

THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Urban freight transport sustainability  
The interaction of urban freight and intermodal transport

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Intermodal road-rail terminal in Gothenburg

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# Urban freight transport sustainability

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## **ABSTRACT**

Intermodal road-rail transport (IRRT) has a significant urban dimension that affects the environmental benefits and the modal shift potential of rail freight. A sustainable modal shift, i.e., growth in rail freight without negative consequences for the sustainability of urban areas, can only be achieved by appropriate actions that demonstrate an understanding of the urban context within which IRRT takes place. The purpose of this thesis is to explore the interactions between urban freight transport and IRRT and their implications for urban sustainability and modal shift strategies.

This research combines empirical case studies to develop a framework for sustainable urban freight transport, and conceptual and analytical research to assess the potential of different measures to enhance the sustainability of IRRT, including: (i) the regulatory framework for pre- and post haulage vehicles to improve cost efficiency; (ii) fast and efficient transhipments to increase the accessibility of rail freight; and (iii) the urban spatial structure to reduce the local impacts of IRRT.

The application of the framework on IRRT identifies the potential of integrating urban freight and modal shift strategies. Local authorities therefore have an important role to play if a sustainable modal shift is to be achieved. However, they often do not have sufficient logistics competence to integrate freight transport and urban sustainability strategies. The framework can guide urban planners on how to overcome the existing shortcomings in urban transport planning. It also illustrates the benefits of a rail-adapted urban planning for local sustainability, which can encourage cities to include rail freight in their sustainable development strategies. From a theoretical perspective, the identified interactions and potentials of an integrated approach provide the context for studies going beyond the usual scope of either urban freight or IRRT focusing on the interaction between these two areas. This thesis therefore contributes to the integration of these streams of research.

*Keywords: Framework for Strategic Sustainable Development, intermodal road-rail transport, longer and heavier vehicles, modal shift, pre- and post haulage, rail freight, sustainable freight transport, transport planning, urban freight transport, urban sustainability.*



## List of appended papers

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

### **Paper I**

Behrends, Lindholm and Woxenius (2008). “The impact of urban freight transport: a definition of sustainability from an actors perspective”, *Transportation Planning and Technology*, 31 (6) pp. 693-713.

### **Paper II**

Lindholm and Behrends (2011) “Challenges in urban freight transport: a review in the Baltic Sea Region”, accepted for publication in *Journal of Transport Geography*.

### **Paper III**

Behrends (2011). “Sustainable freight transport principles and their implications for intermodal road-rail transport”, An earlier version of this paper is published in the proceedings of the NOFOMA Conference 2010, 10-11 June, Kolding, Denmark.

### **Paper IV**

Behrends and Floden (2011). “The effect of transshipment costs on the performance of intermodal line-trains”, Submitted to *Logistics Research*. An earlier version of the paper is published in the Selected Proceedings of the 12th World Conference on Transport Research Society, 11-15 July 2010, Lisbon, Portugal.

### **Paper V**

Bergqvist and Behrends (2011). “Intermodal pre and post haulage - a normative approach for assessing the effects of longer vehicles”, *Transport Reviews*, 31 (5), pp. 591-602

### **Paper VI**

Behrends (2011) “The urban context of intermodal road-rail transport – threat or opportunity for modal shift?”, *Procedia - Social and Behavioral Sciences, Special Issue City Logistics 2011 (forthcoming)*. An earlier version of the paper is published in the Proceedings of the 7<sup>th</sup> International Conference on City Logistics, 7-9 June 2011, Mallorca, Spain.



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Sönke Behrends,

Göteborg, December 2011



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# 1 Introduction

*This chapter introduces the goal and scope of this thesis. It describes the background of the thesis and defines the research purpose, research questions, the delimitations of the thesis and the important terminology used in this thesis.*

## 1.1 Unsustainable freight transport

Freight transport is a vital component for the generation of welfare. It facilitates the movement of goods along a supply chain and therefore it is indispensable for the supply of goods and directly influences the efficiency of the economy. As a result, transport demand is closely linked to economic development. Between 1995 and 2008 the average annual growth of intra European Union (EU-27) freight transport was 2% and hence freight transport grew as fast as the economy, and during the economic downturn (2008-2009) when the GDP in EU-27 decreased by 4.2% freight transport dropped by 11.2% (European Commission, 2011b).

The amount and character of freight transport demand is determined by logistics decisions, which aim to move product efficiently along a supply chain. Changing logistics structures, e.g. decisions to centralise warehousing, and more just-in-time replenishment have led to an increasing demand for the delivery of smaller units in higher frequency and an increasing importance of time, reliability and speed (McKinnon, 2003). The increasing demand for small volume goods flows of at more frequent intervals has limited the scope of rail to maintain market shares (Woodburn, 2003) and many industries have increased their reliance on road transport. As a consequence, the growing demand for freight is mainly met by road while the market share of rail fell from 21% of total EU-27 inland freight transport in 1995 to 17% in 2008 (European Commission, 2011b) (Figure 1).

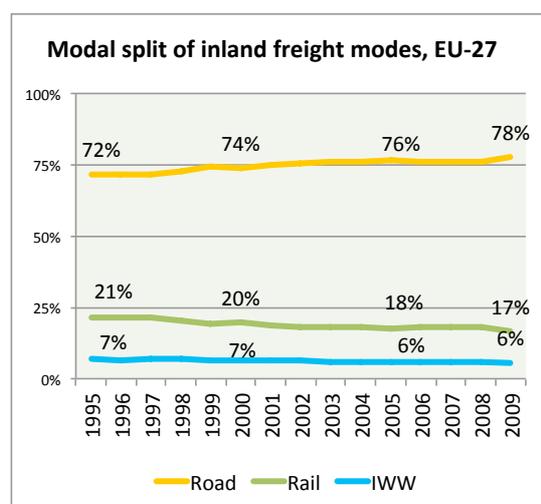


Figure 1: Development of modal split of inland freight modes road, rail and inland waterways (IWW) in EU-27 (European Commission, 2011b)

This development in the freight transport sector is a growing concern for sustainability, since road freight is responsible for a number of negative impacts. These include impacts on the environment (e.g., atmospheric emissions, use of non-renewable fuels, waste and loss of ecosystems), on society (e.g. public health, accidents, noise and reduction of quality of life) and on the economy (e.g. waste of resources and congestion resulting in decreasing journey reliability and city accessibility) (Quak, 2007).

Freight transport therefore finds itself in constant tension between efficient logistics and sustainable development. On the one hand, narrow delivery time windows and smaller consignments make it more difficult to achieve economies of scale in transport operations, while on the other hand there is increasing pressure to significantly reduce the environmental impact. This challenge is most significant in urban areas. Urban freight transport serves industry and trade which are essential wealth generating activities (Anderson et al., 2005). For people, urban freight ensures the supply of goods in stores and for firms it forms a vital link with suppliers and customers (Crainic et al., 2004). Urban freight transport is therefore an important component for economic vitality of cities. However, the urban environment characterised by scarcity of access, e.g., congested roads, space constraints and limitations of infrastructure restricts the efficiency and quality of freight operations (Hesse and Rodrigue, 2004). To make things worse, urban freight is also a threat for urban sustainable development and is increasingly perceived as disturbing activity for passenger transport and citizens. Urban areas constitute the living environment of the majority of the population in Europe and the citizens' demands on a high quality of life increase (European Commission, 2007). Though freight transport operations in cities represent only 20% to 30% of road traffic, they account for up to 50% of the emission of air pollutants (depending on the pollutant considered) by transport activities in a city (Dablanç, 2007).

## **1.2 Measures to improve the sustainability of road freight transport**

Various measures and initiatives have aimed to reduce the environmental impacts of road freight transport. Innovative technologies and alternative fuels are often discussed as measures with great potential. Thanks to the continued tightening of 'Euro' emissions standards for road vehicles and improvements to fuel quality harmful emissions from road transport have declined significantly (European Environmental Agency, 2009). Furthermore, there is a wide range of alternative fuels, which promise a reduction of fossil energy use and CO<sub>2</sub> emissions (EUCAR et al., 2007). Renewable energy resources have the potential to make road vehicles emission-free (Holden and Høyer, 2005), and although there are limitations in terms of resource capacity and economic performance, a combination of the numerous alternative sources could be as inexpensive and available as oil (Rogers et al., 2007).

However, introducing alternative fuels and innovative vehicles cannot be the sole answer for resolving the sustainability problems of road freight transport. Though innovative technology and alternative fuels have reduced the emissions per kilometre driven, these improvements are not enough to offset rising traffic volumes. Between 1995 and 2009 road transport volumes in the EU grew by 46% (European Commission, 2011b) and as a result, the transport sector's greenhouse gas emissions increased by 28% over the period of 1990–2006 (European Environmental Agency, 2009). Since the growth of freight transport activity is projected to increase significantly (in the EU by about 40% from 2005 to 2030 and by 80% to 2050) (European Commission, 2011a), achieving any significant absolute emission reductions would require immense amounts of alternative fuels. This is likely to have significant negative side effects, e.g. competition to food production, and land-use impacts (Holden and Høyer, 2005; Cullinane and Edwards, 2010). Furthermore, greener vehicles and fuels cannot mitigate the increasing traffic levels resulting in growing congestion with associated costs of approximately 1% of the EU's GDP (European Commission, 2007). These congestion costs are projected to increase by about 50% by 2050 (European Commission, 2011c). Several authors therefore conclude that the expansion of road freight growth needs to be addressed (McKinnon, 2003; Holden and Høyer, 2005; Aronsson and Brodin, 2006; Chapman, 2007; Cullinane and Edwards, 2010; Arvidsson, 2011). If a sustainable freight transport system is to be achieved, there is a need to restructure logistics systems and supply chains to limit the growth in freight transport demand and to shift freight to more sustainable transport modes such as rail.

### 1.3 Improvement potential of Intermodal road-rail transport

Although a modal shift from road to rail is desirable, there are also studies which are more pessimistic about its potential contribution to the sustainable development of the freight transport sector (McKinnon, 2003). The first argument often stated against the usefulness of rail freight is its **limited modal shift potential**. Since the extension of the railway network is limited and shunting wagons into private sidings is very costly, rail transport is not accessible for substantial shares of the transport market. Consequently, intermodal road-rail transport (IRRT), the subsequent use of road and rail for moving goods stowed in unit loads, is a logical step for maintaining flexibility yet decreasing the external effects (Woxenius, 1998). By far the biggest distance is performed by rail where the units are consolidated with other shipments and economies of scale are being achieved, while road transport is assigned to the short-haul, or collection and distribution of freight (Bontekoning et al., 2004). The interface between regional pre- and post haulage (PPH) by road and the interregional long-haul on rail is the intermodal terminal (Höltgen, 1995). In this way, IRRT increases the

reach of rail and enhances the efficiency of the transport system (Vrenken et al., 2005).

Since rail freight has significantly lower externalities than road freight (Figure 2), the EU Commission's 2<sup>nd</sup> White Paper on a European transport policy has adopted the modal shift from road to rail as a general objective of European transport policy (European Commission, 2001). In some market segments there has been some progress towards meeting the objective of modal shift. Countries which have liberalised their rail freight markets have seen a rising modal share of rail, which is often attributed to the openness of their markets (Steer Davies Gleave, 2009). However, rail's modal share of inland freight transport in EU-25 continues to decline, despite a series of policy initiatives aimed to at revitalizing rail freight. There are new actors on the market that provide new high-quality services but these are limited to seaport hinterland flows, bulk commodities and other large transport flows over long distances. The shippers and receivers of these services are usually the large or smaller but clustered manufacturing plants, warehouses, logistics centres and/or freight terminals (Janic, 2008). Several authors define the break-even distance for the competitiveness of IRRT in Europe as 500 km (Rutten, 1995; Woxenius and Lumsden, 1996; van Klink and van den Berg, 1998; Woxenius, 1998; Flodén, 2007). The European Commission conceded that road transport was likely to remain at the centre of EU transport operations for the foreseeable future (European Commission, 2006) and sees possibilities for a modal shift only over distances longer than 300 km (European Commission, 2011c). Since most freight flows are transported over shorter distances and/or are too small to facilitate full trains, the potential of IRRT to contribute to the sustainable development of the freight sector is marginal at best. If a significant modal shift is to be achieved rail freight needs to focus on the non-bulk freight over shorter distances (Bärthel and Woxenius, 2004; Bontekoning and Priemus, 2004; Woodburn, 2006).

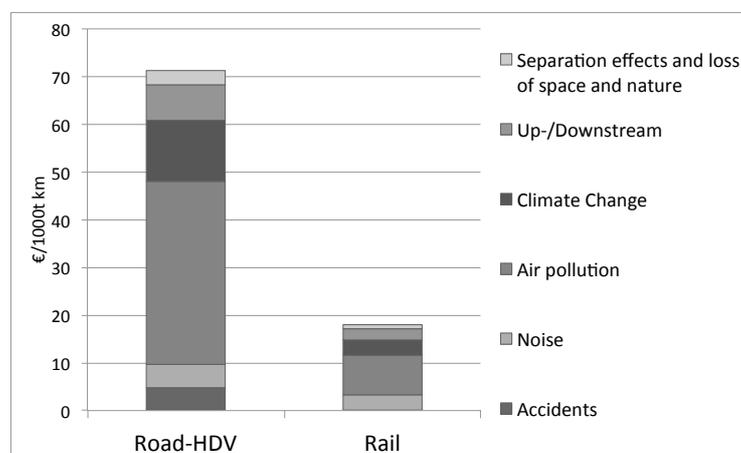


Figure 2: Average external costs, EU-15 + Norway and Switzerland, 2000 (INFRAS/IWW, 2004)

While the volumes of individual shippers are often too small for IRRT, the total transport demand of several shippers in the same urban area may be sufficient to achieve volumes, which are economically viable for intermodal services. The required volumes therefore can be achieved by consolidating the less-than-trainload shipments from different shippers located in close proximity to each other. A city is usually provisioned by hundreds of supply chains since it hosts shippers from many economic sectors (Dablanc, 2011). The required regional consolidation is achieved at the intermodal terminals by road transport collecting and distributing the shipments in the terminal region. This emphasises the importance of the urban transport system and its connection to the inter-regional transport system, since this is where the consolidation occurs (Bergqvist, 2007).

On the other hand, space constraints and limitations of infrastructure in urban areas also represent an impedance factor for intermodal networks. Freight traffic shares the infrastructure with passenger traffic and hence is affected by urban congestion which impairs the quality and efficiency of PPH operations (Woxenius, 2001) and the hours of terminal operation can be limited due to public planning restrictions when located near residential areas (Woodburn, 2008). This impedance from urban freight is especially relevant for shorter IRRT distances, which are more sensitive to additional transshipment and PPH costs because they stand for a great share of total chain costs (Bontekoning and Priemus, 2004). Hence, urban freight transport is both an enabler and barrier to the desired modal shift (Figure 3).

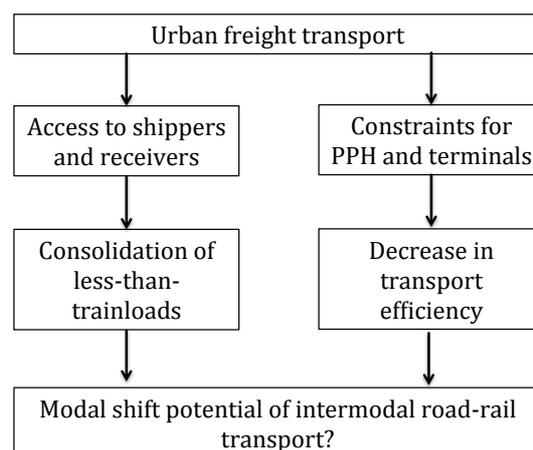


Figure 3: The impact of urban freight transport on the modal shift potential of intermodal road-rail transport

The second argument often stated against the usefulness of a modal shift is the limited **relative environmental advantage** of rail over road. Rail operations are generally considered environmentally friendly since rail is more energy-efficient than road and electric traction provides access to various forms of renewable energy. However,

electrical trains using renewable energy are not completely emission-free since they emit particles mainly originating from wear of rails, brakes, wheels, and carbon contact strips (Fridell et al., 2010). Another significant unsustainable impact of rail is noise in urban areas (CE Delft, 2008) and on existing railway networks the noise impact from freight train is much higher than from passenger trains (Oertli and Hübner, 2008). Rail infrastructure also demands significant amount of land and causes separation effects in urban areas as well as impacts on nature and landscape, i.e., loss and fragmentation of habitats (CE Delft, 2008). Still, Kreutzberger et al. (2006b) show that IRRT can environmentally performance substantially better than single-mode road transport, but the improvement potential depends on many conditions. These factors include the less energy efficient PPH operations by truck, the longer distance of the combined transport route compared to the road route, and the electricity production from non-energy-efficient fossil power plants (Bonnafous and Raux, 2003). Often, the rail freight terminals are located close to the urban core while the shippers and receivers of intermodal freight, e.g. wholesale and freight forwarding are located at the urban periphery with good connection to highway intersections (Hesse, 2008). As a consequence, the PPH and rail distance travelled in urban areas can be higher than the urban driving distance of the single-mode road alternative. In total, due to the superior energy efficiency and easier access to renewable energy that rail has over road, a modal shift mainly decreases CO<sub>2</sub> emissions, and hence the global impact, while air pollution and traffic impacts on the local level may increase (Figure 4). If unfavourable conditions cumulate, IRRT can perform even worse than single-mode road transport (Kreutzberger et al., 2006b). The improvement potential of a modal shift therefore depends on the actual conditions of the road and rail transport chain (Bonnafous and Raux, 2003).

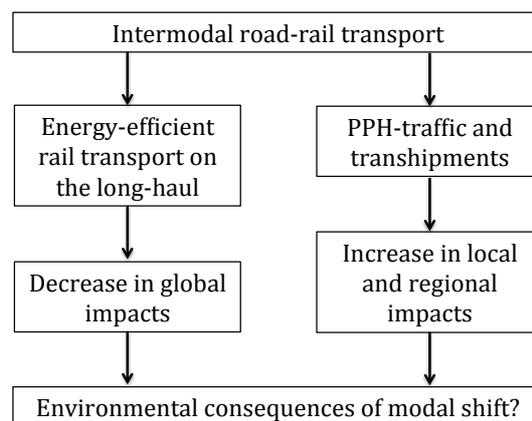


Figure 4: Unclear environmental improvement potential of intermodal road-rail transport

## 1.4 Purpose

IRRT has a significant urban dimension. First, urban transport affects the modal shift potential of IRRT. On the one hand it is vital for achieving the desired modal shift since urban transport increases the reach of rail freight by linking shippers and receivers to rail and enabling the regional consolidation of goods flows. On the other hand, congestion and scarcity of access in urban areas impedes PPH and transshipment operations limiting its effectiveness and capacity. Second, IRRT affects the sustainability of cities. On the one hand, intermodal terminals are embedded in urban freight transport systems and thus transshipments and PPH to and from the terminal can influence the sustainable development of urban areas. On the other hand, access to rail freight can enhance the accessibility of cities seeking to compete in the globalising economy. To achieve an IRRT system that facilitates a significant modal shift without negative consequences for the environment and quality of life, urban transport needs to adapt to the demands of IRRT. In turn, the required change in the way urban transport is organised to balance different interests is likely to have an impact on IRRT networks.

Despite this significant interaction of IRRT and urban freight neither urban studies nor IRRT research has paid particular attention to this subject. A substantial work of research addresses the dilemma of environmental impacts and efficiency of urban freight transport focusing on urban deliveries and retail logistics (e.g., Taniguchi and Van Der Heijden, 2000; Anderson et al., 2005; Dabanc, 2007) as well as seaport gateways (e.g. McCalla, 1999; Roso et al., 2009). Until recently, however, research did not pay much attention to the implications for IRRT networks arising from its urban context. Urban planners and IRRT stakeholders usually focus on their own field and neglect the relationships between IRRT and urban freight transport. IRRT research is usually limited to rail haulage and transshipments while PPH in urban areas is regarded as an activity beyond the system boundaries (Woxenius and Bärthel, 2008). Haywood (2003) found that local transport plans in the UK increasingly include rail freight; however, there was little evidence for effective action. In general, there is a lack of insight in effective IRRT policy measures (Bontekoning et al., 2004). In policy planning, urban freight and IRRT are still handled as separate policy concerns and their interactions are rarely considered (Nemoto et al., 2005).

This thesis contributes to the integration of urban freight and IRRT resulting in more sustainable freight transport. The main hypothesis of this thesis is that a modal shift strategy can only be successful if it takes into account urban sustainability issues, which encourages cities to include rail freight in their strategic urban transport plans. Exploiting these potentials requires IRRT to be understood in the light of sustainable urban freight transport. Accordingly the purpose of this thesis is

*To explore the interactions between urban freight transport and intermodal road-rail transport and their implications for urban sustainability and modal shift strategies.*

## 1.5 Research questions

The concept of sustainability and the development of sustainability strategies need to be clear before the integration of urban freight and IRRT is addressed. Planning for sustainability is complex, since there is probably no limit to the number of possible designs of sustainable societies (Robèrt, 2000). Differing values in society and technological evolution, however, make it difficult to agree on a detailed description of a sustainable future (Ny et al., 2006). In order to deal with this complexity, Robèrt et al. (2002) present a general framework for sustainability planning, which is generally referred to as the Framework for Strategic Sustainable Development (FSSD). The framework consists of five interdependent but distinct levels. The top level ensures a thorough understanding of the functioning of the system in focus (System level), to be able to arrive at a basic definition of success within the system (Success level), which in turn is required for developing a strategy (Strategy level), for implementing actions (Action level) and tools which are needed to monitor the process (Hallstedt et al., 2010). The first three planning levels constitute the analytical framework for this research and are used to break down the research purpose into research questions (Figure 5).

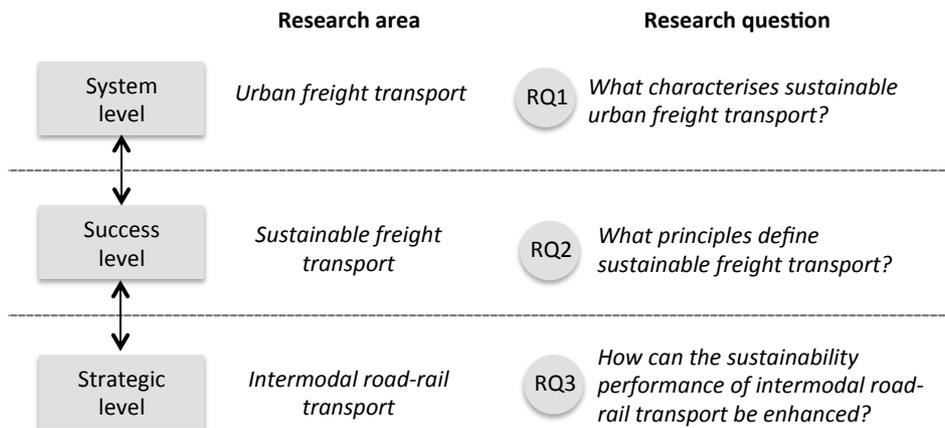


Figure 5: The Research questions based on the Framework for Strategic Sustainable Development

### 1.5.1 Research area 1 – Urban freight transport

Level 1 (The system) represents the overarching system in focus, i.e. the societies and the surrounding ecosystems. Planning within this system must be based on an understanding of the constitutional principles of the functioning of the system (Robèrt

et al., 2002). This thesis addresses the potentials for urban sustainability and modal shift when considering the interactions between urban freight and intermodal transport. Hence, the emphasis is placed on the intermodal activities' embeddedness in urban freight structures. A sustainable modal shift, i.e. a growth in rail freight without negative consequences for urban areas, can only be achieved by appropriate actions that demonstrate an understanding of the urban context within which intermodal road-rail transport takes place. The system in focus therefore is the urban freight transport system, which constitutes both an important and a disturbing factor for IRRT. From a modal shift perspective, it forms a vital link between shippers and intermodal terminals allowing shippers to access customers and suppliers by rail, while for urban citizens rail, PPH and terminal activities are a disturbing factor for the quality of life. A sustainable freight transport system needs to balance these interests. Research Question 1 therefore is:

*RQ1: What characterises sustainable urban freight transport?*

This research question mainly aims to develop a framework for sustainable urban freight transport, but it also has an empirical focus. The empirical contribution aimed for is to identify the current shortcomings in urban freight transport planning leading to unsustainability. The theoretical framework will function as a means towards this end.

