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# Towards CO<sub>2</sub> efficient centralised distribution

# **Christofer Kohn**



2008

Department of Management and Engineering Linköpings universitet, SE-581 83 Linköping, Sweden © Christofer Kohn, 2008 (unless otherwise noted)

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One of the more common questions that you are faced with during the process of writing a doctoral dissertation is "When will you be finished?". At times, this has been an almost agonising question to answer, as the light at the end of the tunnel has felt so far away. The manuscript that you now hold in your hands is the artefact that symbolises that the process has come to an end. In the following paragraphs, I would like to extend my fullest gratitude to all the people, who in one way or another, have contributed to making this such a memorable and worthwhile process

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Sigtuna, October 2008

Christofer Kohn

to go through.

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### **ABSTRACT**

This dissertation treats a topic that has received increasing attention as of late, namely that of the environment and in particular increasing levels of CO<sub>2</sub> emissions caused by transport. The aim of the dissertation is to explain how a shipper, through various measures, can reduce transport-related CO<sub>2</sub> emissions when centralising a distribution system and how this affects the provision of cost efficient customer service. Earlier research has stated that this type of structural change is considered unfavourable from an environmental viewpoint as it increases the amount of transport work generated by the system and thereby transport-related CO<sub>2</sub> emissions. The argument that is made in this dissertation, however, is that transport work is only one aspect to consider when evaluating how transport-related CO<sub>2</sub> emissions are affected by this type of structural change. The reason for this being that a change in structure and management of the same can enable a shipper to make other changes within the distribution system that can prove beneficial from an environmental perspective as they decrease the amount of CO<sub>2</sub> emissions per tonne kilometre.

Theoretically, the dissertation has its foundation in two different areas in logistics research. The first area concerns logistics and the environment, where the frame of reference examines measures discussed in previous research with reference to how a shipper can reduce CO<sub>2</sub> emissions related to transport. The second area treated in the frame of reference concerns how costs and service are affected by the structural change of centralising a distribution system and how this relates to the measures discussed in the first part of the framework.

From a methodological viewpoint, the dissertation is based on case studies. These are presented in four appended manuscripts (a licentiate thesis and three papers), where the results of these studies are used as empirical input for the synthesising analysis that is led in the dissertation.

A key deliverable from the research presented in this dissertation is the classification presented below (see Table 1), which differentiates between measures that increase transport-related  $CO_2$  emissions and measures that decrease transport-related  $CO_2$  emissions when a distribution system is centralised. By presenting this classification, the dissertation extends previous research on the environmental impact of various logistics strategies, where centralised distribution is an example of such a strategy.

Table 1: Classification of measures that increase and decrease transport-related CO<sub>2</sub> emissions when a distribution system is centralised

Measures that increase	Measures that decrease
transport-related CO <sub>2</sub> emissions	transport-related CO <sub>2</sub> emissions
- Reducing the number of warehouses	- Employing a slower mode of transport
- Employing a faster mode of transport	for regular deliveries
for regular deliveries	- Employing intermodal rail-truck
	transport for the consolidated flow
	- Improving the fill-rate for laden trips in
	the consolidated flow (unimodal truck
	transport)
	- Reducing the number of emergency
	deliveries
	- Imposing stricter environmental
	demands on transport providers

With regards to this classification, it is concluded that a shipper that seeks to centralise its distribution system in a more CO<sub>2</sub> efficient manner will aim to identify a structural configuration that minimises the increase in transport work. This is imperative as there is a close link between transport work and CO<sub>2</sub> emissions. Hence, a CO<sub>2</sub> efficient centralised distribution system will include more central warehouses than that advocated by earlier research on centralised distribution. This in turn implies that a shipper may not reach the full potential in economies of scale as advocated in earlier research. However, such a configuration will simultaneously lead to less transport work, whereby a shipper will be able to offset the increase in transport work by employing measures that decrease the amount of transport-related CO<sub>2</sub> emissions per amount of transport work (see Table 1). The results also indicate that in addition to reducing transportrelated CO<sub>2</sub> emissions, some of these measures come with a cost incentive. By employing such measures, a shipper can come to compensate for the potential loss in economies of scale caused by employing a structural configuration that seeks to minimise the increase in transport work rather than to maximise economies of scale. By this means, the dissertation contributes to research on centralised distribution by considering how a reduction in transport-related CO<sub>2</sub> emissions is interrelated with the provision of cost efficient customer service.

## SAMMANFATTNING

Denna avhandling berör ett område som har fått ökad uppmärksamhet på senare tid, nämligen det av vår miljö och transportrelaterade CO2-emissioner. Avhandlingen syftar att förklara hur ett varuägande företag kan minska transportrelaterade CO2-emissioner vid en centralisering av sitt distributionssystem samt hur detta inverkar på företagets tillhandahållande av kostnadseffektiv kundservice. Tidigare forskning har menat att denna typ av strukturell förändring är negativ för miljön då den leder till en ökning av mängden transportarbete i systemet och därmed även en ökning av transportrelaterade CO2-emissioner. Denna avhandling argumenterar istället att transportarbete enbart är en viktig aspekt att ta i beaktande vid en utvärdering av hur denna typ av strukturell förändring påverkar ett varuägande företags transportrelaterade CO2-emissioner. Logiken bakom detta är att en strukturförändring i sig kan ge ett företag nya möjligheter att genomföra andra och nya förändringar inom distributionssystemet, vilka kan visa sig fördelaktiga ur ett miljöperspektiv då de minskar mängden CO2-emissioner per tonkilometer.

Teoretiskt sett tar denna avhandling sin utgångspunkt i två olika områden i tidigare logistikforskning. The första området rör miljölogistikforskning, där den teoretiska referensramen redogör för olika åtgärder ett varuägande företag kan vidta för att minska transportrelaterade CO<sub>2</sub>-emissioner. Det andra området i referensramen avhandlar hur en centralisering av ett distributionssystem påverkar kostnader och service i systemet samt hur detta anknyter till de åtgärder som diskuterades i den första delen av referensramen.

Metodologiskt sett är avhandlingen baserad på fallstudier som presenteras i fyra bifogade manuskript (en licentiatavhandling samt tre artiklar), där resultaten från dessa studier används som empirisk grund för den övergripande analysen som förs i avhandlingens kappa.

Ett viktigt resultat från forskningen som presenteras i denna avhandling är den klassificering som presenteras nedan (se Tabell 1). Denna klassificering differentierar mellan åtgärder som ökar respektive minskar transportrelaterade CO<sub>2</sub>-emissioner när ett distributionssystem centraliseras. Genom att presentera denna klassifikation så bidrar denna avhandling till tidigare forskning kring miljömässiga konsekvenser av olika logistikstrategier, där centralisering av distributionssystem är ett exempel på en sådan strategi.

Tabell 1: Klassificering av åtgärder som ökar respektive minskar transportrelaterade CO<sub>2</sub>-emissioner när ett distributionssystem centraliseras

Åtgärder som ökar transport-	Åtgärder som minskar transport-
relaterade CO <sub>2</sub> -emissioner	relaterade CO <sub>2</sub> -emissioner
- Minskning av antalet lager	- Användning av långsammare
- Användning av snabbare	transportmedel för vanliga transporter
transportmedel för vanliga	- Användning av intermodala transporter
transporter	(jänväg-lastbil) för det konsoliderade
	flödet
	- Förbättring av fyllnadsgraden för
	transporter i det konsoliderade flödet
	(vägtransporter)
	- Minskning av brandkårsutryckningar
	- Ökning av miljökrav på
	transportleverantörer

Med avseende på denna klassificering så dras slutsatsen att en varuägare som önskar centralisera sitt distributionssystem på ett mer CO<sub>2</sub>-effektivt sätt måste försöka identifiera en strukturell konfiguration som minimerar ökningen i transportarbete. Detta är av stor betydelse då det finns ett starkt samband mellan transportarbete och CO2-emissioner. Med andra ord kommer ett distributionssystem som är centraliserat på ett CO<sub>2</sub>-effektivt sätt att innehålla fler centrallager än vad som har förespråkats i tidigare forskning kring centralisering. Detta innebär i sin tur att en varuägare kanske inte uppnår den fulla besparingspotentialen som brukar förespråkas. Å andra sidan kommer en sådan konfiguration samtidigt att leda till en mindre ökning i transportarbete, varigenom en varuägare ges en större möjlighet att kompensera denna ökning genom att vidta åtgärder som minskar transportrelaterade CO<sub>2</sub>-emissioner per mängd transportarbete (se Tabell 1). Utöver detta indikerar resultaten även att en del av dessa åtgärder kan föra med sig kostnadsbesparingar utöver att reducera transportrelaterade CO2-emissioner. Genom att vidta sådana åtgärder kan en varuägare därmed kompensera för det potentiella bortfallet i skalfördelar som är effekten av att använda sig av en strukturell konfiguration som ämnar minimera ökningen i transportarbete snarare än att maximera stordriftsfördelar. Genom att analysera hur transportrelaterade CO2-emissioner är kopplade till kostnadseffektiv kundservice så bidrar denna avhandling även till forskning kring centraliserade distributionssystem.

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# 1 Introduction

The theme of this dissertation is that of logistics and the environment, a topic that is receiving increasing attention. Environmental issues have traditionally been a concern for policy-makers, but considering the current environmental debate, these issues are likely to develop into a strategic matter for companies. This dissertation aims to contribute to the rather limited research on logistics and the environment by addressing how a shipper, through various measures, can reduce transport-related CO<sub>2</sub> emissions when centralising a distribution system and how this affects the provision of cost efficient customer service

### 1.1 Background

A new issue of importance has emerged that companies can no longer hide from, namely that of environmental sustainability. Even though the 1990s was labelled the "Earth decade" (Armstrong and Kotler, 2000) and "The decade of the environment" (Kirkpatrick, 1990), it is only of late that this issue has received increased attention. According to reports such as "Climate Change 2007: Mitigation of Climate Change" (IPCC, 2007) and the Stern report on the economics of changes in our climate (Stern, 2006) there is a need to take immediate action with regards to the deterioration of our environment, specifically with regards to CO<sub>2</sub> emissions. At times, it is argued that this is the duty of public policy-makers, but if we are to find a remedy for the problems we are facing, these issues simultaneously need to be addressed by the business community (Hart, 1997; SOU, 2001; Fromlet, 2002; Östlund et al, 2003; Sperling, 2006).

Environmental sustainability has many aspects, but currently the most alarming threat is that of increasing levels of green house gas emissions and the impact this has on our climate. CO<sub>2</sub> is considered the most important type of green house gas and during the time period of 1970-2004, CO<sub>2</sub> emissions grew by approximately 80% and in 2004, CO<sub>2</sub> represented 77% of total green house gas emissions (IPCC, 2007). Even though many environmental improvements have been made within many sectors in society, e.g. industry, agriculture, and waste management, there are other areas where emissions are increasing at an alarming pace. Transport is one of these areas. Within the European Union, freight transport volumes have grown by 43% since 1992 whereas GDP has only increased by 30% during the same time period, and the larger increase in transport volumes compared to GDP is damaging from an environmental perspective (EEA, 2007). Most freight transport today is performed as road freight and this type of transport constitutes close to 80% of all goods transport in the EU-15 countries (EEA, 2007). What we are experiencing is the downside of a reduction in trade barriers and a corresponding increase in trade, with goods being transported over greater distances and more frequently than ever before (Swahn, 2006; Åkerman and Höjer, 2006; EEA, 2007).

From a shipper's point of view, transport can be regarded a direct consequence of how a shipper<sup>1</sup> designs and manages its logistics system<sup>2</sup>. Transport is also advocated to be one of the largest, if not the largest, contributor of CO<sub>2</sub> emissions in a shipper's logistics system (Wu and Dunn, 1995; Blinge and Lumsden, 1996; McKinnon, 2003; Aronsson and Huge Brodin, 2006; Browne et al,

<sup>&</sup>lt;sup>1</sup> In this dissertation, a shipper is equal to a goods owner. This is also discussed further in section 1.4.2. Also note that the words "shipper" and "company" are at times used interchangeably throughout the dissertation.

<sup>&</sup>lt;sup>2</sup> In accordance with CSCMP's definition of logistics management (ČSCMP, 2007), a logistics system can be defined as a system which facilitates "the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements". This definition also includes the planning, implementation, and control of the flows that are present in a logistics system.

2006). Currently, shippers' logistics systems are designed to find a balance between costs and service, as logistics performance, in generic terms, concerns fulfilling customer service objectives in a cost effective manner (La Londe, 1994; Abrahamsson and Aronsson, 1999; Mentzer et al, 2004; CSCMP, 2007). However, there is a lack of empirically based research into how various logistics strategies affect the environment at large and transport-related CO<sub>2</sub> emissions in particular (Abukhader and Jönson, 2004a/b; Aronsson and Huge Brodin, 2006; Browne et al, 2006). Therefore, the aim of this dissertation is to make a contribution to this body of knowledge.

### 1.2 Identifying a research problem

For a long time, it was advocated that environmentally sound solutions are at odds with the financial aspects of conducting business, i.e. that there exists a basic trade-off between the two (Daly, 1998; Reitan, 1998). Today, we know that this assumption does not always hold true and that efforts should be put into finding a balance between profitable operations and sensible ecological decisions (Holliday et al, 2002). An example of a shipper that is trying to achieve this is the US wholesale company Wal-Mart, which aims at becoming a leader in environmental sustainability. In the quest to achieve this, the company has stated that its aim is to be supplied entirely by renewable energy, create zero waste, and sell products that sustain our resources and our environment (Wal-Mart, 2006). These changes are also expected to lead to efficiency improvements, for instance a use of 30% less energy in stores, which will result in reductions in CO<sub>2</sub> emissions as well as cost savings (Gunther, 2006). In fact, many green initiatives are considered to have a positive financial impact and Willard (2005) argues that such initiatives may lead to a bottom line increase of approximately 40%.

From a logistics point of view, the situation is somewhat similar. There are numerous examples of changes made in logistics systems that are beneficial from a financial perspective as well as from an environmental perspective. Examples of such measures include using in-vehicle communications systems such as GPS/GIS in order to avoid traffic congestion, training drivers in ECO-driving, and improving the coordination and planning of shipments between facilities in order to improve the fill-rate of vehicles. All of these examples are actions that have led to an enhancement in the performance of the logistics system, as measured in terms of costs and/or service, at the same time as they have led to a reduction of transport-related CO<sub>2</sub> emissions.

The examples of logistics measures or changes above have a common denominator, which is that they all relate to tactical or operational changes within a logistics system. Today, there is a consensus among researchers that such changes can lead to simultaneous improvements in cost, service, and environmental performance in the logistics system. However, when the scope is broadened to also include changes in a logistics system that can be classified as strategic (cf.

Ballou, 1978; McKinnon and Woodburn, 1996; Abrahamsson and Brege, 1997; Stank and Goldsby, 2000; McKinnon, 2003; Chopra and Meindl, 2004), a somewhat different picture emerges:

"Many "green logistics" measures have been introduced at the lowest level in this hierarchy, cutting externalities per vehicle-kilometre. Often the beneficial effects of these measures, however, have been offset or negated by higher-level decisions to centralize warehousing, source products from more distant suppliers and/or move to just-in-time (JIT) replenishment, which often increase total vehicle-kilometres. There is a need therefore for companies to take a more holistic view of the effects of their activities on freight transport and related externalities."

(McKinnon, 2003, pp 666-667)

The "higher level decisions" that McKinnon points to in the quote above, are recognised as being of a structural character within a logistics context (see e.g. McKinnon and Woodburn, 1996; Abrahamsson and Brege, 1997; McKinnon, 2003; Chopra and Meindl, 2004; Riopel et al, 2005). Even though structural decisions can refer to a number of issues, they generally concern the location and number of production facilities, warehouses, and terminals within a shipper's logistics system. In this manner, these decisions determine the physical structure of a logistics system in terms of its setup of nodes and links (Coyle et al, 2003) and consequently relates directly to the amount of transport a shipper's logistics system incurs.

Relating to the preceding discussion, this dissertation focuses on a specific type of structural change, namely that of shippers centralising their distribution systems. This type of change has been found to be one of the more important structural changes shippers have made over the last couple of decades with respect to how their logistics systems are designed and managed (Wu and Dunn, 1995; Rodrigue et al, 2001; Abrahamsson et al, 2003; McKinnon, 2003). Hesse and Rodrigue (2004) even go so far as to claim that centralised distribution has become a core concept in logistics today. A fundamental principle in how centralised distribution is applied today is that of measuring the distance between a warehouse in a shipper's distribution system and the customer in terms of lead-time rather than physical distance:

"The time-based distribution concept, with its theoretical basis in re-engineering theories, stresses the importance of lead time reduction, and plays down the importance of geographical distance. By measuring the distance to customers in terms of lead time instead of miles or kilometres, some companies have fundamentally redesigned their physical distribution structures within the European market. Physical distribution has been centralized at one or two warehouses in Europe with order shipped directly to customers in different countries"

(Abrahamsson et al, 1998, p 239)

It is argued that the development that has taken place has a negative impact on the environment, in particular with regards to transport-related CO2 emissions. The reason for this is that a shipper's goods are transported over greater distances in order to reach the customer in a centralised distribution system compared to the situation in a decentralised distribution system (Wu and Dunn, 1995, McKinnon, 2003; Croxton and Zinn, 2005). Relating this to the quote by McKinnon (2003) above, the claim is made that when a shipper centralises its distribution system, total tonne kilometres<sup>3</sup>, will in most cases increase to such an extent that any measures or changes made by the shipper to decrease the amount of CO2 emissions per tonne kilometre are outweighed. Thus, it is generally argued that this type of structural change in a shipper's logistics system is considered detrimental from an environmental perspective. This analysis is based upon the conception that transport work, measured in terms of tonne kilometres<sup>4</sup>, is a main driver of environmental performance due to its close link to actual emissions caused by transport (Rodrigue et al, 2001; McKinnon, 2003; EEA, 2007; McKinnon, 2007). In line with this, the concept of centralised distribution has been used as an example of when efficiency from a traditional logistics perspective (i.e. improved customer service at a lower cost) is at odds with environmental efficiency.

Recent research has come to question this view. Aronsson and Huge Brodin (2006) argue that it can be possible to achieve simultaneous improvements in cost, service, and CO<sub>2</sub> emissions also in those cases when a distribution system is centralised and transport work increases. Fundamental in Aronsson and Huge Brodin's (2006) argumentation is that they try to link the changes of a structural character that affect the amount of transport work to changes of a tactical and operational character that affect the amount of CO<sub>2</sub> emissions per tonne kilometre. For example, the authors show how a structural change that increases the average length of haul, simultaneously can enable a shipper to adopt a new mode of transport in its distribution system that generate less CO<sub>2</sub> emissions per tonne kilometre compared to the old mode of transport. An important aspect of their research is that the whole of a distribution system should be considered rather than the separate parts and that it is necessary to consider how strategic and operational measures relate to one another:

<sup>-</sup>

<sup>&</sup>lt;sup>3</sup> One tonne kilometre is equal to one tonne of goods being transported over a distance of one kilometre. As the weight of a product does not change due to a structural change, any change in tonne kilometres/transport work is only attributable to the amount of kilometres a product is shipped before and after a structural change. This implies that total vehicle kilometres in the quote by McKinnon become the equivalent of total tonne kilometres.

<sup>&</sup>lt;sup>4</sup> Transport work and tonne kilometres are used interchangeably throughout the dissertation.

"One reason for these results might be that the study takes a holistic perspective on structural changes in Logistics & Supply Chain Management, by including both strategic and operational decision making."

### (Aronsson and Huge Brodin, 2006, p 412)

Similarly, Schenker Consulting (2007) presents a case where a shipper centralised its distribution system, owing to which transport work was increased by roughly 38%. However, the structural change simultaneously enabled the shipper to launch a cross docking solution, whereby  $\rm CO_2$  emissions could be cut by 45% compared to the decentralised distribution system thanks to consolidation improvements. This type of cross docking solution was not possible to achieve in the original system configuration.

Thus, the research by Aronsson and Huge Brodin (2006) and the case by Schenker Consulting (2007) help to illustrate that there is not only a need to recognise how a structural change affects the amount of transport work generated by a distribution system. Rather, there is also a need to consider how centralising a distribution system affects a shipper's opportunity to make changes of a tactical and operational character that affect CO<sub>2</sub> emissions per tonne kilometre. A common denominator between the studies presented by Aronsson and Huge Brodin (2006) and Schenker Consulting (2007) is that the effects of the structural change are only discussed and analysed on a system level. What is missing, however, is an explanation as to how different measures individually affect the CO<sub>2</sub> performance of the distribution system, as pointed to by Aronsson and Huge Brodin (2006):

"It has been possible in the analysis to separate different measures taken in restructuring distribution and supply chain system, and to relate them to each other. What is not possible, from our research, is to specifically relate any measure taken to specific environmental effects, as the measures are not taken one by one, but together with each other."

#### (Aronsson and Huge Brodin, 2006, p 412)

This dissertation aims to contribute to this understanding by discussing and analysing the effect of individual measures a shipper can employ to reduce transport-related CO<sub>2</sub> emissions when a distribution system is centralised. Even though environmental issues have increased in importance, it must be recognised that many changes shippers make to their logistics systems are primarily driven by a desire to reduce costs and/or improve customer service. Therefore there is a need to consider how individual measures taken by a shipper to reduce transport-related CO<sub>2</sub> emissions when centralising a distribution system affects the provision of cost efficient customer service. An example of this is change in mode of transport. Such a change will not only affect

CO<sub>2</sub> emissions, but also costs and customer service. This is because different modes of transport perform or rate differently with regards to such aspects as cost of transport, speed, flexibility, and lead-time accuracy (Monczka et al, 2002; Flodén, 2007; Lammgård, 2007; NTM, 2007; *Kohn and Huge Brodin, 2008*). Consequently, there is a need to evaluate how individual measures a shipper can employ to reduce transport-related CO<sub>2</sub> emissions when centralising a distribution system can affect the provision of cost efficient customer service.

