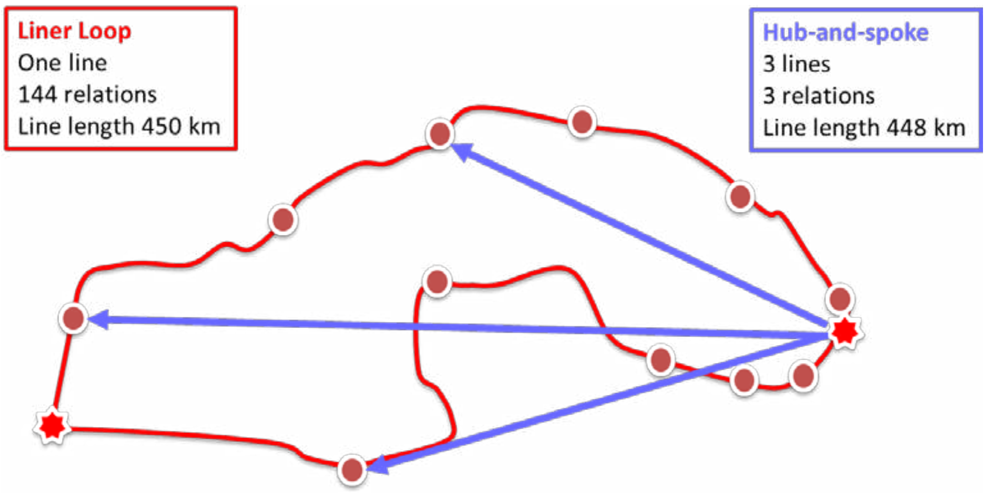


Figure 4. Conceptual sketches of Hub-n-spoke and liner loop traffic.

1.4 Delimitations

Intermodal transport systems considered in the scope of this thesis are strictly based on rail for the line-haul. Albeit the line-haul in short haul intermodal transport chains can consist of other modes as well, such as barges.

Regarding the REGCOMB project, the Stockholm-Mälaren region (in Swedish "Mälardalen") includes the counties of Stockholm, Uppsala, Västmanland, Södermanland and in some cases also Örebro, Östergötland and Gävleborg. The distinction is not completely clear-cut and the latter three counties are not always included as parts of the region, albeit they are included in this project. The project considers only unitized freight flows to, from and within this region. Flows that have not been incorporated further in this study, neither in the qualitative nor the quantitative assessment; have been excluded from the introductory essay of the thesis.

The model developed (ICTM) is concentrated on costs for inter modal transport chain because it is the most important factor for the customer (Lundberg (2006); Bektas & Crainic (2007)). Distances and time are taken into account but exact time tables are not included. Qualitative factors are not included in the model but are discussed in the thesis.

There are many different intermodal transshipment systems planned or tested in pilot-projects around the world found in studies of such as Woxenius(1998); Bärthel & Woxenius (2004); Bärthel (2010). In this thesis we have mainly concentrated to evaluate new and suitable systems which have been developed or tested in Sweden, such as Light Combi, Megaswing and CCT (CarConTrain).

Regarding the BIOSUN project and the sustainability analysis of biofuel transportation; this thesis only includes the following sections; rail mode, the intermodal alternative and terminal handling - the analysis of other modes that have been conducted within the overall research project by other researchers are excluded.

2 Summary of Publications

The contributions of each paper to the specific research questions are addressed in this chapter. It presents a short summary of each paper, their relation to the research questions and other related publications.

2.1 Research Questions and Papers

Table 2 illustrates the main contribution of each paper to the specific research questions. Paper I-IV deals with main project of this thesis, REGCOMB, and the evaluation of rail based transportation in the Greater Stockholm-Mälaren region. The emphasis of Paper I is a literature review in order to learn from previous works and gather the knowledge considered necessary. Paper II mainly addresses research question (RQ) two and the modelling of the technological system in order to evaluate the system's' commercial and environmental viability. It is in Paper II that the model ITCM is first introduced. Paper III implements the theories gathered and the model developed in the previous papers on a case study in order to address the three first research questions; however the emphasis is on RQ2 and RQ3, the latter concerning the evaluation of environmental sustainability aspects of the system. Paper IV addresses all four research questions, however here the emphasis is on RQ1 and RQ4, the former evaluating stakeholder requirements, where the perspectives of shippers, suppliers and local authorities are incorporated in the stakeholder analysis. Paper Iv also addresses RQ4, which deals with the conditions required for the system be evaluated as feasible. Paper V considers the BIOSUN project and addresses all research questions in relation to the evaluation of rail-based multimodal transportation of wood biofuel.

Table 2. The main contribution of each paper to the specific research questions.

Research Questions	RQ1	RQ2	RQ3	RQ4
Papers	III-V	I-V	III-V	IV-V

2.2 Paper I:

The purpose of this paper is to identify and qualitatively evaluate the opportunities, limitations and prerequisites that are associated with intermodal liner trains within urbanized regions. The method used for accomplishing this objective is an extensive literature review.

As the Liner train makes stops at intermediate stations along the route, it enables covering a larger market area than conventional rail freight systems do. The Liner train aims to increase the proportion of rail in intermodal road-rail transport; hence it can reduce the high cost that feeder transports by trucks constitute, the congestion on the road network and the external costs generated by road transport. However, there are several prerequisites that need to be fulfilled in order to get the line train system competitive on short and medium distances e.g. optimized loading utilization along the route and efficient transshipment at terminals. Although the concept is quite untested, an example of a realized liner train system, the Light Combi, will be presented.

2.3 Paper II:

When considering a shift in transport chain design, from a shipper's perspective, a holistic view on the logistics processes is a prerequisite in order to avoid sub-optimization on transport costs. This paper initially deals with the optimization of the logistics system, followed by the main part of the study concerning the estimation of intermodal transport costs. A cost model is presented, Intermodal Transport Cost Model, ITCM, constituting of three integrated cost modules; rail operations, road haulage and terminal handling. As a result of the study the model is applied on a set of transport chain designs in order to investigate the competitiveness of combined rail road transport.

As the operational transshipment cost is commonly an obstacle for the competiveness of combined road rail transport, at least on short and medium distances, the emphasis is put on reducing this cost. Two main approaches are identified; first by strategically minimizing the number of intermodal transshipment points in relation to transshipment points for unimodal road haulage, e.g. in maritime and some urban freight flows. Second, through using more cost-effective transshipment technologies. Conventional transshipment terminals are not suited for all freight volumes and there is a need for cost-efficient small-scale intermodals terminals, CESS terminals. The concept of CESS terminals is presented and their impact on transport costs evaluated.

2.4 Paper III:

This study aims to model a regional rail-based intermodal system and to examine the feasibility of it, through a case study for a shipper of daily consumables, distributing in an urban area, and to evaluate it regarding cost and emissions. The idea of an intermodal liner train is that of making intermediate stops along its route thus enabling the coverage of a larger market area than conventional intermodal services, hence reducing the high cost associated with feeder transports, the congestion on the road network and generated externalities. The results of the case study indicate that the most critical parameters for the feasibility of such a system are the loading space utilization of the train and the cost for terminal handling

2.5 Paper IV:

This study aims to evaluate the feasibility of rail based intermodal transportation in urban regions. The feasibility is evaluated in a bi-sectional manner; first a quantitative assessment is carried out where costs and CO_2 emission are estimated for a set of transport alternatives in the greater Stockholm region, Sweden. The most critical parameters are the train's loading space utilization and the transshipment cost. Second, an analysis is made based on the principles of the 'Delphi' method i.e. experts involved in in-depth interviews, workshops and a survey; regarding stakeholders' perspectives for utilizing such systems. The system must satisfy broader policy objectives of local authorities and commercial corporate interests in order to be adopted.

2.6 Paper V:

This paper aims to analyse the internal and external factors influencing rail-based multimodal transportation of wood biofuel i.e. wood raw materials e.g. chips and branches that are used for production of energy. The analysis is conducted for the Swedish market and by using a bi-sectional qualitative framework. First, a STEEP analysis is conducted in order to analyse the external factors affecting railway transportation of biofuel. STEEP is an acronym for: Social, Technological, Economical, Environmental and Political and it is used as a strategic tool to analyse external factors that influence a business. Second, the internal factors are evaluated through the three main dimensions of sustainability: environmental, economic and social. In essence, it is the factors affecting rail transportation of biofuel and the inherent capability of the rail mode that are addressed. Albeit the two methods are to their nature qualitative approaches, the evaluation is complemented by quantitative analysis of the niche market as well as a case study.

A main conclusion from the qualitative analysis is that rail transportation of biofuel faces a number challenges that in many cases are related to a relatively high volume requirements and operational inflexibility. The main drivers for it are commonly associated with economies of scale and the relatively low environmental impact. Estimates from the case study show that the break-even distance i.e. when the cost for intermodal transports equals unimodal road, is lower for biofuel transport chains than for other commodities and significantly decreases CO_2 emissions compared to unimodal road.

2.7 Other Related Publications

2015, **"Capacity4Rail: Deliverable D2.3.1 Co-modal transshipments and terminals",** Carillo Zanuy, A., Kordnejad, B., Nelldal, B-L.

This report is a deliverable for a research project entitled **"Capacity4Rail"** which is funded by the European commission. The project is organized in several sub projects (SP) and work packages (WP). The report "Conceptual terminals' design methodology for different markets" is in SP2 and WP 2.3 and deals with co-modal transshipment, interchange and logistics. The parts of the report assigned to KTH are written by me and Professor Bo-Lennart Nelldal (KTH Royal Institute of Technology) and PhD Armando Carillo Zanuy (Technical University of Berlin). The project consisted of various project members e.g. Deutsche Bahn (DB) and Port of Valencia; and where main research partners aside from KTH were DICEA Sapienza University of Rome and NewRail Newcastle University.

2015, **"Capacity4Rail: Deliverable D2.3.2** Measurements for Intermodal Transport Chains**",** Kordnejad, B., Nelldal, B-L.

This report is also a derivable **"Capacity4Rail"**. The emphasis of the study in this particular deliverable is on the definition of performances to be achieved by the terminals (by novel technologies and/or operational measures) for the fulfilment of demand targets in identified sensible market segments, including possible unusual cargos. The parts of the report assigned to KTH are written by me and Professor Bo-Lennart Nelldal (KTH).

2016, **"Capacity4Rail: Deliverable D2.5.** "Business Case of terminal operation and financial feasibility analysis of different types of terminals"**,** Kordnejad, B., Nelldal, B-L..

This report is also a deliverable **"Capacity4Rail"**. The emphasis of the study in this particular deliverable is on the financial analysis of transshipment activities. In this deliverable the model **ITCM** introduced in chapter "3.2.1 Intermodal Transport Cost Model (ITCM)", was used in order to carry out a financial analysis on a set of European intermodal terminals; mainly Duss Munich Reim (intermodal terminal typology road-rail) and the port of Valencia (intermodal terminal typology sea-rail). Moreover a small scale automatic liner intermodal terminal with CCT and Hallsberg marshalling yard has been evaluated. The parts of the report assigned to KTH are written by me and Professor Bo-Lennart Nelldal (KTH). The project consisted of various project members e.g. Deutsche Bahn (DB) and Port of Valencia; and where main research partners aside from KTH were DICEA Sapienza University of Rome and NewRail Newcastle University.

2015, **"Sustainable Intermodal Biofuel Transport"**, ISBN 978-91-7246-336-3, BAS Publishing, Gothenburg, Sweden

This book is the final report of the project entitled, **"Sustainable intermodal supply systems for biofuel and bulk freight"**; a project funded by the Swedish Transport Administration and performed by a consortium consisting of:

- School of Business, Economics and Law, University of Gothenburg, Sweden (Project coordinator)
- KTH Royal Institute of Technology, Stockholm, Sweden
- Mariterm AB, Höganäs, Sweden
- WSP Group, Gothenburg, Sweden
- BOKU, University of Natural Resources and Life Sciences, Vienna, Austria

2015, **"A Sustainability Analysis for Wood Biofuel Transport"**, (TBP 2016)

This journal paper is written jointly by me (24%) and Flodén, J., Woxenius, J., Awais, F., (School of Business, Economics and Law, University of Gothenburg); Berglund, M., Billing Clason, H. and Hersle, D., (WSP), Enström, J., (Skogforsk). It is the concluding paper from the research project "Sustainable intermodal supply systems for biofuel and bulk freight"

2015, **"Sustainable development in ICT-futures"**, Routledge, London (Submitted, TBP 2016)

The main structure of the research project "Scenarios and sustainability impacts in information societies" consists of six building blocks which are intended to act as a basis for analysis of local and global sustainability implications for five pre-defined scenarios regarding Information and Communications Technology (ICT) societies. The building block written by me (50%) together with Yevgeniya Arushanyan is **"Production, transportation and distribution"**. Each building block part describes and evaluates the following sections; historical background, current situation, trends and potentials. The final scenario analysis is conducted through the coupling of trends and potentials to each future scenario. The project was coordinated by the "Centre for Sustainable Communications" (CESC) at the Royal Institute of Technology, Stockholm.

2013, **"Regional Intermodal Transport Systems – Analysis and Case Study in the Stockholm-Mälaren Region",** Licentiate Thesis. TRITA-TSC-LIC 13-005, KTH Royal Institute of Technology, Stockholm, Sweden

Parts of this doctoral thesis; paper I-III and some parts of this introductory essay, have previously been published in 2013 in my licentiate thesis.

2012, **"Market for regional intermodal traffic in the Stockholm-Mälaren region"**, (”Marknad för regional kombitrafik i Mälardalen”), Kordnejad, B., Working paper, KTH Royal Institute of Technology, Stockholm, Sweden

This report aims to generate alternatives for a regional rail route in an intermodal transport system in the Stockholm-Mälaren region. Accomplishing this task requires a description of the current market for regional intermodal transports and to identify existing needs of connections within the regional freight transport market. Connections that could potentially be linked by an intermodal liner train system.

3 Methodology

For both research projects the main methodology used in the initial phase of each study was of a descriptive nature i.e. circumstances that have already taken place or currently prevail e.g. knowledge related to the concept of intermodal liner trains and existing transshipment technologies for standardized unit loads. The methodology was also partly of an exploratory nature, an approach applied when there is lack of knowledge that are considered necessary for moving forward in the study. Hence, knowledge was gathered concerning these areas within the studied field; for the REGCOMB e.g. intermodal transportation in an urban context, over short distances, and regarding the Biosun project e.g. factors influencing rail-based multimodal transportation of wood biofuel.

Both qualitative and quantitative methods have been applied in order to evaluate and model the feasibility of short haul intermodal transport systems. Albeit some methods contain both quantitative and qualitative elements, for the sake of clarity they have been categorized accordingly.

3.1 Qualitative Assessment

For both research projects the initial phase consisted of a literature review in order to learn from previous works and gather the knowledge considered necessary. For the REGCOMB project thereafter an inventory of the transport generating activities in the region was carried out e.g. terminals, ports, warehouses, distribution and recycling facilities. The starting point was terminals for freight transported to and from the region and distribution centres that are used internally within the region. The method was to use ports and the major carriers' terminals, primary distribution centres and through corporate and employment registries search for smaller facilities. The market analysis was concluded with an extensive stakeholder analysis in the REGCOMB project.