#### 1.5.2 Research area 2 – Sustainable freight transport

The key of any planning effort is to have a clear definition of the desired outcome. Level 2 (Success) of the FSSD defines the goal based on principles, i.e. the *state* sustainability within the system above (Robèrt et al., 2002). Designing an IRRT system that is sustainable is complicated, since the urban context of IRRT implies a trade-off of environmental impacts and transport efficiency. On the one hand, the urban context is an impedance factor for effective intermodal transport, which limits its modal shift potential, while on the other hand the intermodal activities are an impedance factor for urban sustainability. This makes it complicated to assess whether IRRT has the potential to simultaneously achieve economic benefits, a reduced impact on the eco-system and social responsibility. A complete consideration of sustainable development requires all dimensions to be fulfilled. A prerequisite for assessing the sustainability performance of IRRT and the potential of actions to improve the performance is a clear definition of what sustainable freight transport is. The second research question therefore is:

*RQ2: What principles define sustainable freight transport?*

The theoretical aim of this research question is to present a definition of sustainable freight transport based on principles that ensure relevant aspects of sustainability are

not missed and that is able to handle the trade-offs within urban freight and intermodal transport.

### 1.5.3 Research area 3 – Intermodal road-rail transport

Level 3 (Strategy) of the Framework for Strategic Sustainable Development defines guidelines for a strategy towards sustainability (defined in level 2), i.e. to bring operations closer to principles for ecological sustainability in parallel with improvements in social and economic performance, thereby empowering the extension of the process (Robèrt et al., 2002). Research question 3 therefore addresses the possibilities to improve the sustainability performance of IRRT:

*RQ3: How can the sustainability performance of intermodal road-rail transport be enhanced?*

The aim of this research question is to analyse the effect of different measures on the accessibility, cost and environmental performance of IRRT.

## 1.6 Scope and delimitation

Improving the sustainability performance of IRRT is a challenging task and requires a multitude of actions. The existing capacity bottlenecks on major sections of the European rail network are often mentioned as the major limiting factor for the further growth of rail freight. Enlargement investments of rail capacity and operational measures like increased train lengths therefore are a prerequisite for the desired modal shift. However, these issues are not included in this work. This thesis focuses on the nodes of the intermodal network, i.e. the intermodal terminals and their integration in the local road network, which are relevant for the understanding of the interactions of urban freight and IRRT.

This delimitation has not been made on the consideration that the capacity bottlenecks in the rail network or other methods are less important. On the contrary, the required increase in rail network capacity can only lead to the desired modal shift and positive sustainability effects if they are accompanied by measures focussing on the problems related to the urban context, which encourages cities instead of forces them to integrate rail freight in their sustainable development strategies.

This thesis' focus is intermodal road-rail transport, i.e., the combination of road and rail transport in one transport chain. Intermodal transport chains including shortsea shipping and inland waterways are out of the scope of this thesis.

The empirical studies of this thesis were conducted in the Baltic Sea Region. This thesis therefore has a North-European scope.

## 1.7 Thesis outline

*Chapter 1 (Introduction)* has presented the background, the purpose, the research questions, the scope and the terminology of this thesis.

*Chapter 2 (Frame of Reference)* lays the foundation of the theory used in this thesis. It reviews previous research on urban freight transport, sustainable freight transport and intermodal road-rail transport.

*Chapter 3 (Methodology)* presents the methodology used to reach the purpose of this research.

*Chapter 4 (Summary of the appended papers)* summarises the six papers, which are included in this thesis.

*Chapter 5 (Analysis)* analyses the results of this thesis with regard to the three research questions.

*Chapter 6 (Conclusion)* holistically discusses the results of the research questions in relation to the purpose of this thesis. Furthermore it outlines the theoretical contribution, the practical implications and ideas for further research.

*The appendix* presents the six papers on which this thesis is based as well as the interview guides for the empirical studies.

## 1.8 Terminology

The terminology of the concepts that are central to this thesis is presented here.

*Transportation* is the movement of goods and persons from place to place and the various means by which such movement is accomplished (Britannica, 2011). It is the combination of transport and traffic: The movement itself – transport, and the means by which this movement is accomplished – traffic (Arnäs, 2007).

*Logistics* is the process of strategically managing the procurement, movement and storage of materials, parts and finished inventory (and the related information flows) through the organisation and its marketing channels in such a way that current and future profitability are maximised through the cost-effective fulfilment of orders (Christopher, 2011, p. 2).

*Urban freight transport* includes all goods movements generated by the economic needs of local businesses, that is, all deliveries and collection of supplies, materials, parts, consumables, mail and refuse that businesses require to operate (Dablanc, 2011, p. 13). Urban freight transport also includes through traffic, especially those transports by rail which are handled in terminals located in urban areas where rail-rail exchange takes place. Many actors are involved in or with urban transport, and often have conflicting stakes in it; these are local authorities, carriers, shippers and receivers and

residents (Quak, 2011). The actors share the same physical space and therefore interact, even though they do not have direct business relations.

*Intermodal transport* is the movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without moving the goods itself in changing modes (UNECE, 2001). It enables cargo to be consolidated into economically large units (containers, bulk grain railcars, etc.) optimising the use of specialised intermodal handling equipment to effect high-speed cargo transfer between ships, barges, railcars and truck chassis using minimum labour to increase logistics flexibility, reduce consignment delivery times and minimize operating costs” (Rodrigue et al., 2009, p. 332).

*Intermodal road-rail transport (IRRT)* refers to a combination of road and rail transport in a single transport chain, without a change of loading unit, where road is assigned to the short haul achieving regional consolidation and rail to the long haul in between regions.

*Physical environment* consists of the natural and the built environment. The built environment is composed of an intricate web of roads, open spaces and buildings that collectively form part of the physical urban fabric (Street, 2009, p. 32).

*Spatial structure* is the manner in which space is organised by the cumulative locations of infrastructure, economic activities and their relations (Rodrigue et al., 2009, p. 343).

*Long and heavy vehicles (LHV)* are road-freight vehicles, which exceed the size and weight limits of current heavy goods vehicles (Doll et al., 2009).

## 2 Frame of Reference

*This chapter presents the frame of references used in this thesis. The concepts presented here cover the elements needed for the research questions in the FSSD (Figure 6), i.e. urban freight transport (section 2.1), sustainable freight transport (section 2.2) and intermodal road-rail transport (section 2.3). The chapter concludes with a summary of the key issues for this research (section 2.4).*

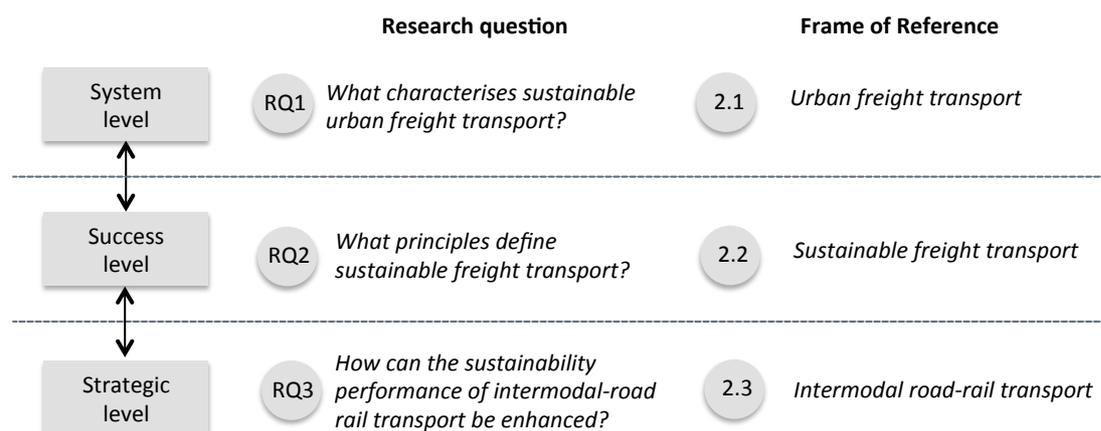


Figure 6: Frame of reference in relation to the research questions

### 2.1 Urban freight transport

This section reviews concepts and previous research, which are important for the understanding of urban freight transport (System level). First, it analyses the context of urban freight transport in relation to logistics, transportation and land-use (section 2.1.1). Then, previous research on integrated planning is presented (section 2.1.2).

#### 2.1.1 The context of urban freight transport

Any producer within a supply chain may be involved in multiple goods movements as either a customer (receiver of goods) or a supplier of goods to its own customers. Logistics is essentially about the flow of materials and goods along a supply chain and includes all related activities. Transportation is the activity within logistics that achieves the movement of products along a supply chain between point-of-origin and point-of-consumption. It creates time and place utility since a product produced at one point has very little value to the prospective customer unless it is available at the point where and at the time when it will be consumed (Stock and Lambert, 2001). Hence, freight transport is a vital component for the generation of welfare.

To move a product from the supplier stage to the customer stage in the supply chain is referred to as distribution. Chopra (2003) states that different distribution network designs exist, e.g., direct shipping from the producer to the customer, distribution

storage with last mile delivery, or retail storage with customer pick-up. Product parameters such as demand (high, medium, low volumes), product value or desired delivery time determine the type of distribution network design which then determines the transport service requirements of the shippers (Tsamboulas et al., 2007). Hence, supply chain strategies form the basis for the quality levels required of transport services. In general, there is a trend of increasing service requirements since decreasing product life cycles and increasing product values have led to innovative logistics approaches like JIT with less storage and more frequent deliveries (Chopra, 2003). The implications for freight transport are a rising demand for the shipping and delivery of smaller units in a higher frequency, an increasing importance of time, reliability and speed.

Wandel et al. (1992) present a hierarchical model for the analysis of logistics, transport and land-use that consists of the three layers freight flow, transport flow and infrastructure (Figure 7). (Later development of the model, e.g. by OECD (1996) introduced information infrastructure and information flow layers.)

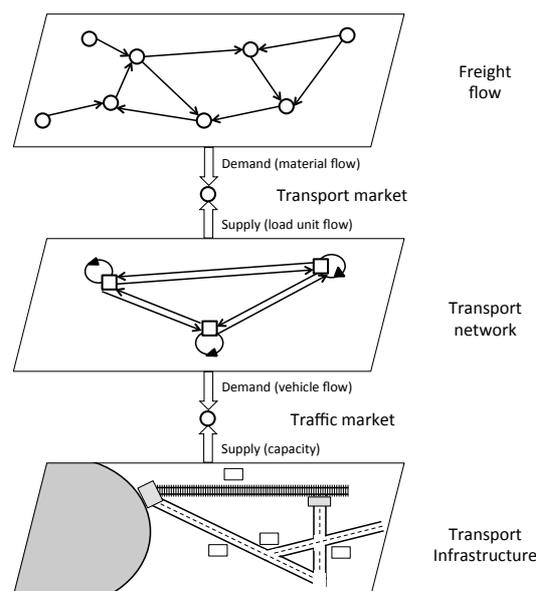


Figure 7: Three layers model of freight transport (modified from Wandel et al. (1992))

The freight flow is the top layer, which represents supply chains consisting of nodes and links. It determines the demand for freight transport in terms of shipment size, frequency, lead-time, delivery precision and flexibility. The second layer is the transport network, which translates the freight transport demand into traffic. It provides transport services, resulting in actual load unit flows that generate demand for vehicle flows. The traffic is realised in an infrastructure layer that consists of, e.g.,

roads and rail tracks on which vehicle movements take place. The layers are connected by markets where supply and demand of the different layers are matched.

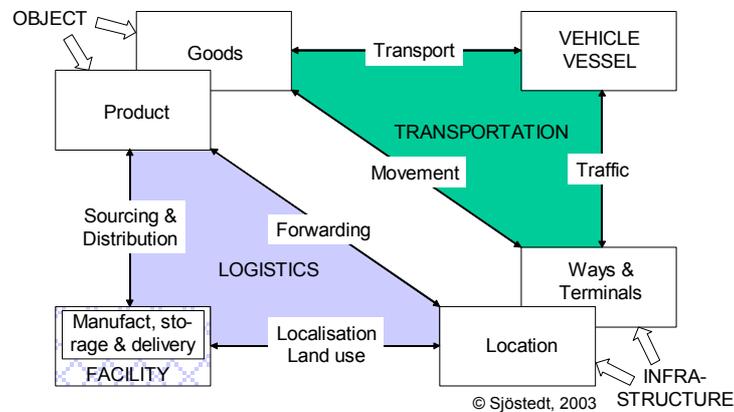


Figure 8: Transportation and logistics as complementary systems (Woxenius and Sjöstedt, 2003)

The hierarchical model of Wandel et al. represents the common perception that the demand for freight transport is derived from the economic activities that it serves and that the organisation of supply chains and transport networks determine the amount of traffic. Drewes Nielsen et al. (2003) state that in this perspective transport is perceived merely as a residual effect of logistics, which makes it difficult to isolate transport as an independent activity. On the other hand, transportation and logistics can also be seen as complementary systems and there seems to be a growing acceptance to analyse transport as an activity embedded in its own systemic logic in transport chains (Woxenius and Sjöstedt, 2003). This perspective is depicted in Figure 8. In this perspective, logistics depends on the mobility of goods, which is enabled by transport networks bridging the distances between the economic activities. It is the location of the logistics activities in relation to transport infrastructure that determines the nature, the origin, the destination, the distance and even the possibility of movements to be realised (Rodrigue et al., 2009). Hence, improvements of freight transport capabilities can induce changes in logistics operations and hence foster transport demand (Hesse and Rodrigue, 2004). Transport networks and services are therefore inherently geographical as they link places together by enabling movements across space (Shaw et al., 2009). The availability of transportation co-determines location decisions of economic facilities, which leads to changes in the land-use system (Geurs and van Wee, 2004). Economic activity, which is the foundation for regional welfare, requires high levels of accessibility to input materials and markets. Therefore, transport infrastructure opens up markets (Lakshmanan, 2011). However, access to transport services is unequal and restricted by location due to unequal investment in transport nodes and links (Knowles, 2006). The regions with high levels of accessibility

tend to be more competitive than peripheral and remote regions (Gutiérrez et al., 2009).

### 2.1.2 Integrated transport planning

Urban freight transport consists of numerous actors with many interactions and varying interest. Cities need to meet social, environmental, political and cultural objectives as well as economic and physical ones (Egger, 2006). Quak (2011) considers three main action areas to achieve sustainable urban freight transport, which need to be used in combination: logistical measures (e.g., re-arranging warehouse activity timing), policy measures (e.g., relaxed delivery time-windows) and technological measures (e.g., quiet and clean vehicles). Most often these measures are brought into practice separately, which limits the actions' effect. A combination of company initiatives and public policies are therefore necessary to develop a sustainable urban freight transport system (Anderson et al., 2005). However, the interrelations of the different stakeholders make the policy making process very complex (Bertolini et al., 2005). Quak (2007) argues that policy-makers and researchers develop urban freight transport in initiatives but the actual results are disappointing because local authorities do not fully understand the impacts of the most common policy initiatives, e.g. time-windows and vehicle restrictions. Generally, local authorities consider freight a private industry. Local transport planning and sustainable development focus on passenger transport rather than on freight transport issues. Results from a survey sent to cities in the BESTUFS (Best Urban Freight Solutions) project show that half of the responding cities had no responsible authority for freight transport issues (Zunder and Ibáñez, 2004). Consequently, freight transport in the urban area is poorly understood and there is a lack of systematic methodology for planning such activities (Crainic et al., 2004). Hull (2008) suggested that there are new approaches to planning practices and that there are well-known tools and instruments to approach inter-sectoral work practices between transport planners and other professions, but that these tools are rarely used. Furthermore, local transport authorities are hindered in their work by 'short-termism' in political decision making as well as contradictions within policy objectives (Hull, 2005).

A widely recognised prerequisite for reaching sustainable transport is integrated transport planning. May, Kelly, & Shepherd (2006) distinguish between three different forms of integration: 1) operational integration; 2) strategic integration between transport policy and land use; and 3) institutional integration within local, regional and national governments. Further, to attain active citizen support, new forms of communication between citizens and experts and the involvement of all major stakeholders are needed (Banister, 2008). The integration of stakeholders and city-wide views requires that local authorities play a pro-active role (Crainic et al., 2004).

However, many cities have not yet found adequate solutions to help optimise the urban movement of goods (Dablanc, 2007).

The European Commission highlights the importance of integrated solutions involving stakeholders, citizens and other planning departments in their Green Paper towards a new culture for urban mobility (European Commission, 2007) and strongly recommends that authorities develop and implement Sustainable Urban Transport Plans (SUTP). SUTP is an integrated approach to manage urban transport by adopting long-term and strategic action plans with the goal of overcoming deficits in the coordination and cooperation across administrative borders (city and surroundings, agglomerations across regional/national borders), as well as between authorities in national hierarchies (local, regional, national governments) regarding their respective plans and policies. The SUTP aims to improve qualities of the planning approach in terms of procedures and actor relations as well as designing planning instruments to ensure the efficient implementation of policies and measures.

Wolfram (2004) defines the requirements, which an SUTP should include and presents a list of 24 obligations and 25 pieces of advice. Although a SUTP should include both passenger and freight transport, the list of recommendations mainly covers passenger transport issues; the obligations on freight transport are rare. Furthermore, while passenger transport issues are discussed in detail, the freight transport issues remain on a general level without providing guidance on how to work with freight issues, e.g., to “optimise freight transport and logistics and reconcile the needs of urban freight transport with the wider transport system” (Wolfram, 2004, p.20).

## **2.2 Sustainable freight transport**

This section reviews previous research relevant for the success level. First, definitions of sustainable freight transport are presented (section 2.2.1). Then, the unsustainable impacts of freight transport are reviewed (section 2.2.2). This section concludes with elements of sustainable freight transport strategies (section 2.2.3).

### **2.2.1 Definitions of sustainable freight transport**

The term “sustainable development” is a contested concept with a wide range of meanings. It first gained major prominence in the report “Our Common Future”, which is also commonly known as the Brundtland Report, published by the World Commission on Environment and Development. Its definition of sustainable development is still widely used today (WCED, 1987, p. 54):

*“Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”*

This definition from a macro perspective is based on the concept that today’s technological systems and social organisation impose negative impacts on the

environment and society with the effect that present and future needs cannot be met. Hence, sustainability consists of three dimensions: the natural environment, society and the economy.

To make the macro perspective of sustainable development applicable from a microeconomic standpoint, Elkington (2004) defines the concept of the 'triple bottom line' which emphasises that environmental, social and economic considerations are equally important in the decision making of organisations. He argues that organisations need to address the social and economic dimensions in a more integrated way if real environmental progress is to be made. This disproves the widely spread perception that some impacts on environment and society are trade-offs for economic prosperity. On the contrary, Carter and Rogers (2008) state that an integration of these three dimensions not only positively affects the environment and society but also leads to long-term economic benefits and competitive advantages.

Since it is difficult to agree on a detailed image of a sustainable future, due to changing cultural and technological conditions, Holmberg and Robèrt (2000) argue that a definition of sustainability must be searched for on the principle level which any sustainable society would need to meet. Such principles are needed to ensure relevant aspects of sustainability are not missed or that today's problems are not solved by creating new problems. To avoid this, sustainability principles (SPs) therefore need to be *science-based*, that is, compliant with relevant scientific knowledge available to date; *necessary for sustainability*, that is, failure to comply with any one of the SPs would make sustainability impossible; *sufficient for sustainability*, that is, the SPs taken together should cover all relevant aspects; *general*, that is, people from various societal sectors and scientific disciplines should be able to understand and use them; *concrete*, that is, capable of guiding actions and problem solving; and preferably *distinct*, that is, mutually exclusive to facilitating comprehension and monitoring (Ny et al., 2006). A scientific consensus process has previously led to the following four sustainability principles (Hallstedt et al., 2010):

In the sustainable society, nature is not subject to systematically increasing

- I. concentrations of substances extracted from the Earth's crust
- II. concentrations of substances produced by society
- III. degradation by physical means

and, in that society

- IV. people are not subject to conditions that systematically undermine their capacity to meet their needs.

Gudmundsson and Höjer (1996) present four basic principles that make up the concept of sustainable development where sustainability and development represent different dimensions. In this concept, the two criteria for "development" describe the perceptible improvement of the quality of human life of the present generation, including 1) the improvement of the quality of life of the individuals, and 2) the

guarantee of a just distribution of quality of life. Two criteria for “sustainability” describe the long-term stability of the social system relevant for future generations, including 3) an environmental dimension, i.e. the protection of natural resources within the pre-established limits, and 4) and an economic dimension, i.e. the maintenance of productive capital for future generation.

The World Business Council for Sustainable Development transfers Brundtland’s definition of sustainable development to transport systems and defines sustainable mobility as the “ability to meet the needs of society to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values today or in the future” (WCED, 1987). The definition of a sustainable transport system by the Council of the European Union<sup>1</sup>, represented by the Ministers of Transport, is more concrete and comprehensive and since it has been reviewed by political mechanisms it received general political acceptance. The European Commission (2005) defines a sustainable transport system as a system that:

- *“Allows the basic access and development of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations*
- *Is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy as well as balanced regional development*
- *Limits emissions and waste within the planet’s ability to absorb them, uses renewable resources at or below their rates of generation, and uses non-renewable resources at or below the rates of development of renewable substitutes while minimizing the impact on the use of land and the generation of noise.”*

Minken et al. (2003) adds an urban dimension to the definition of sustainable transport by including the cultural heritage of cities and accessibility of goods and services in urban areas as sub goals. According to their definition a sustainable urban transport and land use system has the following characteristics (Minken et al., 2003, p.13):

- *“provides access to goods and services in an efficient way for all inhabitants of the urban area,*
- *protects the environment, cultural heritage and ecosystems for the present generation, and*
- *does not endanger the opportunities of future generations to reach at least the same welfare level as those living now, including the welfare they derive from their natural environment and cultural heritage.”*

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<sup>1</sup> The European Sustainable Development Strategy 2001, EU Council Göteborg 2001.

<sup>2</sup> FastRCargo is a project financed by the European Commission within the 6<sup>th</sup> framework programme. The project aims to develop a small-scale horizontal transshipment technology for automated transshipments of intermodal loading units below active contact lines.

<sup>3</sup> The project “Intermodal transport from a haulier’s perspective” was financed by the Swedish Intermodal Transport Research Centre (SIR-C) and

This definition gives particular attention to goods and citizens in urban areas. However, a city is not an isolated system and consequently, the city not only has an impact on systems that occur within it, e.g. the transport system, citizens and economy, etc.; it also has impacts on systems within it exists, such as regional and global ecosystems, transport systems and economies (Egger, 2006).

Richardson (2007) highlights the differences between passenger and freight transport. Based on a detailed analysis framework for sustainable passenger transport as well as for sustainable freight transport, he concludes that passenger and freight transport are driven by different factors. Primary influencers for passenger transport include physical, psychological, and social needs, but in freight transport market forces and government policy dominate.

To summarise, it is generally accepted that a sustainable transport system contributes to social and economic welfare, without damaging the cultural heritage or environment or depleting environmental resources and implies a balancing of current and future economic, social and environmental qualities. However, despite this generally accepted idea there is neither a common definition of sustainable transport nor a set of sustainable transport indicators (Steg and Gifford, 2005). Concerning freight transport in urban areas, Melo (2010) states that there is no clear definition of sustainability and mobility applied on urban freight transport and distribution. This makes it difficult to develop sustainable freight transport strategies, which simultaneously achieve economic benefits, a reduced impact on the eco-system and social responsibility.

### 2.2.2 The unsustainable impacts of freight transport

The unsustainable impacts of transport are numerous and multifaceted and can be categorised according to different dimensions. They may be grouped under social, economic and environmental pillars of sustainability (Nykqvist and Whitmarsh, 2008). Quak (2007) reviews the definitions of several authors and includes the following impacts on this triple-bottom-line (Quak, 2007, p. 1):

- *Impacts on planet (environmental sustainability):*
  - Pollutant emissions including global pollutants, such as carbon dioxide (CO<sub>2</sub>), and local pollutants, such as carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), particulate matter (PM) and volatile organic compounds (VOCs).
  - The use of non-renewable natural resources, such as fossil fuels.
  - Waste products, such as tyres, oil and other materials.
  - The loss of wildlife habitats and the associated threat to wild species.
- *Impacts on people (social sustainability):*

- The physical consequences of pollutant emissions on public health, such as death and illness
- The injuries and death resulting from traffic accidents.
- The increase in nuisance, such as noise disturbance, visual intrusion, stench, and vibration.
- Reduction in quality of life elements, such as the loss of greenfield sites and open spaces in urban areas as a result of transport infrastructure, intimidation, and decrease of attractiveness of a city centre.
- The damage to buildings and infrastructure.
- *Impact on profit (economic sustainability):*
  - Inefficiency and waste of resources.
  - Decrease in journey reliability and delivery punctuality, potentially resulting in less service quality to consumers and lost market.
  - Decrease in economic development.
  - Congestion and decreasing city accessibility.

These impacts differ in time as well as in geographical scale. Some impacts can be limited to a local scale and are palpable only at the locality where the traffic takes place (e.g., noise), while other impacts affect larger regions over a longer time period (e.g., CO<sub>2</sub>). The unsustainable impacts are also multidimensional regarding their mitigation measures as they derive from different aspects of transport. Impacts from traffic and infrastructure require a reduction of traffic volumes while impacts caused by emissions to air can be mitigated on the vehicle level by clean technology. Finally, impacts from the use of fossil energy resources require a change in the energy supply. This categorisation follows a hierarchy as a reduction of traffic volumes will also lead to a reduction of emissions and energy use while on the other hand, alternative fuels and clean engines will not lead to a reduction of traffic or infrastructure impacts. This categorisation is used in the remainder of this section to present the most significant unsustainable impacts. The presentation is based on CE Delft (2008).