### 1.3 Purpose and research questions

The preceding discussion reveals that there is a need for further understanding of how structural changes to a distribution system can enable a shipper to reduce transport-related CO<sub>2</sub> emissions per tonne kilometre and how such measures affect the provision of cost efficient customer service. This dissertation therefore aims to contribute to the rather limited research on logistics and the environment by fulfilling the following purpose:

The purpose of this dissertation is to explain how a shipper, through various measures, can reduce transport-related CO<sub>2</sub> emissions when centralising a distribution system and how this affects the provision of cost efficient customer service

Based on the previous discussion and the above purpose, two research questions have been formulated:

- How can centralising a distribution system enable a shipper to employ measures that reduce transport-related CO<sub>2</sub> emissions per tonne kilometre?
- How can a measure to reduce CO<sub>2</sub> emissions per tonne kilometre in a centralised distribution system affect the provision of cost efficient customer service?

## 1.4 Scope of the research and important delimitations

The following subsections will discuss the scope of this dissertation as well as important delimitations with regards to the problem formulation and purpose presented above.

### 1.4.1 Type of structural change studied

As discussed earlier, the research presented in this dissertation focuses on the specific structural change of a shipper centralising its distribution system. Figure 1-1 presents a generic comparison of the physical structure in a decentralised distribution system and a centralised distribution system. As indicated by the figure, a main difference between a decentralised and a centralised

distribution system is that the latter type of distribution system will have fewer warehouses than the former type of distribution system. In this dissertation, this is the only physical trait that differs between the two types of distribution systems. This implies that both the production unit(s) and the customer(s) are considered to be constant when the distribution system is centralised. The case studies that are discussed throughout the dissertation all have their production units, warehouses, and customers located in Europe, meaning that the dissertation applies a European perspective to centralised distribution (cf. Abrahamsson, 1992).

Throughout the dissertation, the effects on CO<sub>2</sub> emissions owing to the structural change are analysed by using a node-link perspective (also see *Kohn, 2005*). That is, production units, warehouses, and customers represent the nodes, whereas the movement of material, finished goods etc. is represented by the links. This perspective has the advantage that it is undemanding to illustrate the physical structure of a system (in this case a distribution system), whereby it also becomes easy to get a good overview of the system under study. As the dissertation is focused on transport-related CO<sub>2</sub> emissions, the analysis will centre on the activities that take place in the links, i.e. the movement of material and goods.

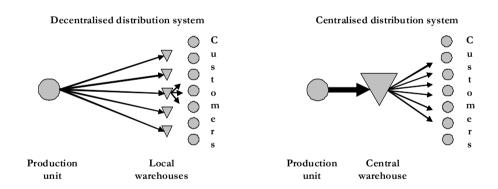


Figure 1-1: Generic illustration of a decentralised and a centralised distribution system (adapted from Abrahamsson, 1992, p 2)

In this dissertation, centralised distribution should also be understood in terms of centralisation of the design and control of the system, an issue that will be discussed further in the frame of reference in chapter 3. By adopting this view of centralised distribution, this dissertation aims at contributing to the field of logistics management by building on previous research on structural changes to a shipper's distribution system (e.g. Coyle et al, 1988; Abrahamsson, 1992; Fincke and Goffard, 1993; Abrahamsson and Aronsson, 1999; Abrahamsson et al, 2003; Coyle et al, 2003), where this dissertation complements and extends the previous research by adding an environmental perspective. To summarise, the system under study in this dissertation is that of a

shipper's distribution system, ranging from its production unit through its warehouse(s) to the customer(s). In addition to the physical structure (i.e. nodes and links), the term distribution system, in this dissertation, also encompasses the design and control of the physical structure of the system.

#### 1.4.2 Applying a shipper perspective

Figure 1-2 below illustrates how it is possible to apply various perspectives in logistics, depicted by three distinct levels in the model. Each level is considered to be an entity in itself, but simultaneously there exist interfaces between them. The highest level depicts the material flows of a single company, a shipper. The nodes and links depict the production plants and warehouses that make up the physical structure of the logistics system, as well as the flow of material, goods, and services that are transported throughout this system. Through material acquisition, production, and distribution, a demand for transport is created, which is illustrated by the links in the model. Many companies today do not hold their own fleet of vehicles to carry out these shipments and consequently this demand has to be satisfied through the procurement of transport services on the transport market. From a shipper perspective this presents a constraint. Carriers, such as DHL, UPS, and Green Cargo, provide these transport services, but in order for them to achieve economies of scale in their operations, they typically consolidate goods from many different shippers. This is demonstrated in the middle level of the model, which aims to illustrate how the material flows of individual shippers at an aggregated level become transport flows for the carriers. However, carriers also work under a condition of constraint, which becomes apparent by adding the third level in the model. Carriers have a demand for infrastructure in order to be able to carry out their operations and this is supplied by society at large through public policy-makers, authorities, and the like.

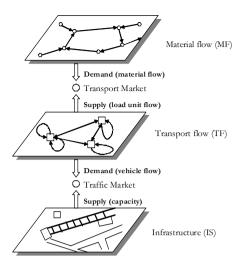


Figure 1-2: A three-tiered model of logistics (Wandel et al, 1992, p 98)

As discussed in section 1.4.1, this dissertation centres on the structural change of a shipper who centralises its distribution system. Consequently, the dissertation has its primary focus on the upper level in Figure 1-2 above. The other levels and associated actors will nonetheless be discussed in some instances. An example of this relates to the fact that the dissertation adopts a view that a shipper procures its transport services. Relating this to the three-tiered model above, this implies that the actual transfer of goods that takes place in the links depicted in Figure 1-1, take place in the middle level of Figure 1-2, since these are performed by a transport service provider in its transport network. Therefore, a measure to reduce CO<sub>2</sub> emissions with regards to the actual vehicle that performs a shipment is not in the direct control of a shipper. The reason for this is that the vehicles are in the domain of the transport service provider rather than the shipper. Nevertheless, it should also be recognised that a shipper will be able to enforce demands on a transport provider in its role as a paying customer. To conclude, even though the focus in this dissertation is on a shipper and its distribution system, some of the discussions will also refer to actors in the lower two levels in Figure 1-2 above.

#### 1.4.3 CO<sub>2</sub> emissions as an indicator of environmental performance

A central aspect of this dissertation is that of environmental performance and it should be recognised that when making an environmental assessment of a distribution system, there are a number of aspects that could be evaluated (Wu and Dunn, 1995; Lumsden, 1998; Himanen et al, 2005):

- Direct physical effects, e.g. air pollution, water contamination, and wear of infrastructure
- Social and indirect effects, e.g. accidents, congestion, and delays
- Subjective effects, e.g. fear of traffic and visual intrusions

This dissertation focuses on the first type of effects, i.e. direct physical effects, and is further delimited to assessing changes in terms of CO<sub>2</sub> emissions. The reason for this is that CO<sub>2</sub> is currently considered the most important of the greenhouse gases due to its close link to the current changes in global climate (IPCC, 2007).

A second reason why CO<sub>2</sub> emissions is used as an indicator for environmental performance in this dissertation is the link between transport work and CO<sub>2</sub> emissions (cf. McKinnon, 2000; EEA, 2007). In this dissertation, the argument is made that transport work does not suffice as a sole indicator of a distribution system's environmental performance. The reason for this is that even though the demand for transport may increase owing to a structural change, it is also important to consider how this demand for transport is manifested. For instance, the same amount of transport work generated by two different modes of transport does not result in the same amount of CO<sub>2</sub> emissions, as various modes perform differently with regards to emissions (also see section 3.2.2 in the frame of reference). Therefore, it is argued that CO<sub>2</sub> emissions serve as an appropriate indicator to describe the environmental performance of a distribution system when structural changes are studied from a shipper perspective, since this indicator, for example, more clearly takes into account the mode of transport used compared to only using transport work as an indicator.

## 1.5 Composition of the dissertation

This dissertation consists of six chapters and four appended manuscripts (Appendices I-IV), and the intention with this section is to give the reader an understanding of the dissertation's composition.

Chapter 1 has introduced the topic of the dissertation as well as the overall purpose it aims at fulfilling. Chapter 2 focuses on methodological issues and it is intended to give the reader an understanding of how the study that has led to the formation of this dissertation has been designed. In chapter 3, the reader is presented with the frame of reference. This chapter also holds a model of analysis that provides the basis for the analysis that is presented later on in chapter 5. Chapter 4 provides the reader with summaries of the results in each of the four appended manuscripts, where theses summaries serve as the empirical basis for the analysis that is presented in the subsequent chapter. In accordance with the previous description, chapter 5 contains the analysis. This chapter aims at providing an answer to the two research questions that

were presented earlier in this chapter (see section 1.3) and it serves as a basis for the conclusions of the dissertation, which are presented in **chapter 6**.

As noted above, the dissertation also includes four appendices and the subsequent sections intend to give the reader an understanding of how the appended manuscripts relate to the overall purpose presented in section 1.3 above. Starting with the **licentiate thesis – Appendix I** (Kohn, 2005), it has the overall aim of describing and analysing how centralisation of a distribution system can affect the environment. As such the licentiate thesis is restricted to focusing on how the environmental performance of a distribution system is affected by this type of structural change. The thesis contributes to fulfilling the overall purpose of the dissertation by suggesting additional factors, besides transport work, that are of relevance when evaluating the environmental effects of centralising a distribution system, where these factors relate to measures that affect the amount of  $CO_2$  emissions per tonne kilometre.

**Paper A – Appendix II** (*Kohn and Huge Brodin, 2008*) uses the results obtained from the licentiate thesis as a starting point and extends the licentiate thesis by including cost and service elements in the performance evaluation of centralising a distribution system. The purpose of the paper is to describe and discuss in which way and under which circumstances it is possible to achieve improvements simultaneously in terms of cost, service, and environmental performance of a distribution system. Consequently, Paper A contributes to the overall purpose of the dissertation by leading a discussion on how cost, service, and environmental performance are affected jointly when centralising a distribution system.

An important result of the licentiate thesis is that it illustrates how centralising a distribution system creates an opportunity to use intermodal rail-truck transport for the consolidated flow that arises in such a system (also see Figure 1-1 above for a generic illustration). The opportunity to use intermodal transport is related to great environmental benefits, but it is often advocated that shippers do not employ this type of transport solution as it impedes the provision of cost efficient customer service. In line with this, **Paper B – Appendix III** (Kohn, 2008) presents three case studies of companies that have actively employed an intermodal transport solution in their respective logistics systems. This paper contributes to the overall purpose of the dissertation by discussing why and for which parts of the logistics system shippers use intermodal transport as well as how the performance of the shippers' logistics systems has been affected by an implementation of this type of transport solution.

**Paper C – Appendix IV** (Kohn and Sandberg, 2006) has a somewhat different focus compared to the other three manuscripts. This paper focuses on the issue of power and how it can be used in a supply chain in order to improve its performance. The licentiate thesis discussed how a shipper

may increase its bargaining position vis-à-vis its transport providers when a distribution system is centralised. Paper C links to the overall theme of the dissertation by discussing and analysing aspects of power in a supply chain setting. As such, the paper does not focus on environmental issues, but provides a framework with regards to bargaining power.

The appended manuscripts are used throughout the dissertation as references and also serve as empirical input to the analysis that is presented in chapter 5, but in order to differentiate the manuscripts from other references they will be referred to in *italics*, e.g. *Kohn*, 2005.

# 2 METHODOLOGY

The aim of this chapter is to present the design and research process that has resulted in this dissertation. The dissertation has applied a case study approach as methodological approach and this is discussed in section 2.1, whereas section 2.2 discusses the overall research design and methodological aspects pertinent to the dissertation as a whole as well as each of the appended manuscripts. In section 2.3, there is a discussion about the quality of the research.

### 2.1 Applying a case study approach

The methodological approach applied in this dissertation is that of a case study approach. A case study approach is suitable when a new topic is pursued (Eisenhardt, 1989), which is the case with this dissertation as, in general, the environmental aspects of logistics is an area within logistics management were research has not been pursued to a great extent (Abukhader and Jönsson 2004a/2004b; Aronsson and Huge Brodin 2006). According to Yin (2003), a researcher needs to consider three separate conditions when deciding on how to conduct a research study; (i) the type of research question that is formulated, (ii) the degree of control a researcher has over behavioural events, and (iii) whether or not the research is focused on contemporary events. The first of these conditions, i.e. formulating a research question, is recognised as being the most important of the three conditions. On this note, Yin goes on to claim that a case study approach is suitable when the research aims at answering questions of a "how" and "why" nature or when the research is exploratory and seeks to answer questions of a "what" nature. The two research questions that this dissertation aims at answering are of a "how" character, which further emphasises that a case study approach is considered to be an appropriate methodological approach. A further reason why the study has applied a case study approach is that case studies are argued to be holistic and context sensitive (Patton, 2002), two features that are linked to one another and that have influenced the decision in choice of approach, as will be discussed below.

With regards to case studies being of a holistic nature, this relates directly to an important feature in much logistics research today, namely that of the application of a systems approach. This approach is viewed as a critical concept in logistics (Persson, 1982; Stock and Lambert, 2001; Vafidis, 2002; Solem, 2003; Lindskog, 2008) and in generic terms, it implies that reality is viewed as objectively accessible and that the parts of a system are explained, and sometimes understood, by the characteristics of the whole (Churchman, 1968; Arbnor and Bjerke, 1997; Stock and Lambert, 2001).

"The systems approach is a simplistic yet powerful paradigm for understanding interrelationships. The systems approach simply states that all functions or activities need to be understood in terms of how they affect, and are affected by, other elements and activities with which they interact."

(Stock and Lambert, 2001, p 4)

This view is relevant for this dissertation, since one aim with this research is to understand the dynamics or interrelationships that are present when considering transport-related CO<sub>2</sub> emissions, cost, and service concurrently, with regards to centralisation of a distribution system. Applying a systems approach is closely linked to context sensitivity, which in generic terms implies that it cannot be taken for granted that the results of a study can be applied to the same

system at a later occasion. This is because a system is dynamic over time, according to the systems approach (Arbnor and Bjerke, 1997). With regards to this dissertation, this implies that a change that will lead to a certain reduction in CO<sub>2</sub> emissions for one shipper must not necessarily lead to the same decrease for another shipper (this aspect relates to one of the more common criticisms raised against case study research, which is that of generalising the results outside the specific case, an issue that is discussed in greater detail in section 2.3).

Both a holistic approach and context sensitivity are of importance for the results presented in this dissertation, as the aim is to create a deeper understanding regarding how centralising a distribution system affects transport-related CO<sub>2</sub> emissions in a shipper's distribution system and how this links to the provision of cost efficient customer service. It has been argued that there is a lack of this type of studies, i.e. of studies that explain the environmental effects of structural decisions in a logistics system and how environmental aspects are related to cost and service issues (see e.g. Wu and Dunn, 1995; Abukhader and Jönson, 2004a/b; Browne et al, 2006). To create a deeper understanding should in this dissertation not be understood in terms of concluding that centralising a distribution system will always lead to a certain result. Instead, it should be understood as creating an understanding for under which circumstances centralising a distribution system can lead to positive results and negative results respectively. Hence, the aspiration is to understand the dynamics that affect transport-related CO2 emissions and its link to the provision of cost efficient customer service in a centralised distribution system so as to be able to explain why certain actions or decisions in a certain situation result in a certain outcome. To achieve this understanding, it is argued that case studies are of utter importance, since the aim with this dissertation is to achieve analytical generalisation rather than statistical generalisation (cf. Yin, 2003). The latter form of generalisations may aid us in drawing up a number of correlations, e.g. that centralisation of distribution systems leads to increased transport work, but it fails to explain why and under which conditions centralisation can give a shipper an opportunity to reduce transport-related CO2 emissions and how this is linked to the provision of cost efficient customer service, which is the focus of this study.

To conclude, given the aim of the research presented in this dissertation, the case study approach was chosen based on the nature of the research in terms of the maturity of the research field itself (i.e. logistics and the environment), the type of research questions that the study aims at answering, and the aspiration to understand the dynamics relating to the environmental effects of centralising a distribution system. How this approach has been applied throughout the dissertation process is described in the subsequent section, which discusses the research design.

### 2.2 Research design

This dissertation is the result of approximately five years of graduate studies and during this time it has been necessary to make numerous decisions with regards to the research. The aim of the subsequent sections is to describe the overarching rationale behind the choices that have been made. The description as such is oriented towards giving the reader an understanding of the dissertation process as a whole and it will discuss the most important methodological issues, rather than the specifics in each of the appended manuscripts. The subsequent three sections will discuss how (i) the theoretical foundations upon which this dissertation is based have come to be, (ii) how cases have been selected and data collected, and (iii) the overarching principle behind the analysis that is presented in chapter 5. In order to obtain a more detailed description regarding methodological issues relating to each of the appended manuscripts, the reader is also advised to read the sections on methodology in these manuscripts.

#### 2.2.1 Theoretical foundations

The research presented in this dissertation started in 2002 with the identification of a research area, which was that of logistics and the environment. The early part of the process was explorative in its character and a lot of time was spent on reading and forming an understanding of literature on the subject. This literature review centred on trying to identify research on the combined area of logistics and the environment, and the review revealed that there were many topics that could serve as a basis for the research. Based on this review, a framework was formulated that has served as a theoretical foundation throughout the research process, where theoretical foundation refers to previous research relevant for the topic of this dissertation. The core of this framework consists of research in two areas; (i) logistics and the environment and (ii) structural changes and more specifically centralised distribution. This literature can be classified as being either of two types; conceptual or empirically based. The first type has mainly consisted of environmentally oriented literature that discusses the environmental implications of logistics on a conceptual level and/or by means of secondary data (e.g. Wu and Dunn, 1995; Beamon, 1999; Rodrigue et al, 2001; McKinnon, 2003; Abukhader and Jönson, 2004a/b). The second type of literature has instead focused on empirical studies that relate to the topic of this dissertation, i.e. that of centralised distribution and the environment (e.g. Abrahamsson, 1992; McKinnon and Woodburn, 1996; Abrahamsson and Aronsson, 1999; Aronsson and Huge Brodin, 2003).

In addition to a framework, the literature review also led to an initial problem formulation that contrasted literature on the environmental effects of logistics (e.g. Rodrigue et al, 2001;

McKinnon, 2003) with logistics literature on centralised distribution (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999). This problem formulation is illustrated in Figure 2-1 below<sup>5</sup>.

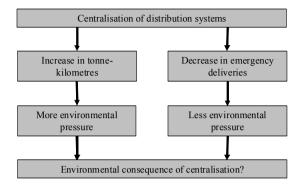


Figure 2-1: Problem formulation in the licentiate thesis - What are the environmental consequences of centralisation?

This framework was first presented in the licentiate thesis (*Kohn, 2005*), but it has been gradually revised and extended throughout the dissertation process. The result of the continuous work with the framework is the theoretical framework and model of analysis that is presented in chapter 3. More specifically, the framework has been extended based on the results obtained in the licentiate thesis, where three aspects were identified as being of importance when considering the environmental effects of centralising a distribution system:

- Consolidated flow
- Modal choice
- Bargaining power

Paper A (Kohn and Huge Brodin, 2008) focuses on the first two of these two aspects and extends the framework from the licentiate thesis by incorporating a literature review on cost and service issues (in addition to environmental issues) in logistics in general and the two aspects of consolidated flow and modal choice in particular. This review comprised literature that was collected in two parts. The first consisted of a structured literature search and the second part applied a snowball approach. For the structured search, pair-wise combinations of terms relating to the results presented in the licentiate thesis served as a basis. This resulted in 114 articles that were reviewed on abstract level in order to identify whether or not they were relevant for the theme of the paper. From this assessment process, the amount of articles was narrowed down to

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<sup>&</sup>lt;sup>5</sup> For a full discussion on this issue the reader is advised to read pages 36-39 in the licentiate thesis (Kohn, 2005).

34, all of which were read and summarised with regards to issues of importance for the research presented in the article.

Paper B (Kohn, 2008) takes its theoretical stance in intermodal research and how this research portrays the shipper. This paper contributes to the dissertation by focusing on a specific modal choice, namely that of intermodal rail-truck transport. The literature review revealed that even though previous research on intermodal transport has applied a shipper perspective, there is a lack of research on how shippers' actually use this type of transport solution in their logistics systems. More specifically, the literature review for Paper B complemented the initial framework presented in the licentiate thesis by including the following aspects; (i) users of intermodal transport view the performance of intermodal transport more positively vis-à-vis non-users, (ii) shippers have the same quality requirements on intermodal transport as they have on unimodal truck transport, (iii) if the cost criterion is emphasised by the shipper when choosing transport solution, this favours the use of intermodal transport, and (iv) intermodal transport offers a promising way of reducing the environmental impact of transport, but when compared to other issues of importance when choosing a transport solution, environmental efficiency ranks very low.

The aspects of a consolidated flow and modal choice are aspects that have been discussed in previous research in logistics management. However, the third aspect, i.e. bargaining power, has not been discussed to a great extent within the area of logistics management. On this topic, Paper C (Kohn and Sandberg, 2006) discusses the use of power in a supply chain setting. From a theoretical perspective, this paper goes outside the boundaries of the two core theoretical topics of this dissertation (i.e. "logistics and the environment" and "structural changes and centralised distribution") as it incorporates marketing channel literature and literature from the field of social science, and applies this in a supply chain context.

The outcome of the gradual refinement of the framework throughout the dissertation process is presented in chapter 3 in the form of this dissertation's frame of reference. However, this frame of reference is also an extension in relation to the individual frameworks, as it also extends the separate frameworks by including additional literature. By synthesising the separate frameworks and adding new literature, a model of analysis has been formulated that serves as a basis for the analysis that is performed in chapter 5. How this analysis has been performed is discussed further in section 2.2.3 below.

#### 2.2.2 Selection of cases and data collection

This dissertation consists of six case studies and Table 2-1 illustrates in which of the appended manuscripts each of the case studies is presented. The subsequent paragraphs will discuss why

these cases have been selected and how data has collected for each of them. The case study of Volvo Parts has nevertheless been excluded from this discussion on the basis that no empirical data from this study has been included in the dissertation's synthesising analysis in chapter 5, as the focus of this case study is not on environmental issues (also see sections 1.5 and 4.4).