In the BIOSUN research project, two formal evaluation techniques were used in order to qualitatively analyse the internal and external factors influencing rail-based multimodal transportation of wood biofuel, where the STEEP analysis (social, technological, economical, environmental and political) was used to analyse external factors and the sustainability analysis for the internal. For the REGCOM project, SWOT analysis (strengths, weaknesses, opportunities and threats) made by experts was used for analysing both the internal as well as the external factors influencing the system.

The methods categorized as qualitative in this thesis are the following:

- Literature review
- Market analysis for regional intermodal transports in the region – past, now and future (REGCOMB)
- Inventory of transport generating activities in the region (REGCOMB)
- Stakeholder analysis; Workshops based on participative research; survey and interviews with experts and potential stakeholders. (REGCOMB) (Paper IV)

- SWOT analysis (Internal and external factors) (REGCOMB) (Paper IV)
- STEEP analysis (External factors) (BIOSUN) (Paper V)
- Sustainability analysis (Internal factors) (BIOSUN) (Paper V)

3.2 Quantitative Assessment

Within the framework of the REGCOMB project, freight flows in the region have been analysed and a set of suitable transfer nodes for the proposed train has been outlined; of which some can be located next to major freight terminals and others located independently at sidings along the route. Subsequently a liner train system between potential transfer nodes has been outlined; where the train will serve as a conveyor belt for distribution and transportation in the region.

A cost model, *Intermodal Transport Cost Model (ITCM*), has been developed and applied on the evaluated transport systems; including modules for rail transportation, transshipment and feeder transports by trucks to and from transfer nodes. The aim has been to identify the most essential variables influencing the feasibility of implementing such a system and find break-even points compared to unimodal road haulage concerning these variables. The results could also indicate a need for improved efficiency of current systems and technologies in order to make the system viable. As minimum quantities of goods are required in order to make freight transport systems competitive there ought to be economies of scale that could be achieved, albeit also qualitative requirements from shippers have to be fulfilled. The limit for the viability of the system could also be shifted as a result of higher costs for road haulage; through increased costs for energy, externalities, congestion and usage of infrastructure. A sensitivity analysis has been conducted for the most significant variables. Note that ITCM and the corresponding quantitative methods developed in the REGCOMB project where later also applied in the BIOSUN project.

The total energy consumption and emissions for the liner train system has been estimated and compared with unimodal road haulage. The estimation concerns the environmental and climate effects of different types of distribution vehicles, terminal equipment and traction types. The aim has been to design the system so that it causes minimal environmental impact. The methods categorized as quantitative are the following:

- Analysis of potential freight flows
- Routing and scheduling
- Transport economics and modelling:
  - Cost estimate for transportation i.e. rail and feeder transportation by road.
  - Cost estimate for terminal handling.
  - Estimation of emissions and energy consumption
- Sensitivity analysis:
  - Identification of essential variables e.g. transport distance and train loading space utilization. Estimation of break-even points versus unimodal road haulage.

3.2.1 Intermodal Transport Cost Model (ITCM)

As illustrated by Figure 5 the categories of input data required for the model developed at KTH (Kordnejad, 2014) 'Intermodal Transport Cost Model' (ITCM) are bisectional; where one part represents the supply i.e. the evaluated transport chain, and the other part represents the transport demand. However, they are not strictly independent as the supply must match the constraints of the demand. The design of ITCM, as for any model, involves the fundamental decision which factors to include in the model and at which level of detail, depending on model objectives. Following the objectives of this study, the core of the model consists of three main components: rail operations, road haulage and terminal handling.

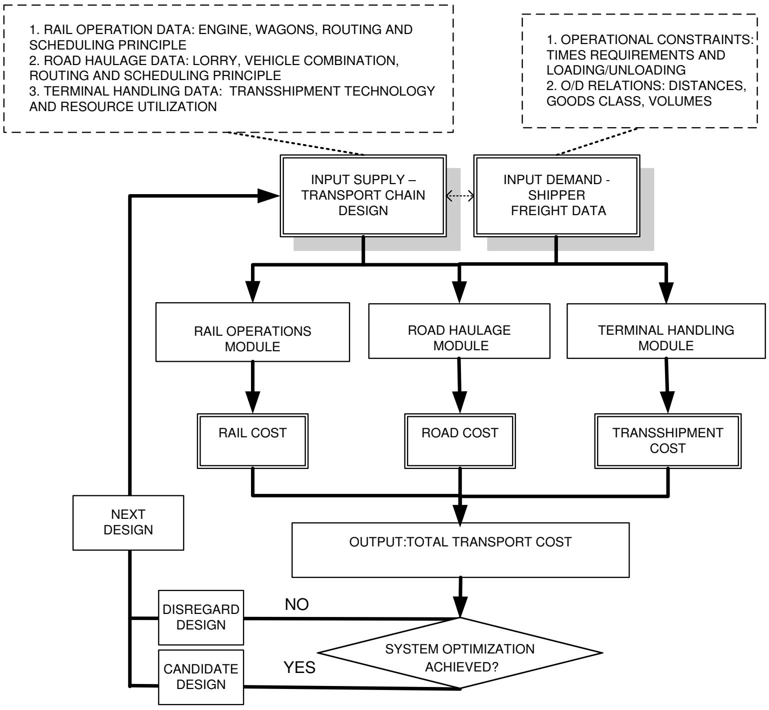


Figure 5. The conceptual framework of 'Intermodal Transport Cost Model' (ITCM).

The conceptual framework of ITCM consists of parallel and serial processes involved with allocating the shipper's transport demand to a given transport chain design. This process consists of two main phases: generating an initial plan that matches the constraints of the demand and to process the demand and supply in the three integrated cost modules. The output generated from each module is expressed per loading unit. The default unit load for the calculations is a twenty foot equivalent unit (TEU) and EURO-pallets. The latter is used as it is it the smallest unit in the European Modular System (EMS) and hence a flexible and precise unit.

The cost model is based on principles of Activity-based costing (ABC); which involves identifying cost drivers and assigning them to specific activities — e.g. overhead allocation to specific activities rather to the entire organization (Velmurugan, 2012).Furthermore, shippers commonly perceive intermodal services as a single integrated service despite the increased actor complexity of these intermodal networks (Bektas & Crainic, 2007), justifying further a general and integrated approach for shippers. Moreover, there is a need for cost information about rail freight in general and intermodal transport in specific; in the scientific field improved cost information is crucial as input for mode and route choice models as well as for four step forecasting models (Troche, 2009). The intermodal assignment based on route tree consists of the following basic steps (Ortuzar & Willumsen, 2011):

1 Generation of direct route legs between all origin and destinations using a unimodal search.
2 Generation of route legs between transfer points using a unimodal search.
3 Construction of route tree.
4 Calculation of costs for all routes and transfer points.
5 Distribution of demand on routes.

The total transport cost (TTC) for a combined transport chain is expressed by formula (1):

$$TTC = RC + HC + TC \tag{1}$$

RC = the total cost generated by the main haul i.e. rail operations.
HC = the total cost for road haulage consisting of pre- and post-haulage to terminals.
TC = the total cost for terminal handling, derived from the estimated cost per loading unit for each type of terminal.

A system perspective on the logistics processes is a prerequisite in order to avoid sub-optimization on specific business functions or processes, in the case of this study the transport cost. Hence, the impact that the regarded solution has on other processes of the shipper should be evaluated in order to find a candidate solution and achieve system optimization for the entire logistics system. ITCM brings integral comparison of multimodal alternatives, however further work and expansive case-studies are needed to make all the costs of the logistics system more explicit. The structure of the terminal cost module is based on a model developed in the study of Nelldal (2012b), which has be modified to incorporate novel transshipment technologies and updated with current values. The basic model is on a highly detailed operational level, however for the sake of clarity and readability only a schematic structure of the components is illustrated in Table 3.

Table 3. The main structure of the terminal handling module.

Infrastructure
Annuity for infrastructure
Maintenance
Transshipment Resources
Annuity for transshipment equipment
Operating costs
Maintenance costs
Energy Consumption → GHG
Shunting
Annuity for shunting engine
Operating costs
Maintenance costs
Energy Consumption → GHG
Overhead
Total Cost → Transshipment cost/UL

Regarding energy consumption, it can be estimated for the train, the shunting engine and other equipment at terminals as well as for the feeder transport on road. The energy consumption can in turn be transformed to GHG-emissions based on the source of energy and the corresponding emission factor. Carbon dioxide (CO_2) is the predominant greenhouse gas (GHG) emitted by motor vehicles and is directly related to the amount of fuel that is consumed by vehicles. Vehicles also emit other GHGs, including methane (CH4), nitrous oxide (N2O), and hydro fluorocarbons (HFCs). In this study an activity based approach for estimation of CO_2 emissions is applied where the main methodology is expressed by formula (2).

$$E(CO_2) = EC \times EF(CO_2) \tag{2}$$

$E(CO_2)$= CO_2 emissions by mode/transshipment technology
EC = Energy consumption by mode/transshipment technology
$EF(CO_2)$ = CO_2 emission factor by energy source

It is important to select the most appropriate emission factor values for each transport mode and terminal handling. Energy consumption and emissions in freight transport do not only occur during the actual shipment, but also at a much earlier stage in the processes leading up to the supply of the tractive energy. The main energy sources used in freight transport processes are diesel fuel and electricity. To compare the environmental impacts of transport processes with different energy sources, the total energy chain has to be considered. As to emissions, in the case of electrically-powered rail transport vehicles, the emissions are produced entirely in the pre-chain whereas for diesel powered transport vehicles, the main part of the emissions are produced during the transport itself. The magnitude of the emissions is also influenced by other factors e.g. the weather, driving style, vehicle maintenance and type of engine (Cefic, 2011). Hence, the results of these calculations have to be seen as an indicator of the magnitude of the environmental impact of the case study rather than exact data.

4 Evaluation Framework and Main Results

During the process of the main project of this thesis, REGCOMB, the contemplated transport system has been evaluated in a bi-sectional manner; first, regarding the social components of the system, referred to as "The market", mainly dealing with potential stakeholders and their requirements. Second, the technical components of the system have been analysed e.g. suitable transshipment technologies and vehicle types, routing and scheduling. The evaluation framework of REGCOMB and key results are summarized in Figure 19. The evaluation framework of the Biosun project is further elaborated in chapter 4.2.1 and illustrated by Figure 27.

4.1 REGCOMB

The results of the two evaluation categories; market structure and technological system, are described according to historical development, present situation and future development i.e. trends for the market and technological trajectories for the system.

4.1.1 The Market

4.1.1.1 Past Development (1990-2011)

From 1990 wagonload traffic in the region declined gradually to a minimum until year 2000. The main reasons were changes in the industrial structure and increased competition from trucks. Under the pressure of exploitation, production plants and warehouses moved further out from the metropolitan areas of Stockholm to more remote locations in the Stockholm-Mälaren region. Moreover, a considerable share of industrial tracks was closed down and the possibilities to transport directly by rail through the capillary rail infrastructure gradually diminished. The increased competition from road haulage, despite increasing fossil fuel prices, consisted of new inexpensive European road operators entering the Swedish market and as a result the market share of road haulage has increased considerably during this period. The increased competition from road haulage in the Swedish freight market, despite increasing fossil fuel prices, is evident as illustrated by the Swedish modal share measured in tonne-kilometres illustrated by Figure 6. Goods transported by road increased dramatically over this period, 1950-2014 (Nelldal, 2013). Goods transported by air are not included in this figure, as the tonnage of air freight transportation is very limited. (STA, 2015)

After 2000, the downward trend of rail freight transports began to shift slightly. In particular the services of unit trains and intermodal transports increased and some completely new transport system by rail emerged. It was largely due to the deregulation, as more operators were now available, as well as to the increased environmental awareness of some shippers demanding environmentally sustainable transports.

New intermodal terminals have been established in the region and even some new industrial tracks have been built. Some shippers have shifted to rail and adapted their facilities and logistics system accordingly. However, the winters of 2010 and 2011 caused immense operational disturbances for the national rail network and it has become apparent that the maintenance of the rail infrastructure had been neglected. As a result shippers' confidence and perception of the reliability and punctuality of the railways decreased. Because of this, and competition from low-cost road hauliers, a large share of the domestic intermodal traffic has been abandoned since 2011, a distinguishable exception is the hinterland transports system of the Port of Gothenburg, see and Figure 9.

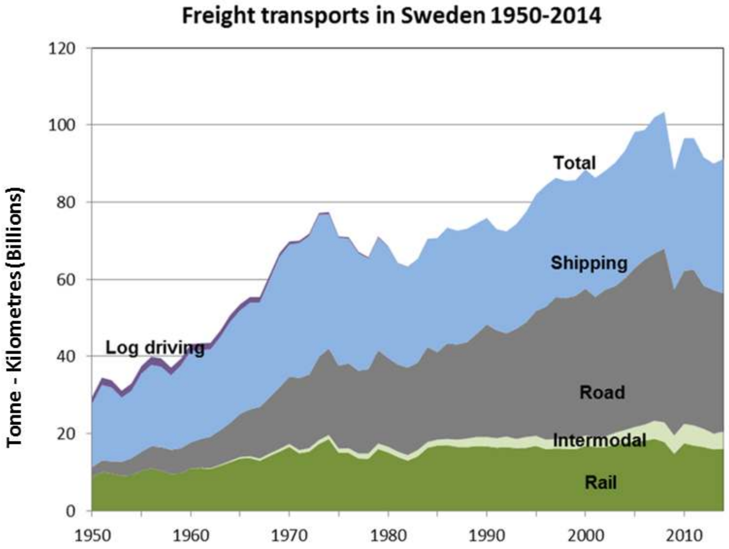


Figure 6. Transport effort in tonnes-kilometres by modes and total in the Swedish freight transport market 1950-2014 (Nelldal, 2015)

As illustrated by Figure 7, from 1950's until the oil crisis of the early 1970s', the volume of domestic goods transportation on rail doubled in Sweden. During the economic recovery of the 1980's, goods transportation in Sweden increased until the domestic recession of the early 1990's. The subsequent economic recovery led to a sharp increase in goods transportation until the global financial crisis in 2008.

A key driver for the sharp increase in road haulage during the 1990's as illustrated by Figure 6, was the fact that a more generous regulatory framework for domestic road haulage was implemented during this period e.g. the elimination of the maximum allowed distance travelled by trucks, an increase in the maximum vehicle weight from 51,4 to 60 tonnes, and an increase in the maximum vehicle length from 24 and to 25.25 meters. The EU standard is 18.75 metres and 40 tonnes. Other important contributing factors were increased competition through cabotage trucks (foreign road haulers operating in Sweden, mainly from other European countries), urbanization, and changes in shipper requirements as transportation became more integrated with the production process e.g. just-in-time processes and lean production (Nelldal & Wajsman, 2015).