#### *Local emissions and air quality*

Traffic gives rise to emissions of air pollutants. The most important ones are PM, NO<sub>x</sub>, sulphur oxide (SO<sub>2</sub>), and VOC. They cause damage to humans, the biosphere, soil, water, buildings and materials. The aspiration of air pollutants causes a series of diseases like asthma problems, lung capacity impairment and bronchial infections. Furthermore, it increases the risk of cancer and reduces resistance to infections. It also causes eye irritation and headaches. In general, it increases the mortality (a reduction of life expectancy) as well as the morbidity (loss of activity days). High air pollution levels, not all of which may be attributed to transport, cost 4 million life-years each year in Europe; hence there is a need for continued attention (European Environmental Agency, 2008).

Negative impacts to the economy include damages to building environment and agriculture. Particles and dust cause soiling of building surfaces and facades. Acid air pollutants like NO<sub>x</sub> and SO<sub>x</sub> lead to degradation through corrosive processes. Furthermore, agriculture suffers from crop losses due to acid deposition and ozone. Acidification and nitrogen over-fertilization as well as heavy metals from tire wear and tear result in a change of ecosystems and biodiversity, i.e., forest damage and the depletion of flora and fauna.

The transport sector's emissions of air pollutants have decreased due to emission reductions realised in road transport as a consequence of fleet renewal with vehicles equipped with catalytic converters and particulate traps and of reduced sulphur content in fuels. However, in many urban agglomerations the concentration of nitrogen dioxide (NO<sub>2</sub>) and PM<sub>10</sub> are still at or above the European air quality limits (European Environmental Agency, 2008).

#### *Traffic and infrastructure*

Congestion arises when transport users compete for limited transport system capacity. This leads to several economic costs of which the increase of travel time is the most important. Others are costs due to unreliability of travel times and additional fuel costs due to higher fuel consumption under stop-and-go conditions. On access-regulated infrastructures such as railway networks, airspace and airport congestion is represented by non-availability of a desired departure or arrival time.

More traffic and congestion also goes hand-in-hand with noise in urban areas which is getting worse year by year (European Commission, 2007), and imposes undesired social disturbances which result in discomfort or inconvenience. It can also cause physical health damages and nervous stress reactions, such as a change of heartbeat frequency, increase of blood pressure and hormonal changes. In addition, noise exposure increases the risk of cardiovascular diseases (heart and blood circulation). Finally, transport noise can result in a decrease of subjective sleep quality.

More traffic also increases the risk of accidents, which cause pain, grief and suffering and are a burden for society. Accidents also cause material damages, administrative costs, medical costs and production losses and are therefore also a burden for the economy. Although road safety has improved considerably, with around 35,000 deaths and more than 1.2 million injured in 2009 (European Commission, 2011b), road remains the least safe mode of transport. The number of road traffic accidents in towns and cities is growing each year: one in three fatal accidents now happen in urban areas, and it is the most vulnerable people, namely pedestrians and cyclists, who are the main victims (European Commission, 2006).

Transport infrastructure like roads and railways requires a considerable amount of land and can often separate areas which functionally belong together and are therefore a barrier, i.e., in cities and in ecosystems. Loss of ecosystems as well as

barrier effects has negative consequences for the local environment and the landscape as well as the cultural environment as it affects both animals and people.

### *Fossil energy use*

Besides air pollution and traffic externalities, the transport sector's oil dependency is a burden to the economy. Oil accounts for ca. 97% of the sector's energy supply. Natural gas (2%), electricity (1%) and renewable resources (<0.5%) as alternative fuels do not play a significant role as energy sources. The dominant user of oil as a fuel source is road transport, accounting for 81% of total energy use of the transport sector (Chapman, 2007). The unequal distribution of oil in the different world regions leads to a dependency on oil producing countries. Together with the economic scarcity of oil the economy faces risks of loss in production capabilities and large sudden price changes (e.g., due to political reasons). Furthermore, there is the risk for future generations to pay higher energy costs and to face energy supply gaps.

Oil dependency also goes hand in hand with greenhouse gas emissions contributing to global climate change. If the worldwide greenhouse gas emissions continue to grow at today's levels the earth will be committed to a warming far outside the experience of human civilization with unforeseeable consequences for physical and biological systems affecting society as well as the economy worldwide. Various impacts include melting glaciers, sea level rise, declining agriculture crop yields, a declining water supply, health impacts, ecosystems and biodiversity, extreme weather events and the risk of major catastrophic events (Stern, 2007).

While the transport sector's emissions of air pollutants decreased considerably, greenhouse gas emissions on the other hand continue to increase. Although improvements have been made in the energy efficiency of various transport modes and non-fossil fuels have been introduced, increased transport demand is outweighing these benefits (European Environmental Agency, 2008).

### *Up- and downstream effects*

The production pathway from extracting, capturing or growing the primary energy carrier to refuelling the vehicles with the finished fuel adds to the unsustainable impacts (Blinge, 1998) as well as the production, maintenance and disposal of vehicles and infrastructure. These up- and downstream effects add to emissions to air and energy use with consequences on other sectors, i.e., the energy crops market as the increased demand for biofuels possibly contributes to rising food prices. Furthermore, substituting fossil energy with renewable sources generally requires more energy so that transport applications may not maximise the greenhouse gas emissions reduction potential of renewable energy since reduction potentials in stationary applications are bigger (EUCAR et al., 2007).

Table 1: Categorisation of unsustainable impacts of freight transport

Impact category	Local	Regional	Global
Emissions to air	Public health Soiling of surfaces	Buildings and material damage Biodiversity loss Ecosystem loss Agriculture crop/forestry losses	
Fossil energy use			Climate change Energy dependency
Traffic/Infrastructure	Noise Accidents Congestion Separation effects Loss of space Habitat fragmentation/ (quality) loss Visual intrusion		
Up- and downstream effects	Production of energy, vehicles and infrastructure adds to energy use and emissions to air impacts, and has external effects on markets other than the transport market, i.e., the energy market		

Table 1 provides a summary of the unsustainable impacts of freight transport and categorises them according to their geographical scale, i.e., whether the impacts are only palpable on a local level where the traffic takes place or whether they have regional or global effects. Impacts from traffic (e.g., noise, congestion and accidents) and infrastructure are mainly local problems. Emissions to air are a problem on the local and regional scale while the use of fossil energy has mainly global impacts. The scale of the local impacts is co-determined by the population density of the locality where the traffic takes place. Hence, it is in urban areas where the unsustainable impacts of freight transport are most severe (CE Delft, 2008).

### 2.2.3 Sustainable freight transport strategy

To achieve sustainability, Jansen (2003) identifies three transition approaches and argues that their scope of time and actions corresponds to their improvement potential (Figure 9). The short-term approach aims at an optimal use of the current system through operational processes. The improvement potentials are limited but can be realised immediately. The medium term approach aims at system improvements through incremental structural changes and offers more improvements. Jump-like changes can only be achieved by a radical system renewal and require long-term changes in structure, culture and technology. Jansen argues that sustainable development requires system renewals; the time to develop these renewals can be

gained with the first two approaches. The three approaches therefore are complementary. According to Dortmans (2005) system changes are restricted because organisations have considerable sunk-costs in terms of equipment, people and expertise. Hence, sustainable development is a complicated process and requires various measures.

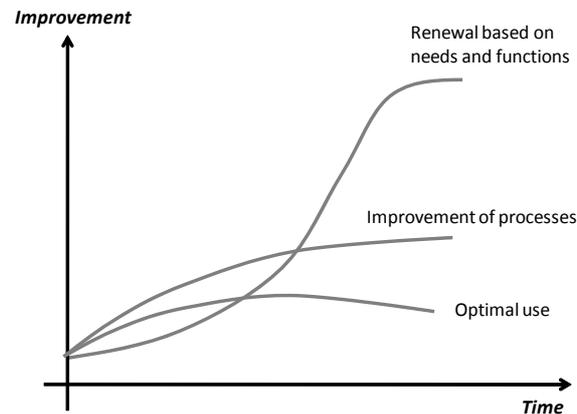


Figure 9: Improvement potentials of different approaches (adopted from Jansen (2003))

Decision making in logistics can be classified into the three planning levels: strategic, tactical and operational. The strategic level broadly shapes the logistics structure and sets the general guidelines for decisions made at the tactical level, which determines goals, rules and limits for the operational level (Crainic and Laporte, 1997) According to Jonsson (2002), these decisions differ in scope and time perspectives. Strategic decisions are targeted to the conditions for future high performance systems. They concern the organisation of systems and contain policy related standpoints. Furthermore, they affect resource investments and influence the relations to external players. The decisions are therefore long-term and may reach several years into the future. Tactical decisions are aimed at increasing the performance of the organisation through reorganising and developing internal resources. Tactical decisions have a medium-term perspective. Short-term decisions are operative decisions that are targeted to creating high performance within the existing resources of an organization.

McKinnon (2003) proposes four categories of decisions to differentiate between different levels of decision making within the field of logistics:

1. The physical infrastructure of the business relates to the numbers, locations and capacity of factories, warehouses, shops and terminals.
2. The patterns of trading links between the company and its customers and suppliers relate to product sourcing, the production process and distribution of finished products.

3. The scheduling of production and distribution translates the trading links into discrete freight flows.
4. The management of transport resources

Aronsson and Brodin (2006) propose a similar framework that corresponds to the levels suggested by McKinnon. They distinguish four levels: At the top are decisions about the product design which concern all products; below that are the logistics structures which concern the supply chain; these are followed by planning/organization concerning one market or one large client, and finally, the operative work deals with single shipments. The framework highlights how decisions at different levels both create opportunities and set limitations for decisions made on another level.

All presented frameworks highlight that the decision-making levels form a hierarchy, i.e., the decisions at one level establish the framework for decisions on the subsequent levels. According to McKinnon (2003) measures with the intention to reduce the environmental impact of transport have been introduced at the lowest level in the hierarchy, i.e., cutting externalities of the vehicle movements. However, the benefits of more efficient and clean vehicle movements have been offset by decisions on superior levels, e.g., centralisation of warehouses, sourcing from more distant suppliers, JIT production, etc., which often increase the demand for vehicle movement in absolute terms. This is supported by Aronsson and Brodin (2006), who state that approaches for reducing the environmental impact focusing on more energy efficient technology have proven to be insufficient. Instead, approaches that address the companies' logistics structures are required.

However, as the different levels interact it is not always possible to distinguish between decisions at different levels. Whether a decision is a "simple" operational decision or of strategic significance depends on the context in which the decision is made (Jonsson, 2008). For many industries the hierarchy seems to be toppled around. For companies heavily dependent on JIT, as, for example, the computer industry, scheduling of product flow seems to be the uppermost layer in the hierarchy (Drewes Nielsen et al., 2003). What makes matters worse is that companies are independent entities. The decision-making on the level of single entities may undermine environmentally friendly intentions, since they disregard indirect effects in relation to other parties in the supply chain, which can have negative consequences for the environment (Öberg et al., 2011). The sustainable development of the freight transport sector is thus a complex long-term problem that involves many material resources and actors with various goals affecting their decision-making and management policies.

An effective methodology to align various measures with each other is backcasting (Robèrt, 2000). According to Dreborg (1996), backcasting is an appropriate approach to deal with problems with the following characteristics:

- complex, affecting many sectors and levels of society
- major changes needed, since marginal changes within the prevailing order will not be sufficient
- dominating trends are part of the problem – these trends are often the cornerstones of forecasts
- problem is a matter of externalities which the market cannot treat satisfactorily
- long time horizon to allow scope for deliberate choice

The traditional forecasting approach is not appropriate in the study of highly complex long-term sustainability problems, because it is based on extrapolating the current underlying trends, which leads to the growing unsustainable impacts. Hence, it is unlikely to generate solutions that would lead to the breaking of these trends. Furthermore, a future sustainable society might be so different from the current trends that forecasting towards it is no longer possible (Hallstedt et al., 2010).

Backcasting is an alternative approach to achieving solutions that focus on the problem to be solved rather than on present conditions and current trends. It consists of first creating a desirable (sustainable) future vision, followed by looking back at how this desirable future could be achieved, before defining and planning follow-up activities and developing strategies leading towards that desirable future (Quist and Vergragt, 2006). However, without forecasts it is difficult to perceive when an on-going development is undesirable. Hence, backcasting and forecasting are complementary, as forecasts are needed to build reference scenarios. Backcasting provides alternatives to such reference scenarios, thus emphasising that what has been forecast is just one possible development (Höjer and Mattsson, 2000).

### **2.3 Intermodal road-rail transport**

This section reviews previous research on IRRT and how the modal shift potential can be improved (Level 3 in the FSSD). It starts with defining the general characteristics of IRRT (2.3.1) and the different transport networks designs and terminals (chapter 2.3.2). Then, previous work on intermodal line-trains is summarised (chapter 2.3.3). The section finishes with a review of PPH research (chapter 2.3.4).

#### **2.3.1 Characteristics of intermodal road-rail transport**

There are five basic transport modes for carrying out the movement of goods: road, rail, air, water and pipeline. Because the modes vary in economic service characteristics (e.g., speed, availability, and flexibility), capacity and cost structure, each mode is the predominant option for a certain type of transport flow (Stock and

Lambert, 2001). Furthermore, the transport modes differ significantly in terms of external costs that they impose on society per ton kilometre transported (INFRAS/IWW, 2004). Table 2 provides a comparison of the financial and service characteristics as well as the external effects of the four main transport modes (excluding pipelines).

Table 2: Cost, delivery service and external effects characteristics of freight transport modes (Adapted from Kohn and Brodin (2008, p. 235) and INFRAS/IWW (2004))

	Road	Rail	Water	Air
<i>Financial characteristics</i>				
Cost level	Moderate	Low	Low	High
Balance fixed/variable costs	High variable costs, low fixed costs	High portion of fixed costs	High variable costs, low fixed costs	High variable costs, low fixed costs
<i>Service characteristics</i>				
Speed (time in transit)	Moderate	Slow	Slow	Fast (distinct advantage)
Availability	High (distinct advantage)	Moderate	Low	Moderate
Delivery accuracy	High	Moderate	Low	High
Loss and damage	Low	Moderate-high	Low-moderate	low
Flexibility	High	Moderate	Low	Low-moderate
<i>Transport flow characteristics</i>				
Market coverage	Point to point	Terminal to terminal	Terminal to terminal	Terminal to terminal
Predominant traffic/goods	All types	Low-medium value, medium-high density	Low value, high density, large load sizes	High value, low-medium density, small shipments
Length of haul	Short to long	Medium to long	Medium to long	Medium to long
<i>External effects (per ton-kilometre)</i>				
Accidents	High	Low	Low	Low
Noise	High	Moderate	Low	Moderate
Air pollution	High	Moderate	Moderate	Moderate
Climate change	High	Low	Low	Very high
Nature and landscape effects	High	Low	Low	Moderate
Urban effects	High	Low	Low	Low
<i>Total external effects</i>	<i>High</i>	<i>Low</i>	<i>Low</i>	<i>High</i>

The fundamental idea behind intermodal transport is that the service and cost advantages of each transport mode are joined together in order to improve the overall efficiency of the transport system. By far the biggest distance is performed by large-scale transport modes like rail, inland waterways, short sea shipping or ocean shipping where the units are consolidated with other shipments and economies of scale are being achieved. Road transport is assigned to the short-haul, or collection and distribution of freight. Intermodal transport thus increases the reach of the larger modes of sea and rail and enhances the efficiency of the transport system (Vrenken et

al., 2005). These physical activities can be separated from administrative activities, e.g., transport administration and marketing (Jensen, 1990). Intermodal transport therefore involves a wide variety of activities, actors and resources (Figure 10), which implies a certain degree of technological as well as organisational complexity and dependency on surrounding systems (Woxenius, 1998).

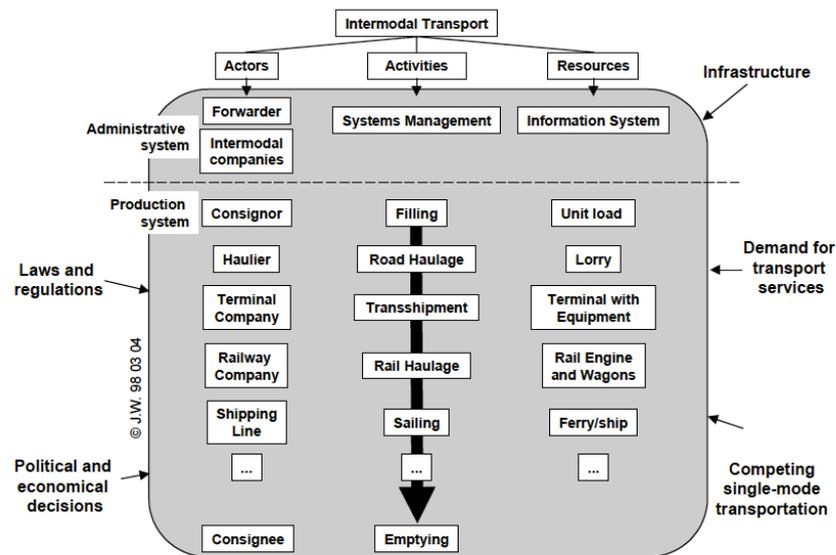


Figure 10: A reference model of intermodal transport (Woxenius, 1998)

If IRRT is to catch market shares it has to be competitive with all-road transport. Jensen (2008) operationalises the competitiveness of IRRT by defining two objectives that an IRRT system needs to fulfil. The first objective is to achieve a significant, sustainable competitive advantage (SSCA). ‘Significant’ in this concept means that an IRRT system needs to provide a big enough difference in the cost-service ratio for customers over the competing alternative. ‘Sustainable’ refers to the need that the cost-service ratio lasts for a sufficient period of time. The second objective is to design a system with good market entry ability (MEA). The need for a long time period increases if market entry barriers are high, incurring high sunk costs if they have to leave the market. Hence, SSCA and MEA are dependent properties, as the time horizon of the significant competitive advantage needs to be related to the pay-off time of the investments, which are needed to enter the market. An understanding of this relationship between the sustainability of SSCA on the one hand and the risk of sunk costs on the other hand is essential for the design of competitive IRRT systems.

### 2.3.2 Transport networks and terminals

#### *Transport networks*

If freight flows are not large enough to fill larger transport units such as trains, consolidation of freight belonging to different origins and/or destinations during common parts of the route is a necessary operation. The advantages of consolidation are relatively higher service frequencies, higher loading degrees and/or more economies of scale, more destinations from each origin and possibly also the smoothing of handling peaks at terminals. The disadvantages are additional transshipments and detours, which result in increasing chain transit time and costs (Trip and Kreutzberger, 2002).

If consolidating flows is decided upon, it is generally done systematically, i.e., according to a transport network design. Transport networks are composed of nodes and links. Nodes can be goods supply points, goods demand points, and points where value adding activities, consolidation of goods and transshipment between vehicles are carried out. Links represent transport activities connecting these nodes and are served by vehicles using infrastructure, e.g. creating traffic on motorways, streets or rail tracks. Different options for transport network design are discussed by several IRRT researchers (e.g., Bontekoning, 2000; Ballis and Golias, 2004; Woxenius, 2007b). Although the research has not arrived at common definitions yet, all researchers distinguish several basic network designs. Woxenius (2007b) defines six significantly different theoretical designs from the perspective of a transport system operator: direct link, corridor, hub-and-spoke, connected hubs, static routes, and dynamic routes (Figure 11).

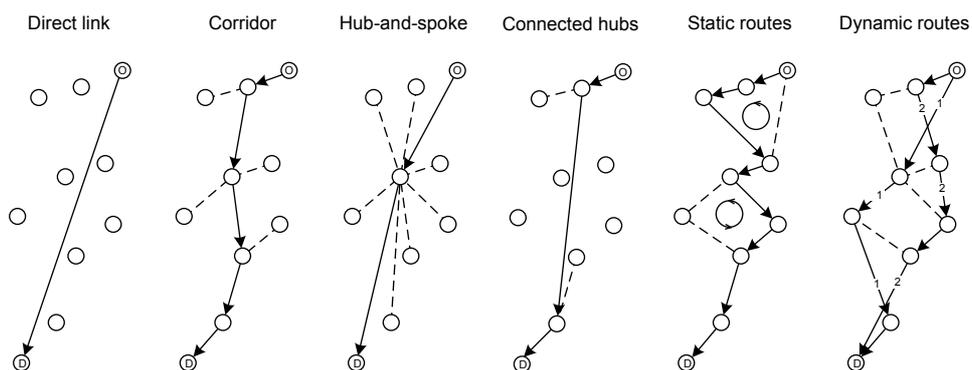


Figure 11: Six options for transport network design (Woxenius, 2007b)

In a *Direct link*, trains run directly between an origin and a destination terminal without handling along the way. Direct links are the best rail product wherever full trainloads with the required frequency can be organised. It is easy to operate and

provides good transport quality and economy for transport flows over long distances. The required annual market volume is about 150,000 to 200,000 tons (UIC, 2007).

Line-trains operated in a *Corridor* pass several terminals on their route between start and end terminal. They are suitable for serving locations with a large total annual market potential (75,000-100,000 tonnes), which, however, is split into several less-than-trainload volumes (UIC, 2007). They offer regular service and higher frequencies and allow for the integration of terminals with smaller demands in a network of IRRT and are therefore often proposed as a measure for competing in the market segment characterised by small volumes or short distances.

In a *Hub-and-spoke network* one node is the hub and all unit loads call this node for transfer. In this design it is possible to offer connections between a large number of origins and destinations with medium and small terminals. At the spoke terminals trains are loaded with shipments bound for many places, which meet at a hub, where the loads are sorted to the outbound trains to the destination spoke terminals (UIC, 2007). This design implies long train formation and bundling times in the hub and detours even for transports between adjacent spoke terminals (Woxenius, 2007b).

In *Connected hubs networks*, short feeder trains connect several terminals of a region to a hub where the loads are consolidated for the long-distance transport between the hubs. It can thus be described as a direct link with regional consolidation. In a *Static routes design* a number of links are used on a regular basis and several nodes are used as transfer points along the route. Transfer is not needed at every node. *Dynamic routes* provide maximum flexibility by designating links depending on actual demand.

Direct links are the best rail product wherever full trainloads with the required frequency can be organised. It is one of the most often employed production system in Europe, connecting agglomerations, centres of industrial production and container ports with major inland locations (UIC, 2007). Night-leaps directly between large-scale transshipment terminals using gantry cranes and reach stackers is the dominating production paradigm in Europe (Bärthel and Woxenius, 2004). The need for rationalising of the railway sector, competition from road transport and the high purchase and exploitation costs of terminal equipment have encouraged a strategy aiming at increasing the economies of scale and abandoning intermediate transshipment or shunting (Trip and Bontekoning, 2002). According to Woxenius and Bärthel (2008), the trend of abandoning networks and instead focussing on direct links between major agglomerations and ports continues, and Gouvernal and Daydou (2005) find that the use of dedicated trains has increased dramatically in the U.K. Also, Woodburn (2009) states that most intermodal freight flows in the U.K. are operated as direct trainloads from terminal to terminal.

Since most freight flows on road are transported over shorter distances and/or are too small to facilitate full trains, the modal shift of IRRT in this system is limited.

According to an analysis made by Lammgård (2007), shippers in Sweden see only limited possibilities to implement modal shift measures due lack of quality of today's intermodal road-rail transport services. This is supported by Rich, Kveiborg et al. (2011) who show in an analysis for the Scandinavian region that a majority of all transports less than 500 km have truck as the only alternative. This imposes a strong inelasticity for modal shift for shorter trips for which truck is the dominant option.

#### *Intermodal terminals*

The transshipment function performed in terminals is an indispensable element in consolidation networks. The terminal functions and performance requirements of the terminals depend on freight flow characteristics, the type of consolidation network and its location in the network. Generally, IRRT researchers distinguish between four terminal types, which differ in their function in the intermodal network (Wiegmans et al., 1999; Bontekoning, 2000; Woxenius, 2007a). These are *start and end terminals*, *intermediate terminals*, *hub terminals* and *spoke terminals*. Woxenius (2007a) provides a detailed assessment of the crucial performance characteristics of terminals and an overview of the implication on the transshipment technologies.

*Start and end terminals* in direct links or corridor networks handle large volumes, which are split into smaller flows for further transport on road. The demands on the transshipment technology are comparably low. Since the trains stay at the terminal throughout the day and are operated overnight as full trains between terminals the performance requirements on the transshipment technology regarding capacity, transshipment time, technical reliability and technological flexibility are moderate.