Table 2-1: Description of which case studies are used in which appended manuscript

	ITT Flygt	Stena Gotthard	Carlsberg Sweden	KappAhl	Stora Enso	Volvo Parts
Licentiate thesis (Kohn, 2005)	X					
Paper A (Kohn and Huge Brodin, 2008)	X				X	
Paper B (Kohn, 2008)		X	X	X		
Paper C (Kohn and Sandberg, 2006)						X

ITT Flygt was the first case study that was conducted and this study took place during the earlier stages of the dissertation process. It is presented in its full content in the licentiate thesis (Kohn, 2005) as well as in a concise version in Paper A (Kohn and Huge Brodin, 2008). The case study is centred on how, during the second half of the 1990s, ITT Flygt centralised its distribution system and the effects this change had on the performance of the distribution system. The case was chosen for two reasons. First, through an initial interview, it was possible to establish that the structural change the company had carried out displayed the features one would expect to find in this type of change. One such feature was that the company had accomplished to reduce its logistics costs at the same time as the level of service offered to the customer was improved (cf. Abrahamsson, 1992). A second reason why this case was chosen concerns accessibility. ITT Flygt provided me with access with regards to respondents for interviews as well as external and internal documentation. The company also arranged so that its transport providers would supply sufficient data to model the distribution system, in terms of nodes and links, both prior and subsequent to the structural change. Furthermore, the company supplied real shipment data in order to compute the environmental outcome of the structural change. These issues are also discussed further in the subsequent paragraphs, which discuss how the data collection was carried out.

The first step entailed conducting interviews with respondents at ITT Flygt with knowledge of the structural change the company had gone through. This part of the data collection focused on grasping various aspects of the process the company had gone through as well as how the distribution system performed with regards to cost and service issues, both before and after the structural change. Based on the focus of the study, a contact person at ITT Flygt compiled a list of respondents. These were sent a cover letter, which explained the aim with the study. In addition to receiving a cover letter, the respondents were also provided with an interview guide in order to be able to prepare themselves before the interview. In total, twelve interviews were

performed, each lasting between one and two hours. Besides the interviews, internal and external documentation was studied. Internal documentation consisted of company reports relating to the structural change, for example project appropriation requests and consultant reports relating to the structural change, whereas annual reports and the company website constituted the external documentation. The primary result of this part of the data collection process is the case description presented in chapter 4 of the licentiate thesis. This case description was also sent to ITT Flygt for revision in order to ensure its correctness and quality.

The second step of the data collection procedure comprised of compiling data with regards to modelling how transport was performed in the distribution system, both prior to and after the structural change. This involved extensive correspondence via telephone and email with ITT Flygt's transport service providers Wincanton and DHL. The data that was compiled included data with regards to the carriers' transport network, for example, transport distances and vehicle payload for different parts of their respective transport networks. The data was used in order to set up the routes that were used for each of ITT Flygt's markets in the two distribution systems (decentralised and centralised), which was done in MS Excel. Besides data from the two transport providers, actual shipment data was also obtained from ITT Flygt. The collected data included the amount of goods that had been shipped in the company's distribution system as well as the origin and destination of each shipment, data which was also entered into MS Excel. The data set comprised a representative time-period in 2003, as the total amount of goods was not allowed to be communicated due to confidentiality reasons. For that same reason, the weight of these shipments has also been indexed as to ensure that no important and confidential data for ITT Flygt is revealed in the calculations. This part of the data collection served as a basis for the quantitative analysis that was made between the two systems in terms of transport work and CO<sub>2</sub> emissions. The process of compiling the data, setting up the routes for all the shipments in the two respective distribution systems, and entering the shipment data took approximately three months. This process involved multiple iterations, where the model in MS Excel had to be revised several times due to such issues as non-conformity in the data as well as lack of certain data supplied by ITT Flygt and/or its transport service providers DHL and Wincanton. A more detailed description of this calculation procedure is presented Appendix D in the licentiate thesis (Kohn, 2005).

In Paper B (Kohn, 2008), the empirical data is based on case studies at three companies; Stena Gotthard, Carlsberg Sweden, and KappAhl. The selection of the companies was based on the following criteria:

- The companies all use intermodal transport solutions within their respective logistics systems
  and this has been an active choice on their part rather than a choice made by their respective
  logistics service provider(s).
- Contacted respondents were interested in the research and accordingly granted accessibility.
- The companies represented different industries with varying characteristics, thus giving a
  breadth to the empirical data with regards to the conditions under which the companies
  operate.

By virtue of the first criterion, the companies serve as critical cases (cf. Patton, 2002) as there is a lack of empirical studies on why shipper companies use intermodal transport, for which part of the logistics system this solution is applied, and how this type of solution affects the performance of the system at hand.

The empirical data was mainly gathered through interviews with respondents from each of the companies and the interviews lasted one to two hours. In total, four interviews were conducted (one each with KappAhl and Carlsberg Sweden, and two interviews with Stena Gotthard). This might raise the question of whether or not this provides a sufficient base for an empirical description as well as an analysis. The aim of the interviews was to learn how the logistics system of the company in question was structured, how it was managed, which performance elements were of importance in evaluating the system, and how intermodal transport was used within the system. Therefore, a decision was made to interview only a few respondents, but the main criterion for their selection was that they had to have extensive knowledge of the logistics system and the use of intermodal transport within this system. Therefore, the respondents in all of the three companies had the position of logistics manager (the additional interview at Stena Gotthard was with an environmental manager). In some instances, the respondents could not provide full answers to the questions and therefore an additional contact person was provided within the company who could give a complementary answer in those cases. This correspondence served the purpose of extending and validating the primary interview for that particular company. Besides personal interviews, archival records and official documentation, such as annual reports and press releases have also been used. The case descriptions were also sent to the respondents for review in order to ensure the quality and correctness of these descriptions.

The final case study that serves as an empirical basis for the analysis in chapter 5 is that of Stora Enso. Although not discussed explicitly in Paper B (*Kohn and Huge Brodin, 2008*), the Stora Enso case was included since it had been analysed with reference to its similarities and dissimilarities with the ITT Flygt case. The goal with this exercise was to identify common patterns, similar to that of a cross-case synthesis (cf. Eisenhardt, 1989; Yin, 2003). The result of this synthesis was the three characteristics (consolidation of freight flows, changes in transport mode enabled by

centralisation, and decrease in the amount of emergency deliveries) that are discussed throughout the paper from a theoretical as well as an empirical viewpoint, and which provide the basic structure of the paper. This case study was compiled by the co-author, Maria Huge Brodin and consequently issues relating to the collection of data are not discussed further here. For a further description of the data collection process, the reader is instead advised to turn to either the appended paper or Aronsson and Huge Brodin (2006), which also includes the case<sup>6</sup>.

Table 2-2 below summarises what type of data that has been collected for each of the case studies. Besides the case study of Stora Enso, the study of Volvo Parts has been excluded from this summary. The reason for this is that this paper contributes to the analysis in chapter 5 by virtue of its framework on bargaining power (also see sections 1.5 and 4.4) rather than its empirics.

Table 2-2: Summary of data collection

ITT Flygt	Stena Gotthard	Carlsberg Sweden	KappAhl
- Interviews with respondents from case	- Two interviews of approximately two	- Interview with the case company's	- Interview with the case company's
company (12) ranging between one and	hours each; one with the case company's	logistics manager (two hours).	logistics manager (two hours).
two hours.	logistics manager and one with the	<ul> <li>Complementary correspondence via</li> </ul>	- Complementary correspondence via
- External documentation in the form of	company's environmental manager.	telephone and email.	telephone and email.
annual reports and website information.	- Complementary correspondence via	- Externa documentation in the form of	- Externa documentation in the form of
- Internal documentation in the form of	telephone and email.	annual reports, website information, and	annual reports and website information.
project plans, consulting reports, RFQs,	- Internal documentation in the form of	newspaper articles.	
and progress reports with regards to the	project plans and progress reports for the		
structural change.	implementation of the newly started		
- Extensive correspondence via telephone	intermodal rail-truck transport solution.		
and email with the case company's logistics	- Externa documentation in the form of		
service providers in order to obtain data to	annual reports, website information, and		
be able to model how transport was	newspaper articles.		
performed both prior to and subsequent to			
ITT Flygt's structural change. This data			
included such aspects as type of transport			
mode, type of vehicle, type of engine, fill-			
rate levels in those parts of the providers'			
transport networks were ITT Flygt's			
shipments were executed.			
- Actual shipment data from the case			
company for a representative time period			
in order to quantitavively analyse how the			
structural change affected the amount of			
transport work and transport-related CO2			
emissions generated by the distribution			
system. The shipment data was provided in			
Excel files, where the data had to be			
converted to fit the calculation model that			
compared how transport was performed in			
the decentralised and the centralised			
distribution system respectively.			

<sup>&</sup>lt;sup>6</sup> In this paper, the case is referred to as PaperComp.

#### 2.2.3 Analysis

The analysis is one of the more difficult aspects of conducting case study research and it is also one of the least codified elements in this type of research (Eisenhardt, 1989; Yin, 2003). Yin (2003) makes a distinction between strategies and techniques for conducting an analysis, where the strategy should define what to analyse and why it should be analysed. Techniques, in turn, are used to sort or examine the empirical data (both qualitative and quantitative) that has been collected.

In this dissertation, two research strategies have been employed, namely relying on theoretical propositions and developing a case description (cf. Yin, 2003). With regards to formulating theoretical propositions, it was discussed earlier in section 2.2.1 how an initial problem formulation was made in the early stages of the dissertation process. This formulation has been gradually revised throughout the dissertation process as new empirical data has been collected and analysed. Generally, it is quite common in case study research that data collection and analysis overlap and that these are performed in an iterative manner (Eisenhardt, 1989; Patton, 2002). In this dissertation, the gradual refinement of the initial problem formulation has culminated in the model of analysis, which is presented in the frame of reference (see sections 3.2.5 and 3.3.6). With regards to the second strategy that has been used in this dissertation, i.e. developing a case description, this has been done in each of the appended manuscripts (see section 2.2.2).

Figure 2-2 below presents a generic illustration of the analysis process. The figure illustrates how the results obtained through the analyses performed in each of the appended manuscripts as well as the extended frame of reference (see chapter 3) have served as input to the model of analysis (see chapter 3). The model of analysis in turn has served as a structure for the synthesising analysis (see chapter 5), the results of which are presented in the form of this dissertations conclusions (see chapter 6).

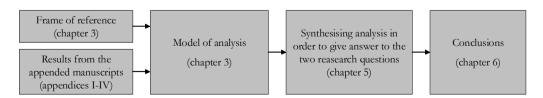


Figure 2-2: The dissertation's analysis process

Together, the two strategies have formed the basis for the analytical technique that has been used in this dissertation, which is that of explanation building. Explanation building is a special type of pattern-matching, which Yin (2003) describes in the following manner:

"To explain a phenomenon is to stipulate a presumed set of causal links about it. These causal links are similar to the independent variables in the previously described use of rival explanations. In most studies, the links may be complex and difficult to measure in any precise manner."

Yin goes on to claim that the process of explanation-building has not been well documented and operationalised in case study research, but that any concluding explanations are likely to be the result of an iterative process that includes the following steps:

- Making an initial theoretical statement or an initial proposition
- Comparing the findings of an initial case study against this statement or proposition
- Revising the statement or proposition
- Comparing other details of the case against the revision
- Comparing the revision to the facts of other cases
- Repeating this process as many times as is needed

The purpose of this dissertation indicates that it aims at having an explanation building approach and therefore the study has followed the suggested process described above. As discussed earlier, the research process leading up to the licentiate thesis was of an explorative character and this part of the process involved forming an initial problem formulation or proposition (see Figure 2-1). This part of the dissertation process represents the first step in the explanation-building process presented above, where the initial proposition stated that it is not sufficient to only consider how centralising a distribution system affects transport work, since transport-related CO<sub>2</sub> emissions are also likely to be affected by other aspects. At this part of the process, emergency deliveries were focused as these have been a fundamental aspect in earlier research on centralised distribution (cf. Abrahamsson, 1992; Abrahamsson and Aronsson, 1999). As discussed earlier, it was revealed that it was not sufficient to only consider how transport work and emergency deliveries were affected when the distribution system was centralised in order to come to a conclusion about how this type of structural change affects transport-related CO<sub>2</sub> emissions stemming from a distribution system. This corresponds to the second step above and based on an additional analysis, the initial problem formulation or proposition was revised so as to mirror the findings of this analysis. This work culminated in the revised model presented in

the conclusions of the licentiate thesis, which corresponds to the third step prescribed by Yin (2003).

The three remaining steps have been conducted in an iterative manner for the remainder of the process leading up to the completion of this dissertation. A first step was to include more aspects in the analysis besides transport work and CO<sub>2</sub> emissions. Thus, the remainder of the dissertation process subsequent to the licentiate theses has aimed at including cost and service issues to a greater extent. This started with Paper A (*Kohn and Huge Brodin, 2008*), where the revised problem formulation served as a basis for the literature search on cost and service issues. Furthermore, the Stora Enso case was included in this paper since the two cases had been analysed with reference to similarities and dissimilarities between them in order to identify common patterns among the cases (cf. Yin, 2003; Eisenhardt and Graebner, 2007).

Even though the aim of the dissertation process has been that of having an explanation building approach, there have been exploratory elements also towards the latter parts of the process. On this note, both Paper B (Kohn, 2008) and Paper C (Kohn and Sandberg, 2006) are to be regarded as papers of exploratory character. However, both the papers build on results obtained through the licentiate thesis (Kohn, 2005) and the aim has been to bring the research presented in this dissertation from an explorative phase to that of a explanatory phase by providing additional empirical data to support the synthesising analysis.

The iterative nature of the explanation-building process has also become evident towards the end of the dissertation process. In order to present a synthesising analysis that considers the results presented in all of the appended manuscripts, the frame of reference has been revised so as to incorporate new literature and extend it compared to the appended manuscripts. By means of contrasting the theoretical frame of reference with the study object of this dissertation, i.e. a centralised distribution system, a new proposed model of analysis could be formed. This model not only takes into account how CO<sub>2</sub> emissions are affected by centralisation, but also presents predicted patterns with reference to how a reduction in transport-related CO<sub>2</sub> emissions can affect a shipper's provision of cost efficient customer service.

In accordance with how the model of analysis is composed, the analysis is performed in two steps according to a pattern-matching approach (Yin, 2003; Eisenhardt and Graebner, 2007). In both steps, the predicted patterns in the model of analysis are matched with the empirics from the appended manuscripts. One important step in this analysis process is that of illustrating, through sample calculations, the effects of various measures a shipper can employ to reduce transport-related CO<sub>2</sub> emissions when a distribution system is centralised. As discussed in the introduction chapter, earlier studies on the effects of structural changes (Aronsson and Huge

Brodin, 2006; Schenker Consulting, 2007) have only made an analysis on a system level and there is a lack of explanation with regards to how individual measures will affect transport-related CO<sub>2</sub> emissions. Consequently, there has been no discussion pertaining to how such measures to reduce CO<sub>2</sub> emissions will in turn affect the provision of cost efficient customer service. Hence, even though the calculations are sample calculations, they make a contribution to the research area of logistics and the environment in that they contrast the potential in individual measures with an increase in transport work caused by the structural change. How each of these calculations has been carried out is explained throughout the analysis chapter. The outcome of the calculations and the comparison of theoretically predicted patterns and empirics are presented in the final chapter (chapter 6) in the form of this dissertation's conclusions.

### 2.3 Quality of the research

All research needs to be evaluated and criteria such as rigor, validity, and generalisability have traditionally come to be recognised as some of the more important aspects to consider in such an evaluation (Patton, 2002). According to Bryman (2004), there exists a discussion as to whether or not these criteria are relevant when conducting case studies. Bryman states that more quantitative oriented authors, such as Yin (2003), claim that that these criteria serve as a relevant yardstick for good research, whereas more qualitative oriented authors do not pay any attention at all to these criteria. The research presented in this dissertation relies heavily on case study methodology as described by Yin and accordingly, it is argued that the criteria mentioned above are important in the evaluation of case study research. There are four tests that are regularly used to assess the quality of any empirical social research (see Table 2-3), of which case studies form a part.

Table 2-3: Four tests to ensure the quality of the research (Yin, 2003, p 34)

Tests	Case study tactic	Phase of research process
	- use multiple sources of evidence	- data collection
Construct validity	- establish chain of evidence	- data collection
Construct validity	- have key informatants review draft o	case
	study report	- composition
	- do pattern-matching	- data analysis
Intonnal validity	<ul> <li>do explanation-building</li> </ul>	- data analysis
Internal validity	- address rival explanations	- data analysis
	- use logic models	- data analysis
	- use theory in single case studies	- research design
External validity	- use replication logic in multiple	
	case studies	- research design
Reliability	- use case study protocol	- data collection
Кенавшту	- develop case study database	- data collection

The following paragraphs will discuss how the research presented in this dissertation has been executed with regards to these tests. All of the tactics that are discussed below are done so with the dissertation as a whole in mind, and consequently, the reader is advised to read the sections on methodology in the appended manuscripts for a more detailed description of how these tests have been applied in the case of each manuscript.

Construct validity refers to how well the researcher manages to establish correct operational measures for the concepts that are being studied, and all three of the tactics listed in Table 2-3 have been applied throughout the research process. First of all multiple sources of evidence have been used in order to ensure data triangulation (Patton, 2002; Yin, 2003). An example of this is that empirics obtained through interviews have been contrasted with archival records. One objective in the research presented in this dissertation has been to ensure a chain of evidence by asserting that the conclusions in the study are in accordance with the theoretical propositions that have been made as well as with the empirical evidence presented. In order to ensure that this chain has been established, other researchers with knowledge of logistics in general and environmental issues in logistics in particular have reviewed the findings throughout the process, something which may be referred to as analyst triangulation (Patton, 2002). Finally, by sending written case descriptions to key informants, it has been possible to ensure a correct description of the situation or phenomenon at hand, and this has helped to ensure a high degree of construct validity in the dissertation.

Internal validity focuses on whether or not the researcher is able to establish a causal relationship. This type of validity is not applicable to descriptive or explorative studies, since such studies, regardless of overall research strategy, do not involve the formulation of causal statements. However, this study aims at illustrating under what circumstances environmental performance and performance in terms of cost and service may coincide, and consequently, internal validity is an issue. According to Yin (2003), it is difficult to identify specific tactics to use in order to achieve this type of validity, but as illustrated by Table 2-3 there are a number of tactics that can be used. The empirics presented in this dissertation rely to a large degree on interviews and consequently the respondents have come to play an important role. The respondents have, so to say, provided a description that illustrates their reality and views, and having multiple respondents answer the same questions has helped to improve the internal validity of this research (primarily ITT Flygt case study). Furthermore, the empirical evidence that has been collected has been contrasted with theory as well as additional empirics in order to find either patterns or significant deviations in the material. Applying such an approach is in accordance with the tactics of patternmatching and finding rival theories, both of which has helped to improve the internal validity of this dissertation.

The third test, external validity, concerns the extent to which it is possible to make generalisations beyond the results of the specific study that has been undertaken. This is an area where case studies generally receive massive criticism from other approaches, especially from advocates of a survey approach (Easton, 2003; Yin, 2003). The reason for this criticism is that the type of generalisation that it is possible to achieve through case studies, i.e. analytical generalisation, is often contrasted with the type of statistical generalisation that may be achieved through the use of surveys. Case studies are best used to achieve a deeper understanding of a case/multiple cases, where the aim is to find the essence that might be assumed to be relevant also in other cases. With reference to this dissertation, this implies that the measures (see chapter 6) that have been identified are considered applicable to cases other than those presented here. However, at the same time, it has to be acknowledged that these measures may have varying importance depending on the context of a single case, an important aspect that is also emphasised by Normann (1970):

"If you have a good descriptive or analytic language by means of which you can really grasp the interaction between various parts of the system and the important characteristics of the system, the possibilities to generalize also from very few cases, or even one single case, may be reasonably good. Such a generalization may be of a particular character; it might be possible to generalize a statement of the type "a system of type A and a system of type B together comprise a mechanism which tends to function in a particular way." On the other hand one cannot make any generalizations about how common these types of systems and interaction patterns are. But the possibilities to generalise from one single case are founded in the comprehensiveness of the measurements which makes it possible to reach a fundamental understanding of the structure, process and driving forces rather than a superficial establishment of correlation or cause-effect relationships."

(Normann, 1970, p 53)

When applying this kind of logic, it can be argued that case study research is concerned with developing theory rather than testing it (Eisenhardt and Graebner, 2007) and this, I would argue, is the essence of analytical generalisation as discussed by Yin (2003).

The fourth and final test is that of reliability and this concerns whether or not another researcher would come to the same results and conclusions. In order to guarantee this to the largest extent possible, standardised interview guides have been used when discussing a specific topic with respondents. Further, the respondents have been provided with drafts of the case description in order to ensure that the empirical description that is conveyed coincides with their view on the issue. Also, for the calculations that have been performed in the analysis in chapter 5 as well as in the licentiate thesis, descriptions of input to the calculations as well as a sample illustration of the calculation procedure (licentiate thesis) have been presented in order to enable other researchers

to conduct corresponding calculations, given the same input data. All of these measures have helped to guarantee the reliability of this study.

Besides the tests suggested by Yin (2003), this research has been put under scrutiny several times throughout the PhD process, which has also helped in improving the quality of the results. First, the appended manuscripts have been reviewed throughout their respective processes. Second, the whole of the dissertation manuscript has been examined towards the end of this process by means of two research seminars. These seminars have provided constructive criticism, which has helped to improve the quality of the dissertation.

## **3 FRAME OF REFERENCE**

The framework presented here serves the purpose of providing the reader with an understanding of the theoretical foundation upon which this dissertation is built. Theoretical foundation should in this instance be understood in terms of previous research within the areas of (i) logistics and the environment and (ii) structural changes and centralised distribution. The frame of reference is in part a summary of the frameworks used in the appended manuscripts, as it includes much of the literature that has been applied during the various steps of the research process. Nevertheless, it also serves as an extension of the frameworks used in the individual manuscripts, as it includes new literature and also relates the individual parts to the overall purpose and research questions of the dissertation.