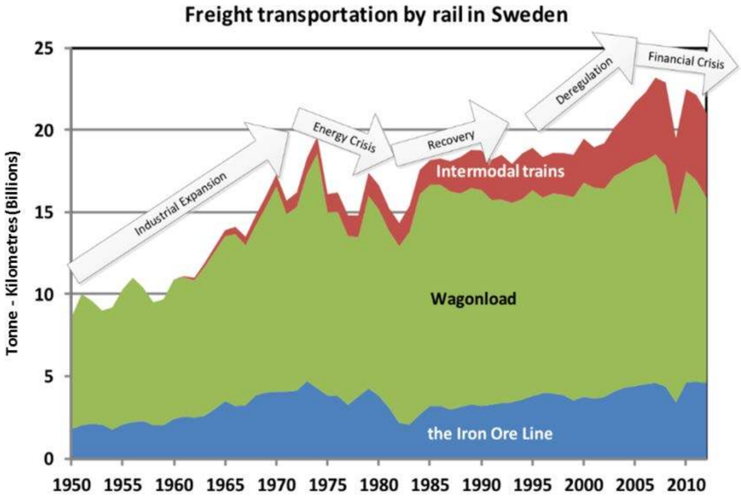


Figure 7. Freight transportation on rail in Sweden 1950-2012. This figure illustrates recessions and recovery periods, and their effect on rail freight transport performance (tonne/km). (Nelldal, 2013)

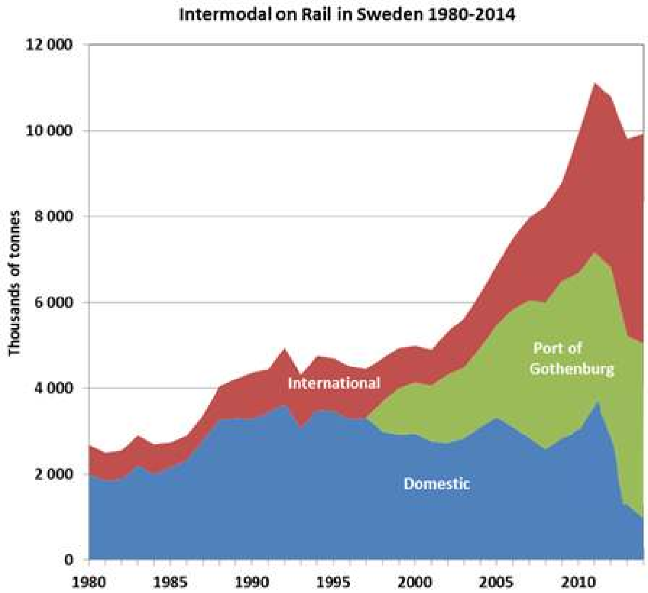


Figure 8 Development of intermodal transports by rail in Sweden in tonnes 1980-2014. (Nelldal, 2015)

Intermodal rail-based freight transport can be categorized as international, national and regional traffic. International European and long-distance national transports are the categories where intermodal transports are the most competitive and enjoy the highest market share in the Swedish freight market. This is mainly due to the fact that the transshipment cost of unit loads is not proportional to the transported distance; hence the competitiveness of regional intermodal transports is restricted.

Geographic regions are being expanded because increasing options for transportation have expanded the range of action of people and businesses. Metropolitan regions require freight transportation that is often categorized by an inflow of food and consumer goods, and an outflow of waste and recycled materials that cannot always be taken care of locally. Therefore, the trend of city logistics and the necessity of developing urban freight transport systems will certainly increase.

The study of Taniguchi and van der Heijden (2000) summarizes initiatives with the potential of overcoming some of the problems within urban freight transportation, where the main emphasis is on cooperative freight transport systems and concepts e.g. cooperative urban distribution centres. Consolidation of freight flows can be favourable for modes such rail and sea transportation due to higher volume requirements. There are aspects of the containerization of maritime flows that have created a favourable situation for national rail-based intermodal transports e.g. that feeder transports going on road to and from ports also require transshipment at ports and the fact that the railways can utilize economies of scale to a higher degree than unimodal road, high volumes of freight are concentrated to ports.

In Sweden, the Port of Gothenburg is a good example of maritime-rail transports, where a network of rail shuttles to a number of dry ports has been established during the last decade, as illustrated by Figure 9. In 1998 the first rail shuttle opened between the port of Gothenburg and the city of Karlstad. In 2000, the proportion of freight transported by rail to and from the port was just over 20%; in 2014 this figure had increased to 49%. Port of Gothenburg is the largest port in Scandinavia and in 2014 it handled 836 631 TEUs. (Port of Gothenburg, 2015a)

Figure 9. The rail shuttle network of Port of Gothenburg (Port of Gothenburg, 2015b)

4.1.1.2 Present Situation (Decision Point)

The market for intermodal transports has increased slightly but steadily during the last decade as described in the previous chapter, one reason being due to the decrease of traditional wagonload traffic and another being that shipper's demand for sustainable and intermodal transports has increased. The main reasons for the latter are bi-sectional; first that end-users are more aware of the environmental aspects of transports, hence sustainable transportation have become a tool for market differentiation; competition and marketing.

Second, congestion problems on the road network in and limited road vehicle regulations in the city of Stockholm, restricted to 16 meters except on dedicated routes where the national regulation of 25,25 meters is permitted; makes road haulage cumbersome - a contributing factor to why the main shippers of daily consumables and groceries in the region (see Figure 10) have shown interest for the conceptual idea of this thesis i.e. intermodal distribution in urban freight. Also the Ports of Stockholm has shown interest for this project, mainly as they have plans for constructing a new container port in Nynäshamn/Norvik (see Figure 11), which could be linked to dryport terminals by rail. Kordnejad (2013) provides visualisation and identification of the major flows on the road and rail network of the region. Flows that have not been incorporated further in this study, neither in the qualitative nor the quantitative assessment, have been excluded from this introductory essay of the thesis.

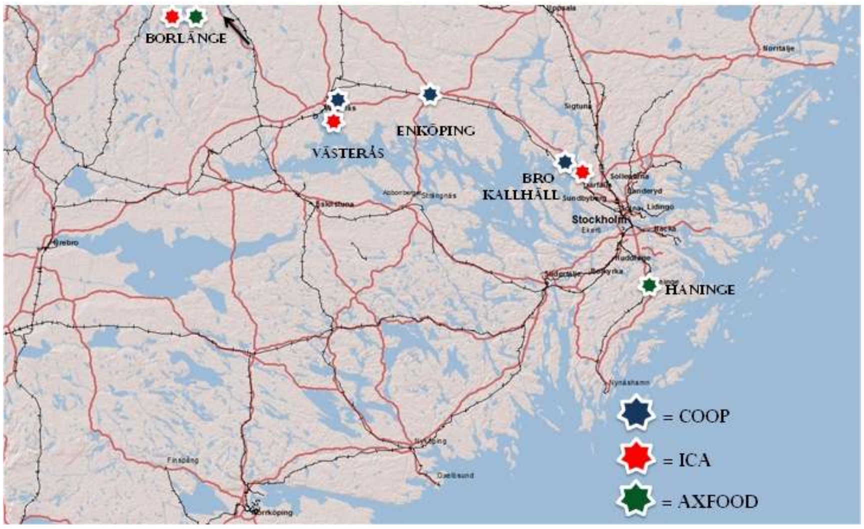


Figure 10. The location of distribution centres of the three of the largest wholesalers of daily consumables in the Swedish market.

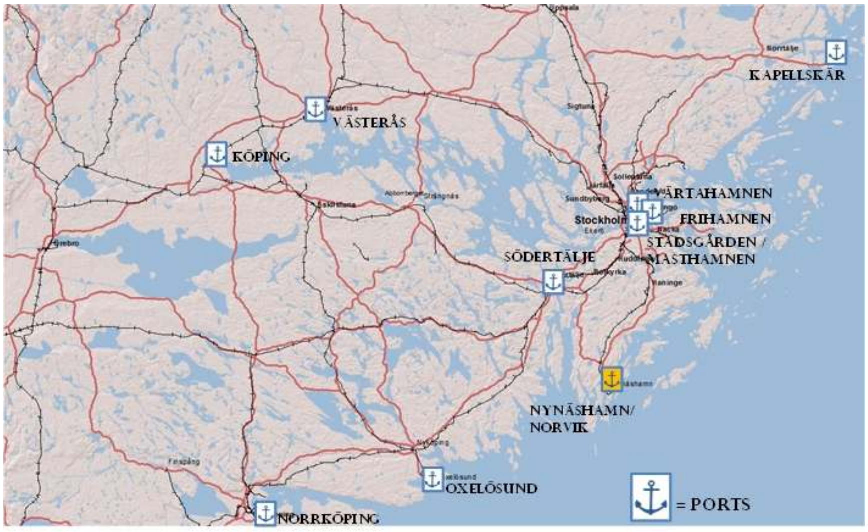


Figure 11. Freight ports in the region, where the planned port in Nynäshamn/Norvik is coloured yellow.

4.1.1.3 Future Development - Coherent plans, Paradigms and Visions for the Market

There are coherent plans, paradigms and visions that intend to influence the factors affecting the feasibility of the contemplated regional transport system. The visions are commonly similar at global, European, national and regional level, albeit with varying focal areas. At a global level there are two visions that can be identified; lower emissions from the transport sector by large and reduced congestion on the road network in urban areas.

Regarding European transport policy, in EU’s White Paper from 2011 energy efficient transports and movement of goods are the areas that are emphasized. In the White Paper it is stated that a shift to rail transports is critical in order to achieve these objectives and the best way of achieving this mode shift is by increasing the competiveness of intermodal transport. ([EU], 2011)

Regarding Swedish national transport policy, efficient transport systems, regional development and environmental as well as health aspects of transports are the most emphasized areas. Concerning the plans and visions of the studied region, a regional development plan for the Stockholm region has been created, where the focal areas are transport connectivity, capacity and regional environment. (RUFS, 2010)

4.1.2 The Technological System

4.1.2.1 Past Development (1990-2011)

As stated in the background chapter the most significant development for intermodal transports was the birth of the shipping container, which enabled transportation to become much more efficient than previously. However, the modes' base requirements on an intermodal unit load differ to a certain extent as illustrated with the following points:

Maritime:

- Ability to top lift
- Stackability
- Standardized external formats

Road:

- Within valid dimension regulations and low tare weight.
- Be able to load and unload Unit loads directly to/from road vehicles

Railway:

- Within loading gauge
- Optimal utilization of axle-load limitations of wagons
- Efficient use of the wagon and train length

The requirements put by maritime transport makes the container the ideal unit load for sea, where those put by road transportation have had the effect that two other types of standardized unit loads have been introduced; the semi-trailer (ST) and the swap-body (SB) (see Figure 12). These unit loads are dimensioned according to the European Modular System (EMS) so that they can accommodate the maximum amount of EUR-pallets and adapted to various road vehicle combinations, referred to as pallet-wide unit loads. No standardized unit load has been developed purely for meeting the requirements of the railways, thus making the handling of unit loads within rail-based intermodal operations relatively cumbersome and complicated e.g. during the transshipment process; especially in electrified intermodal terminals.

A. B. C.

Figure 12. Standardized unit loads (A.) Container (B.) Semi-trailer and (C.) Swap-body

The conventional transshipment technologies used for transferring UL's between modes are Gantry cranes and Reach-stackers. Albeit conventional transshipment technologies offer short operating times at terminals, thus increasing the flexibility of the intermodal services, they require high investment costs and high utilization rate in order to achieve efficiency (Behrends & Flodén, 2012). Hence, they constitute a contributing factor that has restricted combined transports' competitiveness to not only long distances but also to high volume operations.

A number of other transshipment technologies have been developed during the last decades and evaluated in several studies such as Woxenius (1998a); (1998b) and Bärthel (2010). One example is the Light-combi concept, which is one of few implemented examples of intermodal liner freight trains. In 1995 the national rail operator of that time, SJ, started to develop the Light-combi concept. The concept originating from the intermodal liner trains operated by Japan National Railways (now JR Freight), which was an intermodal transport system based on forklift trucks used for transshipment of customized containers under the catenary.

During 1998-2001 the Light-combi concept was implemented as a pilot project, **Dalkullan,** (The Dalecarlian Girl), for transports between the wholesaler Dagab and the retailer Hemköp, both part of the same corporate group, Axfood. The transports consisted of distribution of goods from Dagab's central warehouse in Borlänge to 37 of Hemköp's 100 stores. In April 2001 the project was abruptly ended and in Bärthel & Woxenius (2003), the authors examine if the reasons behind the closure were due to **technical, logistical, financia**l or other deficiencies in the system.

The results show that *Dalkullan* proved that the concept of Light-combi worked well both technically and logistically. Technically, the locomotive drivers were positive towards their additional task of loading/unloading swap bodies using a forklift. Furthermore, the transfer of swap bodies under the catenary, owing to the simple and conventional technology of forklifts, worked well. Also logistically the system functioned well, consisting of a schedule with intermediate stops, about 15-30 minutes each, at unmanned terminals for overnight shipments over medium-and long-range distance. The authors conclude that the closure of the project was largely due to organizational and business related factors. The marketing was inadequate and insufficient volumes were generated. In 2001 SJ was split in two, SJ offered services for passenger traffic and Green Cargo (GC) for freight. In order to achieve competitiveness, GC began a process of rationalization and cost cutting and they focused their core operations on wagonload traffic and unit train services.

The system in Japan called **E&S (Effective and Speedy)**(1) is still in operations today and *'The Super liner container express service'* have established links with intermediate stops between Japan's major cities. The system has changed from loading and unloading at sidings to trains switch directly to a subsidiary main track, where they stop for unloading and loading at a platform, from where they will depart thus reducing terminal time and increasing the overall operation speed of the train. E&S is implemented at 26 freight stations in Japan. The main drivers enabling the operations of the new system is the compact terminal design, upgrades in machinery as well as in the information system dispatching the machine operator (Okumura, 2004).

A. B. C.

Figure 13. (A.) The Reach-stacker, a conventional technology used for transshipment of unit loads at intermodal terminals (source: Coop). (B.) The Light-combi concept (source: Axfood). (C.) JR Freight's "Effective & Speedy" system. (photo: Behzad Kordnejad, 2015)

4.1.2.2 Present Situation (Decision Point)

There are several factors associated with large-scale conventional intermodal terminals based on gantry cranes or reach-stackers that make them unsuitable for all freight flows and thus limit the competitiveness for combined rail road transport. A main obstacle for intermodal transport is still the associated transshipment cost, as this cost is not proportional to transported distance. Some of the underlying reasons for the inefficiency of conventional intermodal terminals are:

- Terminals are designed for the heaviest UL's i.e. semi-trailers and heavy containers
- They require large areas that need to be hardened for high axle loads
- Majority of semi-trailers can still not be transhipped using conventional transshipment technologies i.e. there are not lift on- lift off (LOLO) trailers.
- In electrified rail networks, most terminals are not fully electrified – thus requiring additional diesel driven shunting engines and time-consuming shunting movements where track capacity is limited.
- Limited flexibility in time as opening hours are limited.
- The network of intermodal terminals is scattered and unorganized, thus localization is not always related to market needs.
- High transshipment costs and long drayage distances imply that intermodal rail services are mostly offered in endpoint relations for specific needs and not in a network.