*Intermediate terminals* in corridors handle a limited number of unit loads, which are transhipped at intermediate nodes for distribution in the terminal region. The terminals can include value-adding services, e.g., consolidation of different flows into shipments for customers. Since the train waiting time in each terminal needs to be short in order to keep the train's total travel time acceptable, transshipment technologies need to provide rapid transshipments. Furthermore, at these terminals only a few load units on each train are handled. Therefore, it is of paramount importance that the transshipment technology has low fixed costs and can access any load unit at the train.

*Hub terminals* in a hub-and-spoke or connected hubs network handle an extensive throughput of load units. The load units are transhipped between different trains. No collection and distribution takes place here implying that they are actually not intermodal terminals. All unit loads handled in the entire network go through the hub and a breakdown would paralyse the whole network. Hence transshipment capacity as well as technical reliability is a crucial transshipment technology requirement. It is also important to provide access to any unit load on the train.

*Spoke terminals* in a hub-and-spoke or connected hubs networks consolidate small volumes of load units into bigger flows. The transshipment technology requirements are comparably low; due to the limited amount of load units handled, the transshipment technology should have limited fixed costs.

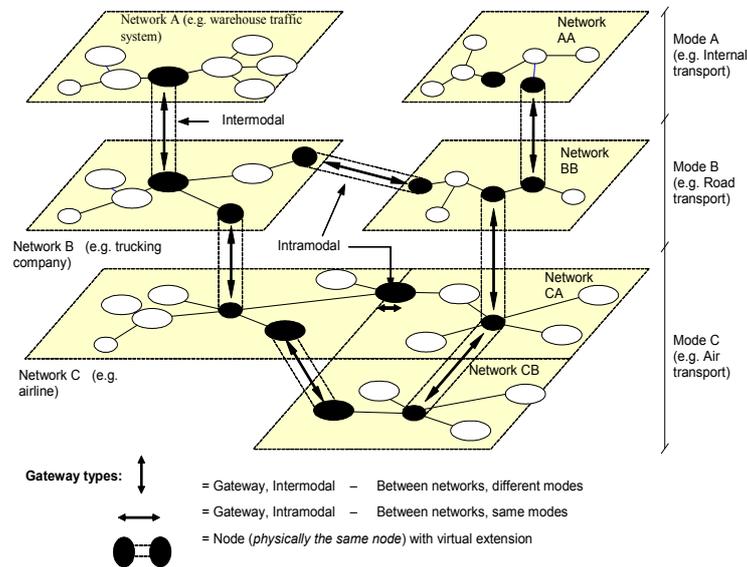


Figure 12: Connecting transport modes and transport networks through gateways (Lumsden, 2006)

Different transport networks are connected by interface nodes that belong to more than one network (Figure 12). These nodes are defined as *gateways* (Lumsden, 2006) which can be inter- or intramodal. An intermodal gateway is an interface between different transport modes. Examples for intermodal gateways are intermodal road-rail terminals that enable rail operators to reach shippers by road, and seaports that enable sea operators to access hinterland services by barge, rail or road. A seaport can also be seen as an intramodal gateway between different operators in which cargo is handed over between operators that are partners in providing a door-to-door service. Another intramodal gateway can be between different networks of the same operator, e.g., consolidation terminals connecting long-distance road transport with pick-up and delivery routes, and seaports offering transshipment between trans-ocean container vessels and feeder vessels.

Besides its vital function as an interface between transport modes, the intermodal terminal is also an interface between different organisations representing local, regional, national and international levels of transport organisations (Höltgen, 1995). Insufficient coordination and cooperation among the different decision makers at the terminal can create bottlenecks in the freight flows.

### 2.3.3 Intermodal line-trains

In order to compete in the road sector's home ground, i.e., in the transport market for semi-finished and manufactured goods at relatively short distances, alternative network and terminal designs are needed. Line-trains are often proposed as a measure for competing in this market segment characterised by small volumes or short distances. A *short distance* is often defined as shorter than the 500 kilometres, often mentioned as the break-even distance for European IRRRT and a *small volume* refers to a volume less than economically viable for direct trains (Woxenius, 2007b). A typical line-train that covers the intermediate markets would stop for transshipment for 15 to 30 minutes approximately every 100 kilometres, hence facilitating shorter PPH.

Line-train services are rarely offered in Europe since the operation of line-trains is challenging. The intermediate terminals must be inexpensive yet efficient to not incur too much time loss and cost, which would deter shippers as elaborated by Bontekoning and Kreutzberger (2001). They found that this requires substantial improvement of the cost-quality ratio. Incremental improvement of conventional terminals and related shunting operations do not suffice. Instead, side-track terminals where unit loads can be transhipped under the overhead contact wire are more promising. The time needed for transshipment along the route is crucial for the overall productivity, the average speed and the possibilities to cover long distances overnight (Trip and Bontekoning, 2002). In recent years/decades inventors have designed numerous sophisticated transshipment technologies for rapid and efficient handling, which awakened the hope to significantly reduce the impedances of consolidation and to justify the operation of innovative networks (Kreutzberger, 2010). Both horizontal and vertical transshipment technologies exist. They promise low fixed costs and therefore allow for economic operations at comparably low transshipment volumes. The big advantage of small-scale horizontal transshipment compared to small-scale vertical transshipment is that only a small vertical lift is needed to tranship the unit load. This allows for transshipping under the catenary and a slimmer dimensioning since only a small force is needed to tranship the load units horizontally (Woxenius, 2007a). However, despite the potential and positive outcomes of technological and economic feasibility studies they share the feature of not being used commercially in a large scale (Bontekoning and Priemus, 2004). Most technologies are still in the development phase of a blue-print or prototype, and many have been abandoned by their inventors (Woxenius, 2007b).

The implementation problems are often attributed to technological as well as organisational complexity of intermodal transport characterised by a wide variety of activities, actors and resources. Implementing rail innovations serving entire networks requires a shift of this intermodal organisational paradigm (Rudel, 2002; Barthel and Woxenius, 2004), which currently typically reflects mass production principles applied to transportation on the basis of economies of scale (Bontekoning and Priemus, 2004).

This paradigm shift remains problematic, since various players are required to cooperate and the interrelated system components have to be replaced at the same time (Bontekoning et al., 2004). Rail operators still focus on cost reductions and efficiency improvements on single routes instead of entire networks (Kreutzberger, 2010). However, these consolidation networks require more complex terminal operations resulting in high transshipment unit costs (Vrenken et al., 2005). Wiegmans, Stekelenburg et al. (2007) argue that the business opportunities of innovative rail services based on entire networks end up at the rail operator while the investments have to be made by the terminal operators. The major barrier to the implementation is a lack of clear and informative statements about the additional costs of transshipments versus the network benefits (Bontekoning, 2002). Hence, implementing rail innovations is not only a matter of simply replacing the transshipment technology but it also imposes significant inter-organisational challenges.

#### 2.3.4 Pre and post haulage

One significant factor that limits the competitiveness of intermodal transport is inefficient pre- and post haulage (PPH) operations (Walker, 1992; Morlok et al., 1995; Niérat, 1997). PPH operations involve the provision of an empty intermodal loading unit to the shipper and the subsequent transportation of a full loading unit to the terminal (Macharis and Bontekoning, 2004). Despite the relatively short distance in relation to the rail haul, PPH can be responsible for up to 40% of the total transportation cost (Bontekoning et al., 2004; Woxenius and Bärthel, 2008). Given the large costs associated with PPH, there is substantial potential for operational improvements and improved cost-efficiency. However, despite its influence on the performance of intermodal transport, little research has been conducted on this aspect (Bontekoning et al., 2004). As previous research has illustrated, it is difficult and challenging to achieve improvements to the organisation of PPH (Niérat, 1997). In Europe, most PPH operations around inland terminals have a distance of usually not more than 25 km, and only a few trips exceed a distance of 100km (Kreutzberger et al., 2006a). Moreover, PPH operations are very fragmented, with various PPH companies serving each terminal. Distribution and pick-up trips to and from shippers are rarely coordinated, resulting in many empty trips (Morlok et al., 1995). In addition to low capacity utilisation due to empty running, which is inherent in pick-up and delivery traffic, the centralised intermodal production system leads to concentrated PPH flows and longer waiting times at large-scale intermodal terminals (Walker, 1992).

From an environmental perspective, PPH by diesel trucks is the major source of air pollution in the intermodal transport chain and it also accounts for a significant share of the transport chain's energy demand. A viable alternative to oil, which can reduce fossil fuel dependency and emissions, will take a long time to be both developed and implemented for the road freight sector (DHL, 2009). Moreover, innovative vehicles

and fuels are usually not suitable for longer transport distances. Furthermore, PPH usually takes place in urban areas where it shares the infrastructure with passenger traffic, and congestion, noise, accidents and air pollution impacts are much higher than for intercity traffic (CE Delft, 2008). Finally, because of the low capacity utilisation the PPH-distance travelled in urban areas is generally higher than for all-road transport (Woxenius, 2001).

One possibility to reduce the PPH costs and environmental impact is a revision of the regulatory framework on weights and dimensions of trucks. McKinnon (2005) shows that the increase in maximum truck weight (from 40 tonnes to 44 tonnes in the UK) yields significant economic benefits. Hence, allowing trucks carrying intermodal units to terminals to operate at gross weights and lengths, which would allow the transport of one additional intermodal loading unit per PPH trip can potentially decrease PPH costs and as a result the costs of the total intermodal chain.

The regulatory framework for the transport market co-determines the cost level of PPH, since it is a complex business burdened by a large number of restrictive government directives and regulations, including maximum vehicle dimensions and weights, operator licensing, limits on driver working times, etc. (Lowe, 2005). Exemptions from the rules for road-freight vehicles which exceed the size limits of current heavy goods vehicles (HGVs) of 16.50 m/18.75 m are subject to special permission given by national governments. The Council Directive 1996/53/EC allows member states to legalise longer and heavier vehicles (LHV), so long as they conform to the standard modular dimensions, which are defined in the directive. The short module 7.82 m, which is a CEN standard for swap bodies, also includes other standardised load units such as 7.45 m, 7.15 m and 20 feet. The long module 13.6 m, which is the European semitrailer length, includes the 40 foot ISO container. These vehicle units are coupled together in combinations in order to achieve a total loading length that is a multiple of the module lengths 7.82 m and 13.6 m (Doll et al., 2009). These exemptions, however, are only valid for transports within their national borders and do not apply for border crossing traffic. Some countries generally allow a vehicle length of 25.25 m and a weight of 60 t (Doll et al., 2009). Sweden and Finland generally allow the use of longer and heavier vehicle combinations (LHV's) consisting of the longest semi-trailer, with a maximum length of 13.6 m, and the longest load-carrier according to "Class-C", with a maximum length of 7.82 m, allowed in the EU. This results in vehicle combinations of 25.25 m, which is significantly longer than the maximum length of 18.75 within the rest of Europe. These vehicle combinations are known as the European Modular System (EMS).

Concerning weight limits, different exemptions from the current maximum weights of 40 tons have been tested or are in use. Sweden and Finland generally allow a maximum vehicle weight of 60 tons. In some states in Germany, trials that allow vehicle lengths of 25.25 m, but not exceeding the current weight limit of 40 tons, have

been conducted (Doll et al., 2009). The Netherlands carried out two LHV trials between 1999 and 2003 and 2004 and 2006 and the results were considered sufficiently positive to justify the general legalisation of LHVs (McKinnon, 2008). Since November 2007, longer vehicles with a weight of 50 tons have been allowed and since May 2008, 60 tons and 25.25 m LHVs are now allowed on Dutch roads (Doll et al., 2009).

The European Commission is considering a revision of the regulatory framework on weights and dimensions of heavy commercial vehicles, which would also allow the use of LHVs in international transport. The expected benefits are a reduction in vehicle operating costs and a reduction in lorry traffic, which would help to alleviate environmental impacts and congestion. However, the reduced operating costs may also have negative environmental effects, since it may induce a modal shift from rail to road and induce additional demand for transport. Furthermore, it could affect safety and could have implications for road transport infrastructure.

Various studies have been undertaken which arrive at different conclusions on the relative economic and environmental costs and benefits of longer road vehicle combinations. In Scandinavia, the experience of using EMS vehicle combinations is mostly positive. A study by Åkermann and Jonsson (2007) indicates that the use of LHVs with EMS in Sweden and Finland have had a positive effect on the economy and environment, while not affecting traffic safety negatively. Furthermore, the Dutch trials indicate that it is possible to operate with LHVs on a limited road network. On the other hand, Doll et al. (2009) conclude that a general extension of the provisions of directive 1996/53/EC towards extra long and possibly extra heavy lorry combinations would result in a considerable shift in the mode of transport from rail to road (between 10% and 30% of rail containers), with negative consequences for the environment, climate and safety. Additional potential negative effects are the generation of new freight traffic if companies respond to the reduction in freight costs, a possible increase in the severity of accidents as a result of the greater weight and size, and a possible increase in expenditures on road infrastructure to accommodate LHVs (McKinnon, 2008). Hence, increasing the maximum length and weight of road vehicles is one of the most controversial issues in the context of transport policy. McKinnon (2008) highlights the difficulties in assessing the net benefits and extrapolating the experience from national trials to the EU as a whole.

## **2.4 Chapter summary**

This chapter presented theoretical concepts and previous research that is relevant for answering the research questions. The key issues in the three levels are summarised here (Figure 13).

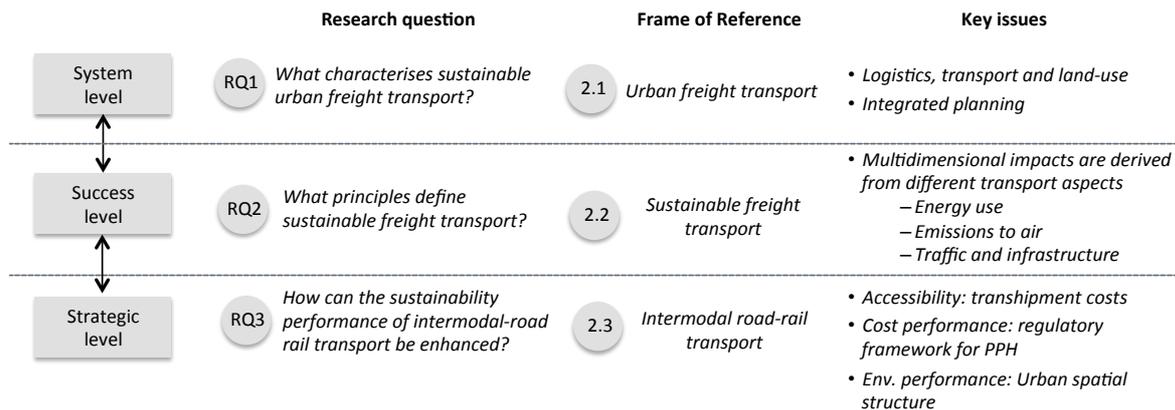


Figure 13: Key issues from the frame of reference for the research questions

### System level: Urban freight transport

The first research question aims to develop an understanding of the mechanisms constituting urban freight transport. A framework for urban freight transport needs to include the **logistics, transport and land-use** elements, as well as the interest of non-freight transport stakeholders, e.g. citizens and passenger transport. To achieve a sustainable urban freight transport system an **integrated planning** approach is necessary.

### Success level: Sustainable freight transport

The second research question aims to define sustainable freight transport. Principles for sustainable freight transport need to take into account that the unsustainable impacts are **multidimensional** in terms of geography (local, regional, global) as well as impact type (economic, environmental, social) and are derived by different aspects of transport, i.e. **energy use, emissions to air and traffic and infrastructure**.

### Strategic level: Intermodal road-rail transport

The third research question addresses possibilities to enhance the sustainability performance of IRRT. Since there are a lot of measures which influence the performance of IRRT, a prerequisite for developing a strategy towards sustainable intermodal transport is to know how the different measures affect the sustainability performance as defined in research question 2.

The first problem of IRRT is the limited market coverage. A pre-requisite for intermodal transport to compete on shorter distances is a higher geographical coverage of intelligently linked intermodal terminals. However, these consolidation networks require more complex terminal operations, which are likely to result in high transshipment costs. Increasing the accessibility of IRRT therefore requires consolidation networks with node operations, which can keep the **transshipment costs** under a certain cost level.

Secondly, the economic performance of IRRT is very sensitive to PPH costs. Despite the relatively short distance in relation to the rail haul, PPH is responsible for a large share of the total transportation cost. Since it is difficult and challenging to achieve improvements to the organisation of PPH, changes to the **regulatory framework** on weights and dimensions of trucks can potentially increase the efficiency of haulage operations.

PPH by diesel trucks is the major source of air pollution in the intermodal transport chain and also accounts for a significant share of the transport chain's energy demand. The amount of PPH traffic is co-determined by the relative location of terminal and shipper/receiver. An **urban spatial structure**, which limits PPH distances, may entail additional potential to substantially reduce the environmental impact and cost of PPH.



### 3 Methodology

*In this chapter the research methodology to reach the purpose of this thesis is described. It starts with a discussion and motivation of the chosen research strategy (chapter 3.1). Then, the research process (chapter 3.2) and the data collection methods (chapter 3.3) are described. The chapter concludes with a discussion about the research quality (chapter 3.4).*

#### 3.1 Research strategy

There are several research strategies to reach a research purpose. Wacker (1998) contrasts analytical research methods that use logic and mathematics with empirical research that uses real world observations. Meredith (1998) differs between rationalist research and empirical case research and states that rationalist research methods are appropriate for testing theories, while empirical case research is appropriate for theory building. Also, Gammelgaard (2004) distinguishes between these two approaches in logistics research and defines an analytical approach on the one hand and a systems approach on the other hand. Hence, there are many research methods available, but not all research questions can be answered by all research methods. It is therefore important to match the methodology with the purpose of the study.

The starting point of this research is developing an understanding of the phenomenon of urban freight transport (the System Level). Developing this understanding requires a systems approach in order to cover the interdependencies between the urban stakeholders. To derive this contextual knowledge about systems it is necessary to analyse and compare cases (Gammelgaard, 2004). Case study research focuses on understanding the dynamics present within single settings (Eisenhardt, 1989) and Yin (2003) argues that case studies are an appropriate strategy especially when the boundaries between phenomenon and context are not clearly evident. This is the case in urban freight transport. Building a framework for urban freight transport requires a rich description of the context since urban freight is not an isolated activity in urban areas but it is affected by the actions of many stakeholders with varying interests. Case studies deliberately include these contextual conditions as they investigate a contemporary phenomenon within real-life settings (Yin, 2003). These in-depth insights of empirical phenomena and their contexts provide unique means for developing theory (Dubois and Gadde, 2002). By investigating small samples using a large number of variables new insightful relationships can be developed (Wacker, 1998). Case studies are therefore a strong research strategy for developing the constructs of theory (Voss et al., 2002). The research strategy chosen to answer research question 1 is therefore empirical case study research.

Research question 2 (Success level) aims to develop the characteristics of sustainable freight transport, including the economic, social and environmental goals of the

various stakeholders. Principles for sustainable freight transport defining success in the urban freight transport system can be derived by logical conclusions from the combination of different theories. This theory development is based on logically combining previous research and theories and does not need empirical data. An appropriate research strategy therefore is conceptual analytical research which logically develops, explains and integrates underlying relationships between concepts and by this can add new insights into traditional problems (Wacker, 1998).

The purpose of research question 3 (Strategy level) is to analyse the effect of certain measures on the sustainability of IRRT. Hence, research in this area aims to analyse relationships between certain factors and the sustainability of IRRT. Revealing cause-effect relationships requires analytical research (Gammelgaard, 2004). According to Wacker (1998), relationships can be evaluated by analytical mathematical research, such as modelling and simulation, providing numeral examples for different conditions.

The research problem addressed in this thesis therefore requires both theory building and theory testing research. The first two levels, i.e. understanding the urban freight transport system (system level) and defining the sustainable freight transport (success level) require theory-building research. In the strategy level, the goal is to analyse the effect of different factors on the sustainability of IRRT as defined in level 2, hence requiring theory-testing research.

## **3.2 Research process**

This section describes how the answers to the research questions are reached. First, the research design is discussed, followed by a detailed description of the studies conducted.

### **3.2.1 Research design**

A research design is a logical plan for how to reach the conclusions to the questions of the study (Yin, 2003). Two main research approaches are generally distinguished: quantitative and qualitative research. Generally, qualitative and quantitative research takes two forms of distinctive clusters of research methodologies: quantitative research entails *deduction* (theory testing) and qualitative research is connected to *induction* (theory building). A deductive approach designs research strategies to test hypotheses which are developed based on theory. An inductive approach collects data to develop a theory as a result of the data analysis. However, the distinction between an inductive and deductive approach is usually tendencies rather than hard distinctions (Bryman and Bell, 2007). Both can be used in combination on the same research project (Saunders et al., 2003). Kovács & Spens (2005) define this combined approach as *abduction*. It is, however, yet to be seen as different from a mixture of deductive and inductive approaches (Dubois and Gadde, 2002). Abduction allows for

a less theory-driven research process than deduction, thereby enabling data-driven theory generation (Järvensivu and Törnroos, 2010). It is useful if the research objective is to discover new variables and relationships (Dubois and Gadde, 2002).

This research combines empirical case studies and analytical research, and therefore it cannot be answered by one particular research approach. Accordingly, this research consists of two phases (Figure 14), which are outlined in the remainder of this chapter. First, the case study's goal is to develop a theoretical framework based on empirical observations and hence follows an abductive approach. The second phase follows a deductive approach using conceptual methods to develop principles for sustainable freight transport and analytical mathematical methods to evaluate factors influencing the sustainability performance of IRRT. The design of the two phases and the studies conducted are explained in the remainder of this section.

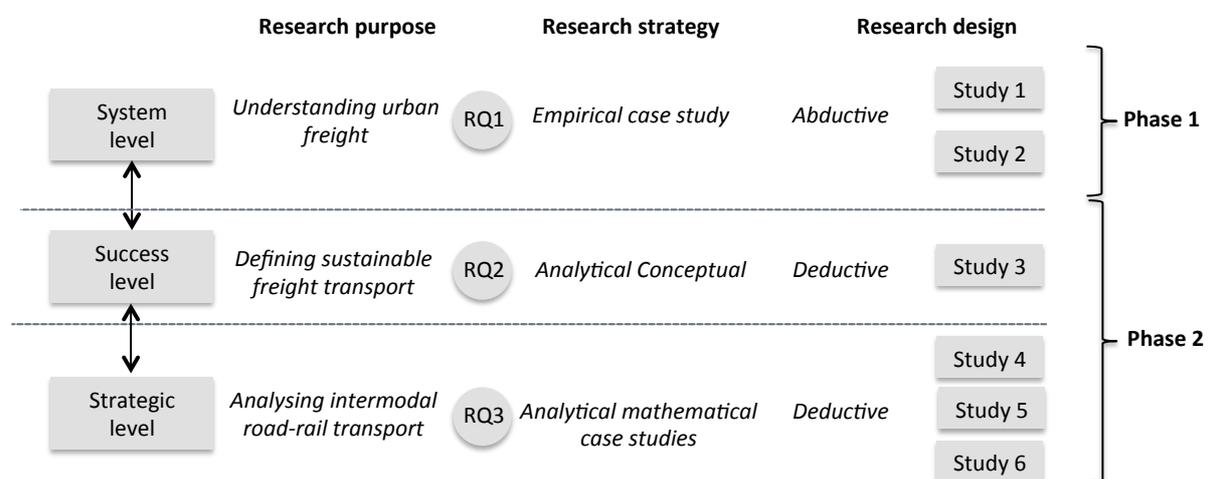


Figure 14: The research approach

### 3.2.2 Phase 1: Sustainable urban freight transport

In the first research phase empirical case studies are carried out following an abductive approach. In studies relying on abduction the original framework is successively modified based on the theoretical insights gained in the course of the study (Figure 15). Like induction, the abductive approach starts with empirical observations and both approaches aim to develop new theory. While induction stops here, the abductive approach includes the application of the developed hypotheses to the empirical research. This application can be characterised as deductive, since the deductive approach has its starting point in theoretical conclusions (Kovács and Spens, 2005). Abduction can consist of different phases throughout the research and it can be abductive in different ways. In some phases, the researcher's logic may follow

abduction in a pure sense; in other stages, the reasoning may lean more toward deduction or induction (Järvensivu and Törnroos, 2010).

In this case study, the urban freight transport system forms the unit of analysis since the goal is to examine the global nature of the urban transport system and not single actor categories. A multiple case study design is chosen since studying the phenomenon in differing contextual conditions makes the overall study more robust (Yin, 2003). Multiple cases represent replications that allow for development of a rich theoretical framework and can be used to predict similar results among replications. Yet, it is important to highlight that due to its unique context each case study is a self-contained experiment of what the case's context is an essential part of. They must not be seen as a single observation of one and the same experiment (Ellram, 1996).