#### 3.1 A point of departure – changes in logistics systems

This dissertation focuses on how shippers can reduce transport-related  $CO_2$  emissions when a distribution system is centralised and how such measures affect the provision of cost efficient customer service. As suggested in the introduction chapter, part of the discussion centres on how changes can be made by a shipper company with regards to a range of activities within a logistics system. A change to a logistics system is in essence an outcome of a decision and this section will briefly discuss some key elements that emerge when examining literature on this issue, as this forms a starting-point for the continued discussion in the framework (also see Figure 3-1 below).

Logistics has a scope that spans over a multitude of activities in an organisation and in generic terms, logistics changes can be categorised as one of three types; strategic, tactical, or operational (e.g. McKinnon and Woodburn, 1996; Ploos van Amstel and D'hert, 1996; Abrahamsson and Brege, 1997; Chopra and Meindl, 2004; Riopel et al, 2005).

- Strategic changes are generally considered to be long-term, to involve a greater amount of resources, and to involve top management in a company, and changing the structure of a logistics system is a typical strategic change (Laughlin and Copacino, 1994; McKinnon and Woodburn, 1996; Abrahamsson and Brege, 1997; Stank and Goldsby, 2000; McKinnon, 2003; Chopra and Meindl, 2004). Centralisation of a distribution system is the change that is focused throughout this dissertation.
- Tactical changes refer to planning issues within a given structure and how to make best use of the structure. Here, companies decide on issues such as safety stock levels, priority rules for various markets or customers, and plan production for various suppliers. (Abrahamsson and Brege, 1997; Aronsson and Huge Brodin, 2003; Chopra and Meindl, 2004).
- Operational changes regard more day-to-day operations and refer to matters such as processing orders, picking a certain order or dock level operations, e.g. load planning (McKinnon and Woodburn, 1996; Stank and Goldsby, 2000; Aronsson and Huge Brodin, 2003).

The following statement by Ballou (1978) can be argued to typify the relationship between changes and decisions at these three levels:

"Strategic — what should our distribution system be? Tactical — how can the distribution system best be utilized? Operational — let's get the goods out!!

(Ballou, 1978, pp 29-30)

To extend the discussion, we must also acknowledge that companies do not make decisions or changes in a vacuum. The decisions and changes a company makes are often done under some form of constraint, which can take on different shapes and forms. In broad terms, a company can be affected by either market elements or contextual elements (e.g. De Witt and Meyer, 1998; Flodén, 2007). Market elements on the one hand consist of those actors with which a company has most immediate contact and includes suppliers, customers, and various forms of competitors. Contextual elements on the other hand, include sociocultural forces, economic forces, political/legal forces, and technological forces. Politicians, universities, stock exchanges, media etcetera are found among these latter forces. Influence can come from either of these two groups, for example in the form of customers demanding a certain recognised standard (e.g. ISO certification) or legal constraints regarding waste disposal (e.g. directives regarding waste electrical and electronic equipment, WEEE). At the same time, it must be recognised that a shipper can also influence these parties, as indicated by the double headed arrows in Figure 3-17.

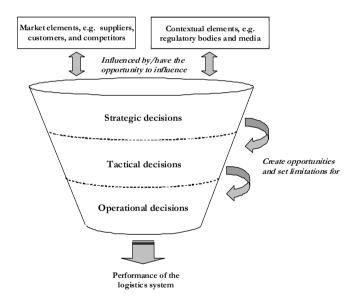


Figure 3-1: Generic illustration of the hierarchical nature of logistics changes (based on De Witt and Meyer, 1998; Aronsson and Huge Brodin, 2006; Flodén, 2007)

The overall performance of a logistics system is determined by decisions taken at all of these three levels, but it is generally acknowledged that changes at a higher level in the hierarchy have a greater impact on the overall performance of a logistics system (McKinnon and Woodburn, 1996; Abrahamsson and Aronsson, 1999; Aronsson and Huge Brodin, 2003; Riopel et al, 2005). This is

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<sup>&</sup>lt;sup>7</sup> It should be noted that the double headed arrows aim at illustrating that there is a two-way influence rather than the magnitude of this influence.

because changes at a higher level, in general, have a wider scope and also because they affect multiple decisions at lower levels in the decision hierarchy.

The type of strategic change considered in this dissertation, i.e. centralisation of a distribution system, is a change that has been widely employed by shippers over the past couple of decades (Abrahamsson, 1992; Wu and Dunn, 1995; Abrahamsson and Brege, 1997; McKinnon, 2003; Hesse and Rodrigue, 2004; Establish, 2007). This change has enabled shippers to achieve so called quantum-leap improvements with regards to the provision of cost efficient customer service, meaning that they have been able to reduce costs significantly at the same time as the overall customer service has been improved. However, as stated in the introduction chapter, centralisation of distribution system is also argued to be of a negative character from an environmental perspective as it increases the amount of transport work generated by the distribution system. In contrast to this commonly held view, this dissertation aims to demonstrate how a shipper can reduce transport-related CO<sub>2</sub> emissions when centralising its distribution system. The underlying logic behind this aim is that a change in a shipper's structure and management of the same (strategic change) can create new opportunities to make other changes within the distribution system, changes that can lead to improvements in CO<sub>2</sub> emissions per tonne kilometre (tactical and operational changes). This logic is also the starting point for the discussion in the following parts of the theoretical framework, which is structured as follows:

- Section 3.2 discusses available measures for a shipper to employ in order to reduce CO<sub>2</sub> emissions stemming from transport in a distribution system.
- Section 3.3 examines how the number of warehouses in a distribution system is argued to affect its performance in terms of cost and service. This discussion also takes into consideration the results of the discussion in section 3.2 with regards to how the provision of cost efficient customer service is linked to transport-related CO<sub>2</sub> emissions.

# 3.2 A shipper perspective on measures to reduce transport-related CO<sub>2</sub> emissions

This section deals with environmental performance from a logistics point of view and more specifically, it deals with how environmental performance might be improved through various measures relating to activities within a logistics system. There are multiple decisions related to logistics that affect the environmental performance of a company and the challenge for a company is to understand how to combine environmental issues with the traditional view of logistics performance, which is that of achieving cost efficient customer service (Wu and Dunn, 1995; Beamon, 1999; Kohn and Huge Brodin, 2008). Within the domain of distribution in a logistics system, which is focused in this dissertation, there are multiple decisions that affect the environmental performance of the distribution system. Examples of such decisions include how

the system is designed in terms of nodes and links, what mode of transport that is used, vehicle routing, and type of packaging (see e.g. Penman and Stock, 1994; Wu and Dunn, 1995; McKinnon and Woodburn, 1996; Rodrigue et al, 2001; McKinnon, 2003; Aronsson and Huge Brodin, 2006).

Even though distribution encompasses a number of activities, a key activity is that of transport. This is because the overall goal of distribution is to move material, usually finished goods or service parts, from a shipper to its customers (e.g. Ballou, 1978; Lambert and Stock, 1993; Wu and Dunn, 1995; CSCMP, 2005). As discussed in the previous chapter, environmental sustainability can concern many issues, of which this dissertation focuses on CO<sub>2</sub> emissions (see section 1.4.3). With regards to CO<sub>2</sub> emissions, transport is currently an area that is being given particular attention. The reason for this is that freight transport volumes are increasing at an alarming pace and over the last fifteen years freight transport volumes in the European Union have increased faster than GDP (EEA, 2007). From a logistics point of view, transport is also that activity within a shipper's logistics system which is most commonly discussed in relation to CO<sub>2</sub> emissions and it has been argued to be the part of the logistics system that has the greatest impact on the system's environmental performance (Wu and Dunn, 1995; Blinge and Lumsden, 1996; McKinnon, 2003; Aronsson and Huge Brodin, 2006; Browne et al, 2006).

Transport and transport-related CO<sub>2</sub> emissions are affected by a number of factors and McKinnon (2003; 2007) gives four critical ratios which should be considered when evaluating opportunities to reduce CO<sub>2</sub> emissions stemming from transport<sup>8</sup>:

- Transport intensity (total tonne kilometres:output<sup>9</sup>)
- Modal split (road tonne kilometres:total tonne kilometres)
- Vehicle utilisation (vehicle kilometres:total tonne kilometres for a specific vehicle)
- Fuel and energy source efficiency (vehicle kilometres: CO<sub>2</sub> emissions)

The subsequent sections will describe each of these ratios and discuss how and in what way each of them is relevant to the purpose of this dissertation.

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<sup>&</sup>lt;sup>8</sup> In his 2003 publication, McKinnon only discusses the three first ratios, although he indicates that the fourth ratio is important. In the 2007 publication, McKinnon distinguishes seven ratios, where three out of the four listed ratios above have been split into separate ratios; transport intensity into handling factor and average length of haul, vehicle utilisation into average load on laden trips and average percentage of empty running, and fuel and energy efficiency into fuel efficiency and CO<sub>2</sub> intensity of energy source.

<sup>&</sup>lt;sup>9</sup> McKinnon (2003) discusses how output can be defined in various ways, for instance in the form of GDP or weight of goods produced and distributed. In this dissertation, the weight of goods is used as an indicator of output since calculations with reference to tonne kilometres in the licentiate thesis were performed using this indicator. For a definition of tonne kilometres, the reader is referred to footnote 2 on p 5 in the first chapter.

#### 3.2.1 Transport intensity

The ratio for transport intensity is influenced by two factors; the handling factor and the average length of haul (McKinnon, 2003; McKinnon, 2007). These two factors relate to how companies make changes with regards to the structure of their logistics systems and thereby relate to issues of a strategic character in the funnel-like model illustrated in Figure 3-1 above.

The two factors determine how much transport work is generated, and the handling factor expresses the length of a supply chain as this measures the number of freight journeys a shipment makes through the supply chain from the state of raw material to final consumption. McKinnon claims that given current empirical evidence, it is not possible to conclude that there has been an overall change in the handling factor since different industries have evolved differently over the last couple of decades. This is illustrated by the following quotation:

"It would be possible to streamline many domestic supply chains by reducing the nodes and links. This would involve eliminating intermediate locations for processing, storage and handling and achieving higher degrees of vertical integration at particular manufacturing or distribution sites. In some sectors this would require a reversal of the process of vertical disintegration that as been prevalent over the past 20 years, while in others it would simply reinforce existing trends."

As illustrated above, the handling factor is mainly an issue when considering a whole supply chain, in which matters of vertical integration, for instance, become an issue. Therefore it will not be discussed further, as the focal point for the analysis in this dissertation is a shipper and its distribution system rather than the structure of a whole supply chain.

With reference to average length of haul, it was already discussed in the previous chapter how transport volumes are currently increasing faster than GDP growth, and that the main reason for this increase is that goods are being transported over greater distances than before (McKinnon, 2003; Swahn, 2006; Åkerman and Höjer, 2006; Christopher et al, 2007; EEA, 2007). In fact, there has been a continuous increase with regards to the average length of haul for a couple of decades now, and within Europe we have been witnessing an average annual increase of 1.5-2% (ECMT, 2000). With reference to this, it must be acknowledged that the type of structural change that is the focus of this dissertation, i.e. centralisation of a shipper's distribution system, contributes to this increase, since goods need to travel further in order to get to the final customer in a centralised distribution system compared to in a decentralised distribution system (Rodrigue et al, 2001; McKinnon, 2000; McKinnon, 2003; Croxton and Zinn, 2005; Kohn, 2005; Schenker Consulting, 2007).

This increase in transport work is of importance when considering transport-related CO<sub>2</sub> emissions, due to the close link that it is argued to exist between transport work and CO<sub>2</sub> emissions (see section 1.4.3). Thus, if a shipper desires to reduce the amount of transport work of its distribution systems and thereby also CO<sub>2</sub> emissions stemming from transport, this would likely call for a change in strategic priorities, since the main way to reduce the amount of tonne kilometres generated by a distribution system is by shortening the average length of haul (Wu and Dunn, 1995; McKinnon, 2003). Relating this to the study object of this dissertation, companies would need to adopt distribution systems with more local and regional warehouses than that advocated by proponents of a centralised approach to distribution (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; Aronsson and Huge Brodin, 2006) in order to reduce the amount of CO<sub>2</sub> emissions that transport in the system generates. This is because the more decentralised the physical structure of a distribution system is, the shorter the average length of haul will be (Rodrigue et al., 2001; Croxton and Zinn, 2005; Kohn, 2005). Even though such a shift would be welcomed from an environmental perspective, it is argued to be an unlikely scenario as the cost trade-offs companies make between transport and other activities within the logistics system are fairly robust (McKinnon, 2000). For instance, computer simulations indicate that transport costs would need to increase by over 100% to make it worthwhile for companies to carry out this type of change to their logistics systems (McKinnon, 1998). Hesse and Rodrigue (2004) even go so far as to claim that centralised distribution has become a core concept in logistics today, which further emphasises the unlikelihood that shippers will make such changes in the near future.

"An important physical outcome of supply chain management is the concentration of storage or warehousing in one facility, instead of several. This facility is increasingly being designed as a flow- and throughput oriented distribution center (DC), instead of a warehouse holding cost intensive large inventories. Recent freight flows tend to be of lower volumes, of higher frequency, often taking place over longer distances. These flows have been associated with modal adaptation. The magnitude of change can be characterized by the growth of geographical areas of interaction, and by the temporal flexibilization of freight flows, both resulting in a rising amount of freight transport. The distribution center thus becomes the core component of such a distribution system."

(Hesse and Rodrigue, 2004, p 176)

To conclude, the structural change of centralising a shipper's distribution systems is considered to increase the amount of transport work, which in turn has a direct negative impact on transport-related CO<sub>2</sub> emissions. However, as discussed earlier, transport work alone does not determine the amount of CO<sub>2</sub> emissions generated by a distribution system. Instead, there is also a need to consider measures of a more tactical and operational character that affect the amount

of CO<sub>2</sub> emissions per tonne kilometre and these types of measures will be examined in the subsequent three sections, which examine the ratios of modal split, vehicle utilisation, and fuel and energy efficiency.

#### 3.2.2 Modal split

Modal split refers to the degree various modes of transport are used in a distribution system and it is widely recognised that various modes of transport have varying characteristics. Table 3-1 below presents characteristics of the four main modes of transport with reference to cost and service issues. Different modes of transport also perform differently with regards to  $CO_2$  emissions and to change to more environmentally friendly modes of transport, primarily from planes and/or trucks to train and/or ship, is a solution that is often advocated from a policy-maker perspective (European Commission, 2001; EEA, 2007). Hence, policy-makers advocate that a greater degree of total transport work should be performed by slower modes of transport (i.e. train and ship). Whether or not such a scenario is feasible is questionable. Whereas some studies argue that this is the most promising way of reducing  $CO_2$  emissions pertaining to transport, others are more pessimistic as will be discussed below.

Table 3-1: Characteristics of different transport modes (Kohn and Huge Brodin, 2008, p 7)

	Road	Rail	Water	Air
Cost level	Moderate	Low	Low	High
Balance fixed/variable costs		High portion of fixed costs	High level of variable costs, low level of fixed costs (inland, USA)	High variable costs, low fixed costs
Market coverage	Point to point	Terminal to terminal	Terminal to terminal	Terminal to terminal
Predominant traffic/goods			Low value; high density; large load sizes	High value; low-mod density; small shipments
Lenght of haul	Short to long	Medium to long	Medium to long	Medium to long
Speed (time in transit)	Moderate	Slow	Slow	Fast (major advantage)
Availability	High (distinct advantage)	Moderate	Low	Moderate
Delivery accuracy (on time delivery)	High	Moderate	Low	High
Loss and damage	Low	Moderate-high	Low-moderate	Low
Flexibility (adjustment to shipper's needs)	High	Moderate	Low	Low-moderate

On the one hand, it should be recognised that slower modes of transport are more energy efficient than faster modes of transport. Table 3-2 below exemplifies this by providing an overview of the amount of CO<sub>2</sub> emissions generated by transporting one tonne of goods over a distance of 500 kilometres. The comparison aims at illustrating the large differences in CO<sub>2</sub> emissions that can exist between various modes of transport and is similar to those which have been done in other studies (cf. Lenner, 1993; International Maritime Organization, 2000; Christopher et al, 2007; McKinnon, 2007; NTM, 2007). The table should not be understood as an absolute truth, as the amount of emissions incurred by transport is not only affected by the mode used, but also such aspects as the distance travelled, how the fuel/electricity has been produced, weather conditions, actions of the driver etc. Nevertheless, it helps to illustrate that, in general, the faster a mode of transport is the more it pollutes.

Table 3-2: Amount of CO<sub>2</sub> emissions (kg) depending on mode of transport when transporting one tonne of goods over a distance of 500 kilometres<sup>10, 11</sup>

	Truck	Truck	Airplane	Airplane
	(payload 26 tonne)	(payload 14 tonne)	(Airbus 300-B4)	(Boeing 737-300QC)
Excluding fuel	24	45	600	580
production life cycle	24	45	000	300
Including fuel	26	48	640	620
production life cycle	20	70	040	020

	Train (T44 diesel engine)	Train (electricity)	Ship (> 8,000 dwt)	Ship (< 2,000 dwt)
Excluding fuel production life cycle	7.9	0.0015	6.5	13
Including fuel production life cycle	8.7	0.034	6.6	13

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<sup>&</sup>lt;sup>10</sup> These results have been obtained by using NTM's calculation tool NTMCalc (<a href="http://www.ntm.a.se/ntmcalc/">http://www.ntm.a.se/ntmcalc/</a>), which allows the user to calculate emissions caused by transport given certain conditions. This relationship between various modes of transport was obtained by setting the amount of goods to one tonne, the distance to 500 kilometres, and the fill-rate to 70%. The values for CO<sub>2</sub> emissions represent average values. NTM, the Network for Transport and Environment, is a non profit organisation, initiated in 1993, aiming at establishing a common base of values on how to calculate the environmental performance for various modes of transport. In order to promote and develop the environmental work in the transport sector, the Network for Transport and Environment (NTM) acts for a common and accepted method for calculation of emissions, use of natural resources and other external effects from goods and passenger transport.

<sup>&</sup>lt;sup>11</sup> The emission values for electrically powered trains will vary depending on the electricity mix of a particular country. In this case, the electricity mix used in the calculation is based on values that pertain to a Swedish setting. The figures used by NTM (2007) have been provided by Banverket, the Swedish Rail Administration and is based on electricity generated through hydropower. Hence, in those cases where electricity has been generated through the use of non-renewable resources (e.g. coal), the emission values for "Including fuel production life cycle" would not be as favourable as in this comparison.

On the other hand, we can acknowledge that most distribution systems in Europe are designed so as to satisfy current customer demands of 24-72 hours delivery lead-times. Relating this to the discussion in section 3.1 of how logistics changes and decisions are made, it can be argued that shippers have designed their distribution systems in such a way that more environmentally friendly modes of transport are not considered to be viable in these types of systems. The reason for this is that the relative environmental advantage of these modes comes at the expense of, for instance, longer and less precise lead-times (also see Table 3-1).

A specific consequence of this modal adaptation (cf. Hesse and Rodrigue, 2004) is that the amount of rail transport has declined from just over 20% of total freight transport to approximately 8% between 1970 and 2000, since rail freight is not regarded as being as competitive as road freight (EU, 2007). An every-day life example of the situation described above is that of the Swedish clothing retailer H&M. In a news paper interview, the company's environmental manager was asked why the company does not employ more rail transport (SvD, 2007). According to the interview, H&M opts for an 80/20 split between road freight and rail freight in favour of the former for its shipments within Europe, but the company would like to use rail freight to a greater degree. H&M argues that this is not feasible today, as lead-times for transport by means of train are too long. A shipment from Rumania to Sweden, for example, takes three days by road, whereas the same transport can take ten days by train. Owing to this, H&M claims that slower modes of transport are not sustainable from a business perspective, given current demands on lead-times. Hence, in this case, H&M's demand on short lead-times are at odds with the company's ability to reduce transport-related CO2 emissions per tonne kilometre by means of employing a slower mode of transport. On the same topic, a recent Swedish study revealed that transporting more freight by rail and using more intermodal transport (truck-rail) were ranked very low as measures implemented by shippers to improve their environmental performance (Lammgård, 2007). Both of these measures were only used by 0.6% of the respondents. The respondents were also asked to rank the importance of environmental efficiency in comparison to other logistics issues when choosing transport solutions. In this ranking, environmental efficiency was attributed a weight of importance of 5%, whereas price was given 58%, transport time 21%, and on-time delivery 17%.

The preceding discussion on modal split is relevant here for three reasons, of which the first relates directly to the discussion on rail freight and intermodal rail-truck transport above. The latter type of transport solution aims at combining the strengths of road freight (speed, flexibility, and accessibility) with the strengths of rail freight (ability to transport goods over long distances at a low cost and with lower amounts of CO<sub>2</sub> emissions) (Kreutzberger et al, 2006; Flodén, 2007; Lammgård, 2007). Both *Kohn (2005)* and Aronsson and Huge Brodin (2003; 2006) have shown that by consolidating transport flows in a distribution system, a shipper can create an opportunity

to change mode of transport from unimodal road transport to intermodal rail-truck transport. This is an important issue in a centralised distribution system, as a consolidated flow is created between the production unit and the central warehouse in such a system (see Figure 3-2). Furthermore, this link in the distribution system is a main contributor of transport work, since all goods are shipped through this link in the system (*Kohn, 2005*; *Kohn and Huge Brodin, 2008*). Hence, a change in mode of transport for this particular flow to a mode that is more environmentally friendly is expected to have a large effect on transport-related CO<sub>2</sub> emissions for the system as a whole. In line with this, the forthcoming analysis will address how transport-related CO<sub>2</sub> emissions for the whole distribution system are affected when an intermodal rail-truck transport solution is employed for the consolidated flow when a distribution system is centralised.