There are two main operational prerequisites that need to be fulfilled in order to get the intermodal liner train competitive on short and medium distances. First, the loading space utilization of the train must be optimized along the route (Davidsson et al.,2007). Second, the transshipment technology utilized at terminals must be efficient and cost-effective. Hence, there is a need for ***cost-efficient small-scale intermodals terminals*** - ***CESS terminals***; and for utilizing cost-effective transshipment technologies. A number of transshipment technologies have been developed in recent decades, both horizontal and vertical. Horizontal technologies enable transshipment under the catenary and require less force; on the other hand they often require customization of the unit loads or chassis and can therefore be technically complicated. There are a number of transshipment technologies on the international market of which most require some sort of modification on the unit loads, thus creating closed transport systems for a restricted set of shippers and “hot spots of resources”.

Three of the most promising technologies handling **standardized unit loads** are evaluated in this study. The suitability of the evaluated transshipment technologies is based on specifications of requirements, which either must (shall) or should be (recommended) fulfilled:

- The technology must allow loading and unloading under the catenary at sidings during the route.
- It must be time-and cost-effective.
- It must enable transshipment on both small and large terminals
- It should allow automatic transshipment
- Train and truck should be time independent

Transshipment is however a sensitive matter, as it is also required to be reliable and uncomplicated in order to reduce the disturbance sensitivity of the intermodal chain. The concept of CESS terminals originates from the previously implemented and evaluated Light-Combi concept. A main limitation of that concept is that forklift trucks can only handle smaller UL’s (20-foot containers and swap-bodies) that are equipped with forklift tunnels and not semi-trailers and larger containers. Utilizing forklift-trucks for transshipment, albeit cheap and simple, composes certain restrictions as well e.g. limited weight/size lifting capability and requiring customization on the UL i.e. forklift tunnels. The concept of CESS-terminals – broadens the previous notion as forklifts are not the sole technology considered.

Novel wagon technologies and innovations e.g. the **Megaswing** wagon(2) (Figure 14 A) can also be regarded as candidate technologies as they enable transshipment on sidings under the catenary without any additional transshipment equipment, thus avoiding the heavy investments associated with conventional terminals. The wagons are designed for semi-trailers of all types, including trailers without the attachment required for handling by the grapple arms of cranes and reachstackers. Hence the market for combined land transport can be broadened as more standardized unit loads can be transhipped. However, the rail investment cost increases as the wagons are more costly than conventional intermodal wagons and standardized heavy containers cannot be transhipped.

CarConTrain (CCT)[(3)] (Figure 14 B) is another horizontal transshipment technology that can be used at CESS terminals. The concept involves hydraulic poles on which unit loads are placed during the transshipment process. Hence, the transfer between modes does not have to be synchronized, offering a higher degree of operational flexibility. (Nelldal et al., 2008) The system is currently at prototype stage but it is designed for handling all types of unit loads; albeit the system requires customization on truck and wagon chassis as well as a sliding transfer unit.

A. B. C.

Figure 14.: (A.) Megaswing wagon (B.) CCT system (photo: Behzad Kordnejad, 2012) (C.) ContainerMover (photo: Behzad Kordnejad, 2014)

CTT is not on the market yet, but there is a technologically similar system the Innovatrain's '**ContainerMover**'[(4)] (Figure 14 C) - which is a horizontal transshipment technology that has been operationalized in recent years in Switzerland that uses compressed air to lift the unit loads so they can be laterally and hydraulically displaced from a rail wagon to a truck and vice versa. The concept is similar to the CCT concept in the sense that it involves hydraulic poles on which unit loads are placed. Hence the transfer between modes does not have to be synchronized, offering a higher degree of operational flexibility. Albeit the technology can handle standard swap bodies and 20' containers; chassis for trucks and wagons gain extra weight as they are customized with additional equipment, reducing precious payload. One of Switzerland's largest wholesalers of daily consumables is currently using this technology and has created an intermodal transport system with several intermediate stations on short distances.

4.1.2.2.1 ***Transshipment Nodes***

Terminals are defined in this study as nodes where there currently is a high concentration of unit loads as well as a possibility to transfer between different modes and railway e.g. intermodal terminals, ports, certain large warehouses and distribution centres. Intermodal terminals in the region can be described according to three main characteristics:

1 Organizational structure
2 Freight typology
3 Site location

Regarding "organizational structure", there are two basic functions that are central in an organizational model for a terminal: ownership and operations. These functions can in principle be fulfilled by the same actor where the owner is also responsible for the operational activities. However, it is a common practice to appoint a suitable operator through a tender. For example the public company Jernhusen's intermodal terminals throughout Sweden are run by different operators. Figure 15 illustrates the public intermodal terminals in the region (green), corporate intermodal terminals (blue) and intermodal terminals that are planned to be built in the region (yellow).

Figure 15. Conventional intermodal terminals in the region.

As stated earlier, one of the underlying reasons for the inefficiency of conventional intermodal terminals is the fact that the network of intermodal terminals is commonly unorganized and their localization is not always related to market needs. This is also the case in the studied region, where a number of relatively new terminals (Katrineholm, Eskilstuna, Bro and Årsta) have been established or modernized within the last decade and which must care for the return of their investment while competing with existing terminals in the region. Unfortunately, the new terminals have had to struggle to attract sufficient freight and hence achieve high utilization rates.

Regarding Cost-efficient small-scale intermodals terminals - CESS terminals, there are places in the region that are suitable, with a possible extension of sidings and storage areas and where unit loads can be transhipped between rail and road. As a part of the feasibility study of the Light Combi project, an inventory was made of appropriate terminal locations in Sweden based on the study of Johansson (1998). Figure 16 illustrates the sites that were found to be suitable terminal locations in the Stockholm-Mälaren region. New and innovative terminal technologies, e.g. the CCT system and the Megaswing wagon presented above, enable handling of all types of unit loads at smaller and more cost-effective transshipment terminals. Also the Light-Combi system can be used in such terminals, provided that the transport demand consists of smaller unit loads (20-foot containers or Swap-bodies) equipped with forklift pockets. The suitability of the sites was assessed according to the following criteria:

1. Location relative to the rail network
2. Location relative to the road network

3. Location relative to the local market
4. Availability for trucks
5. Disturbance sensitivity of the surroundings
6. Technical condition of tracks (e.g. switches and length of sidings)
7. Constructability – tracks
8. Constructability – other land improvements

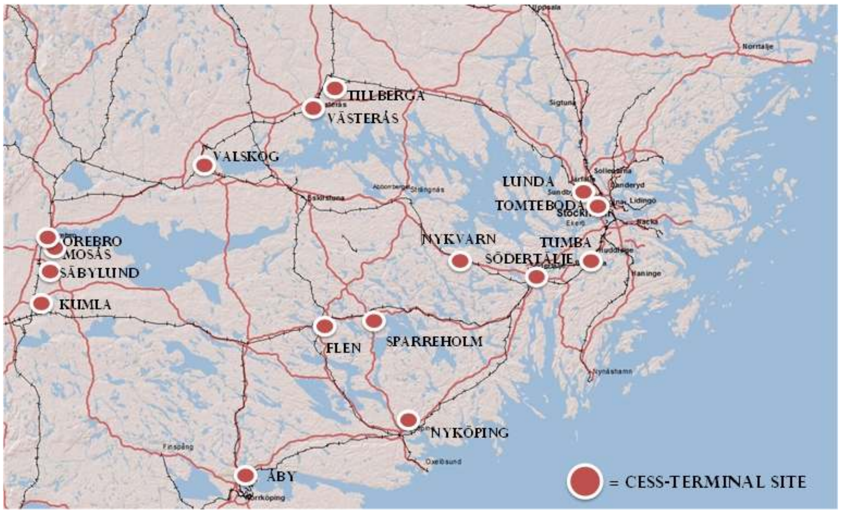


Figure 16. Suitable sites for CESS-terminals in the region.

4.1.2.2.2 ***Routing and Scheduling***

An initial step for the realization of a regional intermodal transport system ought to be to persuade large shippers to use the system. Large shippers should preferably be tied up with long-term contracts thus providing a stable base volume to the system. As the system is developed and stabilized, it can be expanded with multiple short-termed shippers. The large shippers should preferably be those who currently transport their goods to the outer edges of the region for further distribution by road. Hence reducing regional freight transports by trucks.

The initial point for the design of a route for the proposed train is to link a few large terminals with several small intermodal terminals. Two major intermodal terminals in the west-respectively east-end of the regional terminal structure are Hallsberg and Stockholm South Årsta. These terminals are the two largest intermodal terminals in the region, as well as nodes in the Mälar- and Svealand-corridors. Linking these corridors creates a loop around the lake of Mälaren, why this route is referred to as "The Mälaren loop". Stops for loading and unloading in the loop are suggested to take place at both conventional intermodal terminals in the region as well as at suitable sites for CESS-terminals. The possibility to stop at additional sites except conventional intermodal terminals enables more relations to be covered and thus increases the possibility to attract more shippers. Three options for "The Mälaren loop" have been evaluated. The cycle times for the routes are calculated at the maximum speed of the train (STH) at 100 km/h. The results based on the following criteria are illustrated by Figure 17.

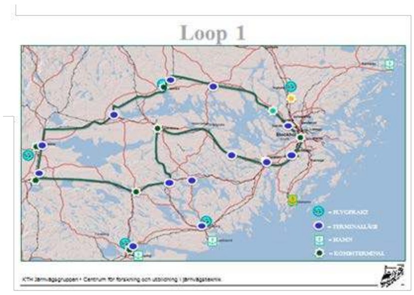
The choice of terminals is based on the following criteria:

1. There should be sufficient freight flows in the terminal and its' surrounding area; either for transshipment between modes or for further transportation.
2. The terminals should not be located too close to each other.
3. The terminal should be favourably located relative to the rail network.
4. The terminal should be favourably located relative to the road network.

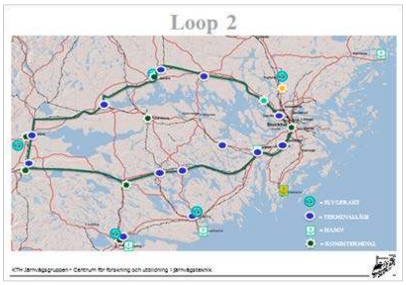
The generation of rail routes is based on the following criteria:

1. The route should connect the main terminals and freight markets in the region.
2. The route should be able to connect to both short- and long distance freight flows to, from and within the region.
3. The route should allow a circulation time of approximately 12 hours, thus enabling two circulations per day.
4. The route should allow the train to run operationally efficient, with minimal delays at entry and exit points from the terminals.
5. The route should be possible to operate in combination with other traffic present on the rail network.

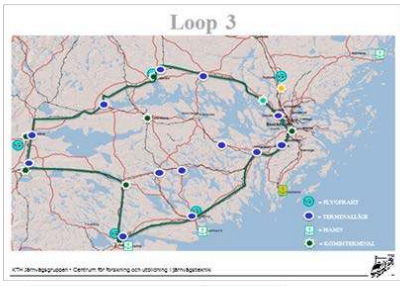
As the majority of freight flows to the region have their destination point in Stockholm, implementing only the Mälaren loop would imply low loading space utilization of the train to the west of Stockholm. In order to overcome this imbalance, a shuttle train with the starting in the planned container port in Norvik/Nynäshamn is proposed to complement the Mälaren loop. To purely run the shuttle train without implementing the loop would imply that too large volumes and long distances are hauled by trucks from the planned port. The shuttle train is planned to make stops at three conventional intermodal terminals: Port of Norvik, Stockholm South Årsta and the planned terminal Stockholm North Rosersberg.



STH (Max speed)	100
Cycle time:	12:58
Distance (km)	466



STH (Max speed)	100
Cycle time:	11:25
Distance (km)	419



STH (Max speed)	100
Cycle time:	12:07
Distance (km)	478

STH	100
Time (one-way)	02:05
Cycle time:	05:40
Distance (km)	92

Figure 17. Evaluated rail routes for the transport system.

Regarding routing on the road network, there are numerous software tools for transportation management, mainly intended for mapping O/D relations and for routing purposes, in which the most common techniques are based on gravity models or linear programming for specific optimization objectives. The latter in the form of a minimization approach for total haulage costs subject to supply and demand constraints. In the REGCOMB project the software **ArcGIS (Network analysis extension)** has been used in order to map and visualize nodes as well as for route optimization on the road network.

The complete transport system that is proposed i.e. rail routes and conceptual encatchment areas of terminals is illustrated by Figure 18.

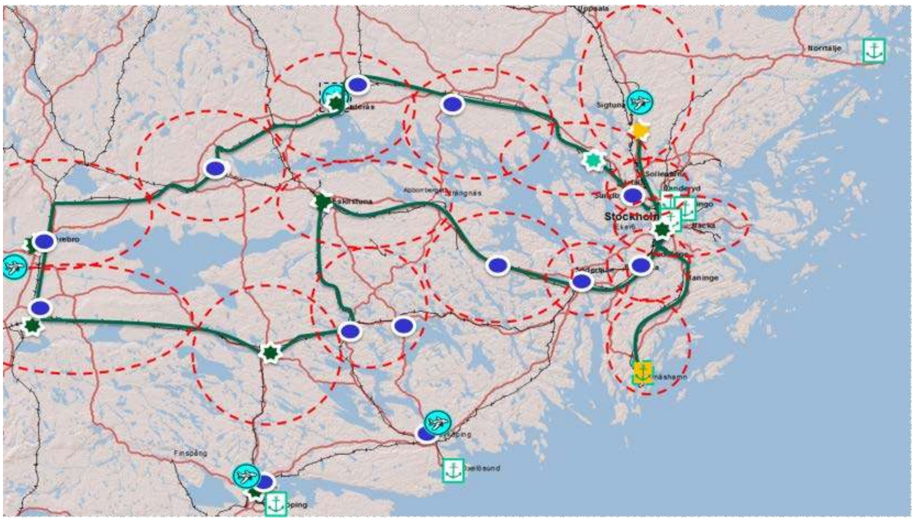


Figure 18. Configuration for the complete transport system; consisting of rail routes and conceptual encatchment areas for terminals.

4.1.2.3 Future Development – Trends and Trajectories for the Technological System

Different plausible scenarios could affect the results of this feasibly study. The following are identified scenarios that would affect the results positively for the intermodal alternative:

- Innovation of improved transshipment technologies. If the CCT technology is fully developed or if novel transshipment technologies are introduced in the Swedish market that in addition to fulfilling the criteria put by CESS-terminals are less costly and energy consuming and more time-efficient and reliable than the studied technologies.
- Increasing fossil fuel prices, in particular diesel prices; or an introduction of infrastructural fees for road hauliers would tilt the results towards would tilt the results towards the intermodal alternative. The actual average annual increase in national diesel prices has been 3,43 %/year during the period 1990-2012.(5)(6)

The following are identified scenarios that would affect the results negatively for the intermodal alternative:

- Diminishing number of sidings in the region that would be suitable locations for CESS-terminals, thus reducing the number of potential transfer nodes between rail and road.
- Increasing electricity prices. After the deregulation of the Swedish electricity market in 1996 the electricity prices was about 0,25 SEK/kWh. Towards the end of the 1990's, the price went down to 0,10 SEK/kWh and by 2010 it had increased to just over 0,50 SEK/kWh.(7) The volatile shifts complicate the task of identifying a trend for electricity prices except that it will most probably increase in the long run.