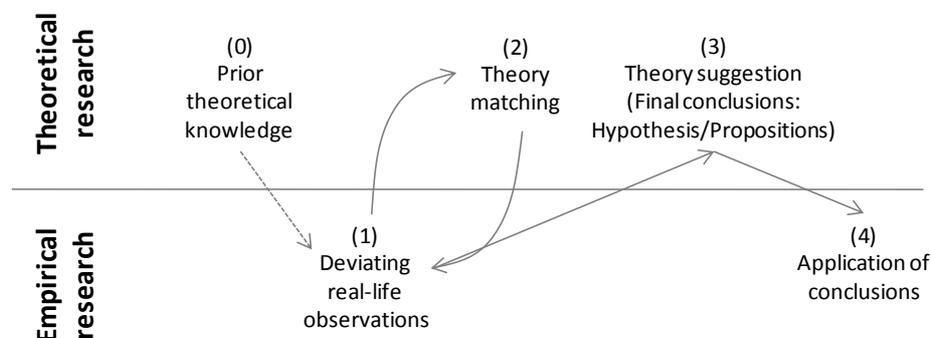


Figure 15: The abductive research process (Kovács and Spens, 2005)

The research in this phase consists of two studies (Figure 17), which were carried out in the BUSTRIP project (**B**altic **U**rban **S**ustainable **T**ransport **I**mplementation and **P**lanning). The BUSTRIP-project was one of the first European projects to test, further develop and implement the concept of Sustainable Urban Transport Plans (SUTP) (see chapter 2.1) in concrete. BUSTRIP has in extensive city/peer co-operation developed SUTPs in 12 cities in the Baltic Sea Region. The project included three elements in each city. First, the municipalities conducted a self-assessment of the current state of transport impacts and the transport planning processes in their city, including passenger and freight transport. The self-assessment was followed by the peer-reviews, i.e. a critical audit of a group of experts. Based on the outcome of the assessment the cities produced a strategic plan to improve their planning capabilities and procedures. Finally, a pilot action was implemented. The experiences made in the cities in the course of the project are compiled in a guidebook on implementing SUTPs (UBC Commission on Environment, 2007). The author has been a member of the project steering group and together with two colleagues responsible for the project management of the planning and implementation of the pilot actions in the 12 cities.

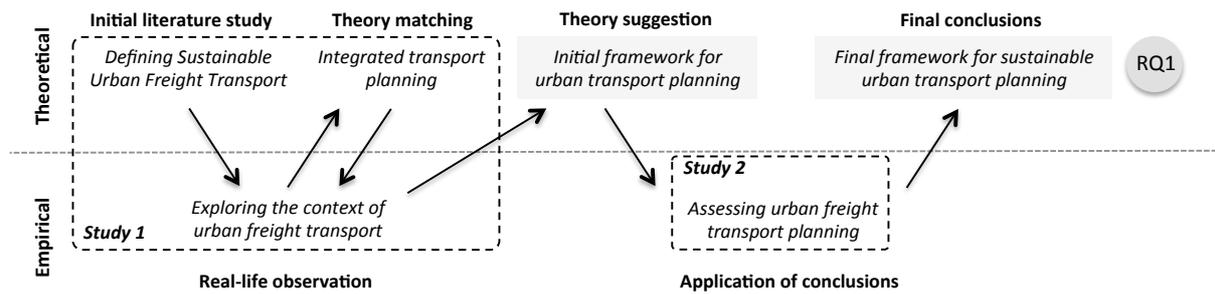


Figure 16: Research process in phase 1

The holistic self-assessment and peer-review provide the empirical data for Study 1, i.e. to explore the context of urban freight transport, which is needed to develop the framework for urban freight transport planning. This framework structures the data collection for an additional in-depth freight review, which provides the empirical data for Study 2. Both studies were performed together with the co-researcher Maria Lindholm. Together, Study 1 and Study 2 develop a framework for sustainable urban freight transport, answering Research Question 1.

#### *Study 1: Exploring the context of urban freight transport*

This study consists of a literature study and an empirical case study. The purpose of the initial literature study is to develop an understanding about how the commonly accepted but broad and vague concept of sustainable development can be applied on freight transport in urban areas. Definitions and previous work in the areas of *sustainability*, *sustainable urban transport*, *urban freight transport* and *sustainable urban freight transport* are studied and merged into a definition of sustainable urban freight transport.

Furthermore, the urban freight transport stakeholders and their relations are identified. The initial theoretical framework highlights the important relationships between different stakeholders interacting in the urban setting and affecting the freight movement in urban areas. The goal of this study is to get a holistic understanding of the urban context of sustainable freight transport and to understand the planning activities of the responsible authorities.

In the second phase of this study, the contextual conditions of urban freight transport are explored. This was achieved in the self-assessment and peer-review in the twelve cities in the BUSTRIP project. The holistic self-assessment was conducted by the local authorities, where all current developments, plans and projects were mapped in a 'Self assessment report' based on a template for SUTP (Wolfram, 2004). The report described the municipality profile (e.g., geography, administration and political issues), the drivers affecting mobility and transport (processes that influence the

transport activities), the impacts on urban sustainability (e.g., indicators for emissions, safety and quality of urban life), as well as relevant plans and policies. After the reports were finalised, the holistic peer-reviews were conducted. A peer-review team consisting of a group of experts, i.e., traffic planners and researchers from the different project cities including the authors, reviewed the self-assessment reports and then visited the cities. Over the course of a week, the review team conducted interviews with, e.g., city representatives, transport operators, politicians and other stakeholders to monitor the contents of the self-assessment report and to identify missing pieces. On the last day of the site-visit, the peer-review team summarised the findings and presented them to the municipality. After the visit, the peer review team wrote a report summarising the findings to help the city authority personnel find relevant factors to act upon when planning and adopting a SUTP. An example programme of a peer review is shown in Appendix VIII.

The author was a member of the peer-review team in three cities: Bremen (Germany), Örebro (Sweden) and Kouvola (Finland). By reviewing the self-assessment report, a one-week site-visit and interviews with several urban stakeholders, the author gained a holistic and rich description of the transport sector's role for urban sustainable development and the actors' perspectives on this issue in the specific context of each city. Furthermore, the author was a member of the steering group of the BUSTRIP project, which met twice a year to discuss the progress in all cities. City specific as well as general issues were identified and their implications for the urban transport planning were assessed. Finally, two project workshops with all cities were conducted. In the first workshop the experiences from the self-assessment, and in the second workshop the experiences from the peer-review were summarised and discussed.

In parallel to the investigations in the cities, academic literature on the subject of integrated transport planning was reviewed. The process is circular as preliminary theoretical assumptions are reformulated and further elaborated on in the course of the city reviews. This intertwined research process, i.e., going 'back and forth' between empirical observations and theory, allows expanding the understanding of both theory and the empirical phenomena (Dubois and Gadde, 2002). Based on the empirical observations in the case studies and the findings from the literature study, the study concludes with an initial framework for sustainable urban freight transport planning.

### *Study 2: Assessing urban freight transport planning*

In this study the focus is narrowed down from urban transport planning in general to freight transport planning. The framework for the analysis of urban freight transport systems developed in the previous steps structured the data collection and analysis and hence it is tested in an empirical setting and further developed based on the case study findings (Research question 1). The goal was to identify common challenges and shortcomings in the planning process that lead to the existing problems of urban freight transport.

This assessment was not part of the BUSTRIP project but was initiated by the author. The self-assessment and peer-reviews did not include or only touched upon freight issues on a very general level. This confirmed the general problem that freight issues in urban areas are rarely considered in urban transport planning. Hence, the author (together with the Co-researcher Maria Lindholm) decided to conduct a complementary study focussing on freight transport. This study was limited to four of the 12 cities in the BUSTRIP project. The cases selected for this part of the study were Bremen (Germany), Gdynia (Poland), Kaunas (Lithuania) and Örebro (Sweden). These cities were selected for both practical (ease of access) and research (diversity) reasons. For practical reasons, the author was a member of the peer-review team in Bremen and Örebro and therefore had good knowledge of the contextual conditions and planning practices in these cities. Moreover, the peer-review visit facilitated relatively easy access to the stakeholders. The co-researcher in this study was a member of the peer-review team in Kaunas and Gdynia and therefore had a good understanding of the contextual condition and had access to stakeholders in these cities.

Table 3: Case study sample (x: cities visited by the author, (x): complementary data via reports, project meetings and workshops)

	Self assessment	Peer review	Freight review
<i>Old EU-Member States</i>			
Bremen (DE)	x	Author	Author, co-researcher
Göteborg (SE)	(x)	(x)	
Kouvola Region (FI)	(x)	Author	
Örebro (SE)	x	Author	Author, co-researcher
Sundsvall (SE)	(x)	(x)	
Turku (FI)	(x)	(x)	
<i>New EU-Member States</i>			
Gdynia (PL)	x	Co-researcher	Author, co-researcher
Kaunas (LT)	x	Co-researcher	Author, co-researcher
Liepaja (LV)	(x)	(x)	
Pärnu (EE)	(x)	(x)	
Tartu (EE)	(x)	(x)	
Vilnius (LT)	(x)	(x)	

The selected four cities represent substantially different ‘political and administrative cultures’ in terms of public planning procedures and capacity as well as the state of economic development, since the study includes both cities from the old member states (OMS) of the European Union, i.e., Bremen and Örebro, as well as cities from the new member states (NMS), i.e., Gdynia and Kaunas. Furthermore, the cities differ in size (Bremen ca. 500,000 inhabitants, Kaunas 320,000, Gdynia 250,000, Örebro 100,000) and geographical conditions (Bremen and Gdynia are port cities, while Örebro and Kaunas are located within the country). Common to the cities though is the strong role of logistics and transport activities for their economy and that they host

inter- and intramodal gateways such as ports and railway terminals or shunting yards with over-regional relevance. The case study sample is depicted in Table 3.

In the in-depth freight reviews in Bremen, Gdynia, Kaunas and Örebro, 34 interviews in total were conducted with actors representing different aspects of the freight transport issue at various levels and functions (Table 4). The actor groups to be interviewed were identified in the literature review in Study 1 and included representatives of the city administration (heads of departments, decision makers, politicians, handling officers), organisations representing transport customers, freight forwarders, transport operators and research institutes. The same actor groups were interviewed in all four cities and the questions were asked following an interview guide with semi-structured and open-ended questions in order to obtain comparable results. The interviews included questions about municipality profile, drivers, impacts, quality of urban life, problems, plans and policies. Additional questions were asked in some interviews and in other cases it was not possible for all actors to answer the questions. The interview guide is shown in Appendix VIII. The interviews were performed by the author and the co-researcher in all four cities and lasted about 1 to 2 hours each. In addition, public reports and planning documents about the cities' transport systems were reviewed to complement the data collection.

*Table 4: Number of conducted interviews per actor category in the in-depth freight review*

	Bremen	Örebro	Kaunas	Gdynia
City administration	4	3	4	3
Transport customer		1	1	1
Freight forwarder	2	2	1	1
Transport operator	1	1	2	4
Research institute	1		1	1

### 3.2.3 Phase 2: Sustainable intermodal road-rail transport

The second research phase follows a deductive research approach. It addresses the effects of different factors on the sustainability of IRRT. Hence, by means of an analytical conceptual study propositions on the sustainability performance of IRRT are developed which are then further analysed in three analytical mathematical studies (Figure 17).

The research in this phase was carried out in two research projects. The first project was the FastRCargo<sup>2</sup> project which addressed the challenge of transshipments in intermodal transport networks. The point of departure was that a cost efficient solution of this technology challenge is crucial for further enhancements of the

<sup>2</sup> FastRCargo is a project financed by the European Commission within the 6<sup>th</sup> framework programme. The project aims to develop a small-scale horizontal transshipment technology for automated transshipments of intermodal loading units below active contact lines.

competitiveness of IRRT. The project aimed to develop a new small-scale horizontal transshipment technology for automated transshipment between rail wagons and lorries below active contact lines, which is achieved by gripping the intermodal transport units at their bottom corners. Unseld and Kotzab (2008) present an overview of technology and potential applications. The project consortium consisted of manufacturers, rail and terminal operators and the universities Copenhagen Business School, Gothenburg University and Chalmers. The universities were responsible for expanding the knowledge of how to integrate the innovative transshipment system into a context of intermodal transport services. The author has been responsible for a work package aimed to develop the characteristics of innovative intermodal services (Behrends, 2010). Studies 3 and 4 were carried out in this project.

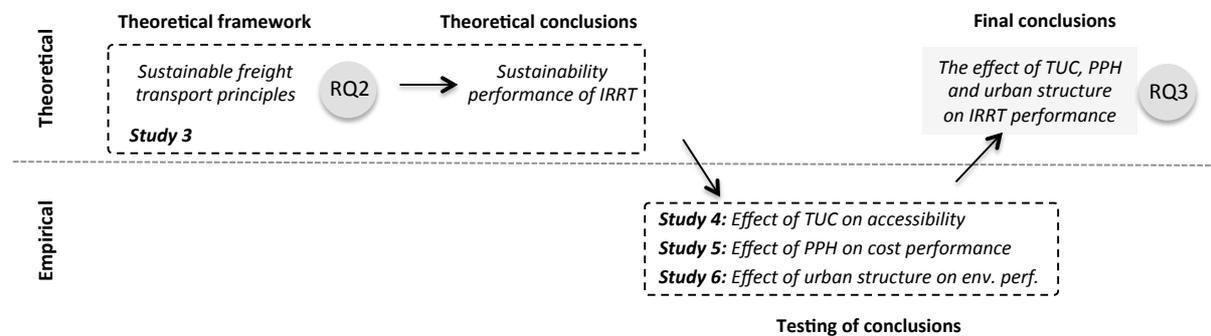


Figure 17: Research process in phase 2

Study 5 was conducted in the project “Intermodal transport from a haulier’s perspective”<sup>3</sup>. This project intended to compensate for the fact that the road haulage part of intermodal transport chains has been neglected in research as well as the public debate, keeping in mind that the activity accounts for a large part of the time and costs consumed and it is practically challenging to organise road haulage efficiently.

Study 6 analysed the environmental consequences of a modal shift. This study was not linked to a research project.

### Study 3: Sustainability performance of IRRT

This study addresses the second research question, which aims to develop a definition of sustainable freight transport. Starting from the theoretical conclusions on sustainable urban freight transport in research phase 1, Study 3 reviews literature on freight transport and sustainable development, and develops the characteristics of sustainable freight transport (research question 3). Principles for sustainable freight

<sup>3</sup> The project “Intermodal transport from a haulier’s perspective” was financed by the Swedish Intermodal Transport Research Centre (SIR-C) and was intended to compensate for the fact that the road haulage part of intermodal transport chains has been neglected in research as well as in public debate, keeping in mind that the activity accounts for a large part of the time and costs consumed.

transport are developed by first identifying functionally different sources for non-sustainability. To describe sustainable freight transport these mechanisms are then negated. In the second part of the study, the developed principles for sustainable freight transport are applied on IRRT. The literature on IRRT is reviewed to develop propositions on the factors influencing the sustainability performance of IRRT. Project meetings and workshops in the FastRCargo project, which discussed potential applications of small-scale horizontal transshipment technologies and barriers to the implementation of innovative IRRT services based on this technology, complemented the literature study. These meetings were, however, not used to collect data for the study but were mainly a source of inspiration and were for confirmation of initial conclusions. The author conducted this study by himself.

In order to answer research question 3, Study 4, Study 5 and Study 6 further analyse these propositions using analytical mathematical methods. Study 4 analyses the effect of transshipment costs on the performance of intermodal line-trains, Study 5 looks into the effect of vehicle regulations on PPH efficiency and Study 6 analyses the impact of the urban structure on environmental performance.

#### *Study 4: The effect of transshipment unit costs on IRRT-accessibility*

This study addresses the economic preconditions of transshipment technologies in intermodal transport services. The goal is to identify the relevance of the transshipment costs for the competitiveness of intermodal line-trains. In a theoretical case study the cost and potential modal share for an intermodal line-train on a corridor in Sweden are analysed. The method is based on modelling a competitive situation between traditional road transport and IRRT using the Heuristic Intermodal Transport (HIT) model. The HIT-model is a heuristic computer model that has its starting point in a competitive situation between all-road transport and IRRT, where the theoretical potential of IRRT is determined by how well it performs in comparison to all-road transport (Flodén, 2007). A transport buyer is supposed to select the mode of transport offering the best combination of transport quality, cost and environmental effects. Given the demand for transport, the model determines the most appropriate modal split and calculates business economic costs, societal costs and the environmental effects of all parts in the transport system. IRRT must match, or outperform the delivery times offered by road transport while offering an equal or lower cost to be selected. The outcome of the study shows under which economic preconditions intermodal line-trains can be a competitive alternative to road transport on relatively short transport distances.

The study was conducted together with Jonas Flodén from the University of Gothenburg who also developed the HIT model.

*Study 5: The effect of LHV on IRRT-cost performance*

This study addresses the possibility of improving the competitiveness of intermodal transport services by improving the cost-efficiency of the PPH activities. It does so by constructing a Strategic Calculation Model that provides insight into the potential of LHV for PPH activities. The principal idea is to implement flexible regulations to allow LHV to be used for specific goods flows between the location of major shippers and the nearest intermodal terminal, where PPH circumstances currently make IRRT solutions unfavourable. The Model is applied on a typical large shipper in order to identify the improvement potential and the factors affecting the potential. The study was conducted together with Rickard Bergqvist from the University of Gothenburg who also developed the Strategic Calculation Model.

*Study 6: The effect of urban structure on the IRRT-environmental impact*

The goal of Study 6 is to analyse the environmental consequences of shifting from all-road transport to IRRT. More specifically, it aims to explore the factors determining the trade-off between additional local environmental impacts and global environmental gains. This is achieved by calculating the external costs of a transport of consolidated cargo by road between a freight forwarder's consolidation terminals. The results were compared with a potential intermodal alternative for this transport.

Since the environmental impact of IRRT depends on many factors, a multiple case study was chosen to cover these differences. Two cases with differing pre-conditions for IRRT are analysed. The first case covers a transport between Gothenburg and Stockholm in Sweden with a relatively long transport distance (ca. 500km) and emission-free rail transport, and hence represents good circumstances for achieving substantial environmental benefits through a modal shift. The second case analyses a relatively short transport distance between Hanover and Bremen (ca. 130km) in Germany where the rail-electricity mix is to a great extent based on fossil energy sources.

Interviews with freight forwarders and transport operators are used to collect freight flow and vehicle data. The emissions are calculated using the methods and data provided by the Swedish Network for Transport and the Environment (NTM, 2005). For the economic valuation of the emissions, the data provided by the "Handbook on estimation of external cost in the transport sector" (CE Delft, 2008) is used. The author conducted the study by himself.

Table 5 summarises the research strategy and data collection method of each study.

Table 5: Summary of research studies

Data collection method	Research strategy
<i>Study 1 – Exploring the urban context of sustainable freight transport</i> Literature study on sustainable urban freight transport and integrated planning, document reviews, interviews, project meetings	Qualitative case study
<i>Study 2 – Assessing urban freight transport planning</i> Interviews, direct observations, document reviews	Qualitative case study
<i>Study 3 – Sustainability performance of IRRT</i> Literature study on sustainability, freight transport, transport geography, intermodal transport	Analytical conceptual
<i>Study 4 – Effect of transshipment costs on IRRT-accessibility</i> Literature study on intermodal transport, Secondary data	Analytical mathematical case study
<i>Study 5 – Effect of LHV on IRRT-cost performance</i> Literature study on pre- and post haulage, Secondary data	Analytical mathematical case study
<i>Study 6 – Effect of urban structure on IRRT-environmental performance</i> Document reviews, Interviews	Analytical mathematical case study

### 3.3 Data collection methods

According to Marshall and Rossman (2006), it is important to match the data collection method with the purpose of the study. Interviews are probably the most widely employed method in qualitative research (Bryman and Bell, 2007). By means of in-depth interviews the participant's view on the phenomenon of interest can unfold as the participant views it. Hence, they are a suitable data collection method for the case study and therefore are used as the main source of empirical evidence. The interviews are complemented by document reviews, observations and literature studies. All applied data collection methods are briefly explained in this section.

#### 3.3.1 Interviews

In qualitative research a rather unstructured interview approach is needed to unfold the interviewee's worldview. Dubois and Gadde (2002) therefore make a distinction between "active data" and "passive data"; active data is what the researcher has set to find out, while passive data is associated with discovery. With this reasoning, active data can be gathered by structured interviews whereas passive data require more unstructured approaches. To help uncover the interviewee's view, the researcher should only introduce a few general topics, but otherwise he needs to respect how the interviewee structures the responses. The focus needs to be on the interviewee's view, not how the researcher views the phenomenon (Marshall and Rossman, 2006). To

ensure this, the questions to be formulated in the interview guide should not be so specific that they prevent the interview from going in alternate directions that might arise in the course of the interview (Bryman and Bell, 2007).

The interviews in both parts of the case study (Study 1 and Study 2) of this research are designed as semi-structured interviews. The interviews are started with an open question to avoid imposing the researcher's frame of reference on the participant and to unfold the passive. More structured questions are introduced later in the interview in order to avoid remaining on too general a level and to bring out the active data, i.e., the specific elements of the phenomenon under study. Furthermore the interview design ensures that all relevant aspects and topics are covered (see Appendix VII). In addition, interviews are used in Study 6. Freight forwarders in both Germany and Sweden were interviewed to design realistic transport chains for the calculation of the external costs. By means of telephone interviews, data on typical transport volumes, routes and vehicle types was collected.

### 3.3.2 Analysing documents

The greatest strength of analysing documents is that it is unobtrusive and nonreactive since it can be conducted without interaction with the settings in any way. Also, transparency is high, since information can be checked by the reader (Marshall and Rossman, 2006). Hence, documents can be a fruitful data source; however, they are not just a representation of facts or reality. Documents can be solicited for the research, i.e., they have been produced/dedicated for the research, or they can be unsolicited. Hence, the context and the use and function of the document need to be taken into account. Criteria for assessing the quality of documents are: a) authenticity, i.e., is it a primary or secondary document; b) credibility, which refers to the accurateness of the document and the reliability of the producer; c) representativeness, i.e., is it typical of its kind; and d) meaning, i.e., is it clear and comprehensible (Flick, 2006).

Document reviews are used in the first phase of this study. The self-assessment reports are produced for the BUSTRIP project and their purpose is to review the current state of the city's transport system and its impact on sustainable development. The reports are produced by an inter-sectoral working group consisting of various planning agencies and cover all transport related issues. Hence, they provide a rich and holistic sustainability assessment of the transport system of the city in question. In the in-depth freight review public reports and planning documents about the cities' transport systems are reviewed to complement the interviews. Furthermore, documents are used in study 6 to collect data for the calculation of emissions and external costs.

### 3.3.3 Direct observations

Direct observations enable the researcher to find out how something factually works or occurs (Flick, 2006). Immersion in the setting permits the researcher to hear, to see and to begin to experience reality as the participants do. It allows the researcher to learn directly from his own experience and provide the researcher with new perspectives and personal reflections (Marshall and Rossman, 2006).

The visits in the BUSTRIP cities enable direct observations of the cities' transport system. They occur automatically, as the researcher actively takes part in the urban transport system during his stay in the particular city. However, they are not designed as a data collection method on its own in this research study since the observations can hardly be standardised or formalised. The experiences gained in the natural setting of the urban transport are a complement to document analysis and interviews and are seen as additional information that provide inspiration for interviews and helps in understanding the context of the urban transport system.

### 3.3.4 Group discussions

The advantage of group discussions is that they stimulate the participants so that they can reach beyond the answers of a single interviewee. The dynamics of discussions enables the development of conversation as the central source of knowledge. Furthermore, they provide some quality control as participants check and balance each other, which weeds out false or extreme views. The main disadvantage is also linked to the group dynamics, which makes it more difficult to formulate conclusions (Flick, 2006).

The project meetings in the BUSTRIP project can be characterised as group discussions. The project steering group meetings and project workshops provided additional knowledge on progress and problems in the cities, which were not visited by the researcher. Moreover, project meetings in the FastRCargo project contributed to Study 3 and Study 4. The group consisted of representatives from several institutions including academics, transport operators and infrastructure providers. The group meetings helped to confirm or to adjust individual conclusions. Hence, the meetings were mainly used as complementary data source and for quality control.

## 3.4 Research quality

In this section, the research quality of the abductive case studies in research phase 1 is discussed. Research phase 1 follows a qualitative research approach, which has been questioned especially by the quantitatively focused research world (Näslund, 2002). The critique is that compared to quantitative research it is too subjective since its findings rely too much on the researcher's views about what is significant and important. The close relationship between researchers and people studied adds to this

point of critique (Bryman and Bell, 2007). The interpretative nature of qualitative research also makes it difficult to replicate. Since the researcher is the main instrument of data collection, the collected data is highly influenced by the researcher's preferences. Another challenge of qualitative research is the problem of generalisation since the scope of the findings is restricted to one or several cases with certain settings (Flick, 2006).

To establish the quality of any empirical social research, four tests are commonly used and these tests are also relevant for case studies (Yin, 2003). The four tests are: (1) construct validity, (2) internal validity, (3) external validity and (4) reliability. Internal validity is only for explanatory case studies, and hence is relevant for the case studies of this research, which are descriptive and exploratory. Internal validity is therefore not addressed in this section.