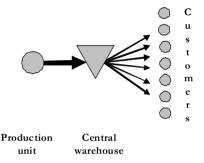


Figure 3-2: Illustration of the consolidated flow that is created in a centralised distribution system

The second reason why modal split is an issue in this dissertation is concerned with an important aspect of centralised distribution, which is that a centralised distribution system is considered to generate a lower need for emergency deliveries compared to a decentralised distribution system (the reduced need for emergency deliveries in a centralised distribution system is enabled by an improved stock availability, an issue that is discussed further in sections 3.3.2-3.3.4). An emergency delivery can be defined as a delivery that occurs when a warehouse is out of stock and the demand therefore needs to be satisfied by shipping the product from another location in the distribution system (Abrahamsson, 1992; Evers, 1997). This type of delivery is often performed by faster modes of transport than are regular deliveries (Abrahamsson, 1992; Kohn, 2005). Consequently, a reduction in the amount of emergency deliveries is also expected to have a positive impact on transport-related CO<sub>2</sub> emissions, as transport work will be shifted from faster and more polluting modes of transport to slower and less polluting modes. That is, by centralising a distribution system, a shipper will alter the modal split as transport work is shifted from a faster mode of transport (emergency deliveries) to a slower mode of transport (regular deliveries). In accordance with this discussion, the forthcoming analysis will address how

transport-related CO<sub>2</sub> emissions for the whole distribution system are affected owing to a decrease in emergency deliveries enabled by centralisation of a distribution system.

The third and final reason why modal split is an issue in this dissertation is connected with another fundamental principle that is often discussed by proponents of centralised distribution. This principle implies that centralisation not only concerns the physical structure of the system, but also the responsibility for the design and management of the system (Abrahamsson, 1992; Norrman, 1997; Abrahamsson et al, 2003). In a decentralised distribution system with many subsidiaries, a different distribution system that suites the specific demands of each subsidiary and its particular market is typically employed (Abrahamsson et al, 2003; Kohn, 2005). This implies that the preferred mode of transport can vary market by market in this type of distribution system. In a centralised distribution system on the other hand, the goal is to achieve economies of scale. One important element in this is the standardisation of logistics activities, something which from a transport perspective implies that a solution that suits the whole of the system is sought (Abrahamsson, 1992; Abrahamsson et al, 2003; Kohn, 2005). Hence, by adopting a transport solution that suits the whole of a distribution system, a shipper will possibly alter the modal split for parts of the distribution system when it is centralised. The effect this will have on CO<sub>2</sub> emissions is dependant on the change in mode of transport, as a change to a more environmentally friendly mode of transport will have a positive effect and vice versa. The coming analysis will therefore address how finding a standard transport solution that suits the whole of a shipper's distribution system will affect the modal split in the system and thereby CO<sub>2</sub> emissions incurred by shipments in the system.

To conclude the discussion on modal split, the analysis will address how centralising a distribution system will affect a shipper's opportunity to change mode of transport with reference to three areas: (i) effects of employing an intermodal rail-truck transport solution for the consolidated flow, (ii) effects of decreasing the amount of emergency deliveries, and (iii) effects of employing a standardised transport solution for regular deliveries that suits the whole of the distribution system.

#### 3.2.3 Vehicle utilisation

Increased vehicle utilisation is the third way in which it is possible to achieve environmental improvements with regards to transport (Wu and Dunn, 1995; Blinge and Lumsden, 1996; McKinnon, 2000; McKinnon, 2003; McKinnon, 2007). McKinnon (2003) argues that this is the area that holds the most promising solutions since these types of improvements tend to finance themselves as they in fact are efficiency improvements.

Samuelsson and Tilanus (1997) examine the efficiency of goods transportation, and claim that overall efficiency is affected by efficiencies in four dimensions; (i) time, (ii) distance, (iii) speed, and (iv) capacity. Time efficiency refers to the percentage of total available time that a vehicle is utilised, whereas distance efficiency refers to the extent to which the shortest route between origin and destination is used. Speed efficiency concerns the extent to which transportation is carried out at maximum speed. Finally, capacity efficiency refers to how well the physical capacity of a vehicle is utilised. The authors divided each of these efficiencies into eighteen partial efficiencies, which they discussed and analysed together with a panel of fifteen experts from road haulage and forwarding companies in Sweden and the Netherlands, in order to assess the overall efficiency in less-than-truckload (LTL) distribution as well as to identify the most promising areas for improvement. Table 3-3 below shows the results of Samuelsson and Tilanus' (1997) study.

Table 3-3: Summary of expert assessments with regards to efficiencies in regional LTL distribution by road (Samuelsson and Tilanus, 1997, p 149)

		Expert assessments			
		Average (%)	Dispersion*	Potential**	
Time	Business	37	1.2	3.2	
	Availability	94	2.8	1.1	
	Utilisation	91	2.4	2.2	
	Driving	50	3.3	3.5	
Distance	Infrastructure	83	1.0	1.0	
	Backhaul	63	2.6	3.4	
	Routing	85	1.6	2.2	
	Detour	62	1.4	1.9	
	Actual	88	2.7	2.6	
Space	Limit	71	1.0	1.0	
	Congestion	75	3.6	1.0	
Capacity	Capacity	27	2.2	1.5	
	Floor space	83	2.7	2.6	
	Height	47	4.1	3.1	
	Pallet	69	2.2	1.8	
	Box	88	1.3	1.2	
	Net product	39	2.5	1.0	
	Actual	86	3.2	2.8	

<sup>\*</sup>Coefficient of variation on a five scale; 1 = very small, 5 = very large.

These efficiencies can be related to the three-tiered model of logistics by Wandel et al (1992) and to the shipper perspective applied in this dissertation, as discussed in section 1.4.2. With regards to this perspective, it can be argued that most of these efficiencies are not the primary domain of a shipper that procures its demand for transport services from a transport provider. Rather, most of these efficiencies relate to decisions and changes made by policy-makers (e.g. laws influencing the size of vehicles, infrastructure, speed limits, resting time for drivers) and transport service providers (e.g. vehicle routing, backhaul management, load/unloading time).

<sup>\*\*</sup>Potential for improvement on a five point scale; 1 = very little, 5 = very much

However, there is one area where it is argued that a shipper is able to improve on vehicle utilisation in a centralised distribution system, and that is with reference to the fill-rate on laden trips. Aronsson and Huge Brodin (2003; 2006) and *Kohn (2005)* illustrate in their respective studies how shippers have been able to achieve fill-rate improvements for the consolidated flow that arises in a centralised distribution system. The authors conclude that a reason for these results is that this particular flow is a replenishment flow that is of a stable and reoccurring character, which implies that it is easier to manage and plan in comparison to other flows in the distribution system. In *Kohn (2005)*, for instance, the shipper in question had undertaken a fill-rate improvement programme for the whole distribution system after it had been centralised. However, results of this programme indicate that the shipper only managed to achieve continuous month-to-month fill-rate improvements in the consolidated flow, whereas the shipper could not achieve the same results in other parts of the distribution system.

From an environmental perspective, an improvement in fill-rate will have a direct positive effect since the relative fuel consumption decreases as the fill-rate increases. Blinge and Lumsden (1996), for instance, claim that fuel consumption only increases by 20% when the fill-rate is increased from 50% to 100%, thus resulting in lower CO<sub>2</sub> emission per tonne kilometre. Similar figures have also been found by other authors (International Maritime Organization, 2000; *Kohn, 2005*). Figure 3-3 below illustrates how the fill-rate affects the amount of CO<sub>2</sub> emissions per tonne kilometre for a heavy truck with a payload of 26 tonne, where the emission values are based on data from NTM (2007).

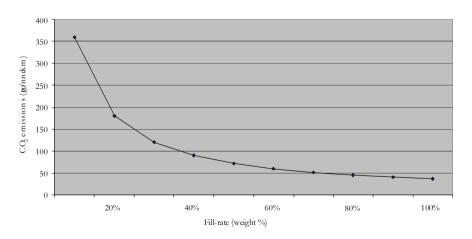


Figure 3-3: Amount of CO<sub>2</sub> emissions per tonne kilometre as a function of fill-rate

To conclude, the discussion on vehicle utilisation, the analysis will address how centralising a distribution system will affect a shipper's opportunity to achieve fill-rate improvements for the consolidated flow between the production unit and central warehouse in such a system.

#### 3.2.4 Fuel and energy source efficiency

Fuel and energy source efficiency is a category of measures that includes enhancements that reduce CO<sub>2</sub> emissions per tonne kilometre that pertain to technology improvements of various kinds and changes in driving behaviour. Ang-Olson and Schroeer (2002) discuss ten types of readily available measures pertaining to long-haul road freight in a US context, which in cumulative terms represent a possible reduction in fuel consumption by 33%. However, McKinnon (2007) argues that it must be acknowledged that some of these measures are counteractive, meaning that an improvement in one measure will impact negatively on another. An example of such a trade-off is that of reducing the average speed from 65 mph to 60 mph. Even though this decrease will have a positive effect on fuel consumption, it will simultaneously reduce the effectiveness of improvements with regards to tractor and trailer aerodynamics (Ang-Olson and Schroeer, 2002). The percentages presented by the authors are cautious estimations as these types of measures are often associated with some uncertainty. With regards to driver training, for instance, the authors discuss a potential reduction of 4%, whereas McKinnon (2007) point to studies where this type of measure is expected to yield 8-10% savings<sup>12</sup>.

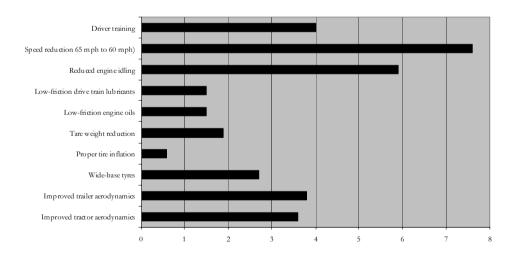


Figure 3-4: Reduction in fuel consumption (%) relating to various measures (based on Ang-Olson and Schroeer, 2002)

<sup>&</sup>lt;sup>12</sup> Driver training has also been tested for rail freight. A pilot project by Green Cargo has shown that fuel consumption can be lowered by as much as 20% for a diesel T44 locomotive if drivers are trained in fuel efficient driving (Flodén, 2007).

Besides employing the measures presented above, it is also possible to improve the efficiency by adopting fuel types that emit less CO<sub>2</sub> per vehicle kilometre, an area that Wu and Dunn (1995) stress that logistics managers need to take into consideration when evaluating the environmental impact of transport:

"Logistics managers need to take the use of alternative fuels into account when selecting carriers for their business because other things being equal, an environmentally responsible carrier may prove a better long-term choice."

(Wu and Dunn, 1995, p 33)

Table 3-4 below illustrates the CO<sub>2</sub> reduction potential associated with various types of biofuels. A difficult issue when it comes evaluating the positive effects of biofuels is how they are produced. For instance, an assessment by the Swedish Environmental Protection Agency with reference to the potential in using ethanol, showed that the CO<sub>2</sub> reduction potential varied between 40% and 100% depending on how the fuel was produced (Naturvårdsverket, 2004).

Table 3-4: Example of potential CO<sub>2</sub> reductions with reference to various types of biofuels (Scania, 2007)

	Ethanol	Synthetic diesel	Biodiesel	Biogas
	(sugar cane)	(biomass)	(FAME, RME, etc.)	(from waste and sewage)
Reduction in CO <sub>2</sub> including fuel production life cycle	< 90%	< 80%	< 70%	< 100%

Similar to the discussion on vehicle utilisation, measures associated with fuel and energy efficiency can be argued to lie outside the organisational boundaries of a shipper that uses a logistics service provider to handle its transport and thereby also outside the scope of this dissertation. Nevertheless, as a procurer of transport services, a shipper can affect the amount of emissions incurred by transport by means of carrier selection (Wu and Dunn, 1995; Björklund, 2005) and by choosing a carrier that employs measures such as those described above, a shipper can indirectly reduce transport-related CO<sub>2</sub> emissions per tonne kilometre. This is interesting as centralised distribution not only implies that the physical structure of the system is centralised, but also that the management of the system is centralised (Abrahamsson, 1992; Norman, 1997; Abrahamsson et al, 2003). As a result, procurement of transport services is also centralised, meaning that whereas each subsidiary procures transport services for its particular market, these services are procured centrally for the whole distribution system in a centralised system. Typically, a shipper will reduce the number of transport providers operating in the distribution system

when it is centralised, which will improve its bargaining position compared to its transport providers (Coyle et al, 2003; *Kohn, 2005*; Aronsson et al, 2008):

"By reducing the number of carriers it uses, a shipping firm increases the freight volume and freight revenue that it gives to a carrier, thereby increasing the ability to have the carrier provide the rates and services the shipper needs. As the shipper concentrates its freight business in a limited number of carriers, the shipper becomes more important to each carrier; and each carrier, in becoming more dependent on the shipper's business, is more willing to negotiate with the shipper."

(Coyle et al, 2003, p 375)

Coyle et al (2003) emphasise that single sourcing is the ultimate concentration of market power, and one in which a shipper can maximise its power per freight dollar spent. However, single sourcing is simultaneously associated with a great deal of risk, since transport in a shipper's distribution system in such a case becomes heavily dependant on that particular transport provider having a smoothly functioning transport network.

In line with the discussion above, the analysis will address how centralised management of a distribution system can affect a shipper's opportunity to reduce transport-related CO<sub>2</sub> emissions indirectly through an improved bargaining position with its providers of transport services.

## 3.2.5 Model of analysis with regards to analysing the effect of measures for reducing CO<sub>2</sub> emissions per tonne kilometre

The previous discussion relates directly to how a shipper can reduce transport-related CO<sub>2</sub> emissions when a distribution system is centralised. Four important ratios have been examined and related to the purpose of this dissertation; (i) transport intensity, (ii) modal split, (iii) vehicle utilisation, and (iv) fuel and energy source efficiency. The discussion has also illustrated how measures connected to these ratios relate to a number of key characteristics of a centralised distribution system, where a characteristic denotes a trait or feature of the system. With regards to the centralisation of a distribution system, the following three characteristics have been identified and examined, based on previous research relating to centralised distribution (Abrahamsson, 1992; Norrman, 1997; Abrahamsson et al, 2003; Aronsson and Huge Brodin, 2003; Kohn, 2005; Aronsson and Huge Brodin; 2006; Kohn and Huge Brodin, 2008):

- The creation of a consolidated flow between the production unit and the central warehouse
- A decreased need for emergency deliveries
- Centralised management and standardisation of logistics activities for the system as a whole

These characteristics relate to the examined ratios, but in different ways. Therefore, the first part of the forthcoming analysis will address how these characteristics affect a shipper's opportunity to reduce transport-related CO<sub>2</sub> emissions per tonne kilometre when a distribution system is centralised. This is depicted in Figure 3-5 below, which illustrates the focus for the first part of the analysis that is presented in section 5.1. In line with the discussion in the previous sections, the following areas will be analysed:

- (i) Effects of employing intermodal rail-truck transport for the consolidated flow (connection between consolidated flow and modal split)
- (ii) Effects of a fill-rate improvement for the consolidated flow (connection between consolidated flow and vehicle utilisation)
- (iii) Effects of decreasing the amount of emergency deliveries (connection between emergency deliveries and modal split)
- (iv) Effects of employing a standardised transport solution for regular deliveries that suits the whole of the system (connection between centralised management and modal split)
- (v) Effects of shipper's improved bargaining position compared to its providers of transport services (connection between centralised management and fuel and energy source efficiency)

It should also be noted that this analysis will not directly address how or to what extent transport intensity is affected when a distribution system is centralised. The reason for this is that previous studies have showed how this type of structural change will have a negative effect on transport intensity, since the average length of haul is increased (Rodrigue et al, 2001; McKinnon, 2003; *Kohn, 2005*; McKinnon, 2007; Schenker Consulting, 2007). Rather, the analysis will address how centralising a distribution system can create an opportunity for a shipper to employ measures that improve the other three ratios (i.e. modal split, vehicle utilisation, and fuel and energy source efficiency) and also illustrate the potential of such measures. Given that centralising the distribution system causes an increase in transport work, the analysis will contrast and compare these opportunities with various levels of increase in transport work (also see section 5.1).

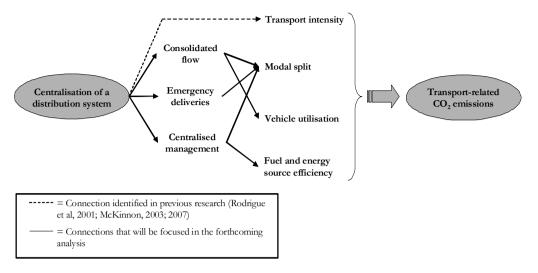


Figure 3-5: Focus in the first part of the analysis

So far, the discussion has centred on how a shipper can reduce transport-related  $CO_2$  emissions when centralising its distribution system. However, if environmental issues are to become an integrated part of logistics decisions, as called for by some researchers (Wu and Dunn, 1995; Beamon, 1999; Skjoett-Larsen, 2000), it is also important to form an understanding of how these measures will relate to the more traditional performance issues in logistics of cost and service. This will be discussed further in the subsequent section, which will examine how the measures to reduce transport-related  $CO_2$  emissions discussed above are considered to be connected to the provision of cost efficient customer service with regards to a shipper's distribution system.

# 3.3 Examining potential interrelationships between a reduction in transport-related CO<sub>2</sub> emissions and the provision of cost efficient customer service in a shipper's distribution system

Trade-off considerations are an integral part of logistics management, where trade-offs in broad terms can concern trade-offs such as cost vs. cost, cost vs. service, or cost vs. sales (e.g. Ballou, 1978; Dowdle, 1985; Lambert and Stock, 1993; Jackson et el, 1994; Coyle et al, 2003). With regards to the distribution side of a logistics system, one of the more important issues a logistics manager has to deal with is deciding on the number of warehouses, as this greatly affects the total cost of distribution and the service the system provides (Coyle et al, 1988; Abrahamsson, 1992; Ballou, 2001; Coyle et al, 2003; Croxton and Zinn, 2005; Gill and Bhatti, 2007). As discussed in section 3.2.1, the number of warehouses in a distribution system is also considered to affect transport-related CO<sub>2</sub> emissions and a decentralised distribution system with more warehouses is considered more favourable (Wu and Dunn, 1995; Rodrigue et al, 2001; McKinnon, 2003;

McKinnon, 2007). This section will therefore discuss how the number of warehouses in a distribution system affects the system's performance in terms of cost and service, and the possible interrelationships that exist between a reduction in transport-related CO<sub>2</sub> emissions and the provision of cost efficient customer service. These interrelationships can exist in terms of a either a trade-off between a reduction in transport-related CO<sub>2</sub> emissions and cost efficient customer service or in terms of a situation where a reduction in transport-related CO<sub>2</sub> emissions will not affect the provision of cost efficient customer negatively.

The objective of the traditional trade-off analysis is to identify the lowest distribution cost by contrasting warehousing costs and transportation costs (Croxton and Zinn, 2005). These two costs are found in many total cost models, as they constitute the two largest costs in a distribution system (Copacino and Lapide, 1984; Abrahamsson and Aronsson, 1999; Croxton and Zinn, 2005; Establish, 2007). However, it is also quite common to find that a trade-off analysis includes other costs. The most common cost to be included is that of inventory costs (Coyle et al, 1988; Lambert and Stock, 1993; Abrahamsson and Aronsson, 1999; Aronsson, 2002; Croxton and Zinn, 2005). Together, these three costs are considered to constitute approximately 90% of total distribution costs (Copacino and Lapide, 1984; Abrahamsson and Aronsson, 1999; Establish, 2007). Examples of other costs that are included at times are administrative costs (Abrahamsson and Aronsson, 1999; Aronsson, 2002; Establish, 2007), order handling costs (Lambert and Stock, 1993), packaging costs (Abrahamsson and Aronsson, 1999; Aronsson, 2002), and cost of lost sales (Coyle et al, 1988; Abrahamsson, 1992). The cost of lost sales in particular has been found to be of great importance when considering the number of warehouses in a distribution system and whether a centralised or a decentralised distribution system is to be preferred (Coyle et al, 1988; Abrahamsson, 1992). This type of cost is associated with the level of customer service that the distribution system can provide. The significance of customer service has increased in importance in logistics and from mainly being concerned with cost performance back in the 1970s, logistics performance at present relates to a higher degree to customer service objectives (e.g. Christopher, 1998; Lambert and Stock, 1993; Innis and La Londe, 1994; Riopel et al, 2005; CSCMP, 2007). Nevertheless, the need to control costs is not ignored; instead cost objectives are typically incorporated into the customer oriented approach that signifies logistics (Poist, 1974; Chow et al, 1994; Ploos van Amstel and D'hert, 1996; Coyle et al, 2003; Riopel et al, 2005). Customer service can imply a number of different things depending on the type of situation:

"Anyone who has ever struggled to define customer service soon realized the difficulty of explaining this nebulous term. Thus, different people will understandably have different interpretations of just what customer service means."

With regards to earlier research on centralised vs. decentralised distribution, customer service is primarily discussed in terms of stock availability, order lead-time, and precision in lead-time (Coyle et al, 1988; Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; *Kohn, 2005*; Aronsson and Huge Brodin, 2006). When the discussion centres on the number of warehouses in a distribution system and the expected impact this will have on the service provided by the system, customer service is considered in terms of cost of lost sales. This type of cost has been found to be of great importance when contrasting the view of Coyle et al (1988; 2003) with that of proponents of a centralised approach to distribution (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; Aronsson and Huge Brodin, 2006). Accordingly, the next subsections will examine the following costs and their relation to the number of warehouses in a distribution system:

- Warehousing costs
- Inventory costs
- Transportation costs
- Cost of lost sales (indicated by stock availability, order lead-time, and lead-time precision)

Each of the four following subsections will examine these costs one by one. The discussion will first centre on how earlier research has portrayed how these costs are affected by the number of warehouses in a distribution system. This discussion will in turn be related to the discussion in section 3.2 on how a shipper can reduce its transport-related CO<sub>2</sub> emissions when a distribution system is centralised. As described in section 3.2.5, the first part of the analysis will focus on five different areas connected to transport-related CO<sub>2</sub> emissions; (i) effects of employing intermodal rail-truck transport for the consolidated flow, (ii) effects of a fill-rate improvement for the consolidated flow, (iii) effects of decreasing the amount of emergency deliveries, (iv) effects of employing a standardised transport solution for regular deliveries that suits the whole of the system, and (v) effects of a shipper's improved bargaining position compared to its providers of transport services.