- Increasing emission factor of electricity as the Swedish electricity market is getting integrated with the European.
- Longer road vehicle combination, High Capacity Transports (HCT). There is a general trend for longer and heavier vehicles for freight transport operations. In Sweden longer road vehicle combinations, High Capacity Transports (HCT), allowing two Semi-trailers per truck are currently investigated. Thus the maximum length of a truck would be 32 meters instead of 25,25 meters. The maximum length in most European countries is 18,75 meters.

Figure 19 summarizes the evaluation framework and the key results from the feasibility study including the identified trends and trajectories. As illustrated by Figure 19, the evaluation of the market and the technological system act as a foundation for the scenario analysis conducted in the case study; which in turn is input to the stakeholder analysis.

Regional Intermodal Transport System - A Socio-Technical System		
Past Development (1990-2011)	**Present Situation - Decision Point**	**Future Development (- 2030)**
Market Structure	**Private Stakeholders**	**Market Structure (coherent visions and paradigms)**
Freight transport	**Carriers and service providers**	**Global:**
National Railway and Road administration merged in 2010	Increased number of rail operators and service providers due to deregulation	Lower emissions from the transport sector
Increase in international containerized maritime flows	Previous incumbent carrier still dominating the rail freight market	Reduced congestion on the road network in urban areas
Introduction the European Modular System (EMS)	Existing transhipment technologies for Loading Units	**EU: The White Paper 2011**
Rail freight transport	**Shippers**	Energy efficient transports and movement of goods emphasized. Shift to intermodal transports advocated in order to achieve objectives.
National rail freight market deregulated	Shippers face constraints with urban transportation on the road network	**National transport policy**
Regional rail capillary infrastructure phased out	Increased demand for sustainable freight transport	Efficient transport systems, regional development and environmental as well as health aspects of transports emphasized
Decrease in national wagonload traffic	Uncertainties regarding the railways' operational reliability and punctuality	**Regional development plan RUFS 2010**
Operational constraints for rail freight during winter time	**Public Stakeholders**	Transport connectivity, capacity and regional environment emphasized
Road freight transport	Capacity constraints on some sections of the rail network e.g. during rush hours in Stockholm.	**Development Trajectories and Trends for Technological System**
Increasing fossil fuel prices	Timetable constraints: Timetable slot allocation possible but require long-term planning	Innovation of improved transhipment technologies e.g. CTT
Increasing number of inexpensive European road operators entering the Swedish market	Transhipment constraints: Available sidings for CESS-terminals decreasing	Increasing fossil fuel prices
Technological System		Number of sidings and suitable locations for CESS-terminals will continue to diminish
Past experiences from regional intermodal transport systems: The Light Combi concept		Increasing electricity prices
Increased number of intermodal terminals in the region		Increasing emission factor for electricity
Dryport and Hinterland concepts emerging e.g. Port of Gothenburg		Longer road vehicle combinations, High Capacity Transports (HCT)

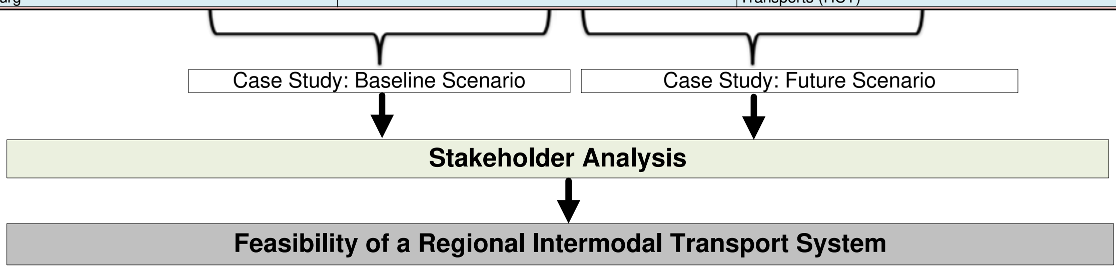


Figure 19. The evaluation framework of the feasibility study.

4.1.3 Baseline Scenario

Based on the case study analysis conducted in paper III and paper IV, the feasibility of creating a rail based intermodal transport system in the region has been quantitatively evaluated. As a way of evaluating such a system, freight volumes from a major actor within the Swedish consumer goods market have been attained. The assignment consists of the wholesaler COOP's distribution of consumables and groceries to retail shops within the region of Stockholm. The shipper's data have been applied as a case study and input for the proposed model ITCM.

Table 4 presents the results for transshipment cost and emission for the studied transshipment technologies, generated as an output from the terminal module in ITCM. The transfer cost for six different terminal types have been calculated as illustrated by , one conventional reach-stacker based and medium-sized intermodal terminal (handling 50 000 TEU's/Year) and five types of CESS-terminals (handling 15 000 TEU's/Year):

1. Conventional Intermodal Terminal - Medium sized, using reach-stacker.
2. CESS Terminal 1A: Light-Combi. Forklift trucks stationed at transfer terminals.
3. CESS Terminal 1B: Light-Combi. Engineer handles the forklift truck, thus reducing the operator cost.
4. CESS Terminal 1C: Light-Combi. Multipurpose forklift trucks are used half of the time for other purposes at terminals, thus reducing the cost for transshipment equipment.
5. CESS Terminal 2: Specialized wagon - Megaswing
6. CESS Terminal 3: CarConTrain (CCT) technology

Table 4. Cost and CO_2 emissions per lift and unit load for the evaluated transshipment technologies

Transshipment Technology	Cost / UL (SEK)
Conventional Terminal	268
CESS Terminal 1A	257
CESS Terminal 1B	159
CESS Terminal 1C	170
CESS Terminal 2 Megaswing	143
CESS Terminal 3 CCT	106
CO_2 -Emissions	**CO_2 / UL (KG)**
Medium Intermodal Terminal	4,5
CESS Terminal 1 - LightCombi	1,7
CESS Terminal 2 - Megaswing	0,9
CESS Terminal 3 - CCT	0,3

As stated in chapter 3.2.1 and fully elaborated in paper II, ITCM consists of two main phases: generating an initial plan that matches the constraints of the demand and to process the demand and supply in the three integrated cost modules; terminal handling, rail and road transport. Thus the first step is to examine the constraints of the demand.

As seen in Figure 20 (A) the shipper has three distribution centres (DCs), each handling a separate goods class; common (i.e. non-tempered), refrigerated and frozen goods. The set of terminals that are considered are actual conventional intermodal terminals in the region and potential sites for CESS-terminals.

The required cycle time of train is another main parameter influencing the scheduling. A 466 km long rail route consisting of a loop around the region is evaluated in the case study. The route was considered the optimal route within a set of evaluated routes. The rail route connects the set of conventional intermodal terminals and sites for CESS-terminals in the region, Figure 20 (B). The intermodal alternative is estimated in a 'maximized' scenario i.e. all available terminal locations along the route are selected, and the cost performance of the intermodal alternative is presented as a function of train loading space utilization.

A. B.

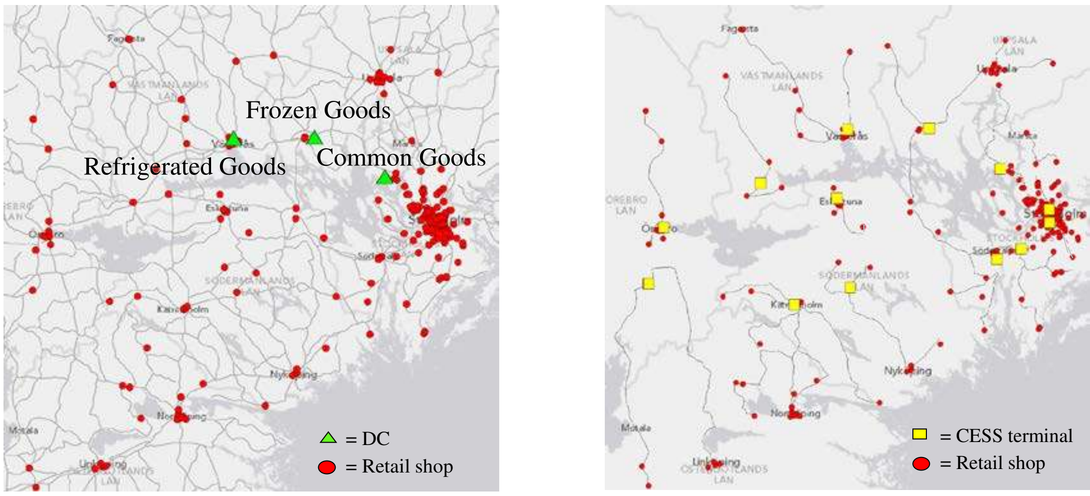


Figure 20. (A) Origins and destinations for the unimodal road alternative; (B) Allocation of shops to CESS-terminals for the intermodal alternative.

Results for the **baseline scenario i.e. for the current market structure and existing transshipment technologies**, regarding estimated transport costs using different transport chains and transshipment technologies, are illustrated by Figure 21.

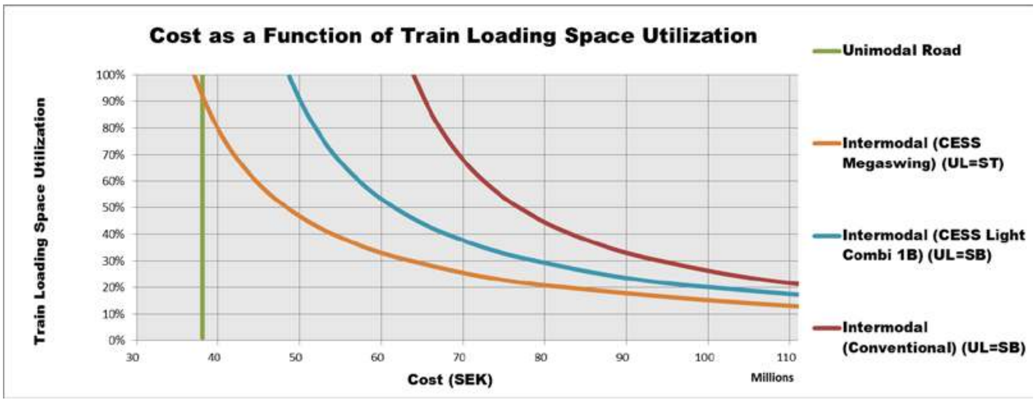


Figure 21. Total transport cost for the evaluated transport chains in the baseline scenario.

A break-even point is found when using the estimated costs of the evaluated transshipment technologies if the loading space utilization is increased to 92% for the reference train and using CESS terminals with Megaswing wagons. The reference train is 396 meters and consists of one locomotive and 14 wagons. No break-even points can be found for either the Light-combi or the conventional option.

Note that the Semi-Trailer (ST) has a capacity of 33 EUR-pallets and the SB 18 EUR-pallets; hence using ST's require fewer number of transshipments. However using SB's enables trucks with higher capacity, 2 SB's and 36 EUR-pallets, whereas using ST's enables a truck capacity of one ST and 33 EUR-pallets and hence a higher cost for road haulage. A remark is that longer road vehicle combinations allowing two ST's per truck are currently investigated in Sweden. Regarding the analysed case study, the lower cost for road haulage and transshipment cost/unit load do not compensate for the higher number of transshipments, thus the lowest total transport cost is generated by Megaswing alternative as illustrated by Figure 21.

Hence, based on the results of the case study for the baseline scenario it is concluded that a rail based intermodal transport system is on the threshold of feasibility in the studied region, when addressing RQ2 i.e. if an operationally cost-effective system can be implemented. The loading space utilization of the train and the transshipment cost are the most critical parameters. Regarding loading space utilization, it is necessary to consolidate other freight flows in the train in order achieve high and balanced loading space utilization along the route. Results of emissions of each transport chain in both the baseline scenario and the alternative future scenario are presented in the following chapter.

4.1.4 Alternative Future Scenario

As stated 4.1.2.3 'Future Development – Trends and Trajectories for the Technological System', different plausible scenarios could affect the results of this feasibility study. A scenario that would affect the results positively for the intermodal alternative is the innovation of improved transshipment technologies e.g. if the CCT technology is fully developed or new transshipment technologies similar systems such as the ContainerMover technology would be introduced in the Swedish market.

CCT is estimated to have the lowest cost per transshipment 106 SEK/UL (see Table 4). The analysis from the case study shows that the break-even point i.e. when unimodal cost equals the intermodal (with the train loading factor set to 80%), regarding transshipment cost is 67 SEK/Swap-body (SB) when using CCT. If the train length is increased, the total transport cost decreases as long as the loading space utilization of the train is maintained. The train length is however subject to infrastructural constraints e.g. the length of sidings and meeting stations on the rail network. If the train length would increase to 501 meters i.e. 4 Megaswing wagons more, the intermodal cost is equal to the cost for unimodal road haulage at 79% train loading space utilization.

Moreover, another plausible and quantifiable scenario is the increase of fossil fuel prices. If diesel prices would increase so would the feasibility of the intermodal option. As illustrated by Figure 22 if the diesel prices would increase with 25%, which is estimated to take place by year 2020, the total cost for the reference train (396 meters) is equal to the cost for unimodal road haulage at 74% train loading space utilization when using CESS-terminals with Megaswing wagons and 99% when using CESS terminals with CCT. For this scenario, if the train length is set to 501 meters when using CESS terminals with Megaswing wagons, the break-even point decreases to 63% train loading space utilization.

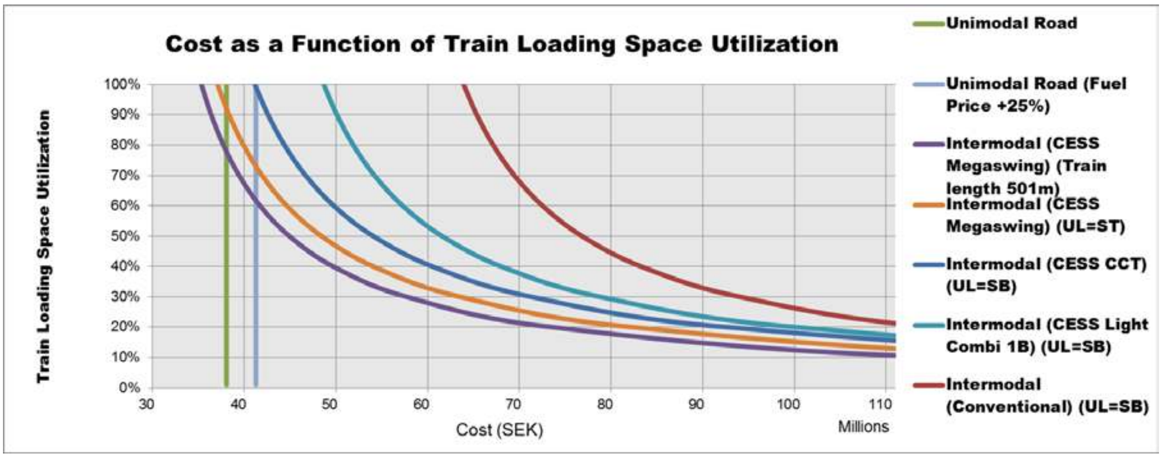


Figure 22. Total transport cost in SEK for the evaluated transport chains in the alternative future scenario.