#### 3.4.1 Construct validity

*Construct validity* establishes correct operational measures for the concepts being studied. In this study, the main source of empirical evidence is semi-structured interviews. However, interviews have certain limitations and weaknesses. Flick (2006) argues that collecting the relevant data cannot be realised in advance by designing an interview guide since it depends on how the actual interview situation develops. Typical for interviews is the personal interaction, which influences the participant. Furthermore, participants may be unwilling to share their knowledge or viewpoints or their answers are untruthful and incorrect. Hence, conducting interviews requires the researcher to have certain skills such as listening and personal interaction skills in order to handle unplanned developments in the course of the interview (Marshall and Rossman, 2006).

To secure construct validity multiple sources of evidence should be used. In the case studies, document reviews and observations complement interviews as data sources. Furthermore, the key findings of the interview-series in both the peer-reviews and freight reviews are discussed with the project coordinators of the respective cities at the end of each city review. Two interviewers always conducted the interviews. While in the peer-reviews of this study the peer review team consisted of six persons who shared the interview work, in the freight review the same two researchers always conducted the interviews. After each interview the two interviewers produced a shared interview protocol.

#### 3.4.2 External validity

External validity is the degree to which findings can be generalised. In this study external validity is achieved by using the replication logic in multiple-case studies. Studying the phenomenon in multiple cases with differing contextual conditions makes the results more robust (Yin, 2003), and helps to avoid observer bias (Voss et al.,

2002). In total 12, cities were included in the case study. Four of these cities with different contextual conditions, which cover many types of cities, have been studied in detail. The results are therefore believed to represent a qualitative view of the urban freight transport problems and possibilities for local authorities in many European cities.

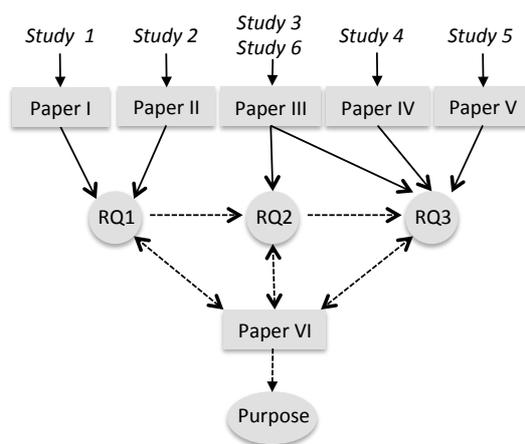
### 3.4.3 Reliability

Reliability demonstrates that the operations of a study, such as the data collection procedures, can be repeated with the same results. In this study, the consistency and the reproducibility of the self-assessment reports is increased by a template that has been used by all cities. Furthermore, the semi-structured interviews followed a predefined interview guide and the results were collected in a case study database.

For each city, the notes from the interviews were summarised and analysed through meaning condensation, meaning categorisation and thematic analysis, followed by an analysis of similarities and differences between the case cities. The categories of the framework developed in the literature studies structure the analysis to explain similarities and differences and to identify emerging relationships.

## 4 Summary of the appended papers

*This chapter briefly presents the six appended papers on which this thesis is based. Figure 18 shows an overview of how the studies and papers contributed to the research questions and purpose of the thesis. Generally, each paper presents the results of one study. Paper III includes the results of two studies, hence contributing to two research questions. Paper VI holistically discusses the purpose of this thesis based on the results of all research questions.*



*Figure 18: Contribution and relation of research studies and appended papers to research questions and purpose*

### 4.1 Paper I: The impact of urban freight transport – A definition of sustainability from an actor’s perspective

The purpose of this paper is twofold: first, to develop the characteristics of sustainable urban freight transport (SUFT), which are commonly-held by all public and private stakeholders, and second, to propose a method for the development of a set of applicable indicators to monitor and evaluate urban freight transport.

A definition of sustainable urban freight transport (SUFT) has been put forth and an indicator matrix for the distribution of goods has been developed. Urban freight transport has various actors and stakeholders with differing interests concerning the economy, society and the environment. A sustainable urban freight transport system contributes to the sustainable development of urban areas and balances the different interests of all stakeholders. Hence, it fulfils all the following objectives:

- to ensure the accessibility offered by the transport system to all categories of freight transport
- to reduce air pollution, greenhouse gas emissions, waste and noise to levels without negative impacts on the health of the citizens or on nature

- to improve the resource- and energy efficiency and cost-effectiveness of the transportation of goods, taking into account the external costs, and
- to contribute to the enhancement of the attractiveness and quality of the urban environment, by avoiding accidents, minimising the use of land and not compromising the mobility of citizens.

Table 6: Indicator matrix for distribution of consumer goods

Involved actors	Transport intensity	Traffic intensity	Technical capability
City administrations/ Planning agencies	<i>Land use planning</i> urban sprawl	<i>Infrastructure</i> length of traffic network (road, rail, etc.) number of loading/unloading zones location of loading/unloading zones  <i>Regulations</i> congestion charge access restrictions	<i>Regulations</i> low emission zone
Consignor/ Consignee	<i>Shipment</i> number of shipments average size of shipment frequency of delivery		
Freight forwarder		<i>Mode choice</i> modal split  <i>Terminal location (excl. City consolidation terminals)</i> average distance between terminal and city centre	
Transport operator		<i>Route planning</i> average distribution distance number of distribution trips total distribution km	<i>Vehicle choice</i> vehicle size load factor engine technology fuel type
Impacts		<i>Accessibility</i> <i>Accidents</i> <i>Land use</i>	<i>Air pollution</i> <i>Greenhouse gas emissions</i> <i>Energy use</i> <i>Waste</i> <i>Noise</i>

The matrix shows that the impacts originate in the traffic level and level of the technical capability (Table 6). It also shows the consignor/consignee determines the

demand, the freight forwarder determines the traffic, and the transport operator determines the technical capability. Yet, the actors are not limited to their “own” column to contribute to a sustainable development. By setting requirements they can influence the actions of the actors downstream on the causal chain. City authorities and planning agencies can influence all segments and thus play an important role in designing sustainable development strategies. However, the matrix also shows that they cannot solve the problem alone. An integrated approach that involves all actors is then necessary.

#### **4.2 Paper II: Challenges to urban freight transport planning – A review in the Baltic Sea Region**

Freight transport in urban areas is still not well understood and there is no methodology aimed at the analysis and planning of such areas. To achieve urban sustainability, new models for the management of urban freight movements are needed, in which local authorities play a pro-active role. The aim of this paper is to contribute to lay the groundwork for designing strategies to overcome the challenges involved in sustainable urban freight transport.

The first part of the paper develops a framework (Figure 19) for sustainable urban freight transport, which structures the analysis in the second part. The framework is based on four basic elements: *facilities* where the economic activities take place, *goods* that demand transport to and from these facilities, *vehicles* that provide transport services, and *infrastructure*. These elements interact in pairs in four different subsystems, which are: accessibility, land use, transport and traffic. Together, the interaction of the subsystems determines the performance of the transport system. Industrial production facilities and shopping centres are usually located within city borders as well as transport infrastructure facilities like seaports or rail terminals. As a consequence, logistics facilities like warehouses and terminals are established in the vicinity of commercial centres and transport infrastructure. Since economic activities require the movement of goods, a prerequisite for a functioning urban economy is the *accessibility* of goods to these facilities. Providing this accessibility is the main function of urban freight transport and it is the accessibility needs which drive the whole urban freight transport system. The *land use* subsystem comprises the supply of transport infrastructure as well as the location of the facilities in relation to the traffic infrastructure, which are both crucial factors for accessibility. In the *traffic* system, actual physical movements of vehicles are realised in physical networks in which traffic units absorb infrastructure capacity. In the *transport* system, the demand for goods movements to and from the facilities is matched by transport services, which require vehicles to be moved. The model also includes: 1) the external factors which influence the urban freight transport system; 2) the SUTP concept and its planning principles as

integrating elements; and 3) the unsustainable impacts as an outcome of external factors and urban freight transport planning and measures.

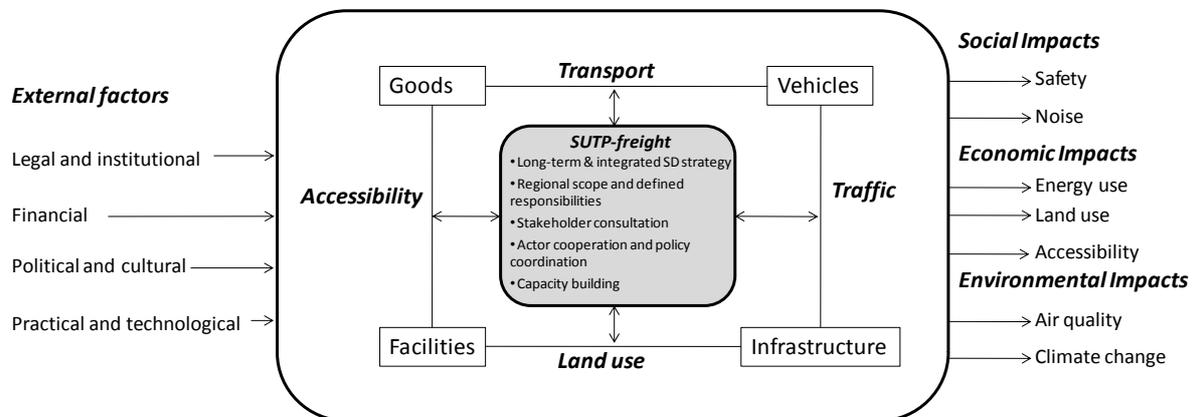


Figure 19: The relationship between factors affecting SUTP-freight (developed from Sjöstedt, 1996)

Most of the negative impacts of freight transport take place at the traffic system level where vehicles consume energy and produce emissions. However, the impacts are the result of the interaction of goods, facilities, infrastructure and vehicles in the four subsystems: accessibility, land use, transport, and traffic. Integration is at the core of any promising approach aiming to reduce the impacts and achieve a sustainable urban freight transport system. The subsystems accessibility, land use, transport and traffic need to be targeted in an integrated way, and local as well as external factors need to be acknowledged.

The second part of the paper presents the empirical findings of the current shortcomings of urban freight transport. The results show that freight transport services are increasingly important for the regional competitiveness while freight traffic is a growing threat for urban sustainability. In turn, the urban context is a barrier for efficient freight operations. However, local authorities as well as transport and logistics operators neglect these problems arising from freight in urban areas. Freight transport appears in the periphery of urban transport planners' daily work, but they do neither know how nor have the capacity to tackle the issue. To overcome the barriers, first of all an overall awareness is needed to understand that urban freight transport is an area to work with for both local authorities and transport operators. A deeper integration of freight transport and urban sustainability strategies can be beneficial for the efficiency of freight transport networks as well as for local sustainability and regional competitiveness.

### 4.3 Paper III: Sustainable freight transport principles and their implications for intermodal road-rail transport

The purpose of this paper is to assess whether IRRT has the potential to contribute to the sustainable development of the freight transport sector. In order to achieve this, this article developed a holistic definition of sustainable freight transport based on sustainable development principles. This definition reduces the complexity and allows guidance for decision makers on how to attain sustainable freight transport and is therefore an important contribution to the existing knowledge on sustainable freight transport. The sustainability assessment of IRRT on the basis of these principles suggests that rail has the potential to offer sustainable freight transport services, but in the present centralised terminal network with limited geographical coverage IRRT is only competitive for large transport flows over long distances. The economic benefits can therefore only be realised for a minor share of the transport market.

Concerning the environmental consequences of a modal shift, the case study calculating the external costs of the long-distance transports in a freight forwarders less-than-truckload network (Gothenburg-Stockholm in Sweden and Hannover-Bremen in Germany) indicates that the environmental benefits of IRRT in terms of climate impact are achieved at the expense of higher traffic impacts (Figure 20). Furthermore, the scenario with an alternative terminal location (“IRRT-Sc. Terminal location”) indicates that the scale of this trade-off depends on the relative location of terminal and shipper and receiver in the spatial structure of the city. This shows the importance of rail-adapted urban land-use planning for the improvement potential of IRRT. LHV slightly reduce the impacts in all categories (“IRRT-Sc Longer vehicles”).

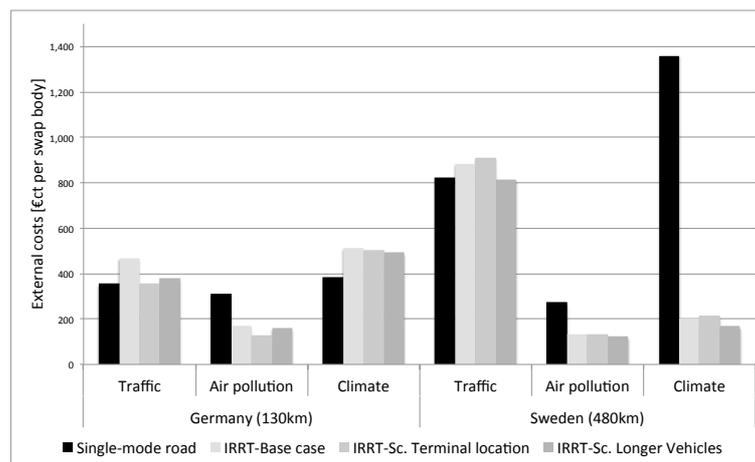


Figure 20: The environmental consequences of a modal shift by impact category

#### 4.4 Paper IV: The effect of transshipment costs on the performance of intermodal line-trains

The purpose of this paper is to analyse the effect of transshipment costs on the network performance of intermodal line-trains. It analyses how the transshipment cost that a transport system operator has to pay influences the modal split along a corridor in Sweden starting in Gothenburg and ending in Stockholm with four intermediate stops along the route (Figure 21).

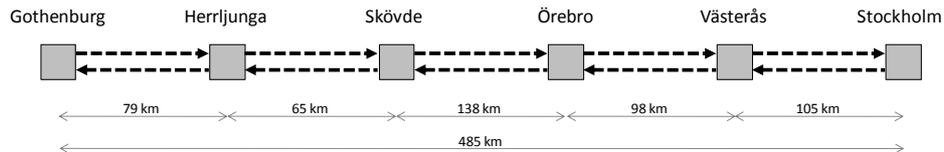


Figure 21: Corridor between Gothenburg and Stockholm with four intermediate stops

The results indicate that the transshipment costs have a significant impact on the potential of intermodal line-trains (Figure 22). The higher the transshipment costs the lower the share of the intermodal alternative. If transshipment costs are lower than 150 SEK, IRRT is competitive for all transports except for the transport flow between the nodes with the shortest distance. Between 200 and 250 SEK, the modal share of IRRT significantly decreases. Hence, a cost range of 200 to 250 SEK is identified as a critical transshipment cost. For this cost range, the line-train is not competitive on the links between two terminals with very short distances, but IRRT is partly competitive for transports between adjacent terminals where the distance is somewhat longer. The different PPH distances do not have any major effect on the competitive situation since the differences are relatively small. For transshipment costs of 300 SEK, IRRT is not competitive on any relation.

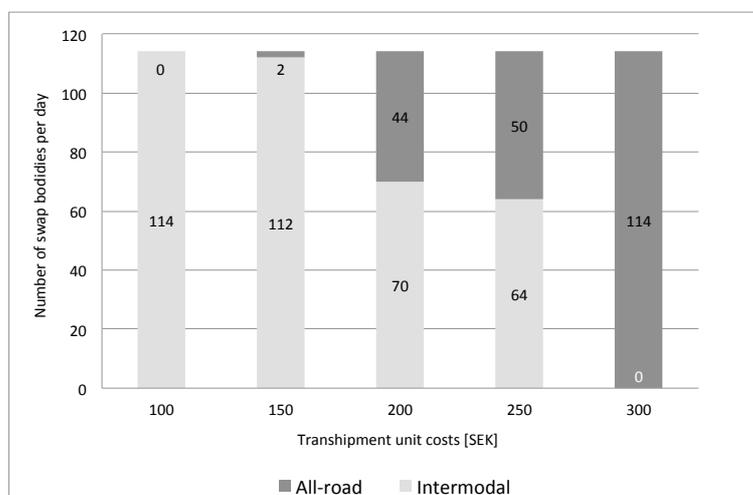


Figure 22: Modal split for different transshipment costs

With growing transshipment costs, less freight is transported intermodally, and consequently the cargo capacity utilisation (CCU) of the intermodal line-train decreases. Figure 23 depicts the CCU of the line-train for transshipment costs of 200 SEK. The CCU is still close to the maximum capacity on large shares of the corridors, while near the start and end-terminals of the corridor, the train has a large number of empty spaces. The results confirm that *in theory* intermodal line-trains can provide competitive services on short and medium transport distances in case transshipment costs are kept low. Naturally, lower transshipment costs reduce the production costs, but of even greater importance is the ability to achieve a higher CCU, which decreases the door-to-door transport costs per load-unit. Low transshipment costs therefore open up business opportunities for operators and cost savings potential for shippers in a market segment, which is dominated by road transport.

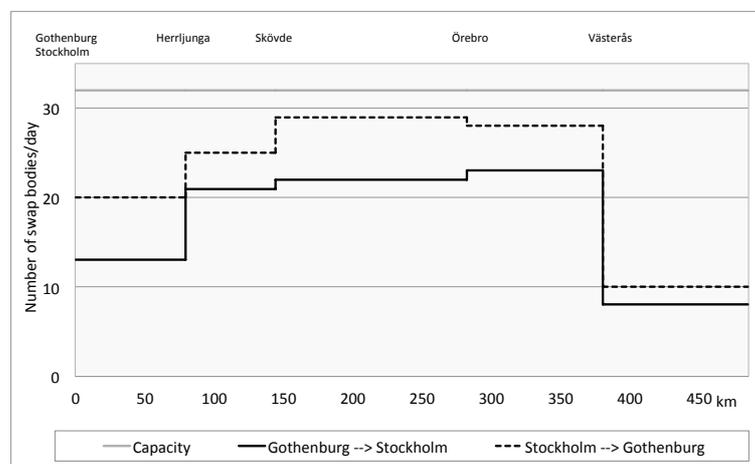


Figure 23: Train capacity utilisation for transshipment unit costs of 200 SEK

#### 4.5 Paper V: Assessing the Effects of Longer Vehicles – The Case of Pre- and Post-haulage in Intermodal Transport Chains

Since it is difficult and challenging to achieve improvements to the organisation of PPH, this paper looks into the possibility of changed regulations related to vehicle setups for PPH. The current regulations in Sweden allow for vehicle combinations with a maximum length of 25.25 m and a maximum weight of 60 tons. These vehicle dimensions permit the carrying capacity of 3 TEU. To increase the efficiency of haulage operations, exemptions from the current regulations could allow longer and heavier vehicles allowing the carriage of 2\*40 foot or even 2 semi-trailers. The two versions of the intermodal transport chain are illustrated in Figure 24.

The results indicate that there is substantial potential associated with flexibility in the regulatory framework of intermodal transport. Assuming that PPH accounts for about

20% of the total cost of the intermodal chain, the total cost for IRRT services of a typical large-scale shipper is decreased by about 5-10%, in case LHV are allowed for PPH carrying one additional load-unit. This change might not seem that impressive, but it can be enough to achieve a substantial modal shift as the break-even point is reduced. The sensitivity analysis shows that the higher the PPH's share of the total chain costs, the higher the cost savings potential of changed regulations. Furthermore, a significant increase in relative PPH costs only slightly reduces the savings from the extended regulations. A prerequisite for utilising the potential savings is that the shippers must have a high share of shipments, which are bigger than 3 TEU.

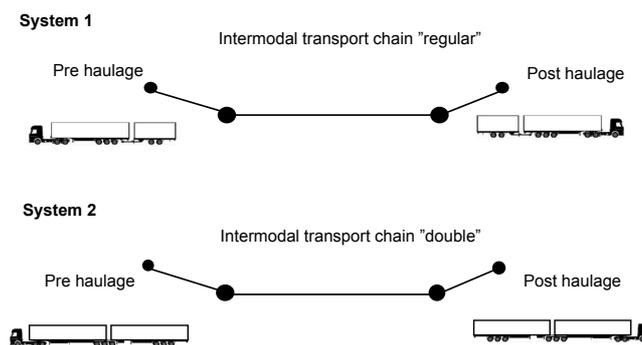


Figure 24: Two system designs of an intermodal transport chain regarding pre- and post-haulage regulations

#### 4.6 Paper VI: The urban context of intermodal transport – Threat or opportunity for modal shift

This paper examines the relationship between urban transport and IRRT with the goal to identify possible actions on a local level to improve both the competitiveness of rail freight and urban sustainability. To achieve this, the paper further developed the framework presented in Paper 2 and applies it to IRRT. The challenge for intermodal transport arising from the urban context is that an increasing demand on both transport quality and volumes faces efficiency problems and capacity constraints. The usual approach to cope with these challenges is to extend the capacity of nodes and links. In the long-term this approach is neither feasible in urban areas nor is it a promising solution for a significant modal shift since the limited geographical coverage excludes a substantial share of the transport market. Hence, in the current IRRT production paradigm based on a limited number of high-volume corridors and large-scale terminals, the urban context is a threat for the desired further growth of rail freight.

Coping with these challenges requires an approach that integrates all relevant stakeholders including the actors providing transport services, actors demanding these

transport services and public authorities that determine the operational conditions of urban freight and the urban spatial structure. In this way, the urban context offers opportunities which can increase the market potential of rail freight, increase the efficiency of PPH and reduce the urban impacts of intermodal transport. Integrated land-use and transport planning can be significant in this respect. Local authorities can play a key role in enabling the cooperation among shippers and transport operators by involving all stakeholders in the strategic land-use and transport planning processes. This stakeholder participation can also function as a forum for raising awareness among stakeholders and citizens that they have a common interest in sustainable urban freight transport, which is a pre-requisite for successful cooperation.

#### 4.7 Summary

The research results of each paper in relation to the research questions are summarised in Table 7. Table 8 describes the authors' role and responsibility for the papers.

*Table 7: The papers' contribution to the research questions*

<i>Paper</i>	<i>RQ1 – Urban freight transport</i>	<i>RQ2 – Sustainable freight transport</i>	<i>RQ3 – Sustainability performance of IRRT</i>
Paper I: The impact of urban freight transport...	<ul style="list-style-type: none"> <li>• Definition of objectives of sustainable urban freight transport</li> <li>• Interactions between urban stakeholders</li> </ul>		
Paper II: Challenges to urban freight transport planning...	<ul style="list-style-type: none"> <li>• Initial framework for sustainable urban freight transport</li> <li>• Shortcomings in contemporary urban freight transport planning</li> </ul>		
Paper III: Sustainable freight transport principles...		<ul style="list-style-type: none"> <li>• Definition of sustainable freight transport based on principles</li> </ul>	<ul style="list-style-type: none"> <li>• Effect of urban structure on IRRT environmental performance</li> </ul>
Paper IV: The effect of transshipment costs...			<ul style="list-style-type: none"> <li>• Effect of transshipment costs on accessibility of IRRT</li> </ul>
Paper V: Assessing the Effects of Longer Vehicles...			<ul style="list-style-type: none"> <li>• Effect of vehicle regulations on IRRT production costs</li> </ul>
Paper VI: Urban context of intermodal transport...	<ul style="list-style-type: none"> <li>• Final framework for sustainable urban freight transport</li> </ul>		

*Table 8: The author's responsibility for the papers*

<i>Paper</i>	<i>Main author</i>	<i>Secondary author</i>	<i>Responsibilities</i>
Paper I: The impact of urban freight transport...	Behrends and Lindholm	Woxenius	The paper design, data collection and analysis were done in cooperation by the main authors. The secondary author contributed with a conceptual model for the analysis and in the writing process
Paper II: Challenges to urban freight transport planning...	Lindholm and Behrends		The whole work was done in cooperation by the two main authors
Paper III: Sustainable freight transport principles...	Behrends		Sole author
Paper IV: The effect of transshipment costs...	Behrends	Flodén	The paper design was done in cooperation of the main and secondary author. The data collection was the responsibility of the secondary author. The main author took the largest part in the analysis and writing.
Paper V: Assessing the Effects of Longer Vehicles...	Bergqvist	Behrends	The paper design was done in cooperation of the main and secondary author. The first author took the largest part of the work, the secondary author contributed to analysis and the writing process.
Paper VI: Urban context of intermodal transport...	Behrends		Sole author

## 5 Analysis

This chapter analyses the results of this thesis with regard to the three research questions (Figure 25). Research question 1 deals with the characteristics of sustainable urban freight transport to which IRRT needs to adapt (section 5.1). Section 5.2 answers research question 2 and presents a definition of sustainable freight transport based on principles. This definition is used to answer research question 3, which assesses the effect of different measures on the sustainability performance of IRRT (section 5.3).