The aim of this discussion is therefore not to have reservations about whether or not centralised distribution can improve a shipper's performance in terms of cost and service, but rather to

identify which of the cost and service elements listed above that are relevant to consider with reference to the five areas listed above. In this way, the discussion will result in what is the focus for the second part of the analysis. This part will seek to address how the discussed measures to reduce transport-related CO<sub>2</sub> emissions per tonne kilometre will affect the provision of cost efficient customer service in a shipper's distribution system.

#### 3.3.1 Warehousing costs

Warehousing costs typically include costs for running the facilities (e.g. rent, heating, and electricity costs), personnel and equipment costs related to running these warehouses, and costs for transfers within a facility (Coyle et al, 1988; Abrahamsson and Aronsson, 1999; Aminoff et al, 2002; Aronsson, 2002; Coyle et al, 2003). These costs are considered to be of a semi-fixed character in a shorter timeframe as they do not change in direct proportion to the amount of inventory in the distribution system. Instead, this type of cost is considered to be dependant on the number of warehouses and is expected to decrease/increase in accordance with the number of warehouses. That is to say that as the number of warehouses in a distribution system increases, so will the cost of warehousing.

From the discussion on transport-related  $CO_2$  emissions earlier in the dissertation, it can be understood that there is a negative trade-off between warehousing costs and transport-related  $CO_2$  emissions. The reason for this is that the total amount of vehicle kilometres in a distribution system is said to increase as the number of warehouses in a distribution system decreases (also see sections 1.2 and 3.2.1), whereby the transport intensity of the distribution system, as measured in terms of tonne kilometres, will increase (Wu and Dunn, 1995; Rodrigue et al, 2001; McKinnon, 2003; Croxton and Zinn, 2005; *Kohn, 2005*; McKinnon, 2007).

However, as discussed in section 3.2.5 and also above, the analysis will not primarily focus on whether or not transport work is affected when a distribution system is centralised, but rather on how a shipper is provided with new opportunities to make changes with regards to measures that will reduce transport-related CO<sub>2</sub> emissions per tonne kilometre. That is, the analysis will take its starting point in the fact that a shipper will on the one hand decrease warehousing costs (Coyle et al, 1988; Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; Aminoff et al, 2002; *Kohn, 2005*) and on the other hand increase transport work (Wu and Dunn, 1995; Rodrigue et al, 2001; McKinnon, 2003; Croxton and Zinn, 2005; *Kohn, 2005*; McKinnon, 2007) by virtue of centralising the distribution system. Consequently, warehousing costs will not be included in the second part of the analysis. The reason for this is that whereas warehousing costs are more closely associated with the structural change itself (e.g. that they decrease as a distribution system is centralised), the forthcoming analysis will focus on how the measures to reduce CO<sub>2</sub> emissions

per tonne kilometre (see sections 3.2.2-3.2.4) affect the provision of cost efficient customer service in the new centralised distribution system.

#### 3.3.2 Inventory costs

Whereas warehousing costs are of a semi-fixed character, inventory costs are variable and proportional to the amount of inventory stored in a warehouse. The cost for carrying inventory can be divided into cost of tied up capital and costs for insurance, wastage, and obsolescence (Coyle et al, 1988; Lambert and Stock, 1993; Aronsson, 2002). Even though inventory costs are variable, they are not considered to increase in a linear manner as the number of warehouses increase. The reason for this is that as the number of warehouses increases, so does the total amount of slow-moving goods for the system as whole, since each facility will hold a certain amount of slow-moving goods (Coyle et al, 1988; Zinn et al, 1989; Coyle et al, 2003). Hence, as the number of warehouses in a distribution system increases, the cost for holding inventory is expected to increase exponentially. By reducing the number of warehouses, it is possible to decrease the total amount of inventory for the system as a whole at the same time as it is possible to increase product availability. The former of these two opportunities is related to the square root law, which in generic terms illustrates by how much inventories can be decreased as the number of warehouses is reduced (Maister, 1976; Zinn et al, 1989). The reason why product availability is expected to increase in a centralised distribution system is attributed to the fact that a central warehouse, due to its larger size, is able to hold a fuller range of products compared to that of a single warehouse in a decentralised system (also see section 3.3.3). As the central warehouse supplies multiple markets as opposed to a single market, oscillations in demand between the various markets can be evened out, thus resulting in a higher availability13 (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999).

Turning the discussion to the identification of potential interrelationships between a reduction in transport-related CO<sub>2</sub> emissions and inventory costs, the latter cost becomes an issue when one of the five areas that will be examined in the forthcoming analysis, namely that of employing intermodal rail-truck transport for the consolidated flow, is considered. The reason for this is that even though this transport solution has the advantage of combining the strengths of road and rail freight, it comes at the expense of generally longer and less precise lead-times, which is the primary disadvantage of rail freight (Coyle et al, 2003; Flodén, 2007; Lammgård, 2007; Kohn, 2008). Therefore, if a shipper desires to maintain its level of customer service towards the end customer in terms of stock availability, order lead-time, and lead-time precision, the increase in lead-time and lead-time precision between the production unit and the central warehouse will need to be compensated by an increase in safety stock levels. It is therefore argued that there is a

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<sup>&</sup>lt;sup>13</sup> Note that the discussion does not focus on availability measured in terms of customer lead-time or the like, but rather whether a certain product is in stock or not at the time of a customer request.

potential negative trade-off between inventory costs and a reduction in transport-related CO<sub>2</sub> emissions from employing an intermodal rail-truck transport solution for the consolidated flow in a centralised distribution system.

With regards to the other areas that will be discussed in the analysis, inventory costs do not become an issue. The reason for this is that inventory costs are mainly associated with keeping stock at the nodes in the distribution system, whereas transport-related CO<sub>2</sub> emissions are affected by the transport activity that takes place in the links of the distribution system.

To conclude, inventory costs will only be included with reference to the effects of employing an intermodal transport solution for the consolidated flow in the coming analysis on how a reduction in transport-related CO<sub>2</sub> emissions will affect the provision of cost efficient customer service.

#### 3.3.3 Transportation costs

Transportation costs are those costs associated with transporting a product to the customer and in contrast to warehousing costs and inventory costs there is not a consensus as to how transportation costs are affected by the number of warehouses. Coyle et al (1988; 2003) on the one hand, argue that this type of cost decreases as the number of warehouses increases. The reason for this is twofold, as discussed by Croxton and Zinn (2005):

"Adding warehouses generally decreases the number of miles travelled because the total distance a unit is shipped, from the supplier to the warehouse and then to the customer, gets closer to a straight-line. In addition, the most expensive portion of that journey is often from the warehouse to the customer as those are usually less-than-truckload shipments. The average distance of this leg of the journey is reduced when there are more warehouses in the network."

(Croxton and Zinn, 2005, p 149)

What this quotation illustrates, is that the average length of haul becomes shorter and more direct as the number of warehouses increases and that the last part of distribution, i.e. that between the warehouse and the customer, is usually the most expensive part of distribution. This view is based on the notion that the distance between a shipper and its customers should be measured in terms of physical distance. Thus, when adopting this view there is a close link between the amount of transport work and transportation costs generated by a distribution system.

Abrahamsson (1992) presents a somewhat different view, and claims that transportation costs must not necessarily increase even though total transport work will increase as goods will need to

be shipped further when the number of warehouses in a distribution system is reduced (Coyle et al, 1988; Croxton and Zinn, 2005). There are two reasons for this; the first concerns the need to distinguish between transportation costs for regular deliveries and transportation costs for emergency deliveries within the distribution system (Abrahamsson, 1992). An emergency delivery can be defined as a delivery that occurs when a warehouse is out of stock and the demand therefore needs to be satisfied by shipping the product from another location in the distribution system (Abrahamsson, 1992; Evers, 1997). Whereas costs relating to regular deliveries are affected by the volume handled, i.e. the amount of transport work that they generate, costs for emergency deliveries are said to be affected primarily by stock availability (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999). This view contrasts with that of Coyle et al (1988; 2003) and states that it is only transport work linked to regular deliveries that are affected by the geographical distance between a shipper's warehouse and the customer. By centralising the distribution system, it is possible to improve product availability while at the same time the total amount of inventory is reduced. This is because a central warehouse is able to hold a fuller range of products and even out fluctuations in demand for various markets. In line with this, Abrahamsson (1992) argues that the improvement in stock availability will reduce the need for emergency deliveries caused by stock outs. As this type of delivery is often urgent, faster transport solutions that are more costly than using the regular and preferred solution are often used to perform these shipments. Hence, even though total transport work is expected to increase as the number of warehouses is decreased, it is argued that total transportation costs must not necessarily increase, given that it is dependant on costs for both regular and emergency deliveries (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999).

The second reason why it is argued that transportation costs can stay constant despite an increase in transport work relates to how a centralised distribution system is managed, an issue that has been discussed earlier in the framework as well. By standardising the logistics activities in the distribution system, the procurement of transport services will also be centralised (Abrahamsson, 1992; Norrman, 1997; Abrahamsson et al, 2003). Owing to this, a shipper will be able to obtain better freight rates when approaching carriers than would a single subsidiary (Abrahamsson, 1992; Coyle et al, 2003). Hence, a shipper has the potential to decrease the transportation cost in relation to transport work when the distribution system is centralised, due to economies of scale. To summarise this discussion, Figure 3-6 below illustrates how Coyle et al (1988; 2003) and Abrahamsson (1992) respectively, view the cost of transport as a function of number of warehouses.

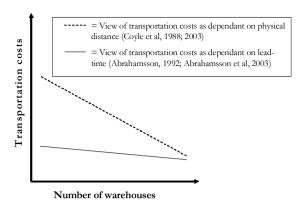


Figure 3-6: Number of warehouses and transportation costs

Transportation costs are also an issue for all of the five areas that will be discussed in the following analysis. The subsequent paragraphs will discuss the expected effect each of the areas will have on transportation costs.

With reference to rail-truck intermodal transport, it has already been argued that this type of transport solution aims at combining the strengths of rail and road freight, of which the former has a cost advantage for transport over longer distances (Flodén, 2007; Lammgård, 2007; Kohn, 2008). Thereby, a change from unimodal truck transport to intermodal rail-truck transport for the consolidated flow in a centralised distribution system is expected to have a positive impact on transportation costs. Flodén (2007), for example, concludes through simulations that intermodal rail-truck transport is almost always competitive from a cost perspective compared to unimodal truck transport and that its main disadvantage is associated with its service performance in terms of pick-up and delivery times.

Turning to the impact on transportation costs that a reduction in emergency deliveries will have, a reduction in emergency deliveries is expected to have a positive impact on transportation costs. The reason for this is that emergency deliveries are more costly than regular deliveries, since they are often performed by faster modes of transport (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; *Kohn, 2005*). Hence, by transferring part of the total transport work from emergency deliveries to regular deliveries, a shipper will improve on transportation costs. As discussed above, this is one of two reasons why Abrahamsson (1992) argues that transportation costs should not be thought to increase as a distribution system is centralised, even though the total amount of transport work will increase.

With regards to how employing a standardised transport solution for regular deliveries in a centralised distribution system will affect transportation costs, the expected outcome will most likely be dependant on the type of transport mode that is employed in the centralised distribution system. If a slower mode of transport is employed compared to the one that has been employed by the local subsidiaries in the decentralised distribution system, then it is expected that transportation costs will decrease and vice versa.

With regards to fill-rate improvements, this is expected to have a positive impact on transportation costs. This is because in essence an improvement in fill-rate is an efficiency gain (Blinge and Lumsden, 1996; McKinnon, 2003; *Kohn, 2005*).

Finally, with regards to how centralised management of the distribution system will affect a shipper's opportunity to reduce transport-related CO<sub>2</sub> emissions by means of an improved bargaining position vis-à-vis its providers of transport services, the expected effect on transportation costs is dependant the reaction of the transport service provider. Some of these changes are costly (Blinge and Lumsden, 1996), whereby there is a risk that this cost will be pushed onto the shipper, in terms of higher transport prices.

To conclude, Table 3-5 below summarises how each of the ratios, associated characteristics, and areas discussed in section 3.2.5 relate to transportation costs. In line with this, transportation costs will be included in relation to all five areas in the second part of the analysis, which addresses how a shipper's measures to reduce transport-related CO<sub>2</sub> emissions per tonne kilometre when a distribution system is centralised will affect the provision of cost efficient customer service.

Table 3-5: Summary of how a reduction in transport-related CO<sub>2</sub> emissions with reference to the ratios and characteristics examined in the first part of the analysis is expected to affect a shipper's transportation costs

Ratio	Characteristic	Focus in the first part of the analysis	Expected impact on transportation costs
Modal split	Consolidated flow	Effect on CO <sub>2</sub> emissions of employing intermodal rail-truck transport	Positive impact as intermodal transport is considered less costly compared to unimodal truck transport (Flodén, 2007; Lammgård, 2007; Kahn, 2008).
	Emergency deliveries	Effect on CO <sub>2</sub> emissions of a decrease in emergency deliveries	Positive impact as slower modes of transport are less costly than faster modes of transport (Abrahamsson, 1992; Flodén, 2007; Lammgård, 2007; <i>Kahn, 2005</i> ).
	Centralised management	Effect on CO <sub>2</sub> emissions of finding a standard solution for the whole of the distribution system	Impact is expected to be dependant on the solution in question. If a change is made to a slower mode of transport then it is expected that costs will decrease and vice versa (Flodén, 2007; Lammgård, 2007; Kohn and Huge Brudin, 2008).
Vehicle utilisation	Consolidated flow	Effect on CO <sub>2</sub> emissions of a fill-rate improvement for the consolidated flow	Positive impact as this is an efficiency gain (Blinge and Lumsden, 1996; McKinnon, 2003; <i>Kohn</i> , 2005).
Fuel and energy source efficiency	Centralised management	Indirect effect on CO <sub>2</sub> emissions by means of imposing more strict demands on transport service providers	Impact is expected to be dependant on reaction of the transport service provider as these types of changes are costly (Blinge and Lumsden, 1996), whereby there is a risk that this cost will be pushed to the shipper in terms of higher transport prices.

#### 3.3.4 Cost of lost sales

With regards to cost of lost sales, there is a similar discrepancy between Coyle et al (1988; 2003) and Abrahamsson (1992) pertaining to how they view this cost in relation to the number of warehouses. Coyle et al (1988; 2003) on the one hand argue that cost of lost sales is expected to decrease as the number of warehouses increases. The reason for this is that the gap between the shipper and its customers that the distribution system aims at bridging is measured in terms of geographical distance. This implies that by holding inventory physically close to the customer, a shipper can uphold a greater level of service than if inventory is held further away. The authors go on to argue that when customer service demands are high, inventory should be kept as close to the customer as possible so as to not jeopardise the relationship with the customer and ultimately, sales volumes:

"One factor affecting the number of warehouses is the need for customer service. There is usually a strong correlation between the need for rapid customer service in local market areas and the degree of substitutability of a product. If competitors are giving rapid service into a market area, a company can be adversely affected in sales volumes if its service to customers in terms of lead time is inferior."

(Coyle et al, 1988, p 278)

From a customer perspective, level of customer service in this instance becomes the equivalent of transport lead-time. The extent to which a shipper can uphold a high degree of customer service in terms of short lead-times is with this view primarily dependant on the geographical distance between a warehouse and the customer. Given this assumption, it is apparent that the more warehouses there are in a distribution system, the shorter the final transport between a warehouse and the end customer will be on average, thus minimising lead-time between the warehouse and the end customer (cf. Croxton and Zinn (2005) above).

Abrahamsson (1992) challenges this traditional view. In contrast to Coyle et al (1988; 2003), the argument is put forward that the gap between a shipper and its customers should be considered in terms of lead-time as opposed to geographical distance (hence the denomination time-based distribution). More specifically, he argues that it is not sufficient to only consider transport-related lead-time, as this only helps to explain part of total customer lead-time. This observation is also made by McKinnon (1989):

"This contradicts the frequent claim that a wide dispersal of stocks is necessary to provide customers with fast delivery. Stock dispersal is only one of a number of factors affecting the order lead time. Christopher et al found that most of the variation in order lead time stemmed from differences in the rate at which firms handled documentation. According to Sweet (1984), the centralisation of stockholding enabled Elida Gibbs, the personal products division of Unilever, to accelerate order processing and thereby reduce order lead times. The centralised facility also maintained a higher level of product availability, despite the fact that it held only half as much stock as was previously dispersed in regional depots."

(McKinnon, 1989, p 114)

An important service aspect in a time-based centralised distribution system is that of stock availability. As discussed in relation to inventory costs, it is possible to simultaneously reduce the total amount of inventory and increase stock availability by reducing the number of warehouses. Thus, it is possible to achieve a higher degree of customer service with regards to stock availability in a centralised distribution system compared to a decentralised distribution system (see Figure 3-7).

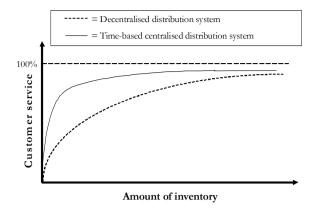


Figure 3-7: Customer service as a function of amount of inventory (Abrahamsson, 1992, p 242)

Through a higher degree of stock availability, it also possible to reduce the lead-time as well as improve its precision, as a greater portion of a customer orders can be delivered directly when an order is placed. Based on this improvement in service, Abrahamsson (1992) argues, in contrast to Coyle et al (1988; 2003), that cost of lost sales should not increase as the number of warehouses decreases (see Figure 3-8).

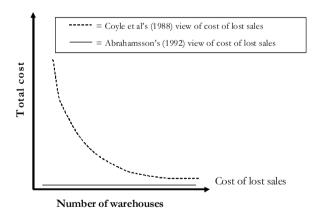


Figure 3-8: Number of warehouses and cost of lost sales

The discussion on the service provided by a distribution system in terms of stock availability, lead-time, and lead-time precision above is also relevant when considering the five different areas with regards to transport-related CO<sub>2</sub> emissions that will be the focus of the first part of the analysis. The following paragraphs will therefore discuss how a shipper's measures to reduce transport-related CO<sub>2</sub> emissions per tonne kilometre is expected to affect stock availability, lead-

time, and lead-time precision with reference to these areas, associated ratios, and characteristics examined earlier in the frame of reference.

With regards to the consolidated flow and employing an intermodal rail-truck solution, this type of solution is slower and is advocated to offer a lower degree of service compared to unimodal truck transport (Flodén, 2007; Lammgård, 2007; Kohn, 2008). In a recent study aiming at developing a model for strategic modelling of intermodal rail-truck transport, Flodén (2007) concludes that even though this type of transport solution offers great advantages from a financial and environmental perspective compared to using unimodal truck transport, the greatest challenge or obstacle in using this solution is that of competitive performance as regards pick-up and delivery times. As this type of solution is slower and has a lower degree of lead-time precision compared to unimodal truck transport (Flodén, 2007; Lammgård, 2007; Kohn, 2008), this is likely to have a negative effect on stock availability in the centralised warehouse unless safety stock levels are revised to compensate for longer and less precise lead-times in the consolidated flow (also see section 3.3.2).

As regards emergency deliveries, the interrelationship between transport-related CO<sub>2</sub> emissions and service is reversed. That is, it is an increase in stock availability (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; *Kohn, 2005*) that will enable a shift in mode of transport for part of total transport work, which in turn will be beneficial from an environmental perspective.

Similar to the discussion about transportation costs, the effect that employing a standardised transport solution for regular deliveries will have on service is likely to be dependant on the type of transport mode that is employed in the centralised distribution system. If a change to a slower mode of transport is made, then it is expected that service in terms of lead-time (length and precision) will decrease and vice versa (Flodén, 2007; Lammgård, 2007; Kohn, 2008).

With reference to the final two types of improvements, i.e. vehicle utilisation for the consolidated flow and fuel and energy efficiency, these changes are not expected to affect stock availability and the lead-time offered by the central warehouse. The reason for this is that these types of improvements are not considered to affect the mode of transport, but rather be limited to efficiency gains for a particular transport mode (Blinge and Lumsden, 1996; *Kohn, 2005*; Aronsson and Huge Brodin, 2006).

To conclude, Table 3-6 below summarises this discussion of how the ratios and associated characteristics discussed in section 3.2.5 relate to the three dimensions of customer service; stock availability, lead-time, and lead-time precision. The discussion has indicated that stock availability will be considered with reference to the effects of employing an intermodal rail-truck transport

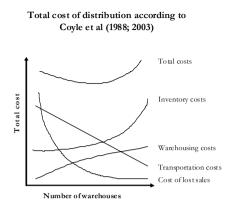
solution for the consolidated flow as well as the effects resulting from a decrease in emergency deliveries. Lead-time (length and precision) on the other hand will be considered with regards to the effects of finding a standard transport solution for the whole of the distribution system (excluding the consolidated flow).

Table 3-6: Summary of how a reduction in transport-related CO<sub>2</sub> emissions with regards to the ratios, characteristics, and measures examined in the first part of the analysis is expected to affect a shipper's level of customer service

Ratio	Characteristic	Focus in the first part of the analysis	Expected impact on service
Modal split	Consolidated flow	Effect on $CO_2$ emissions of employing intermodal rail-truck transport	Intermodal transport is slower and has a lower degree of lead-time precision compared to unimodal truck transport (Flodén, 2007; Lammgård, 2007; Købn, 2008). This will have a negative impact on stock availability and thereby customer lead-time from the central warehouse unless safety stock levels are revised to compensate for longer and less precise lead-times in the consolidated flow.
	Emergency deliveries	Effect on $CO_2$ emissions of a decrease in emergency deliveries	Reverse relationship, meaning that it is an increase in stock availability (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; Kohn, 2005) that will enable a shift in mode of transport for part of total transport work that will be beneficial from an environmental perspective.
	Centralised management	Effect on CO <sub>2</sub> emissions of finding a standard solution for the whole of the distribution system	Impact is dependant on the solution in question. If a change is made to a slower mode of transport, then it is expected that service in terms of lead-time (length and precision) will decrease and vice versa (Flodén, 2007; Lammgård, 2007; Kohn and Huge Bradin, 2008).
Vehicle utilisation	Consolidated flow	Effect on CO <sub>2</sub> emissions of a fill-rate improvement for the consolidated flow	Since mode of transport is kept constant, this change is not expected to affect stock availability and lead-time offered by the central warehouse (Kahn, 2005; Aronsson and Huge Brodin, 2006).
Fuel and energy source efficiency	Centralised management	Indirect effect on CO <sub>2</sub> emissions by means of imposing more strict demands on transport service provides	Technology-related improvements by a shipper's transport provider are not expected to affect the level of service in a shipper's distribution system (Blinge and Lumsden, 1996).