The results of CO_2 emission for both scenarios are illustrated by Figure 23. The emission from electrification is assumed to stem from electricity produced in Sweden. As shown by the figure, using CCT will result in the lowest amount of CO_2 emissions, 613 tonne (66,2% reduction compared to unimodal road). If medium-sized conventional intermodal terminals where used at each CESS-terminal site, the annual CO_2 emissions is estimated to 1198 tonne (33,9 % reduction compared to unimodal road). For CESS terminal Light Combi, the CO_2 emissions are estimated to 800 tonne (55,9% reduction compared to unimodal road) and for CESS terminal Megaswing to 776 tonne (57,2% reduction compared to unimodal road).

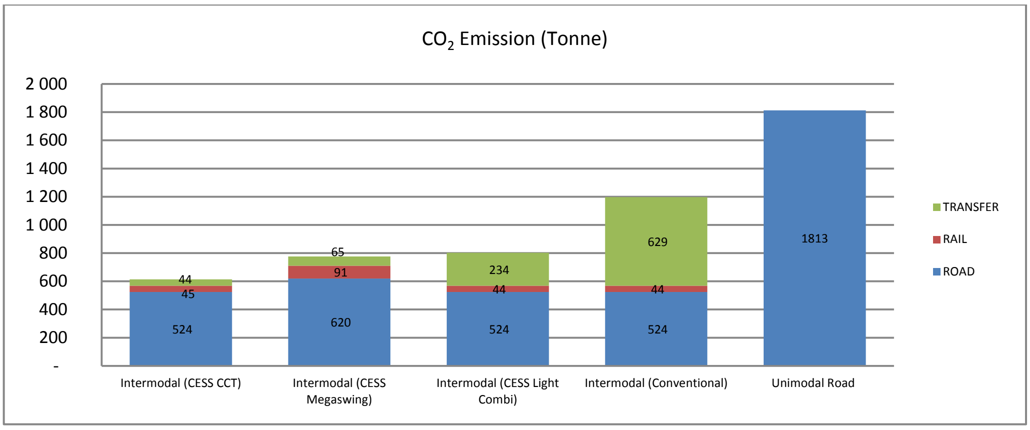


Figure 23. CO_2 emission for the evaluated transport chains.

4.1.5 Stakeholder Analysis

As stated in the evaluation framework, in the second phase of the feasibility study a stakeholder analysis is conducted. The analysis regards stakeholders' perspectives, barriers, demands and preference for implementing and utilizing such systems. A stakeholder analysis is conducted for a proposed business model for the system, the 'local cooperation model'. The analysis is carried out through participative action research; experts involved in interviews, two workshop rounds and a survey. The method was based on the principles of the Delphi method in the sense that it is a method for gathering data and analysing opinions gathered from experts within their specific field. The technique is designed as a group communication process which aims to achieve a convergence of opinion on a specific issue (Hsu & Sandford, 2007).

The study of Dinwoodie (2006), investigating the potential of urban rail freight distribution in UK, concluded that urban authorities will only adopt sustainable urban freight distribution strategies if they "satisfy broader policy objectives as well as commercial corporate interests." This conclusion is very well in line with the results derived from this analysis i.e. for the system to be considered feasible there has to be a corporate commercial interest and local authorities' incitements are guided by broader sustainability policies. Only then could the conceptual idea of this study be considered feasible. The key point for this decision making process is 'corporate commercial interest', which for a specific technology or mode is based on the ability to offer cost leadership for their value networks or to offer market differentiation. Cost leadership depends on a wide range of factors e.g.; "the scale of operations, linkages, resources utilization, coordination, integration, level of standardization, regulatory framework as well as time related and locational factors" (Ibid). Thus the regulatory framework can significantly influence the ability to achieve cost leadership, especially given that profit margins are very low in the Swedish freight market. If the regulatory framework is structured in order to satisfy broader policy objectives; the ability of short haul intermodal rail freight services to achieve cost leadership will increase accordingly.

Moreover, in an efficient intermodal transport system the actors and activities have to be organized and coordinated in a business model i.e. a model for how a company conducts its' business. It can be defined as the set of activities that a company performs in order to create a profit, how and when it performs them (Osterwalder, 2004). Note that the concept entails how a company makes a profit and not just how it generates revenues. Flodén (2009) adopts the same framework as Osterwalder (2004) and categorizes four typical business models for intermodal transport systems; subcontractor, complete transport, own-account and local cooperation model – arguing that prevailing intermodal services represent one of the models or a mixture between them. The main characteristics of each of the models are described by Figure 24.

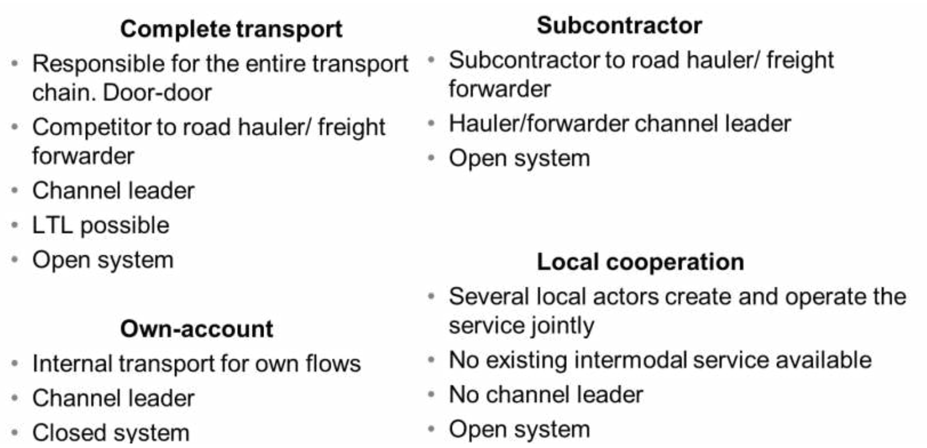


Figure 24. Categorization of four typical business models for intermodal transport systems

The model that represents the conceptual idea of the study is 'the local cooperation model', where the intermodal transport is organized by several local actors along a transport route, commonly in cooperation with local authorities. Local cooperation model will often occur in areas where there is no previous intermodal road-rail service. On the demand side, the constellation of shippers consists of several private actors that are interested in a shift to intermodal transport, but where no single actor has sufficient volumes to operate the intermodal service on their own.

On the supply side, the actors include operators and infrastructure owners. This model is considered challenging in the sense that it is difficult to agree on an appropriate division of responsibilities and revenues among the partners and that there is no clear channel leader. This enables flexibility but also increases the risk of conflicts and power struggles. The organization can vary in form; it could be anything from a jointly owned company to an agreement where one partner acts at the formal coordinator. Maintaining this partnership of core partners is important for the business model to be successful.

Within the scope of this study, two rounds of workshops have been arranged in order to create a platform for consensus finding and the establishment of partnerships among the stakeholders as well as to explore the possibilities for the continuation of the project with the desired outcome of a pilot project. The workshops participants are presented in Table 5.

Table 5. Workshop participants

Workshop Round 1		Workshop Round 2	
Response rate: 14/21		Response rate 15/21	
Private stakeholders	**Nr. of experts**	**Private stakeholders**	**Nr. of experts**
Shipper	1	Shipper	3
Terminal operator	2	Terminal operator	2
Road haulier	1	Rail operator	1
		Road haulier	1
Public stakeholders		**Public stakeholders**	
Terminal owner	1	Terminal owner	1
Port owner	1	Port owner	1
Local government	4	Local government	2
Transport administration	3	Transport administration	2
Research institute	1	Research institute	1

During the workshops a survey study was conducted investigating the experts' opinions about the system, regarding both market related and technological aspects. Other objectives were to investigate the stakeholder's requirements and preferences regarding routes, frequencies, times, terminal sites, and business model. Some of the most relevant and summarizing questions and entries from the survey are presented below. Same experts were invited for the two workshop rounds and the response rates were almost equal, however the constellation of experts was not the same.

Question 1. Business model. Choose the actor that best represents your organization in the table below as well as the activities that your organization may be able to contribute with in the proposed transport system. Feel free to add other activities or actors to the table.

Actor \ Activity	Shipping	Local road haulage	Coordination of local road haulage	Transhipment of loading units	Terminal services	Rail transport	Coordination of the rail transport	Marketing of the system	Provide loading units	Provide rail wagons	Coordination of the complete intermodal transport chain	Short and long term planning of infrastructure	"Reparations"
Shipper	3												
Road haulier		2	2	1	1			2	2		2		1
Forwarder		1	1					1	1		1		
Terminal owner				1	1			1			1		
Terminal operator		2	1	2	2			2	1		1		1
Rail operator						1	1			1	1		
Infrastructure owner		2	1	1	1			1				1	

Figure 25. Actors and activities in the local cooperation model.

Question 2. SWOT analysis. What strengths, weaknesses, opportunities and threats do you associate with the implementation of the proposed transport system? (Recurring entries are stated in Figure 26)

SWOT Analysis		
INTERNAL Characteristics of the transport system	**Strengths** • Low energy consumption (5) • Reduced congestion on the roads (2) • Development of the railway sector (2) • Cost (2)	**Weaknesses** • Lack of track capacity (3) • Investment in infrastructure (2) • Technically complicated (2) • Inefficient transshipment (2)
EXTERNAL Characteristics of the surroundings (e.g. shippers, competitors and society)	**Opportunities** • Streamlining local transport (3) • Environment (2) • Higher fossil fuel prices (2)	**Threats** • Unregulated competition from road hauliers (3) • Cost (3)

Figure 26. Results of the SWOT analysis

Question 3. Do you think it is realistic to implement the proposed transport system?

Table 6 Responses from the experts.

Alternative	Entries
Yes - under current conditions	4
Yes - provided that road haulage becomes more expensive	4
Yes - provided that intermodal transports becomes more efficient	5
No	0
Do not know	2

Figure 25 represents the actors that the respondents identified themselves as and the activities they stated they could contribute with. On the demand side, during round 1, only one shipper attended and two other invited shippers left last minute cancellations. Albeit being the second largest wholesalers in Swedish grocery market – a mismatch between supply and demand emerged. During the second round all three shippers attended; including the largest wholesaler in the Swedish grocery market as well as the incumbent postal service provider. The two shippers of grocery were positive towards cooperation within the transportation segment. However, the competitive relationship within their core business was an obstacle for cooperation from the perspectives of their organizations.

During the workshops it was also revealed that the time requirements of the postal service provider's package delivery segment and those of the shippers within the grocery industry differed to the extent that it did not enable a joint rail service. However, a business relation was established between one of the shippers and a terminal owner – who initiated a discussion for a pilot project in one of the sections of the suggested route.

On the supply side, there was a positive attitude towards the project and suggestions were made for taking actions in order to facilitate the implementation of the potential system. One example was when an urban planner suggested overviewing regulations within the city limit and in vicinity of terminal sites. Another example was a terminal infrastructure owner from a surrounding municipality who offered a terminal site for a demonstration project.

Furthermore, a set of possible routes and mode alternatives were evaluated and stakeholders' underlying assumptions about the transport system were explored. Consensus was found for a suitable conceptual business model, 'the local cooperation model'.

Figure 26 is the most summarizing question from the survey. Here opinions are stated regarding internal strengths and weaknesses of the system as well external opportunities and threats. Internal refers to characteristics of the system and external to those of the surrounding e.g. shippers, competitors and society. What is perceived as the as the strongest internal strength of the system is the low energy consumption. Other equally strong factors were; reduced congestion on roads, development of the railway sector and reduced operational costs. The weakest internal characteristic is thought to be the lack of track capacity. This is mainly a problem in Stockholm during rush hours. There are also concerns regarding the complexity of the transshipment technology. External opportunities generated by the system are; streamlining local transportation, increasing fossil fuel prices and environmental attention. The external threats associated to the system are related to the competition from road haulage; that the market is perceived as not sufficiently regulated and that cabotage road haulage i.e. the haulage of goods in one EU member state by a vehicle registered in a different member state; generates price pressure on the freight market. The survey was conducted during round 1. Afterwards, the statements from the SWOT analysis were compiled by the author and disseminated to the respondents, thus enabling them to react and give feedback to the compilation during round 2.

Responses from the experts to question (3) in Table 6 reveal the overall assessment of the experts regarding the feasibility of the proposed system. None of the participants stated that the implementation of the system was unrealistic. Only four out of 15 experts believed that the system is implementable under current conditions. Equal share of the participants believe that it is so - provided there is an increase in prices from road hauliers. Five of the participants stated that the system needs to become more efficient from a technical perspective.

4.2 BIOSUN

4.2.1 Evaluation Framework

The evaluation is conducted for the Swedish market and follows a methodology in accordance to (Piotrowicz & Cuthbertson (2012)) and by using a bi-sectional qualitative framework. First, a STEEP analysis is conducted in order to analyse the external factors affecting railway transportation of biofuel. Second, the concept of sustainability is defined and internal factors affecting rail transportation of biofuel are evaluated through the three main dimensions of sustainability: environmental, economic and social (Moldan et. al (2012)). In essence, it is the factors affecting rail transportation of biofuel and the inherent capability of the rail mode that are addressed. Albeit the two methods are to their nature qualitative approaches, the analysis is complemented by design and quantitative assessment of a case study. The evaluation framework is illustrated by Figure 27.

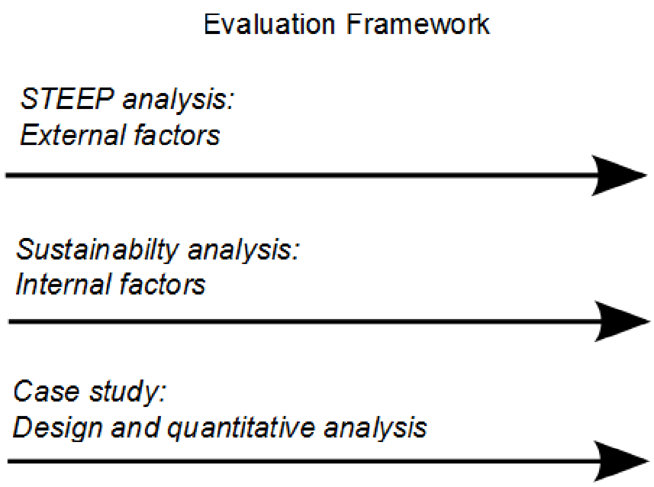


Figure 27. Illustration of the evaluation framework; STEEP and sustainability analysis and a case study.

4.2.2 Baseline Scenario

The baseline scenario design is based on interviews with the heating plant and terminals in the area. The break-even distance analysis show that distances should be kept above 250 km. Among the major sourcing areas for biofuel in Sweden, the two closest areas above 250km are the regions of Dalarna and Småland, in Figure 28 illustrated by (A) respectively (B). Due to the importance of a high utilization of the train, a five day per week scenario is selected operating three days a week to Småland and two days a week to Dalarna. In Småland, logging residue wood chips are picked up, which is the most common biofuel in Sweden. In Dalarna bark is picked up. Dalarna is rich in wood industries and their by-products are the second most common fuel in Sweden (Awais & Flodén, 2014).