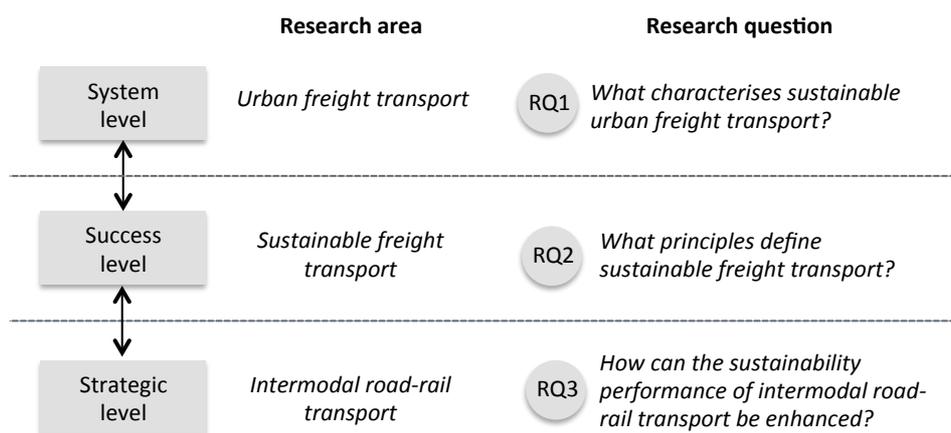


Figure 25: Connection of research areas and research questions

### 5.1 Characteristics of sustainable urban freight transport

The first research questions aim to develop an understanding of the mechanisms constituting urban freight transport:

*RQ1: What characterises sustainable urban freight transport?*

An understanding of the urban context within which IRRT takes place is a prerequisite for a sustainable modal shift, i.e. a growth of rail freight without negative consequences for urban areas. Hence, the answer to this research question is a framework showing the constructs of the functioning of urban freight transport.

Urban transport is the result of a triadic relationship of the logistics system, the transportation system and the physical environment. These systems are the fundamental elements of the developed framework for urban freight transport, which is depicted in Figure 26. The different elements of the framework and their interactions constitute the characteristics of sustainable urban freight transport. The characteristics are explained in the remainder of this section.

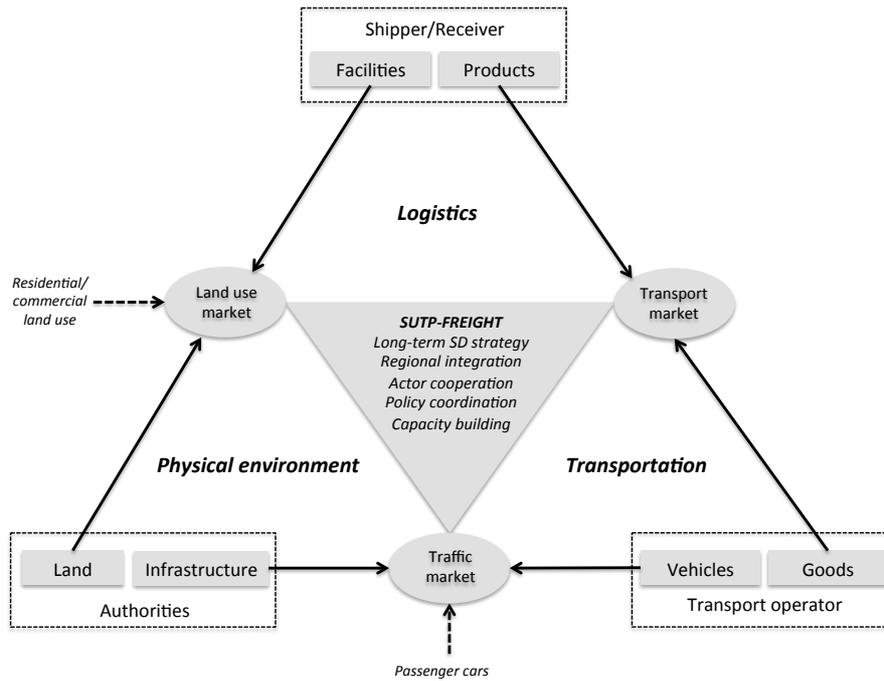


Figure 26: Framework for sustainable urban freight transport

The *logistics system* deals with the movement of the products on links of a supply chain between the facilities where economic activities are executed. The *transportation system* deals with the movement of goods and the means achieving this movement by vehicles. The transportation system is therefore the combination of transport and traffic. The *physical environment* provides the physical setting for the economic and transport activities. It is comprised of the natural and built environment, including the land for economic facilities and transport infrastructure, e.g., roads and rail tracks on which vehicle movements take place.

Urban freight transport has various actors and stakeholders, which are responsible for the design of the logistics system, transportation system and the physical environment. The key actors are shippers and receivers, transport providers and local and regional authorities. *Shippers and receivers* act in the logistics system and deal with the movement of products on links of a supply chain between facilities where economic activities are executed. A prerequisite for a functioning economy is the accessibility of goods to the facilities where the economic activities take place. Providing this accessibility is the main function of urban freight transport and it is the accessibility needs which drive the whole urban freight transport system. The shippers' decisions on supply chain and logistics strategies determine the transport demand in terms of shipment size, frequency, lead-time, delivery precision and flexibility. The main interest for the shippers/receivers is a high accessibility to their suppliers and customers.

The *transport providers* design the transportation system and provide the transport services demanded by the shippers and receivers. The major issue for the operators is how to achieve high resource utilisation in providing the demanded transport quality. The required quality of service determines the amount of transport resources needed to produce the service.

*Local and regional authorities* have mandates on the design of the physical environment, which influence urban freight transport. They use land-use and traffic planning to improve the built and social environment of urban regions. They provide land for economic facilities and transport infrastructure, e.g., roads and rail tracks on which vehicle movements take place. The goals of local authorities are twofold: First, for economic reasons they aim for a high accessibility of their city-region to the over-regional transport network and an effective intra-urban transport network to increase their attractiveness for economic activity, which is a generator for regional welfare. Second, for social and environmental reasons they aim to reduce the impacts of freight traffic as the requirements of people living and working in cities, for a high quality of life increase.

The logistics, transportation and the physical environment interact with one another. These interactions can be described by markets, in which the demand and supply in each element are met. In the *transport market* the material flow demand is matched by the supply of transport services, resulting in actual goods flows, which generate demand for vehicle flows. This demand is matched by the supply of transport infrastructure capacity on the *traffic market*. In the *land-use market* the shippers' demand for locations for their economic facilities is matched with the supply of land by local authorities, which aim for economic settlements in their city-region.

Since urban areas are complex systems with various stakeholders representing different interests, logistics and freight actors face competition with other stakeholders in these markets. In urban areas freight and passenger vehicles share the same infrastructure and compete with one another for limited infrastructure capacity. In the land-use market, logistics facilities and transport infrastructure compete with other land-use forms, e.g., businesses and housing, for limited physical space.

As a result, the actors in urban freight transport have strong interdependencies and local authorities find themselves in constant tension between local sustainable development and freight transport network performance. On the one hand, shippers and receivers require efficient links to the gateways of inter-regional transport networks, while on the other hand increasing freight traffic is a threat for local sustainable development. To achieve a sustainable urban freight transport system, which meets the economic, social and environmental goals of all stakeholders, integrated planning that connects all stakeholders and markets is needed. City authorities and planning agencies can influence all other stakeholders and thus play an important role in designing sustainable development strategies. However, they cannot

solve the problem alone. To achieve a sustainable urban freight transport system that meets the economic, social and environmental goals of all stakeholders, integrated planning that connects all stakeholders and markets is needed. Central planning principles are:

- The existence of an *urban freight transport strategy*, which is embedded in an overall sustainable development strategy with a long-term perspective;
- *Regional scope*, defining the whole “urban agglomeration” as the transport planning area; and defining responsibilities to ensure full commitment;
- *Stakeholder consultation*, to secure transparency and to improve the quality, acceptance, effectiveness and legitimacy of the actions;
- *Actor cooperation and policy coordination*, to ensure integration between all transport modes and policy sectors, as well as geographical coverage of the entire functional urban agglomeration; and
- *Capacity building*, in order to ensure that personnel have the necessary skills.

## 5.2 Principles for sustainable freight transport

The aim of the second research question is to develop a definition of sustainable freight transport that can ensure relevant aspects of sustainability are not missed and can handle the trade-offs within urban freight and IRRT:

*RQ2: What principles define sustainable freight transport?*

Many definitions of sustainable freight transport are based on the downstream effects of transport, hence describing the symptoms of unsustainability. The usefulness of these definitions for solving sustainability problems is limited. The principles for sustainable freight transport developed in this thesis are based on the upstream sources of the unsustainable impacts, i.e., the underlying system errors leading to unsustainability. These upstream sources for the downstream impacts are, first, *low transport quality and high transport costs* which impair the supply of goods and a competitive economy and, secondly, an *unequal provision of transport*, which impairs the economic development of peripheral regions. Third, the freight sector’s *dependency on oil* results in GHG emissions contributing to climate change and energy supply risks. Fourth, *emissions of air pollutants* cause health impacts, material and ecosystem damages and crop losses. Finally, freight transport generates *traffic*, causing congestion, noise and accidents requiring *infrastructure* with land-use and separation effects. The principles for sustainable freight transport are formulated by negating these upstream-sources of unsustainability. Accordingly, a sustainable freight transport system:

1. does not impair an undisruptive goods supply at a reasonable cost
2. does not impair the accessibility of peripheral regions versus central regions

3. does not use fossil resources or renewable resources over their rates of generation
4. does not emit air pollutants
5. does not generate traffic and infrastructure in sensitive urban areas and ecosystems.

Principles 3, 4 and 5 are concrete propositions and hence allow monitoring as well as guiding actions. Admittedly, principles 1 and 2, on the other hand, are rather vague and controversial. Principle 1 requires an undisruptive goods supply at a reasonable cost, which is a rather imprecise statement, since it does not quantify what reasonable costs are. It is often argued that freight transport in general is too cheap, inducing “unnecessary transport” and that transport generally must be much more expensive if a sustainable freight transport is to be achieved. From this perspective, limiting transport costs should not be part of the definition of a sustainable freight transport system. In the same direction of reason principle 2 can be questioned as well, since many infrastructure projects with negative impacts on the environment are often justified to be necessary for economic development.

However, assessing the sustainability of a transport system must not be done on the basis of individual principles. A sustainable transport system must comply with all five principles; failing to comply with any of the principles would make the whole system unsuitable. Taking into account this condition implies that a transport system, which is very cheap, hence complying with principle 1, is unsustainable if the induced transport demand results in an extensive use of fossil fuels, hence violating principle 2. At the same time, a transport system, which is completely emission-free, hence complying with principles 2 and 3, but impairs the supply of goods since it is too expensive, hence violating principle 1, is also unsustainable.

Certainly, based on this definition any transport system is unsustainable, since supplying goods to society will always generate freight traffic in urban areas, requiring energy, etc. Due to the complex interdependencies of logistics and transport and the interrelations with land-use, the energy system, etc. reasonable transport costs, a “safe” amount of energy, emissions, traffic, land-use, etc. are extremely difficult to forecast. The definition based on principles aims for guiding decision making by focusing attention upstream on all the cause–effect chains leading to unsustainable freight transport.

Taken together, these principles cover all relevant aspects of sustainability. They are not limited to the unsustainable impacts of transport (principles 3, 4 and 5), but also include the important contribution of transport to meeting the needs of the present generation (principle 1) and a fair distribution of life quality (principle 2). Hence, a definition based on these principles is sufficient for sustainability. The principles are also distinct, i.e., mutually exclusive, as they require different mitigation measures. Impacts from traffic and infrastructure require a reduction of traffic volumes while

impacts caused by emissions to air can be mitigated on the vehicle level by clean technology and impacts from the use of fossil energy resources require a change in the energy supply. Furthermore, the principles are general, that is, they are easy to understand so that people from various societal sectors and scientific disciplines should be able to use them; hence, the principles can facilitate guiding actions and formulating strategies for sustainable freight transport where stakeholders from different sectors need to cooperate.

### **5.3 Sustainability performance of intermodal road-rail transport**

Research question 3 addresses the possibilities to improve the sustainability performance of IRRT:

*RQ3: How can the sustainability performance of intermodal road-rail transport be enhanced?*

The effect of three factors on the sustainability based on the principles as defined in Research Question 2 was addressed in this thesis. First, the effect of LHV on the cost performance (principle 1); second, the effect of transshipment costs on accessibility (principle 2); and third, the effect of the urban spatial structure on fossil resource use (principle 3), emission of air pollution (principle 4) and traffic (principle 5) are analysed.

#### **5.3.1 The effect of longer and heavier vehicles in pre- and post haulage on the cost performance of intermodal road-rail transport**

Principle 1 addresses the mobility of goods and the costs of the movements. One important factor determining the cost efficiency of IRRT is PPH operations which - despite their relatively short distance compared to rail haul - are responsible for a significant share of the total cost of the intermodal chain. If IRRT is to compete with all-road transport on short and medium distance transports, PPH is an even more critical activity for competitiveness. Since it is difficult and challenging to achieve improvements to the organization of PPH, changes to the regulatory framework on weights and dimensions of trucks can potentially increase the efficiency of haulage operations.

Paper V shows that a flexible regulatory framework for PPH can help achieve a modal shift as the break-even distance for competitive IRRT is reduced. The potential savings, however, highly depend on the cost share of PPH in relation to the total chain cost. The higher the PPH's share of the total chain costs, the higher the cost saving potential of changed regulations. This makes a more flexible regulation especially interesting for the short distance transports. Furthermore, a significant increase in relative haulage costs only slightly reduces the savings from the extended regulations. This implies that there is room for additional costs to implement the extended

regulations, such as special regulations on speed, route, etc., without losing too much of its cost-advantage compared to the “regular” haulage setup. One factor limiting the potential of the relaxed framework is that shippers require a high share of shipments bigger than 3 TEU, otherwise the improvement potentials cannot be utilised. As a consequence, extended regulations alone may not lead to a modal shift in the market segment of smaller shipments.

### 5.3.2 The effect of transshipment costs on the accessibility of intermodal road-rail transport

Principle 2 addresses the accessibility of peripheral locations. Economic activities require locations with good accessibility to raw materials and customers. Due to an unequally developed infrastructure some regions are more competitive than others for settlements of economic activities. This accessibility gap between central and peripheral regions hinders a fair distribution of economic activities, which is the foundation for regional welfare. The current IRRT system contributes to this accessibility gap. Intermodal rail services are only provided when conditions are favourable, resulting in a highly concentrated rail network with a relatively small number of nodes focusing on a limited number of high-volume corridors over distances of 500 km and more. Many regions lack access to rail transport and have truck as the only transport option, especially on short and medium distance transports.

If IRRT is to contribute to a fair distribution of welfare, it must increase the accessibility in peripheral regions. A decentralised network of small-scale terminals can increase the geographical coverage of rail freight and enables IRRT to compete on shorter distances, hence integrating short and medium distance transport in the IRRT system. However, a decentralised network requires innovative transshipment technologies facilitating fast and efficient transshipments, which is likely to increase the terminal costs. The major implementation barrier therefore is the uncertainty regarding costs of these innovative terminals and their network benefits.

The modelling of a line-train service in Sweden presented in Paper IV confirms previous research (e.g., Rutten, 1995; Trip and Bontekoning, 2002) that *in theory* IRRT can be competitive for transport flows over distances of approximately 100 km in case the transshipment costs are kept low. Naturally, lower transshipment costs decrease the production cost, and hence increases the competitiveness of IRRT over road. Of even greater importance, however, is the ability to achieve higher load factors on the train, as this decreases the transport costs per load unit since a larger number of load units carry the fixed cost of the train. Higher transshipments costs, on the other hand, decrease the CCU of the intermodal train, resulting in a higher transport cost per load unit. This “vicious cycle” causes IRRT to rapidly lose competitiveness when the transshipment costs increase. The cost level of transshipments therefore plays a crucial role for the accessibility of IRRT.

Another crucial factor is the terminal time of the train. In the present rail production paradigm, the transshipment operations in the terminals are adapted to the conventional rail operations with transshipments concentrated around morning arrivals and evening departures. Time is not a crucial factor, since the trains usually remain in the terminal during the day. Increasing the number of intermediate terminals requires fast transshipments, enabling short terminal times in order to keep total travel time acceptable.

### 5.3.3 The effect of the urban spatial structure on the environmental performance of intermodal road-rail transport

The impacts on the environment are multifaceted and therefore are divided into three principles. Principle 3 addresses the use of fossil resources causing global resource depletion and climate change. Principle 4 covers the emission of air pollutants and Principle 5 the impacts caused by traffic and infrastructure. The analysis of the environmental consequences of a modal shift from road to IRRT confirms that a modal shift can result in reduced climate and air pollution impacts as a result of the general environmental benefits of rail in terms of energy use and air pollution. However, these benefits are achieved at the expense of higher traffic impacts in more sensitive areas. The activities that are most critical to the local environmental impacts, are PPH and rail traffic in urban areas. Urban PPH traffic is especially important because PPH often takes place during rush hour and hence contributes to urban congestion while the single-mode road transport often takes place during night with no congestion effects. The externalities of PPH compared to single-mode road freight are therefore significantly higher.

Taking an urban perspective on the environmental improvement potential of IRRT therefore reveals that a modal shift is mainly beneficial for intercity-regions, while the externalities in the origin and destination cities can increase significantly. It is the transport facilities' locations that suffer from their extensive land use and traffic externalities. The scale of this geographical trade-off is largely determined by the relative location of the intermodal terminal and shipper and receiver in the spatial structure. This structure can vary significantly. In the current spatial structure of many cities where the intermodal terminals are often located close to the city centre while the shippers and receivers of intermodal freight are often located at the urban fringe areas with good connections to the surrounding highway-ring, the PPH and rail distance travelled in urban areas is much higher than the urban driving distance of the single-mode road transport. An alternative terminal location closer to the shippers and receivers can significantly decrease the distance of PPH trips in urban areas and hence decrease its traffic impacts. These savings can be substantial and can even result in better results than for all-road, if the terminal and the shipper are located in close proximity to each other, resulting in short PPH distances. Consequently, making a

modal shift also beneficial for the origin and destination cities requires spatial structures, which limit the distance of the PPH trips in urban areas.

## 6 Conclusions

*Three research questions have been posed and answers to the research questions were given in the previous chapter. In this chapter, the findings are combined and discussed in relation to the purpose of this thesis. Furthermore, the theoretical contributions and implications for practitioners and politicians are outlined. The chapter concludes with an outlook on future research possibilities.*

### 6.1 The interactions between urban freight and intermodal road-rail transport

The proposition followed throughout this thesis is that modal shift and urban sustainability strategies do not take into account their interactions in the urban transport system. They are still separated policy fields and research areas with the consequence that IRRT is not adapted to the urban environment, and that the urban transport system is not adapted to rail freight. As a result, IRRT in its current form limits both the environmental benefits and the modal shift potential of rail freight. The overall purpose of this thesis was to explore the main interactions between urban freight transport and intermodal road-rail transport and their implications for urban sustainability and modal shift strategies. This thesis has identified the characteristics for sustainable urban freight transport as well as elements of a strategy towards sustainable IRRT. Now, this section aims to conceptualise the urban context of IRRT. The interactions between urban freight and IRRT and the implications for both urban sustainability and modal shift strategies are presented in the four elements of the developed framework for sustainable urban freight transport (Figure 27):

- Logistics system: Local cooperation of shippers/receivers
- Transportation system: Local cooperation of transport providers
- Physical environment: Rail adapted land-use and traffic planning
- Urban rail freight strategy: Integrating intermodal road-rail transport into urban freight transport planning

#### 6.1.1 Local cooperation of shippers/receivers

Generally, there is a trend of increasing requirements shippers have on costs and quality of transport services. Decreasing product life cycles and increasing product values leads to logistics approaches like JIT with less storage and more frequent deliveries. As a consequence, patterns of sourcing and distribution as well as scheduling of freight flows have resulted in smaller and more frequent shipments. Timing, frequency and punctuality are now of significant relevance in freight movements since they are part of supply chain management strategies (Rodrigue, 2008). The increasing customer demands on transport quality have limited the scope of rail to maintain market shares and many industries have increased their reliance on road transport (Woodburn, 2003).

Kohn and Brodin (2008) show that shipment consolidation in a centralised distribution system of a supply chain can enable a change in transport mode. The necessary volumes for a modal shift can also be achieved by the local consolidation of freight flows belonging to different shippers and receivers as a city is usually provisioned by hundreds of supply chains of many economic sectors (Dablanc, 2011). However, the major problem is that a modal shift is often not possible for shorter trips, which usually have road freight as the only alternative (Rich et al., 2011). Intermodal rail freight lines link larger cities with one another, but do not link to the small towns situated along the line. Smaller economic regions where transport demand is comparably small and dispersed are usually not served by rail. To overcome the barrier of a limited geographical coverage of rail services, IRRT needs to go beyond the conventional approach with a focus on large flows over long distances. As a complement to this centralised network, a decentralised network with intermediate nodes for consolidation is required. The line-train simulation study confirms the importance of low transshipment costs, which are difficult to realise in peripheral regions where rail-suitable freight flows are small. Hence, the economic operation of a terminal in peripheral regions requires the consolidation of a great share of the shippers' goods flows in the region.

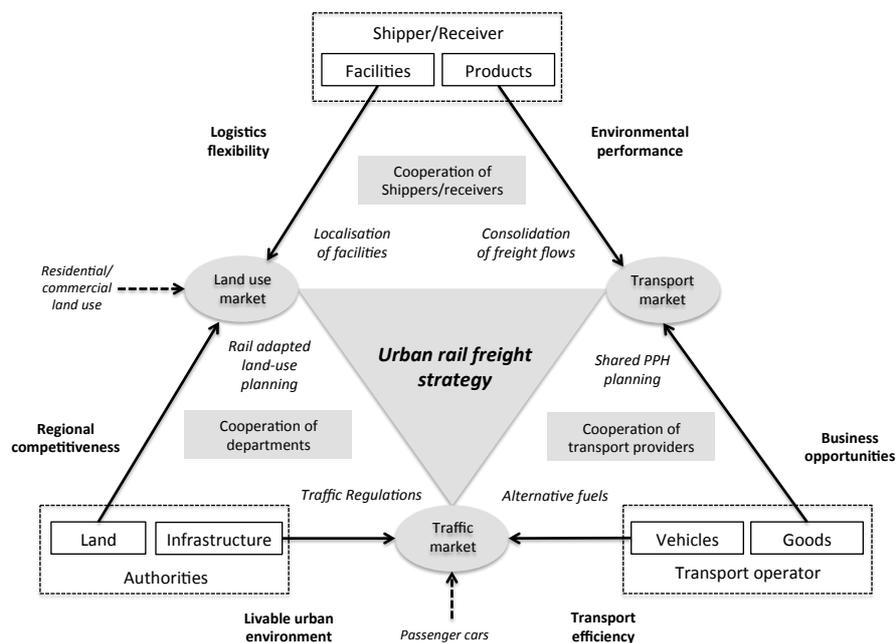


Figure 27: The opportunities of the urban context for intermodal road-rail transport

Flodén (2007) shows that the rail freight volumes can drastically be increased by more relaxed pick-up and delivery times. This reduced service quality eventually worsens the shippers' position in the market, where short lead times and delivery precision are required to remain competitive. However, Dekker et al. (2009) point out that the

longer transit time in intermodal transport can be offset by positioning shipments in advance to intermodal terminals, which can lower transport costs and response times. Furthermore, since minimising the environmental impact from transport has gained importance (Lammgård, 2007), relaxing time windows and consolidation of freight flows can also entail long-term benefits for the shippers. Since there are doubts that technology can solve the environmental problems of road freight (DHL, 2009), shippers and receivers require a viable alternative to road freight in the future. Furthermore, as argued by Christopher and Holweg (2011), volatility in the business environment has increased and is very likely to continue in the foreseeable future. Hence, supply chain structures that can cope with this turbulence are required. Access to rail services implies an additional transport option for shippers and thus a reduced dependency of road transport, which could protect supply chains from fuel price volatility, unreliable deliveries due to congestion problems and higher costs due to a shortage of drivers.

Hence, local cooperation with other shippers with the goal to increase the preconditions for rail freight can help shippers increase their logistics flexibility. In turn, intermodal operators can benefit from new business opportunities, and new rail freight services to the region that hosts the terminal can be beneficial for the economic situation of the region as a whole.

#### 6.1.2 Local cooperation of transport providers

The second challenge for the sustainability of IRRT arising from the urban impact is inefficient PPH operations. Due to the rail production principle based on night jumps, PPH trips usually take place in the morning and afternoon during rush hour, and thus can be affected by urban congestion, which reduces the efficiency of PPH. Furthermore, the centralised intermodal production system leads to concentrated PPH flows and waiting times at the large-scale intermodal terminals (Konings, 1996). At the same time, PPH operations contribute to the negative impacts on local sustainability. A cooperation of PPH operators and other transport companies operating in the urban area entails benefits for both PPH operators aiming for low operation costs and local authorities aiming for local sustainability. Often, PPH trips to and from shippers are not coordinated, resulting in many additional empty trips. A coordinated transport planning of hauliers serving the same terminal could increase the PPH efficiency. Morlok et al. (1995) show that spatial market division or sharing transport equipment can avoid empty driving, and Walker (1992) states that an increase in transport volumes allows a more efficient use of drivers. Both effects can result in lower PPH costs and a decreased transport distance at which intermodal transport can compete with road freight.