# 3.3.5 The importance of economies of scale in centralised distribution systems

To recapitulate the discussion of how the number of warehouses in a shipper's distribution system affects the total cost of distribution, Figure 3-9 below contrasts the traditional view of Coyle et al (1988; 2003) with a time-based view (Abrahamsson, 1992). As discussed earlier, the difference between the two paradigms is found when transportation costs and cost of lost sales are considered. This is illustrated by the downwards shift in these two curves in the right hand part of Figure 3-9.



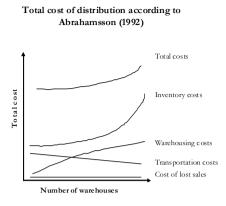


Figure 3-9: Comparison of total cost of distribution depending on number of warehouses according to Coyle et al (1988; 2003) and Abrahamsson (1992)

By adopting a time-based approach to centralisation of a distribution system, it is possible to achieve significant improvements in the provision of cost efficient customer service. Examples show that shippers have been able to cut logistics costs by 25-30% while customer service has been enhanced considerably in terms of improved stock availability and shorter and more secure lead-times (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; Abrahamsson et al, 2003). This is an outcome that is also recognised by Coyle et al (2003), albeit with a little scepticism:

"Surprisingly, decreasing a system's number of warehouses is becoming the preferred way to meet the same needs [improved customer service and reduction in transportation cost]...Combining the utilization of fewer warehouses with a reliable transportation system can improve customer service and lower transportation costs through consolidation opportunities."

(Coyle et al, 2003, p 298)

An important aspect of the time-based approach to distribution, which is partly indicated in the quotation above, is that of achieving economies of scale in the operations of the distribution system. Coyle et al (2003) refer to consolidation, but it must be recognised that that the centralised approach does not only imply a consolidation of flows into a centralised warehouse, but also centralisation of the design and control of the system (Abrahamsson, 1992; Fincke and Goffard, 1993; Norrman, 1997; Abrahamsson et al, 2003). This is an aspect that is recognised as a prerequisite for achieving improvements in customer service and reductions in logistics costs simultaneously:

"Only through centralized planning and co-ordination of logistics can the organization hope to achieve the twin goals of cost minimization and service maximization."

(Christopher, 1998, p 142)

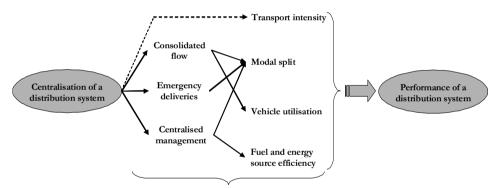
This can be related to the discussion in section 3.1 on changes and decisions in logistics systems, where proponents of a centralised approach argue that decisions taken higher up in the funnel-like model should be handled centrally, whereas decisions further down in the decision hierarchy should be handled locally. By virtue of central design and control, a shipper will standardise the logistics activities with the distribution system (Christopher, 1998; Abrahamsson et al, 2003), whereby the efficiency in the distribution process can be improved in three ways (Norman, 1997; Abrahamsson et al, 1998):

- When a distribution system is centralised, it is possible to exploit economies of scale with regards to warehousing, materials handling, transport, and administration
- By separating aspects of physical distribution from aspects related to sales, it is possible to increase specialisation and expertise in the respective areas
- Through the use of IT/IS, it is possible to achieve a more transparent distribution system with increased coordination and control, within functions as well as between functions

Hence, the stance that can be found among proponents of a time-based approach to distribution (Abrahamsson, 1992; Abrahamsson and Brege, 1997; Norrman, 1997; Abrahamsson and Aronsson, 1999) is that a change in the structure and management of a distribution system (strategic change), can provide a shipper with new opportunities but also impose restrictions with regards to other changes and decisions (tactical and operational) within the distribution system. This line of reasoning is the very core of this dissertation and can be exemplified by considering the discussion on modal split in section 3.2.2 earlier in the frame of reference. By centralising its distribution system, a shipper can create an opportunity to use an intermodal rail-truck solution for the consolidated flow between the production unit and the central warehouse (Kohn, 2005; Aronsson and Huge Brodin, 2006). However, centralising the distribution system will also imply that a standard mode of transport is sought for the distribution system as a whole. This is a restriction, if compared to a decentralised distribution system where each subsidiary typically decides on its own mode of transport (Abrahamsson, 1992; Abrahamsson et al, 2003; Kohn, 2005; Aronsson and Huge Brodin, 2006). Both of these changes will not only affect transport-related CO<sub>2</sub> emissions but also the provision of cost efficient customer service, as discussed in the previous sections. How this will be analysed in chapter 5 is described in the subsequent section, which presents the model of analysis with reference to the second part of the forthcoming analysis.

## 3.3.6 Model of analysis with regards to interrelationships between a reduction in CO<sub>2</sub> emissions per tonne kilometre and cost efficient customer service

One of the major challenges facing logistics managers with regards to environmental issues is how to incorporate such matters with the traditional view of providing the customer with a sufficient level of service at a low cost (Wu and Dunn, 1995). Building on the discussion from section 3.2, there is a need to form an understanding of how individual measures a shipper can employ to reduce transport-related CO<sub>2</sub> emissions per tonne kilometre when a distribution system is centralised affect the provision of cost efficient customer service. This is the focus of the second part of the analysis and based on the discussions in the previous sections, Figure 3-10 below illustrates the interrelationships between environment, cost, and service that will be considered in the forthcoming analysis.



Ratio	Characteristic	Interrelationships focused in the analysis			
		- Environment	- Cost	- Service	
Modal split	dal split Consolidated flow - Transport-rela emissions		- Inventory costs - Transportation costs	- Stock availability	
	Emergency deliveries	- Transport-related CO <sub>2</sub> emissions	- Transportation costs	- Stock availability	
	Centralised management	- Transport-related CO <sub>2</sub> emissions	- Transportation costs	- Lead-time (length and precision)	
Vehicle utilisation	Consolidated flow	- Transport-related CO <sub>2</sub> emissions	- Transportation costs	- N/A	
Fuel and energy source efficiency	Centralised management	- Transport-related CO <sub>2</sub> emissions	- Transportation costs	- N/A	

Figure 3-10: Focus of the second part of the analysis

## **4 SUMMARY OF APPENDED MANUSCRIPTS**

The four appended manuscripts address somewhat different issues in relation to the overall purpose and research questions of the dissertation, and the aim of this chapter is to summarise these texts. The summaries provide an empirical basis for the analysis that is presented in the subsequent chapter.

## 4.1 Licentiate thesis – Centralisation of distribution systems and its environmental effects

The decision to centralise distribution can be characterised as a strategic logistics decision and earlier research has helped to illustrate how such decisions have greater impact on the overall performance of a distribution system than decisions taken at subsequent levels (tactical and operational). The reason for this is that strategic decisions help to create new opportunities to make other logistical decisions that are beneficial for the performance of a distribution system, as measured in terms of costs and service. It is also acknowledged that there is a lack of research illustrating the actual environmental effects of centralisation. This area is the theme of this thesis and the overall purpose is to describe and analyse how centralisation of a distribution system can affect the environment. This overall purpose is divided into two research questions, the first of which focuses the direct environmental consequences, measured in terms of CO<sub>2</sub> emissions, caused by centralising a distribution system. The second question focuses how this decision has influenced decisions taken at a lower level in the decision-hierarchy, i.e. at a tactical level as well as at an operational level.

Based on a single case study, an analysis was conducted in two parts. The first part concerned how transport work and CO<sub>2</sub> emissions had changed as a direct consequence of the change in the set-up of nodes and links that constitute the physical structure of the distribution system. The second part focused on the indirect consequences of the change in distribution system and whether or not this change had enabled the case company to make other changes to the distribution system that could prove beneficial from an environmental perspective. Key findings that relate to the subsequent analysis in chapter 5 include:

- The structural change resulted in an increase in transport work by approximately 34%, whereas CO<sub>2</sub> emissions increased by 42%.
- Through the structural change, ITT Flygt managed to reduce its amount of emergency deliveries by over 60%, measured in terms of transport work. However, as this type of delivery only constituted less than one percent of the total transport work prior to the structural change, this change had no substantial effect on an aggregated systems level.
- Centralising a distribution system implies that a consolidated transport flow is created between the production unit and the central warehouse. In the case of ITT Flygt, this part of the distribution system constituted almost two thirds (65%) of the total transport work in the centralised distribution system. Given the characteristics of this centralised and pooled flow, ITT Flygt has been able to achieve a fill-rate of approximately 85% for this particular part of the system. Despite efforts in this direction, ITT Flygt has not managed to achieve the same results for other parts of the distribution system.

- The structural change also enabled ITT Flygt to test intermodal rail-truck transport for the consolidated transport flow described above. This opportunity did not exist in the decentralised distribution system. Even though ITT Flygt has opted not to implement this type of solution, such a measure could imply that CO₂ emissions for the current centralised distribution system could be cut by almost half, thus providing a substantial environmental opportunity.
- By virtue of also centralising and consolidating the procurement of transport services, ITT Flygt has improved its bargaining position vis-à-vis its logistics service providers. This in turn, has created an opportunity to put a greater demand on the providers to improve the environmental performance of their services, e.g. through cleaner vehicle engines or driver education in ECO-driving.

By means of the comprehensive case study of ITT Flygt's structural change, the thesis contributes to the rather limited research on the environmental effects of logistics. The results of the study indicate that even though a centralised distribution system incurs more transport work than does a decentralised distribution system, this does not necessarily mean that the same conclusion can be made about CO<sub>2</sub> emissions. Instead, it is argued that it is of paramount importance to understand the characteristics of the system at hand in order to fully grasp how this system performs from an environmental perspective. Four characteristics, alongside transport work, were identified; (i) emergency deliveries, (ii) centralised flow, (iii) modal change, and (iv) bargaining power. The results indicate that in order to conclude whether or not centralisation of a distribution system will lead to an increase in CO<sub>2</sub> emissions, one must consider how the system at hand performs with respect to these characteristics, both prior to and subsequent to centralisation.

# 4.2 Paper A – Centralised distribution systems and the environment: How increased transport work can decrease the environmental impact of logistics

Albeit that centralisation of a distribution system is considered beneficial from a cost and service perspective (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999), it is at the same time used as an example of a structural change that increases the amount of transport work of a logistics system and thus, from an environmental perspective is considered harmful (Wu and Dunn, 1995; Rodrigue et al, 2001; McKinnon, 2003). In contrast, more recent research (Aronsson and Huge Brodin, 2003; *Kohn, 2005*) claims that structural changes to a logistics system do not have to result in increased environmental pressure, but rather, that it is possible to achieve simultaneous improvements regarding costs, service, and environmental performance. In order to achieve such multiple benefits, it is essential to understand the characteristics of the system at hand. Examples of such characteristics include:

- Consolidation of flows, enabled by centralisation
- Changes in transport mode, enabled by centralisation, and
- Decrease in the amount of emergency deliveries, an effect of centralisation.

The purpose of the paper is to describe and discuss in which way and under which circumstances it is possible to achieve improvements simultaneously in terms of cost, service, and environmental performance of a logistics system with reference to the three characteristics presented above. The paper discusses the three characteristics from a theoretical perspective as well as from an empirical perspective. The key findings for the analysis are summarised in Table 4-1 below.

Table 4-1: Summary of key findings from paper A

	Cost	Service	Environment
Consolidation	decrease in transportation costs, given that the pricing model of the 3PL provider rewards higher fill rates.	Consolidation enables better planning for the distribution system as a whole. This in turn, enables a higher degree of availability for the end customer. This is achieved at the expense of longer lead-times.	consumption and consequently total
Transport mode	transport set-up and the cost of transport for rail compared to road is lower. However, rail transport involves more handling, which causes more damages to goods and this in turn is costly.	A change to intermodal transport will most likely increase the lead time for shipments between the production unit and central warehouse. This increase will however not be noticable to the end customer, who instead, experiences an increase in availability.	Intermodal transport solutions cause considerably lower environmental impact in comparison to pure road freight solutions.
Emergency deliveries	emergency deliveries and this has a positive effect on overall transport costs. This is the main reason why it is possible to keep transport costs at a constant in a centralised system vis-a-vis a decentralised system despite the fact that transport work		Emergency deliveries are often performed by means of faster modes of transport that are more polluting and by reducing this type of delivery environmental impact will also decrease.

The contribution of the paper lies in that it illustrates that even though centralisation of a distribution system results in an increase in transport work, this change can also function as an enabler for other changes in the distribution system that are beneficial from an environmental perspective, without impeding the cost efficient provision of customer service. In order to achieve such results, a contingency approach, as well as an understanding of the characteristics that drive and affect the performance of the system at hand, are prerequisites. It is also concluded that the characteristics discussed in the paper trigger and affect each other in various ways.

## 4.3 Paper B – A shipper perspective on intermodal transport: Exploring the role of rail-truck intermodal transport in three shippers' logistics systems

Even though intermodal transport solutions are often advocated as one possible remedy for coming to terms with emissions from transport, they are not employed very extensively in industry. One reason for this could be the fact that decisions influencing logistics and transport are made by different actors that apply fundamentally different logics in their decision-making. Whereas public policy-makers and authorities that govern the railway infrastructure set their system boundaries from a regional or national perspective for instance, companies most often design their logistics systems from a pan-European perspective. Moreover, whereas decisions regarding logistics from a company perspective are made with reference to the overall goal of achieving cost efficient customer service, public policy decisions are made with respect to e.g. a country's transport policy, of which companies only account for one part of the total decision scope.

In contrast to much of the earlier research on intermodal transport, this paper focuses on shippers' views and presents three companies that have employed or are about to employ an intermodal rail-truck transport solution. The paper has an empirical focus and the aim is to explore the experiences these companies have had during their respective processes of implementing an intermodal solution and more specifically, the paper addressed two research questions:

- Why do companies use intermodal transport and for which parts of the logistics system do they use intermodal transport?
- How has the implementation of intermodal transport affected the performance of the companies' logistics systems?

The major contribution of the paper is that it addresses how shippers use intermodal transport in their logistics systems and their concrete experiences of this choice. This is a perspective that has not been applied in research on intermodal transport, as indicated by the literature review in the paper. Key findings with regards to the analysis in chapter 5 include:

The findings indicate that intermodal transport is a viable transport alternative for various types of goods, ranging from metal scrap to fashion clothing. A common denominator among the companies is that they have all centralised their logistics operations in one form or another, thus enabling them to consolidate their transport flows. As such, consolidation should be regarded an enabler for intermodal transport.

- The companies experience some of the common disadvantages with using rail freight in an intermodal set-up, for instance longer and less precise lead-times, but this is compensated by the cost advantage that this solution provides.
- The companies only use intermodal transport for those parts of their logistics systems where they know that the overall performance of the system will not be jeopardised.
- All the companies stress that if this type of transport solution is to be applied more extensively, it is very important that public authorities, logistics service providers, and other stakeholders that have an impact on the performance of intermodal transport get a better understanding of what issues shippers prioritise with regards to their logistics systems.

# 4.4 Paper C – Exploring supply chain captaincy: Why power matters in supply chain collaboration – The case of Volvo Parts

Even though supply chain management (SCM) has grown in popularity over the last decade, it is more of a product on paper than it is practiced in industry. With the exception of a few best practice cases, empirical research shows that collaboration based on the SCM philosophy is not common practice in today's supply chains. Relating to this, the paper suggests that one reason for this might be the absence of a channel captain in the supply chain. Although touched upon in some SCM literature, this subject has not been discussed in great detail.

In line with this, the purpose of the paper is to act as a catalyst in the discussion on channel captaincy in SCM literature. The results of the paper are not relevant for the theme of this dissertation per se. Instead, some of the results in the other appended manuscripts are discussed from a power perspective, where the paper focuses on how power can be used as a tool to initiate improvements in a supply chain. Key findings from the paper include:

- Power issues are relevant in a supply chain setting and an unawareness of the power structure in a supply chain can cause a passive supply chain, whereby great opportunities for improvements can be lost if power is not brought to the surface.
- Power can serve as a useful framework in order to get a deeper insight into supply chain relationships and collaboration throughout a supply chain.
- By using power in a conscious manner, a company may achieve supply chain improvements that would not be possible to achieve otherwise.

### 5 Analysis of Results

The analysis holds three main sections, where the two first sections will discuss and analyse how a shipper can reduce transport-related CO<sub>2</sub> emissions when a distribution system is centralised (section 5.1) and the interrelationships that exist between such a reduction and the provision of cost efficient customer service (section 5.2). These two sections will present an analysis in accordance with the model of analysis presented in the frame of reference (see sections 3.2.5 and 3.3.6), where the connections between the three ratios (modal split, vehicle utilisation, and fuel and energy source efficiency) and associated characteristics (consolidated flow, emergency deliveries, and centralised management) will function as a structure for this analysis. These two sections of the analysis aim at providing an answer to the two research questions that were presented in the first chapter. Besides taking a starting point in the frame of reference and model of analysis, results from each of the appended manuscripts (i.e. the licentiate thesis and the three papers) are incorporated into the analysis in order to present a synthesising analysis of the results. In addition to these two parts, the analysis also holds a third part, where the discussion is centred on transport intensity (section 5.3). The aim with this part is to illustrate how the increase in transport work, due to centralising a distribution system, can vary depending on the structural configuration of the distribution system.

# 5.1 Analysis of measures for a shipper to reduce transport-related CO<sub>2</sub> emissions when centralising a distribution system

This part of the analysis will focus on measures a shipper can employ to reduce transport-related CO<sub>2</sub> emissions when centralising a distribution system. The subsequent sections will present an analysis with reference to the three ratios (modal split, vehicle utilisation, and fuel and energy source efficiency) and associated characteristics (consolidated flow, emergency deliveries, and centralised management). These measures nonetheless need to be weighed against the increase in transport work due to an increase in the average length of haul that is a consequence of this type of structural change (Rodrigue et al, 2001; McKinnon, 2003; *Kohn, 2005*; McKinnon, 2007). There is a general lack of empirical studies that show how much transport work will typically increase when a shipper's distribution system is centralised (Abukhader and Jönson, 2004a/b), but both *Kohn (2005)* and Schenker Consulting (2007) provide examples where transport work has increased by 30-40% when a shipper's distribution system has been centralised. Therefore, the analysis will assume an increase in transport work by 20-80% caused by centralising the distribution system. This increase will be weighed against the reduction in CO<sub>2</sub> emissions a shipper can achieve through simultaneously employing measures that reduce CO<sub>2</sub> emissions per tonne kilometre, measures that were not available in the decentralised distribution system.

#### 5.1.1 Modal split

The frame of reference illustrated how different modes of transport emit different amounts of CO<sub>2</sub> per tonne kilometre, where it in generic terms can be concluded that the slower a mode of transport is the better it is from an environmental perspective (Lenner, 1993; International Maritime Organization, 2000; Christopher et al, 2007; McKinnon, 2007; NTM, 2007). The discussion also revealed that choice in mode of transport is an issue for all of the three characteristics of a centralised distribution system (consolidated flow, emergency deliveries, and centralised management) and the subsequent three sections will analyse each of these characteristics as to how they affect transport-related CO<sub>2</sub> emissions when a shipper centralises its distribution system.

#### Consolidated flow

With regards to a change in mode of transport, it is often advocated from a policy-maker perspective that intermodal transport solutions that incorporate rail freight and/or ship freight need to be employed more extensively (European Commission, 2000; EEA, 2007). The discussion in the frame of reference pointed out that when a shipper makes a structural change towards a more centralised physical structure, this implies that a large portion of transport work is concentrated to the consolidated flow between the production unit and the central warehouse in a shipper's distribution system.

Table 5-1 below provides calculations indicating the potential in applying an intermodal rail-truck transport solution for the consolidated flow in a centralised distribution system when the distribution system is centralised, all other things being equal. The sample calculations are based on a number of conditions, all of which are presented in the lower half of Table 5-1. The percentages indicate how much transport-related CO<sub>2</sub> emissions will increase/decrease for the whole of the distribution system depending on two conditions;

- (i) Overall increase in transport work due to centralisation
- (ii) How large a portion of total transport work that is attributed to the consolidated flow

The calculations indicate that if an intermodal rail-truck solution that reduces CO<sub>2</sub> emissions per tonne kilometre is employed when the distribution system is centralised, this can outweigh the overall increase in CO<sub>2</sub> emissions that is the result of an increase in total transport work owing to the structural change. If, for instance, transport work increases by 20% due to centralisation, but the structural change simultaneously creates a consolidated flow that accounts for 60% of total transport work in the centralised distribution system, then transport-related CO<sub>2</sub> emissions for the system as a whole will decrease even though transport work increases. As indicated by the figures in the table, the increase/decrease is also dependant on whether a diesel powered or electrical powered train is used for the rail portion of the intermodal transfer, where the latter will have a more positive effect on CO<sub>2</sub> emissions per tonne kilometre for the consolidated flow.

What the calculations in Table 5-1 also help to illustrate is that the relative size of the consolidated flow, measured in terms of transport work in comparison to transport work for the whole system, has a significant influence on the potential that this opportunity brings. The greater the consolidated flow is compared to total transport work, the greater the potential is that a reduction in CO<sub>2</sub> emissions for this part of the distribution system will have a significant impact on the distribution system as a whole. On this issue it can be acknowledged that the greater the proportion of total transport work that is attributed to the consolidated flow in a centralised distribution system, the further away the central warehouse is from the production unit in the distribution system. For instance, if the consolidated flow accounts for 60% of total transport work, this implies that on average 60% of the total distance that a good travels between a production unit and the end customer is attributed to the distance between the production unit and the central warehouse.