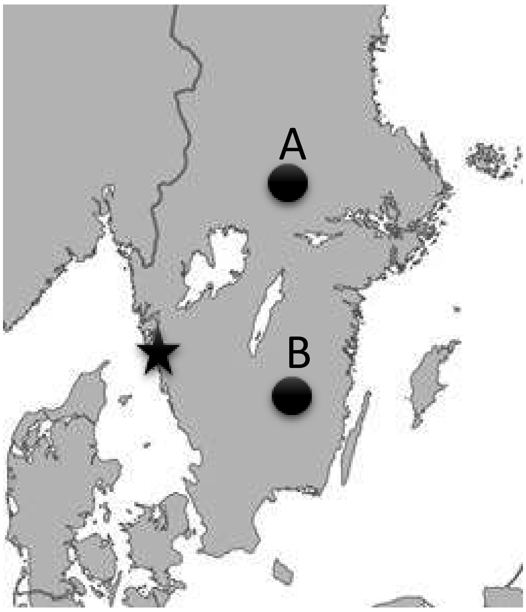


Figure 28. The heating plant (star) and sourcing terminals (A and B).

STEEP is an acronym for: Social, Technological, Economical, Environmental and Political. The STEEP acronym is used as a strategic tool to analyse external factors that influence an industry, a firm or a business area. The STEEP framework is used in order to identify two main areas; “Drivers” illustrating the reasons for using and implementing rail transportation of biofuels, while “Challenges and Limitations” emphasize on the obstacles for it. Rail faces a number challenges and limitations, in many cases related to a relatively high volume requirements and operational inflexibility. The main drivers for it are associated with economies of scale and rail freight’s relatively low environmental impact. The result of the STEEP analysis is summarized in Table 7.

Table 7. STEEP analysis for rail-based multimodal transportation of biofuel.

STEEP Criteria	Drivers	Limitations and challenges
Social	Energy consumption and emissions from rail transport are relatively low and perceived positively by shippers and society	Shippers are generally not willing to pay extra for environmental friendly transport. The reliability and punctuality of the Swedish rail freight system should be improved in order to be trusted by more shippers.
Technological	Low energy consumption. Higher utilization of allowed weight and volume per length compared to trucks.	Higher volume and coordination requirements than for trucks. Shippers may have to adapt their logistics system and supply chain structures.
Environmental	The mode generating the least emissions. Intermodal terminals can be combined with facilities for processing wood biofuels. This has been further developed as intermodal biofuel terminals were established in order to handle fallen trees after storms.	Emissions and fuel consumption by shunting and transshipment operations could be improved. Inflexible network structures for biofuels transport, requiring trucks at least at the supply end.
Economic	Economies of scale achieved over long distances. Can increase the distance for sourcing of raw-material supply in biofuel production.	Limited competitiveness over short distances. Long road vehicles are allowed in Sweden. Increasing electricity and track access costs.
Political	Efficient rail freight transport in general and intermodal terminals in particular are factors that are perceived by local authorities as having a good impact on local industry.	The rail freight market is deregulated but it exhibits signs of oligopoly and have high entry barriers and the former incumbent operator is dominant.

Sustainability is commonly divided into environmental, economic and social sustainability (Moldan et. al (2012); Carter & Rogers (2008)). To be considered sustainable, a traffic mode must perform well in all three areas. The impact will in the analysis further be divided into three levels. Level 1 is the impact within the organization, level 2 is impact on supply chain partners, and level 3 is external impact. The first level includes aspects such as the employees' working conditions, company profits etc. The second level includes aspects such as customer satisfaction, on-time delivery, flexibility etc. The third level includes factors such as pollution, use of non-renewable resources, providing employment in geographical areas, supporting local businesses etc. The result of the sustainability analysis is summarized in Table 8.

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Table 8. Sustainability analysis for rail-based intermodal transport of biofuel.

Pillar	Level	Sustainability	Overall
Environ-mental	Within the organization	Some tendency to rely on the inherent capabilities of rail not focusing enough on improvements.	
	In the supply chain	Resource efficient part of the supply chain lowers total emissions.	
	External	Saves CO_2 emissions compared to road transport and often also compared to shipping dependent on transport geography.	
Economic	Within the organization	Difficult to compete for short distances and smaller volumes. High cost for terminal handling and shunting.	
	In the supply chain	Accounts for a small part of total transport costs. Allows for rather distant sourcing of biofuels.	
	External	Can increase the range of sourcing of raw material.	
Social	Within the organization	Comparatively few jobs created. Personnel away from home for long times.	
	In the supply chain	In a wider sense, if rail provides a larger geographical market for biofuels jobs can be created in less populated areas.	
	External	Safe in comparison to many trucks on the road.	

4.2.2.1 Break-even Distance and CO_2 Emission

The break-even distance between road and rail transport is of key importance to determine the minimum length of a rail transport, as a first step in designing the base scenario. Several studies have made contributions in finding general results for the minimum distance that intermodal rail–road transport can compete with unimodal truck services. The results for European conditions are found in the range 300-800 km, shown in for example Williams & Hoel (1998); Nelldal et al. (2008) and Kim & Van Wee (2011).

A typical biofuel train is selected for the case, consisting of 22 wagons type Sgns, electric engine type Rd, Innofreight XXL load units, transporting 2 300 MWh of logging residue chips. Rail has a 50km pre-haulage by road to the rail terminal, using a 93 MWh woodchip container truck. The train runs directly to the heating plant and is unloaded at the plant. Diesel shunting engine is used at both the terminal and the heating plant. The train is assumed to run three days per week, 26 weeks per year. The full round trip, including cost of the empty return transport is included. Road transport is represented by a wood chip truck carrying 103 MWh where 40% of the flow is transhipped at a road-road terminal. 23 trucks are needed for the road transport and are assumed to return empty. Chipping is assumed to take place roadside in the forest in both systems. The calculations show the break-even distance at 250 km.

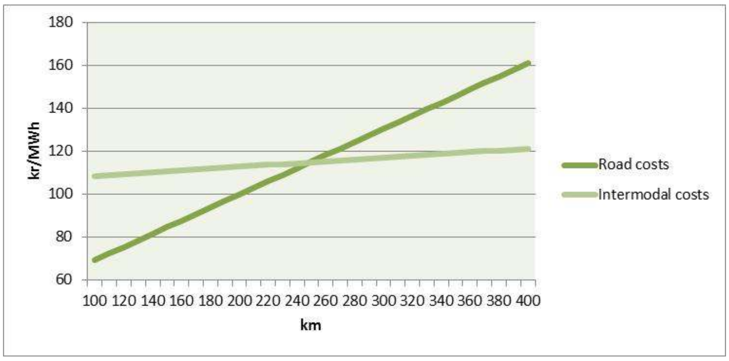

Figure 29. Cost per intermodal loop at 3 departures per week

Extending the train operations to five days per week pushes the break-even distance down to 180 km, showing the positive effect of high train utilization. Thus the results of the case study show that the break-even distance is considerably lower for biofuel transport chains than for other commodities; 180-250 km.

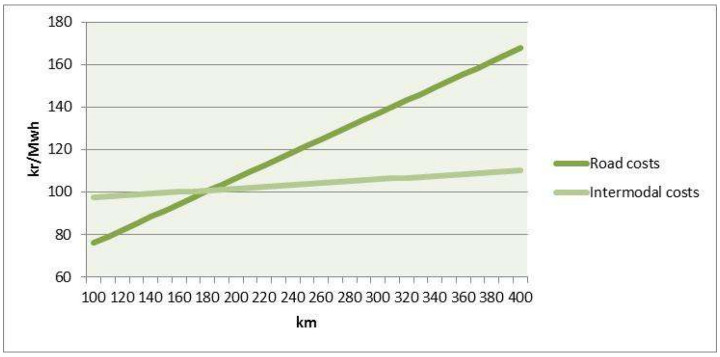

Figure 30. Cost per intermodal loop at 5 departures per week

From an environmental perspective, the advantage of the intermodal solution is clear. The intermodal transport chain produces significantly lower CO_2 emission compared to the all-road solution. The majority of this comes from the pre-haulage by road, chipping and terminal handling as the rail transport in Sweden generate very low en-route CO_2 emission. Hence the emission for the intermodal chain is almost constant for the estimated distances.

Figure 31. CO_2 emission per intermodal loop.

5 Conclusion

This chapter presents the main conclusions derived from the research conducted, the evaluation of the two case studies and how they relate to the research questions.

5.1 REGCOMB

Table 9 summarizes the main conclusions derived from the REGCOMB project within the PSI framework for the design of complex systems as presented in 1.3 'System Characteristics'. The table illustrates the design problems dealt with in this thesis and the complexity of the multi-dimensional system.

Table 9. The PSI framework for the design of the evaluated intermodal transport system

PSI Framework					
Product space			Social space		Institutional space
Disciplinary complexity	**Structural complexity**	**Knowledge availability**	**Perspectives**	**Capabilities**	**Regulatory framework**
Vehicle technology	Rail: Optimized loading space utilization	Partially available among stakeholders; need of integration and dissemination.	Shippers	Shippers	Local
Transport management			Service providers	Service providers	Regional
Business economics	Terminal: Efficient and cost effective processes for transshipment and shunting		Local authorities	Infrastructure owners	National
Socio-economics			Societal		European
Sustainability studies			Academia		Global
Urban and regional planning					
Governance and politics (Local, Regional, National, European, Global)	Road: VRPs - route optimization				

The REGCOMB study has provided a framework for evaluating the feasibility, regarding cost and emissions, of concepts and technologies within intermodal freight transport. Hence, the main aim of this thesis project has been fulfilled i.e. to analyse under which conditions an intermodal transport system with the railway as a base can be implemented in the Stockholm-Mälaren region. **The loading space utilization** of the train and **the transshipment cost** are the most **critical parameters for cost leadership**. The latter restricting the competitiveness of intermodal services on short distances as it is not proportional to transported distance but rather to the utilization rate of resources.

Hence, the concept of cost-efficient small scale (CESS) terminals was introduced in this study. Regarding loading space utilization it is necessary to consolidate other freight flows in the train in order achieve high loading space utilization and a balanced flow along the route. The third parameter which is critical for the results are the fuel prices, where the sensitivity analysis of the results shows that if diesel prices would increase so would the feasibility of the intermodal option. The same is also valid for train length increase as long as the loading space utilization is maintained. In this study the importance of CESS terminals has been illustrated as well as the most significant cost components for a shipper when evaluating different transport chains and mode choice.

The results of the case study show that the cost performance of the transport chain with conventional intermodal transshipment technology is far from that of road haulage. The transshipment concerns the technical feasibility of the system, mainly concerning research question 2, and the loading space utilization is related to the stakeholders' requirements, research question 1. If these factors are optimized an intermodal system can compete with unimodal road cost-wise and outmatch it regarding the environmental impact.

Although the quantitative assessment of this feasibility study has shown that the studied transshipment technologies are closing the gap for intermodal transport to unimodal road haulage regarding transport cost over short- and medium distances and that they contribute in reducing emissions; the transport quality, in particular regarding reliability and punctuality, has to be ensured. These aspects require practical and operational testing, which is why a demonstration project is recommended. This is particularly crucial regarding the novel transshipment technology.

Also from the findings of the qualitative assessment of the feasibility study it is concluded that a rail based intermodal transport system is on the threshold of feasibility in the studied region if CESS terminals are used. From the findings of the stakeholder analysis, it can be concluded that a rail based intermodal transport system faces a number of challenges albeit also offering a number of opportunities. The challenges are mainly related to organizational and physical coordination. The need of organizational coordination is evident in the proposed 'local cooperation' business model as there is a lack of formal channel leader; consisting of several equal shippers and the supply side is commonly fragmented. Physical coordination is also a concern, as transshipment is a matter of reliability and trust and not only costs and environmental impact. Novel technologies must prove themselves reliable. The main opportunities with the system are associated with lower level of impact on the environment and a better utilization of existing infrastructure in the region.

If a corporate commercial interest for using shot haul intermodal rail freight services and CESS terminals prevails and local authorities' adopt sustainable freight transportation strategies where the regulatory framework is based on broader sustainability policies; only then could the conceptual idea of this study be considered feasible. The key point for this decision making process is **the intensity of the corporate commercial interest and local authorities prioritization of sustainable freight transportation strategies**. The former is for a specific technology or mode based on the ability to offer cost leadership for their value networks or to offer market differentiation.

This study has showed that in the studied region, rail based intermodal services could offer cost leadership in certain relations if resource allocation and utilization are optimized. However, albeit interest for regional intermodal transport is shown by individual public officials as for instance expressed in our workshops; the political will from local authorities in the region must be more consolidated and concretized for the system to become a feasible solution for shippers. Regions were cost-leadership and a strong will from local authorities prevail, have created a foundation for implementing regional rail based intermodal services e.g. the operational examples from Japan and Switzerland presented in this thesis.

The following are short summarizing answers to the research questions, related to each case study:

RQ1 What stakeholder requirements exist for short haul intermodal rail transport systems?

(Further elaborated in chapter 5.1 REGCOMB and Paper IV)

1. What is the interest of shippers using the system; where are the greatest needs and how can they be combined?

There are interested shippers but their shipments need to be coordinated. The following flows are identified as suitable base volumes and can be combined using a regional intermodal liner train service;

- Distribution of daily consumables in the Stockholm area
- Maritime flows connected to regional ports.

2. What is the interest of service providers to supply the system?

There is an interest but their services are fragmented. At a regional level, the services lack leadership and coordination. In particular terminal operators in the region have shown interest for the conceptual idea of the thesis as it implies connecting the intermodal terminals in the region with an intermodal liner train and thus achieve higher utilization rates for their operations and reduce idle times that several of them experience.

3. What policies guide authorities that influence the system?

There are European and national policies that influence the regional freight market. Regarding European transport policy, in EU's White Paper from 2011 energy efficient transports and movement of goods are the areas that are emphasized. In the White Paper it is stated that a shift to rail transports is critical in order to achieve these objectives and the best way of achieving this mode shift is by increasing the competiveness of intermodal transport.

There is also RUFS2010, which is the regional plan that sets the visions for the region. As for concrete regulations; the permitted road vehicle length is restricted in the city of Stockholm to maximum 16 meters except on dedicated routes. Otherwise, there is no broad strategy or policy for environmental sustainable freight transportation strategies in the region that would imply cost-leadership for intermodal transports.

RQ2 How can a system be implemented in the evaluated region that is both technically efficient and cost-effective?

(Further elaborated in chapter 5.1 REGCOMB and Paper I-III)

1. Is it possible with the existing combinations of terminals and technologies or is further development required?

The synthesis of the case study indicates the evaluated transshipment technologies are closing the gap cost-wise relative to unimodal road distribution in the evaluated region. Moreover, the E&S system in Japan and the Innovatrain system in Switzerland are operational examples showing that these systems can be competitive given appropriate sustainability regulations in the freight transport market that promote intermodal transports.