Moreover, PPH by diesel trucks is the major source of air pollution in the intermodal transport chain and is a contributor to urban air pollution. It also accounts for a

significant share of the transport chain's energy demand. Renewable energy resources have the potential to make PPH trips emission-free (Holden and Høyer, 2005); however, vehicles with alternative propulsion systems and alternative fuels are usually not compatible with the conventional infrastructure and require special maintenance and refuelling points, which initially are geographically limited (Blinge, 1998). Hence, innovative vehicles and fuels are usually not suitable for longer transport distances and therefore are difficult to introduce in freight transport. Since these systems usually have a limited driving range, they are currently preferably tested or employed in passenger transport. Most passenger cars and public buses operate in a limited region and therefore do not require a widespread coverage of refuelling and maintenance infrastructure. The same accounts for the lorries serving an intermodal terminal. Since the distances driven from that terminal are comparatively short, PPH is well suited for employment of vehicles with alternative propulsion systems and alternative fuels, which has the potential to reduce the harmful emissions in urban areas (Macharis et al., 2007). As the case studies showed, most cities actively support the introduction of alternative fuels in the public bus fleet and for the passenger cars of their citizens. Therefore, in many cities there is already a refuelling and maintenance infrastructure for alternative fuels and propulsion systems, which also could be used by PPH operators. Sharing the refuelling and maintenance infrastructure with passenger transport facilitates lower costs through economies of scale and a reduction of risk for PPH operators since they do not need to make own investments.

### 6.1.3 Rail-adapted land-use and traffic planning

As local authorities are responsible for land use and transport planning, they plan the location of sites for rail and roads as well as terminals and economic facilities, and by this determine the amount of PPH traffic, which is an important factor for the modal shift potential of IRRT. Thus, there is a clear role for the land-use planning system and other local authority functions in facilitating the growth of rail freight (Haywood, 1999). Dablanc (2011) argues that urban land-use planning is one of the key strategies for reducing road freight traffic in urban areas. Local authorities are expected to have due regard for rail freight facilities when formulating their development plans (Woodburn, 2008). Sites that offer potential for intermodal terminals where road-rail interchange could take place should be protected for future development and new freight developments should be served by rail wherever possible. However, modern intermodal terminals are among the most space-extensive consumers of land in metropolitan areas (Slack, 1999), which has consequences on the possibilities for capacity extension. Land availability in urban areas is limited and potential land use conflicts are high (Wagner, 2010). In order to minimise these conflicts, local land use planning needs to geographically separate terminals and shippers as well as roads and rail tracks from other land use forms, e.g., residential areas and areas for shopping and culture, in order to reduce the local impacts that IRRT generates on other urban

stakeholders. Generally, by a geographical separation of logistics and residential land-use a mixing of freight and passenger traffic can be avoided, making access to the terminals easier and standstill periods in urban traffic shorter. Moreover, noise, congestion and air pollution impacts are minimised since they avoid sensitive urban areas.

Regarding traffic planning, a relaxation of the rules in force on weights and dimensions of heavy vehicles can lead to a reduction in vehicle operating costs. However, increasing the maximum length and weight of trucks is a very controversial issue (McKinnon, 2008), since that negatively affect safety and has implications for road transport infrastructure in urban areas. Since PPH operations are embedded in urban transport, allowing the use of LHV for PPH is even more problematic than for intercity road freight. In order to minimise the potential negative implications, restrictions on the local road network regarding speed, route and time of day, etc. can be applied by local authorities. This underlines the importance of integrated transport and land-use planning which separates freight and passenger transport. It also emphasises the importance of an approach that integrates modal shift and urban freight transport strategies. Allowing LHV for PPH without taking into account the urban consequences could lead to strong resistance on the local level.

#### 6.1.4 Urban rail freight strategy: Integrating urban freight and intermodal road-rail transport

The previous sections described three main potentials of integrating urban freight transport and IRRT: First, a cooperation of shippers and receivers to increase the amount of goods suitable for rail freight; second, a cooperation of PPH operators to reduce empty running and emission intensity; and third, a cooperation of urban planning departments to reduce the amount of urban freight traffic and its related negative impacts. The potential benefits are: first, for shippers and receivers more transport options increasing their logistics flexibility and environmental performance; second, for transport providers, more efficient transport operations and more business opportunities; and third, for local authorities, a liveable urban environment and higher regional competitiveness. Hence, integrating urban transport and IRRT can help resolve the critical issues of IRRT, improving its sustainability potential.

Due to the strong interdependency of the actors in the urban setting, there is a need for coordinated actions in all three segments. An urban rail freight strategy, which coordinates actions of shippers and receivers, and transport providers and authorities, can strengthen the effect of individual actions. For example, the coordination of freight flows by the shippers and receivers to increase the rail suitable freight volumes can be supported by targeted land-use and traffic planning. Transport time is often very critical for the transport of high value goods, and since the time window between pick-up at the shipper and terminal closing time is often too short for a delivery to the

terminal before terminal closing time, these freight flows have road as the only alternative. Shorter PPH distances and improved traffic conditions can reduce the time needed for PPH and by that IRRT can be suitable for more freight flows. Shorter distances also reduce PPH costs and hence the costs of the total intermodal chain, making IRRT a more attractive transport option. In turn, higher rail freight volumes increase a city's attractiveness for rail operators, which can benefit from additional business opportunities. New rail freight services to the region that hosts the terminal are beneficial for the companies located in the region as well as for the economic situation of the region as a whole.

Hence, an urban rail freight strategy needs to integrate all actors, i.e., shippers/receivers, transport providers and local planning agencies. Local authorities have to play a key role in facilitating the required cooperation since they can influence all other stakeholders. Hence, it is important that the planning personnel have logistics and rail freight competence. The urban rail freight strategy needs to be embedded in the city's overall sustainable development strategy to ensure the long-term effectiveness of the strategy. Furthermore, it requires a cooperation and adaptation of the strategy with neighbouring municipalities to avoid competition between terminals.

Cities should not see this as an additional burden but as an opportunity to strengthen their local sustainable development. Dablan (2011) shows that the urban context involves complicated trade-offs between competing environmental, social and economic issues; however, there are possibilities for progress at low costs with great benefit. As argued by Bergqvist (2007), regional logistics collaboration can contribute to the competitiveness of firms and the attractiveness of regions. Together with the fact that an IRRT system which is adapted to the local environment, e.g., a decentralised intermodal network with small-scale nodes for consolidation, imposes much fewer traffic impacts on their locality may further encourage cities to include rail freight in their strategic urban transport plans.

## **6.2 Contributions and implications**

This section outlines the theoretical contributions as well as the implications of this thesis for practitioners and politicians.

### **6.2.1 Theoretical contributions**

The first contribution is the framework for sustainable urban freight transport, which integrates logistics, freight transport and land-use decisions (see chapter 5.1 and Figure 26). The relationship between logistics and freight transport decisions has been the subject of various works (Drewes Nielsen et al., 2003; McKinnon, 2003; Aronsson and Brodin, 2006) and all developed frameworks highlight that decisions at different levels both create opportunities and set limitations for decisions made on another level. In this way, they underline that making freight transport sustainable requires

close cooperation by actors vertically along the supply chain. Decisions made by local and regional authorities, however, are seldom included in these frameworks, although horizontal cooperation between private and public actors in regional logistics networks can contribute to competitiveness of firms and attractiveness of regions (Bergqvist, 2007). The framework developed in this thesis links urban freight transport with the main concepts of logistics and transportation and in this way indicates the need of public-private cooperation on a local and regional level. It shows the relations between the urban stakeholders and how the integration contributes to the quality of the urban environment, transport network effectiveness and logistics performance. The developed framework provides an understanding of the constitutional principles underpinning the functioning of the urban freight transport system. The framework can be a reference point for future theory development and empirical research on urban freight transport.

The second contribution of this thesis is the developed definition of sustainable freight transport based on principles (see chapter 5.2). Despite the generally accepted idea of sustainable development, there is neither a common definition of sustainable transport nor a set of sustainable transport indicators (Steg and Gifford, 2005). Existing definitions either fail to come to grips with larger systems and side effects of decisions, or the definitions are too complex so they fail in guiding on how to attain sustainability (Goldman and Gorham, 2006). A definition for dealing with the more abstract concept of sustainability therefore should be based on non-overlapping principles which any sustainable society would need (Holmberg and Robért, 2000). Ny et al. (2006) argue that in order to be useful these principles need to cover all relevant aspects of sustainability, need to be easy to understand and capable of guiding actions, and should be able to facilitate monitoring. The definition based on principles developed in this thesis provides these qualities by not only analysing the freight transport sector's impact on environment and society, but also the freight sector's significance for the ability of today's generation to meet their needs. Hence, the principles cover four criteria defined by Gudmundsson and Höjer (1996), who argue that sustainability and development represent complementary dimensions. This definition therefore can contribute to a more holistic understanding of sustainable development, which still is mostly one-dimensional, focussing only on the environmental dimension (Seuring and Müller, 2008). It is by violation of these principles that freight transport causes the unsustainable impacts. The sustainability assessment of IRRT on the basis of these principles showed that the definition is applicable to a freight transport context and that it can be useful for analysing a wide variety of transport systems.

The third contribution of this thesis concerns the regulatory framework for road freight (see chapter 5.3.1). McKinnon (2008) highlights the difficulties in assessing the net benefits of increasing the maximum length and weight of road vehicles and extrapolating the experience from national trials to the EU as a whole. This thesis

shows that a relaxation of the rules in force on weights and dimensions of PPH vehicles can result in a substantial reduction of IRRT chain costs, if PPH stands for a relatively high share of door-to-door transport distance and if shipment sizes are large. Hence, this thesis contributes to clarifying the net benefits of LHV as it identifies under which circumstances a reduction can be achieved.

The fourth contribution is the analysis of the effect of transshipment costs on the network performance of intermodal line-trains (see chapter 5.3.2). The uncertainty among actors about the costs and benefits of alternative transshipment technologies is a significant implementation barrier (Trip and Kreutzberger, 2002). In particular, little attention has been paid to the cost and performance of line-train networks and line terminals (Bontekoning, 2002). This thesis contributes to filling this knowledge gap as it found that transshipment costs play a crucial role in the ability to achieve high load factors in the rail haul, which is key for the competitiveness of line-trains.

The fifth contribution concerns the environmental improvement potential of IRRT (see chapter 5.3.3). Kreutzberger et al. (2006b) argue that IRRT can have substantially better environmental performance than all-road transport, but that these benefits of IRRT are achieved at the expense of higher local impacts. This thesis shows that the scale of this trade-off depends on the relative location of terminal and shipper and receiver in the spatial structure of the city. Consequently, this thesis shows that research on the sustainability potential of IRRT needs to include the integration of the intermodal terminal and the shippers' and receivers' location in the urban spatial structure.

Finally, the application of the framework for sustainable urban freight transport on IRRT identifies the potential of integrating urban freight and modal shift strategies (see chapter 6.1). Both fields have received considerable interest, but urban freight and IRRT are still handled as separate research fields and their interactions are seldom considered on a strategic level. Urban freight, on the one hand, focuses on urban deliveries and city logistics (Taniguchi and Van Der Heijden, 2000; Anderson et al., 2005; Dablanc, 2007), while IRRT research, on the other hand, focuses on the core of intermodal transport including rail haulage and transshipments (Woxenius and Bärthel, 2008) regarding PPH as something beyond the system boundaries. The identified interactions and potentials of an integrated approach therefore contribute to the integration of these streams of research. In this way, this research can provide the context for studies going beyond the usual scope of either urban freight or IRRT focusing on the interaction between these two areas.

### 6.2.2 Implications for practitioners and policy makers

This thesis shows that IRRT has the potential to offer sustainable freight transport services. However, the urban environment characterised by scarcity of access, e.g., congested roads, space constraints and limitations of infrastructure restricts the

efficiency and quality of PPH operations. Congestion at terminals and access roads reduces transport speed and decreases the reliability to meet the scheduled times of arrivals. Urban freight transport therefore is an impedance factor for IRRT efficiency. The current limitations and barriers of the urban context should be seen as challenges to overcome rather than as impediments to progress. One possibility to improve the efficiency and the environmental performance of IRRT is to extend the regulatory framework for PPH. This thesis shows that regulatory exemptions related exclusively to intermodal haulage activities deserve to be taken seriously and viewed with open minds by policymakers. Since inefficient PPH operations significantly affect the competitiveness of IRRT, an adapted regulatory framework for PPH operations can be an effective policy measure for a modal shift strategy. An additional policy measure supporting modal shift is the internalisation of external costs, which can decrease the transport distance at which IRRT can compete with all-road transport (Macharis et al., 2010). However, this thesis shows that in order to be effective, these policy measures require a careful integration with urban transport policies. In case of unfavourable geographical conditions of terminal and shipper and receiver in the urban setting, a modal shift can increase the amount of urban traffic. Since in the future an increase of marginal congestion costs (due to increasing congestion problems in cities) and a decrease of the marginal external costs for air pollution and climate change (due to advances in the field of vehicle technology and alternative fuels) can be expected (Macharis et al., 2010), an internalisation of external costs may not lead to the desired modal shift, especially for short and medium distance transports for which PPH stands for a significant share of the total externalities.

A policy approach to modal shift focussing on incremental improvements in the present IRRT systems, i.e., to adapting the regulatory framework and external cost internalisation, would not be sufficient if a significant modal shift is to be achieved. Even if the competitiveness of IRRT can be improved in a way that it would attract significantly higher shares of the transport market, IRRT would fall victim to its own success. As argued by Konings (1996) a significant modal shift entails the growth of PPH traffic around terminals, which threatens the accessibility of the terminal itself. Furthermore, the resulting congestion, emissions and noise would lead to significant congestion externalities reducing the environmental benefits of a modal shift. Moreover, due to the additional negative local impacts, planning for new or expanded terminal developments which are viewed positively at large faces negative responses at the local authority level (Woodburn, 2008). Hence, the current approach of IRRT based on large-scale terminals focusing on a few large flows and long distance corridors is neither feasible in urban areas, where freight transport is increasingly perceived as a disturbing factor for local sustainability, nor is it a promising strategy, since many regions lack access to long-distance relations and are dependent on road freight as the only available transport mode.

IRRT policy makers and practitioners therefore need to take into account the urban context of IRRT when designing strategies for modal shift. This thesis strongly proposes that policy makers and practitioners regard the urban context as a chance rather than as viewing it as a threat for modal shift. According to Hesse and Rodrigue (2004), constraints for the usual path of development can be a source of creativity and can induce innovation. Hence, the required adaptation to the urban environment does not necessarily result in additional friction but can be considered to be positive. The urban context also offers opportunities, which can increase the market potential of rail freight, increase the efficiency of PPH and reduce the urban impacts of intermodal transport. Cooperation among actors and integrated land-use and transport planning can be significant in this respect. Local authorities can play a key role in enabling cooperation among shippers and transport operators by involving all stakeholders in the strategic land-use and transport planning processes. This stakeholder participation can also function as a forum for raising awareness among stakeholders and citizens in that they have a common interest in sustainable urban freight transport, which is a pre-requisite for successful cooperation.

Policy planning therefore must consider the interactions of urban freight and IRRT instead of handling them as separate policy concerns. Local authorities, which are responsible for land-use and transport planning, have an important role to play if a sustainable modal shift is to be achieved. However, local authorities perceive the economic interests on the one hand and environmental and social interests on the other hand as trade-offs and there is no long-term strategy to balance these interests. Authorities often lack planning capacity and logistics competence and a holistic understanding of the implications of freight transport in urban areas is missing. Even in countries with strong local policy entities, policy leverage is weak regarding urban freight (Dablanc, 2011). The framework for sustainable urban freight transport planning can guide urban planners on how to overcome the existing shortcomings in urban transport planning and also illustrates the benefits that rail-adapted planning can have for local sustainability.

### **6.3 Further research**

The main contribution of this thesis is the framework for sustainable urban freight transport and sustainable freight transport principles. The framework provides a thorough understanding of the functioning of urban freight transport systems and the principles define the desired outcome of strategic urban freight transport planning. Together these findings provide local authorities with a framework for planning towards sustainability to better understand the nature of urban goods movements and their impacts. However, the large majority of cities have not found yet adequate solutions (Dablanc, 2007). Wagner (2010) shows that a careful integration of new logistics developments in the urban transport system is generally neglected, and

Dablanc (2009) states that most regional governments in Germany and France appear to be less involved in the actual promotion of rail freight activities than they were a few years ago. Hence, there is a need for guidelines to implement actions within this framework and tools to monitor the process.

Furthermore, this thesis found that the usage of LHV could increase the cost efficiency of IRRT. However, LHV are a very controversial issue, especially from an urban perspective, which often sees LHV as a safety risk. This makes it problematic to use LHV for PPH since the intermodal terminals are often embedded in an urban transport system where an increased accident risk could have severe consequences. Hence, there is need for further research on how LHV can be integrated in an urban transport system without hampering traffic safety in urban areas.

An additional finding of this thesis is that low transshipment costs are a prerequisite for increasing the spatial reach of IRRT. Due to the high fixed costs of terminal equipment, conventional transshipment technologies cannot achieve the required transshipment costs at small-scale terminals where transshipment volumes are low. Inventors have designed numerous innovative solutions for small-scale transshipment technologies but they share the feature of not being used commercially in a large scale (Bontekoning and Priemus, 2004). Implementing rail innovations is therefore not only a technological challenge but also requires a shift of the intermodal technological and organisational paradigm (Bärthel and Woxenius, 2004). Hence, thorough knowledge about the nature of technical and organisational innovation in IRRT systems is essential for a successful implementation of alternative intermodal services. Studying the barriers to the implementation of rail innovations therefore is an interesting field of future research.

Finally, the developed propositions on the urban context of IRRT need empirical research to confirm and develop the interactions between urban freight and IRRT. An interesting opportunity for future research is therefore to use the framework for an empirical study on urban rail freight strategies to test the framework and propositions on the barriers and potentials in the urban planning context.

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## **APPENDIX VII – Study 1**

- Interview guide BUSTRIP Peer Reviews
- Example of Peer Review Schedule



## Session 2

### Peer Review Responsibility Matrix

Partner City.....

Review team leader.....

Dates of review.....

Indicate who will have overall responsible for each theme

	Peer review themes	Peer review team				
		Manager	name	name	name	name
<b>Drivers</b>						
	Urbanisation					
	Economic					
	Transport					
<b>Impacts</b>						
	Noise					
	Air pollution					
	Health					
	Safety					
	Congestion					
	Social equity					
	Quality of urban life					
	others					
<b>SUTP Planning</b>						
	SUTP and Sustainable Development Strategy					
	Responsibility for SUTP					
	Citizen participation and stakeholder consultation					
	Policy coordination through actor cooperation					
	Gender equity and equality					
	Capacity building					
<b>SUTP Plan</b>						
	SUTP scope and definition					
	Analysis of baseline scenario					
	Definition of a vision, objective and targets					
	Implementing actions and allocating finance.					
your policies:	General principles					
your policies:	Reducing the need for transport					
your policies:	Transport management					
your policies:	Developing clean and fair transport systems					
	Detailed assignment of responsibilities and resources					
	Monitoring and evaluation arrangements					
	Plan adoption, approval and assessment					
<b>Pilot Actions</b>						

## Session 8 Example programme Peer review City of.....

	Monday 17 <sup>th</sup> November	Tuesday 18 <sup>th</sup> November			Wednesday 19 <sup>th</sup> November			Thursday 20 <sup>th</sup> November			Friday 21 <sup>st</sup> November
08.00		breakfast			breakfast			breakfast			
09.00		Introduction to the city Confirm agenda and agree any changes			Interview with City owned service companies (which ones to be agreed)	Interview with cycling pressure groups	Interview with Skane regional representative	Interview national politicians	Meeting with officers responsible for EMAS	free	Photo-call with politicians and press release.
10.00		Coach tour of the city I			free	free	Meeting with editor of local paper	free	free	Meeting with officers responsible for Local Investment Programme	Presentation
11.00					Interview with environment officers (air quality)	Interview with mobility planning officers	free	Interviews with representatives from green and environmental groups	Interviews with vice mayor for sustainable development	Interviews with representatives of the executive board	Discussions and the next steps Interviews with television and radio.
12.00		lunch	lunch	lunch	lunch	lunch	lunch	lunch	lunch	Lunch	
13.00		Interview with Education committee Interview with cultural and leisure and recreation committees	Interview with representatives of City District Councils		Interview with local doctors and health professionals	Interview with train operators	free	Interviews with logistics management in city centre		Interviews with officers responsible for economic development	Team depart
14.00		free	free	free	free	free	councils	Keep free	Keep free	Keep free	
15.00		Meeting with directors of bus company	Meeting with Director of traffic planning		Meeting with City owned energy company	Meeting with officers responsible for climate change programme	free	preparation	preparation	preparation	
16.00		Continue meeting	Continue meeting	Meeting with unemployed young people	Continue meeting	Continue meeting	Meeting with economic development policy officers	preparation	preparation	preparation	
17.00		free	free	free				preparation	preparation	preparation	
18.00	Working dinner and sharing hypothesis	Public meeting: an opportunity for citizens of the city to meet with the peer review team to explain their concerns about their city. This should be widely publicised and it is hoped that 100 people will attend			Meeting with teachers from schools in the city.	Meeting with students from the university		free			
19.00					Dinner			Dinner			
20.00		Close public meeting and private dinner									
21.00	End dinner										

## **APPENDIX VIII – Study 2**

- Interview guide BUSTRIP Freight Review



## Interview guide – Study 2

The interview guide for the freight review in Study 2 (see chapter 3.2.2) is presented here. The guide represents the overall structure with issues covered in the interview. The questions were adapted to the actor category and their scope of actions. For example, the questions about integrated planning are mainly targeted at authorities and the questions about transport are mainly for operators. However, all questions were asked to all actors, for example, the questions on integrated planning were also stated in the interviews with transport operators, asking if they are aware of these planning issues or how they perceive them, etc.

### Introduction

Presentation of BUSTRIP project and purpose of “freight review study”

Please tell about your company/authority and your activities relating to urban freight transport

### Integrated planning

*Freight and logistics planning capacity and competence*

How much of your work is related to freight transport?

*Long-term freight sustainable development strategy*

Does your city have a long-term sustainable development strategy?

How is transport in general included in the strategy?

Is freight transport included in city’s long-term sustainable development strategy? If yes, how?

*Policy coordination between departments*

Does your department work together with other departments?

With what department do you work together and on what issues?

*Regional scope*

Does your city work together with your neighbouring municipalities on transport issues?

Does this cooperation include freight related issues?

*Stakeholder consultation*

Do you work together with private and public stakeholders in freight transport and logistics related issues?

- Citizens
- Retailers
- Manufacturing

- Freight forwarders
- Transport operators
- Research institutes
- Etc.

How is the consultation/cooperation organised?

How do you perceive the usefulness of the cooperation?

### **Accessibility**

What are the main industries/economic activities in the city?

What is the role of freight transport and logistics for the city's economy?

What is the city's role in national/international transport network (port, airport, rail terminal, distribution centres, warehouses, etc.)?

### **Land use**

How is the urban spatial structure in relation to logistics and transport activities?

- Retail (Central business district and external shopping centres)
- Manufacturing
- Logistics (warehouses and DCs)
- Transport infrastructure

### **Transport**

#### *Modal split*

What is the modal split for your transport activities?

What is the modal split for the city as a whole?

Why is rail not used to a larger extent?

What rail services are available in the city?

#### *City logistics*

Are you aware of any city logistics schemes in the city?

What was the outcome of the scheme (successful/not successful)?

What were the success/failure factors?

### **Traffic**

#### *Freight flows*

Do you have data about freight flows in the city (in, out, through traffic, where in the city)?

### *Infrastructure and congestion*

Are there any congestion problems? On what routes?

- Road
- Rail
- Seaports
- Etc.

How is the situation with loading/unloading space in the CBD?

How does congestion/lack of loading space affect your business?

What future infrastructure investments are planned?

- Road
- Rail
- Etc.

### *Vehicles and fuels actions*

Are you aware of any restrictive measures?

- Weight restrictions
- Time restrictions
- Environmental vehicle class
- Etc.

Are you aware of any incentives for alternative fuels and vehicles?

- Alternative fuel infrastructure
- Clean vehicles
- Environmental zones
- Etc.

### **Impacts**

What are the transport impacts in the city? Are there problems with:

- Noise
- Air pollution
- Accidents

On what roads are the impacts most severe?

What is the share of freight traffic for these impacts?