2. What conditions influence the competitiveness of the system against the prevailing market prices of road hauliers?

The regulatory framework structuring the market influences the competitiveness of each mode concerning e.g. capacity, infrastructural fees, operational hours and cabotage rights. It is also of high importance that these regulations are monitored and incentivized. The stakeholder analysis carried out in this study indicates that this is an area that stakeholders experience as problematic.

RQ3 How can the design of the system influence the environmental sustainability in the evaluated region?

Through resources optimization and choosing renewable fuels and low-emission technologies. The results derived from the case study indicate that a significant CO_2 emission reduction can be achieved. Furthermore, a mode shift from would imply less congestion on the road network in the region.

As for emissions, the results of the case study show that all evaluated intermodal transport chains contribute to a significant decrease in CO_2 emissions compared to unimodal road.

1. How can transshipment and traction technologies with low-emission propulsion systems and fuels be used?

Renewable energy can be used in all three operation segments; road, rail and transshipment. The latter constituting a larger share of generated emissions in short haul intermodal transport chains.

RQ4 What are the contextual conditions for feasibility of the system?

Corporate commercial interest and local authorities' prioritization of sustainability policies; further elaborated in chapter 5.3 Conditions for Feasibility.

5.2 Biosun

Rail transportation of wood biofuel in the Swedish market is not only an important subject for research from an operator perspective in terms of utilization of resources at the terminals. Several of them were established in order to handle fallen trees after a major storm in 2005 and now experience idle times to a varying degree. It could also enable the shippers i.e. heating plants, to increase the range of sourcing for their supply of raw material while decreasing the emissions generated by their transports. Rail-based transportation can increase the geographical range that is economically viable for the sourcing for biofuel production.

The STEEP analysis albeit generic and wide, offers a structured approach for qualitatively analysing **external factors** influencing a business. A main conclusion from the result of STEEP analysis is that rail transportation of biofuel faces a number challenges and limitations and in many cases these are related to relatively high volume requirements and operational inflexibility. The main drivers and motivations for it are commonly associated with rail freight's relatively low environmental impact and economies of scale.

The sustainability analysis on the other hand, enabled qualitatively analysing the **internal factors** influencing a business. The results of the sustainability analysis indicate that rail transportation of biofuels in the environmental dimension is highly sustainable, albeit there are a few areas with potential of improvement e.g. in shunting and terminal operations. However regarding the other two dimensions; economic and social, the competiveness of rail transportation is not as strong and there are several areas requiring improvement. Albeit rail as a traffic mode is considered economically sustainable, in particular for large volumes and over longer distance relations, there are some cost components e.g. transshipment cost and train capacity utilization, which constitute obstacles for the competitiveness of rail transportation of biofuels. The overall social sustainability is also acceptable, mainly due to the employment opportunities created and for the high level of safety achieved. The social sustainability is on the other hand affected negatively by the tough commercial conditions in the Swedish rail freight market.

The case study offered an opportunity of designing a rail-based multimodal transport chain for the supply of a heating plant in Sweden. Much care has been taken in finding good input data for modelling the transport alternatives, in particular the cost data. The model is a combination of several models developed by researchers in their field of expertise, where each handled distinct parts of the intermodal transport chain; rail, road and terminal handling. The results of the case study show that the break-even distance i.e. when intermodal transports equal unimodal road, is considerably lower for biofuel transport chains than for other commodities; 180-250 km compared to 300-800 km, which is mainly due to the fact that transshipment is required for unimodal road haulage; approximately 40% of the flow is transhipped at a road-road terminal as well as the fact that Intermodal terminals can be combined with facilities for processing wood biofuels.

The intermodal transport chain produces as expected significantly lower CO_2 emission compared to the unimodal road solution Hence, albeit being generally more beneficial both from environmental and economic perspective, the competitiveness of intermodal transportation is still restricted for short distances and smaller volumes due to high cost for terminal handling as well as due to high volume requirements and qualitative factors e.g. low operational flexibility, punctuality and reliability.

The following are short summarizing answers to the research questions, related to each case study:

RQ1 What stakeholder requirements exist for short haul intermodal rail transport systems?

(Further elaborated in 5.2 Biosun and paper V)

1. What is the interest of shippers using the system; where are the greatest needs and how can they be combined?

It can increase the sourcing distance of heating plants. The needs of heating plants increase as local supply declines, thus forcing shipper to source from more distant sites.

2. What is the interest of service providers to supply the system?

Coordination is not a big issue, as heating plants require high volume shipments. However, seasonal variation in demand constitutes an obstacle for service providers and requires innovative commercial measures. Moreover, intermodal biofuel terminals established after the storm Gudrun experience idle times.

3. What policies guide authorities that influence the system?

Efficient rail freight transport in general and intermodal terminals in particular are factors that are perceived by local authorities as having a good impact on local industry. Moreover, the rail freight market is deregulated but it exhibits signs of oligopoly and have high entry barriers and the former incumbent operator is dominant. Another type of polices influencing the system is direct or in-direct subsidises e.g. the establishment of intermodal biofuel terminals after the storm was subsidized by the authorities.

RQ2 How can a system be implemented in the evaluated region that is both technically efficient and cost-effective?

(Further elaborated in 5.2 Biosun and paper V)

1. Is it possible with the existing combinations of terminals and technologies or is further development required?

Intermodal terminals can be combined with facilities for processing wood biofuels.

2. What conditions influence the competitiveness of the system against the prevailing market prices of road hauliers?

Further elaborated in chapter 5.3 Conditions for Feasibility. A main operational condition example is if local supply of raw material declines, than rail can increase the sourcing distance of heating plants.

RQ3 How can the design of the system influence the environmental sustainability in the evaluated region?

Through resources optimization and choosing renewable fuels and low-emission technologies. The results derived from the case study indicate that a significant CO_2 emission reduction can be achieved. Furthermore, a mode shift from will imply less congestion on the road network in the region.

A main conclusion from the qualitative analysis within the BIOSUN project is that the main drivers for heating plans to use rail transportation of wood biofuel are commonly associated with economies of scale and the relatively low environmental impact, where rail is the mode that is evaluated as the most sustainable from environmental perspective.

1. How can transshipment and traction technologies with low-emission propulsion systems and fuels be used?

Renewable energy can be used in all three operation segments; road, rail and transshipment. The latter constituting a larger share of generated emissions in short haul intermodal transport chains.

RQ4 What are the contextual conditions for feasibility of the system?

Corporate commercial interest and local authorities' prioritization of sustainability policies; further elaborated in chapter 5.3 Conditions for Feasibility.

5.3 Conditions for Feasibility

As stated by in the 1.3 System Characteristics, although the characteristics of the two evaluated transport systems differ, the main objective of the two research projects are similar i.e. to evaluate under which conditions the socio-technical combined transport system with the railway as a base can be considered feasible i.e. RQ4 What are the contextual conditions for feasibility of the system?

As stated in 4.1.5 Stakeholder Analysis, the key points for this decision making process when evaluating if an intermodal transport system is a feasible solution, are related to the intensity of the corporate commercial interest and interlinked with local authorities' prioritization of sustainability policies. The former is for a specific technology or mode based on the ability to offer cost leadership for their value networks or to offer market differentiation. Regarding cost leadership there are three main conditions that are the most decisive for the success of an intermodal transport system:

1. Technical requirements for efficient operations
2. Business model
3. Market structure

For short haul intermodal transport systems, the main technical requirements for achieving cost-leadership are time and cost-effective transshipment at terminals, the loading space utilization of the train and route optimization of the feeder transports on road. The business model is the strategy required for the technical and social components of the system to generate revenues and lay the foundation for efficient coordination and integration of stakeholders and resources.

Regarding market differentiation; there are other identified requirements for cost-leadership that are essential to shippers when making their mode choice, the most common are; transport time, reliability, punctuality, accessibility, flexibility and environmental impact.

Unfortunately it is only the latter requirement where intermodal transportation is superior to unimodal road. Although this is increasing in the attention sphere of shippers, it has to a certain extent been thwarted by the decline in the performance of the rail network, in particular regarding reliability and punctuality.

This leads to the third condition for feasibility, local authorities' prioritization of sustainability policies, where maintenance and investment in the rail infrastructure is an essential part. Also the regulatory framework instituted by local authorities which defines the market structure, can tilt the cost leadership in favour of certain mode - regulations regarding e.g. vehicle dimensions, labour regulations, operating areas and time slots. However, the regulations will not suffice if their fulfilment is not monitored and incentivized to be upheld.

6 Contributions and Further Research

This chapter presents the main contributions to intermodal transport research derived from the conducted research, concluding discussion as well as planned and recommended paths for further research.

6.1 Contributions to Intermodal Transport Research

In this dissertation, it has been shown that the key to effective short haul intermodal transport systems relies on a set of performance parameters, which delineates the performance capabilities of the transport system. Through this set of performance parameters the *Intermodal Transport Cost Model (ITCM)* introduced in this thesis can help to model, evaluate and explain issues related to the competiveness of short haul intermodal transport systems, corresponding principle strategies e.g. the introduction of measures and concepts such as the *Cost-Efficient Small Scale (CESS) Terminals* or the evaluation of the intermodal liner train and the reduction of the break-even distances towards unimodal road haulage. The modules for rail and transshipment are based on previous models from KTH Nelldal (2008); Troche (2009); Nelldal et al. (2012b), which have been updated, expanded, restructured and incorporated into ITCM. The road module on the other hand was entirely constructed by the author. The input data for the supply of the evaluated transport chains was partly generated by routing in the software ArcGis Network Analysis Extension.

ITCM intends to apply a shipper perspective, as they are the actual users of the intermodal services. Shippers commonly perceive intermodal services as a single integrated service despite the increased actor complexity of these intermodal networks (Bektas & Crainic, 2007) - justifying further a general and integrated approach for shippers. Moreover, there is a need for cost information about rail freight in general and intermodal transport in specific; in the scientific field improved cost information is crucial as input for mode and route choice models as well as for four step forecasting models. The validity of the results has been supported by peer-reviewed publications, reference groups with field experts in both research projects and strengthened further as ITCM was used in the deliverables of the European research project "Capacity4rail", where the output from the model was compared and calibrated with operational data received from large European terminal operators e.g. DB in Duss Munich Reim (Germany) and Port of Valencia (Spain). Much care has been taken in finding good input data for modelling the transport alternatives; in particular the cost data received from multiple operators and equipment providers.

This thesis has also provided an evaluation framework and key results from the feasibility study of the socio-technical systems that short intermodal transport systems constitute - a set of benchmark methodologies to quantifiably as well as qualitatively evaluate the market and the technological system, conduct financial and scenario analysis in the two separate case studies as well as stakeholder analysis. The latter in regards to stakeholders' perspectives, barriers, demands and preference for implementing and utilizing such systems. A stakeholder analysis is conducted for a proposed business model for the system, the 'local cooperation model'. The analysis is carried out through participative action research; experts involved in interviews, two workshop rounds and a survey. The method was based on the principles of the Delphi method in the sense that it is a method for gathering data and analysing opinions gathered from experts within their specific field.

Hence this thesis has integrated several fields within intermodal research in order to provide a holistic evaluation framework for the feasibility of short haul intermodal transport systems. Previous studies have emphasized mainly one part of these systems e.g. the transshipment technology e.g. Woxenius(1998); Bärthel & Woxenius (2004); Bärthel (2010) and Flodén & Behrends (2012); or the management and structuring of the system i.e. studies dealing with business models and stakeholder integration in intermodal transports found in e.g. Flodén (2009); Osterwalder (2004) and Dinwoodie (2006); or the regulatory framework and the prevailing market structure in which these systems operate e.g. estimations of the break-even point towards unimodal road haulage in the studies of Williams and Hoel (1998); Nelldal et al. (2008) and Kim & Van Wee (2011). However, this integration has been arduous as intermodal transport research is still an emerging transportation research application field and in a pre-paradigmatic phase categorized by (Bontekoning et al. 2004):

- Several independent small research communities working on their own problems.
- Little references to other researchers and research communities.
- Lack of common problem definitions, hypothesis, definitions and concepts

Thus this thesis has intended to counteract these characteristics in the field of intermodal transport research when evaluating and modelling short haul intermodal transport systems.

6.2 Concluding Discussion and Further Research

Research on such concrete challenges in the real world has to deal with finding ways to put rigor to common-sense discussions and decisions of real stakeholders. It is always difficult to do research into real world practical systems instead of models only. Therefore this thesis is only a contribution, trying to find pathways in a world with many more uncertainties and influences than those covered in this thesis. Based upon the approach followed here, there is conditional optimism about the feasibility of an intermodal short haul freight solution for the Stockholm-Mälardalen region.

One could argue that the larger development of the economy or the national and international climate policies for transport will be more influential on the chances of intermodal regional railway logistics becoming reality than the factors studied here. However, for any policy or economic driver to have an effect, there needs to be a way to implement the intended consequences. This thesis provides the feasibility of one of these pathways, in case the policy might move into this direction. Then the drivers will become larger than those of the current stakeholders explored in this thesis, making the case stronger. The research here has considered the smallest critical size for this railway solution to become reality. Any larger amount will benefit the case.

One of the main limitations of a holistic feasibility study of socio-technical systems is related to path-dependency. There are several paths to choose from as initial point for attacking problems of a multi-faceted system. The path chosen in this research is initiated by the requirements of shippers, where earlier studies unanimously indicate that cost is the most valued factor. Hence, modelling costs of transport chains in order to evaluate measures for minimizing costs related intermodal transportation have constituted the initial path, which in turn have guided the methodological choices made and the corresponding results. It is highly possibly that other methodological choices would have been made if the path dependency was configured differently.

For the REGCOMB project, no claims are made at integrating mode choice with multimodal route optimization. The latter is required for finding the break-even point regarding transport distance. Several intermodal researchers have made contributions in finding the minimum distance that conventional end-point intermodal relations between two nodes can compete with direct unimodal road haulage in Europe. Their results are found in the range 300-800 km. However, comparing distribution routes for unimodal road haulage with an intermodal liner train system, with intermediate stops along the route, composes a much more complex combinatorial optimization problem, where the literature is lacking and further work is recommended.

Furthermore, the research carried out in the REGCOMB have received further funding for continuation by the Swedish Energy Agency within the framework of the research project "HARLIM" (Sustainable Regional Logistics in the Stockholm- Mälaren region). The work will be carried out together with researchers at TfK – a Swedish research institute within transportation and logistics. The aim of the study is to identify the possibility of creating a regional trimodal logistics system based on inland waterways and short intermodal rail. Import and export flows of unit loaded goods will be integrated with a regional transportation system, where standardized and more cost-effective ships, terminals and processing equipment are used. For rail transportation, the conditions for the implementation of port shuttles and the integration of them into the region's overall logistics system will be evaluated. The study will also analyse the environmental benefits and energy savings that can be generated by a regional logistics system built on sea and rail transport. Furthermore, the logistical impacts such as the effect on lead times are highlighted. An analysis is carried out regarding the obstacles and bottlenecks for the system and regional transportation measures and solutions will be proposed. The proposals are based on the flow differentiation; analysing which flows are best suited for sea transportation/inland waterways respectively by rail, with the aim of reducing the distance transported on road.

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