Table 5-1: Illustration of the potential in applying an intermodal rail-truck transport solution for the consolidated flow when a distribution system is centralised

		Increase in transport work due to centralisation			
		20%	40%	60%	80%
Amount of transport work stemming	20%	10% (3%)	28% (20%)	46% (38%)	64% (55%)
from the consolidated flow in the	40%	-1% (-14%)	16% (1%)	32% (15%)	49% (30%)
centralised distribution system	60%	-11% (-30%)	4% (-19%)	18% (-7%)	33% (4%)
centralised distribution system		-22% (-47%)	-9% (-38%)	5% (-30%)	18% (-21%)

- Numbers without brackets = diesel powered train
- Numbers within brackets = electrical powered train

#### Decentralised distribution system:

- Two types of trucks have been used, one with a payload of 26 tonne (fill-rate 70%) and one with a payload of 8.5 tonne (fill-rate 50%). 95% of the transport work is handled by the larger of the two vehicles. CO<sub>2</sub>/tonne kilometres is set to 0.051 kg and 0.17 kg (NTM, 2007), thus resulting in an average of 0.057 kg CO<sub>2</sub>/tonne kilometre.
- Only regular deliveries are considered.

#### Centralised distribution system:

- Intermodal transport is only used for the consolidated flow. For this flow 90% of transport work is handled by rail freight whereas 10% is handled by road freight, where road freight is performed by a truck with a payload of 8.5 tonne (fill-rate 50%) and CO<sub>2</sub>/tonne kilometre is set to 0.17 kg (NTM, 2007).
- $\rm CO_2/tonne$  kilometre for diesel powered train is set to 0.017 kg (NTM, 2007), thus resulting in an average of 0.0323 kg  $\rm CO_2/tonne$  kilometre when combined with 10% road freight.
- $\rm CO_2/tonne$  kilometre for electrical powered train is set to 0.000068 kg with an electricity mix based on values from the Swedish Rail Administration (NMT, 2007), thus resulting in an average of 0.0171 kg  $\rm CO_2/tonne$  kilometre when combined with 10% road freight.
- For distribution from the central warehouse to the end customer the same assumptions have been made as regards road freight in the decentralised distribution system. Hence, an average value of 0.057 kg CO<sub>2</sub>/tonne kilometre has been used.
- Only regular deliveries are considered.

Figure 5-1 below provides an example based on the calculations presented above, where the figure illustrates how transport-related  $\rm CO_2$  emissions are affected on a systems level if an intermodal rail-truck transport solution is applied for the consolidated flow when a distribution system is centralised, given that total transport work simultaneously increases by 40% due to centralisation. What this figure helps to illustrate is that even though the consolidated flow only accounts for 20% of total transport work, employing a diesel based rail-truck intermodal transport solution for this part of the distribution system will imply that transport-related  $\rm CO_2$  emissions will only increase by 28% even though transport work increases by 40% due to the structural change. If the consolidated flow on the other hand accounts for 60% or more of total

transport work (cf. ITT Flygt in *Kohn*, 2005), then applying an intermodal solution for this part of the distribution system can counterbalance the increase in transport work.

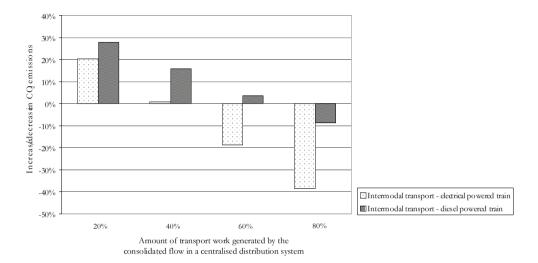


Figure 5-1: Example of a shipper's potential to affect CO<sub>2</sub> emissions for the whole of a distribution system linked to the consolidated flow and rail-truck intermodal transport in a centralised distribution system (based on a 40% increase in transport work due to the structural change)

Relating to the calculations above, empirics in this dissertation indicate that a consolidated flow is an enabler for using an intermodal transport solution that combines truck and rail freight for this part of the distribution system (Kohn, 2005; Kohn and Huge Brodin, 2008). The case of ITT Flygt, for instance, illustrates how the structural change has given the company an opportunity to test an intermodal rail-truck transport solution for the consolidated flow between Lindas, Sweden and Metz, France. In fact, one of the reasons why Metz was chosen as a location for the new distribution centre was that it was possible to get access to a rail connection. The company viewed this as a benefit as it was expected that future laws and regulations could force companies to employ more rail freight. ITT Flygt also performed a trial run with train for this part of the distribution system, but decided to use road transport instead of an intermodal rail-truck solution. The main reason for this was that the latter type of solution at that time did not suffice from a cost and service perspective. What the case of ITT Flygt nonetheless illustrates is that by pooling a large amount of transport into a consolidated flow, the company was provided with an opportunity to change mode of transport for this particular flow. This opportunity did not exist in the decentralised system as transport flows to each of the local warehouses were not large enough. This is also supported by empirics from Carlsberg Sweden and Stena Gotthard (Kohn,

2008) as well as Stora Enso (Kohn and Huge Brodin, 2008). These cases display that the decision to increase the use of intermodal transport has been linked to decisions to restructure their respective systems towards a more centralised system with a higher degree of flow consolidation. This is also the case in Aronsson and Huge Brodin's (2006) study, where, in addition to PaperComp/Stora Enso, FurniComp managed to change mode of transport, owing to a consolidation of transport flows. Based on this, it can be concluded that a consolidation of transport flows can act as an enabler for changing to a slower mode of transport for this particular part of a centralised distribution system. The reason why this becomes feasible is that a consolidated flow has a more stable character than smaller transport flows, thus making it more manageable from a transport planning perspective.

To summarise, the analysis pertaining to how intermodal rail-truck transport for the consolidated flow in a centralised distribution system affects transport-related CO<sub>2</sub> emissions indicates that:

Employing an intermodal rail-truck transport solution for the consolidated flow when a distribution system is centralised can render a reduction in transport-related  $CO_2$  emissions per tonne kilometre for this part of the distribution system that can outweigh the increase in  $CO_2$  emissions caused by the increase in transport work that is a result of centralising the distribution system.

This confirms and complements earlier studies that have argued that intermodal rail-truck solutions can lead to great reductions in transport-related CO<sub>2</sub> emissions (McKinnon, 2003; Aronsson and Huge Brodin, 2006; Kreutzberger, 2006; EEA, 2007; Flodén, 2007; McKinnon, 2007). However, the analysis also adds a dimension to earlier studies in that it illustrates how the consolidated flow, which is created when a distribution system is centralised, can act as an enabler for launching an intermodal transport solution. Also, the analysis helps to illustrate the magnitude of the potential in CO<sub>2</sub> reductions on a system level that comes with transferring only the consolidated flow in a centralised distribution system from a unimodal road transport solution to an intermodal rail-truck transport solution that includes a slower and more environmentally friendly mode of transport.

#### **Emergency deliveries**

One of the main advantages with a centralised distribution system is that it is expected to decrease the need for emergency deliveries due to inventory stock outs (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; *Kohn, 2005*). In the frame of reference it was discussed how this reduction in emergency deliveries and the differentiation between regular deliveries and emergency deliveries is of importance also when considering transport-related CO<sub>2</sub> emissions. The reason for this being that even though transport work increases on a system's level for the distribution system when it is centralised (Rodrigue et al, 2001; McKinnon, 2003; Croxton and

Zinn, 2004; *Kohn, 2005*), part of those deliveries that were handled as emergency deliveries in the decentralised system will in a centralised system be performed with the regular and preferred mode of transport (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; *Kohn, 2005*). Since regular deliveries are in most cases performed by a slower mode of transport than the one used for emergency deliveries, this will consequently have a positive effect on CO<sub>2</sub> emissions relating to this transport work as slower modes of transport generally emit less CO<sub>2</sub> per tonne kilometre compared to faster modes (Lenner, 1993; Christopher et al, 2007; McKinnon, 2007; NTM, 2007).

This logic, which was also presented in section 3.3.3, is depicted in the upper part of Figure 5-2 below. The analysis indicates that there is a need to carefully assess the situation both before and after the structural change in order to understand whether or not a centralisation will lead to an increase or decrease in CO<sub>2</sub> emissions with regards to emergency deliveries. This is illustrated in the lower part of Figure 5-2, which provides examples of cut-off or break-even points for when centralisation can prove beneficial from an environmental perspective pertaining exclusively to emergency deliveries. What this figure aims at illustrating is how large the ratio of emergency deliveries to total transport work needs to be in a decentralised system (indicated by the number "3" in the lower half of the figure), given varying increases in overall transport work (indicated by the number "1" in the figure) and decreasing levels of emergency deliveries (indicated by the number "2" in the figure). For example, if transport work increases by 50% and emergency deliveries decrease by 50% owing to centralisation, then there would be a net increase in transport-related CO<sub>2</sub> emissions if emergency deliveries constitute less than 9% of total transport work prior to centralisation. Vice versa, there would be a net decrease in transport-related CO<sub>2</sub> emissions if emergency deliveries constitute more than 9% before the system is centralised.

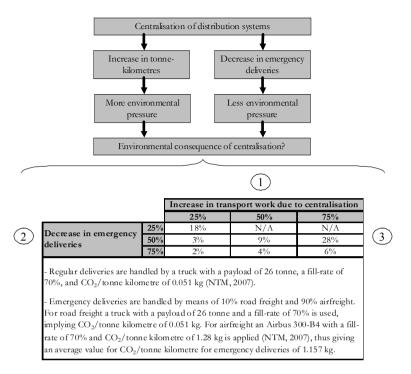


Figure 5-2: Break-even points (% of emergency transport work to total transport work) for when centralisation can prove beneficial from an environmental perspective pertaining exclusively to emergency deliveries<sup>14</sup>

Figure 5-3 below presents an additional example relating to this discussion, where an increase in transport work by 50% is assumed. What the figure illustrates is how transport-related CO<sub>2</sub> emissions are affected on a systems level depending on the proportion of emergency deliveries to total transport work in the decentralised distribution system and the decrease in emergency deliveries owing to centralisation of the distribution system. The figure helps to illustrate that if transport work is increased by 50% due to centralisation, then emergency deliveries would on one hand need to constitute a substantial amount of total transport work prior to centralisation and on the other hand be reduced significantly if a shipper is to avoid an increase in transport-related CO<sub>2</sub> emissions when the distribution system is centralised.

<sup>14</sup> Kohn (2005) provides similar calculations, but with the important exception that they do not provide any breakeven points.

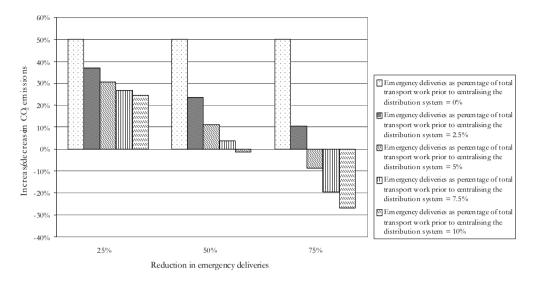


Figure 5-3: Example of how CO<sub>2</sub> emissions in a distribution system are affected by a reduction in emergency deliveries depending on the extent of emergency deliveries before centralisation (based on a 50% increase in transport work due to the structural change)

Based on the presented calculations above, it can be supposed that the effect that centralising a distribution system will have on transport-related CO<sub>2</sub> emissions with regards to emergency deliveries is dependant on the character and context of that specific system. In particular there is a need to consider three aspects; (i) how large the overall increase in transport work is due to centralising the distribution system, (ii) how much of total transport work that stems from emergency deliveries prior to centralising the distribution system, and (iii) how much emergency deliveries decrease overall due to centralising the distribution system.

With regards to these three aspects, Figure 5-2 above illustrates that the greater the overall increase in transport work is, the greater the proportion emergency deliveries needs to be prior to the structural change and the greater the decrease in emergency deliveries needs to be. If emergency deliveries on the one hand constitute a small amount of total transport work prior to the structural change, then centralising the distribution system will not lead to any substantial reductions in CO<sub>2</sub> emissions. This was the situation for ITT Flygt (Kohn, 2005), where a reduction in emergency deliveries by 64% had a very small impact on total transport-related CO<sub>2</sub> emissions as emergency deliveries constituted less than 0.2% of total transport work in the decentralised distribution system. This is also a likely scenario if emergency deliveries constitute delivery of spare parts. This is because spare parts are likely to weigh considerably less than the whole of a product, which implies that spare parts are also likely to only constitute a small part of the total transport work in a distribution system. If emergency deliveries on the other hand

constitute a large amount of total transport work prior to centralisation, then the structural change will lead to considerable reductions in CO<sub>2</sub> emissions if emergency deliveries are reduced owing to the structural change. This would be a likely scenario for a shipper that has a large portion of emergency deliveries in a decentralised distribution system for the actual product it is selling rather than for spare parts or the like.

To summarise, the analysis regarding the effect on transport-related CO<sub>2</sub> emissions owing to a decrease in emergency deliveries when a distribution system is centralised indicates that:

Centralisation of a distribution system decreases the need for emergency deliveries, thus enabling a change in mode of transport for part of total transport work that is beneficial from an environmental perspective as it reduces the amount of transport-related  $CO_2$  emissions. The effect for the whole system of this shift is dependant on the following features of the structural change in question:

- (i) The overall increase in transport work
- (ii) Amount of transport work that stems from emergency deliveries prior to the structural change
- (iii) Decrease in the amount of emergency deliveries

Albeit that a change in mode of transport from faster to slower modes of transport has been acknowledged as a main way to reduce transport-related CO<sub>2</sub> emissions in earlier research (Wu and Dunn, 1995; McKinnon, 2003; Aronsson and Huge Brodin, 2006; McKinnon, 2007), this dissertation makes a contribution to the discussion on modal split by acknowledging the existence of emergency deliveries (cf. Abrahamsson, 1992; Abrahamsson and Aronsson, 1999) and how a reduction in this type of transport, enabled by centralising the distribution system, can have a positive impact on transport-related CO<sub>2</sub> emissions.

#### Centralised management

The third and final characteristic of a centralised distribution system with regards to change in mode of transport that was discussed in the frame of reference is that of centralised management. When the design and control of a distribution system is centralised, the aim is to find a transport solution for regular deliveries that suits the whole system (Abrahamsson, 1992; Abrahamsson et al, 2003; *Kohn, 2005*). As discussed earlier, a slower mode of transport emits less CO<sub>2</sub> emissions than a faster mode and three generic scenarios can be identified with regards to how finding a transport solution that suits the whole of a distribution system will affect transport-related CO<sub>2</sub> emissions, all other things being equal:

- (i) If the preferred mode of transport is faster than that employed in the decentralised distribution system, then CO<sub>2</sub> emissions will increase, as faster modes of transport generally cause more CO<sub>2</sub> emissions (Lenner, 1993; Christopher et al, 2007; McKinnon, 2007; NTM, 2007).
- (ii) If the preferred mode of transport is the same both before and after the structural change, this will also lead to an increase in CO<sub>2</sub> emissions, all other things being equal, as the average length of haul will be longer in a centralised distribution system vis-à-vis a decentralised distribution system (Wu and Dunn, 1995; Rodrigue et al, 2001; McKinnon, 2003; Croxton and Zinn, 2005; Kohn, 2005; McKinnon, 2007).
- (iii) If the preferred mode of transport is slower in the centralised distribution system compared to the decentralised distribution system, then the effect on CO<sub>2</sub> emissions will be dependant on two factors that need to be analysed jointly in order to evaluate whether the change will result in an increase or a decrease in CO<sub>2</sub> emissions, all other thing being equal. The first is CO<sub>2</sub> emissions per tonne kilometre for the respective modes of transport before and after the structural change and the second is how much transport work has increased due to the structural change.

These three scenarios can be applied to the case of ITT Flygt (Kohn, 2005; Kohn and Huge Brodin, 2008). In the decentralised distribution system where each subsidiary designed and controlled the way in which their transport was to be performed, there where two subsidiaries (the UK and Ireland) that used ship freight for large parts of total transport work, whereas all other subsidiaries used road freight. When the distribution system was centralised, ITT Flygt centrally decided that all regular deliveries were to be carried out by means of road freight. Hence, by taking over the design and control of the distribution system, ITT Flygt underwent a change in mode of transport for regular deliveries that was a combination of scenarios one and two above (scenario one for the UK and Ireland and scenario two for all subsidiaries). Hence, when this situation is analysed with regards to transport-related CO2 emissions, it becomes clear that CO2 emissions stemming from transport will increase vastly owing to this change, since trucks emit more CO<sub>2</sub> than ships (Lenner, 1993; Christopher et al, 2007; McKinnon, 2007; NTM, 2007) and a centralised distribution system generates a greater amount of transport work compared to a decentralised distribution system (Wu and Dunn, 1995; Rodrigue et al, 2001; McKinnon, 2003, Kohn, 2005). This was also the main reason why transport-related CO<sub>2</sub> emissions increased more than transport work (42% compared to 34%) when ITT Flygt centralised its distribution system (Kohn, 2005).

There is no empirics in this dissertation that supports that centralisation of a distribution system will enable a shipper to employ a slower mode of transport for all its regular deliveries.

Nonetheless, such a change cannot be ruled out entirely on the basis of the empirics presented here. However, the case of KappAhl (Kohn, 2008) illustrates how a shipper by means of centralised management can employ a slower mode of transport for parts of its distribution system (in addition to the consolidated flow, which has already been discussed above). With regards to this issue, this case illustrates that by centrally managing the shipments from the company's distribution centre to its retail stores, KappAhl is able to employ an intermodal rail-truck transport solution for parts of these shipments. The company is well aware of the negative aspects of employing such a transport solution (i.e. longer and less precise lead-times) and therefore this transport solution is only employed in those parts of the distribution system where the shipper's transport provider has a proven track record with regards to fast and reliable lead-times. Hence, this case helps to illustrate that by centralising management of a distribution system, a shipper can obtain a holistic approach whereby it is possible to employ a slower mode of transport in parts of the distribution system without jeopardising the overall level of service provided by the distribution system (in this case short and reliable lead-times).

Even though the case of KappAhl illustrates that a shipper that centrally manages its distribution system can apply a slower mode of transport in some instances, it needs to be acknowledged that the desire to find a transport solution that suits the whole of a distribution system is argued to be linked to a modal adaptation for many shippers:

"Structural change is associated with modal shift away from rail and waterway transport, supporting road and air modes."

(Hesse and Rodrigue, 2004, p 176)

This is further emphasised by the fact that road freight has become by far the most preferred choice in mode transport in the EU-15 countries (EEA, 2007). Thus, it can be argued that the desire to find a transport solution that suits the whole of the distribution system is more likely to lead to a change in accordance with either of the two first scenarios rather than in accordance to the third scenario. Based on this, the following summary can be made with reference to the connection between the characteristic of centralised management and the ratio for modal split:

Applying a preferred mode of transport for regular deliveries in a centralised distribution system can lead to either an increase or a decrease in transport-related  $CO_2$  emissions, where the former outcome (i.e. an increase) is the more likely to occur than the latter outcome (i.e. a decrease).

The connection between the characteristic of centralised management and the ratio for modal split can be claimed to be at the centre of the argumentative logic in earlier research, which states

that centralisation of a distribution system will lead to an increase in transport-related CO<sub>2</sub> emissions by means of an increase transport work (Wu and Dunn, 1995; Rodrigue et al, 2001; McKinnon, 2003; McKinnon, 2007). Hence, this dissertation confirms earlier research, as it illustrates how a shipper's desire to find a transport solution that suits the whole of a distribution system is more likely to lead to an increase in CO<sub>2</sub> emissions than a decrease with regards to only considering the preferred mode of transport for regular deliveries in a distribution system. A main reason for this is that centralised distribution systems are based on a fast and reliable transport system, in many cases on a pan-European level. This implies that shippers in most cases have no other choice than to employ road transport, as this is currently the only mode of transport that can fully support a larger transport operation for a shipper acting on a pan-European market at a reasonable cost. This dissertation also complements earlier research by illustrating how centralised management can provide shippers with a holistic view of the whole distribution system, whereby a change to a slower mode of transport for regular deliveries can be achieved in parts of the distribution system without jeopardising the system's performance in terms of short and reliable lead-times.

#### 5.1.2 Vehicle utilisation

Improvements in vehicle utilisation are argued to be an area that holds great promise for shippers as these types of improvements are self-financing as they concern efficiency improvements (McKinnon, 2003; McKinnon, 2007). Since the focus in this dissertation is on a shipper that procures its transport services, it was stated in the frame of reference that the analysis will only focus on improvements with regards to fill-rate improvements on laden trips.

Table 5-2 below illustrates how transport-related CO<sub>2</sub> emissions are affected on a system's level if a shipper manages to improve the fill-rate for the consolidated flow from 70% to a level of 80% and 90% respectively when a distribution system is centralised<sup>15</sup>. The reason why it is possible to achieve a higher fill-rate for the consolidated flow is linked to the fact that a centralised warehouse can even out oscillations in demand for various markets (Abrahamsson, 1992), whereby this makes the planning of replenishment orders easier for a shipper for this consolidated flow (Kohn, 2005). Owing to fill-rate improvement in the consolidated flow, CO<sub>2</sub> emissions must not increase as much as transport work on a systems level when the distribution system in centralised.

<sup>15</sup> The former of the two fill-rates has been chosen as representative for long-haul freight based on data from NTM (2007) as well as DHL and Wincanton (Kohn, 2005). The percentages for the improved fill-rate (i.e. 80% and 90%) represent approximate fill-rate levels that ITT Flygt was able to achieve in the consolidated flow after the company initiated its fill-rate improvement programme (Kohn, 2005).

Table 5-2: Illustration of potential in improving the fill-rate for the consolidated flow when a distribution system is centralised

		Increase in transport work due to centralisation			
		20%	40%	60%	80%
Amount of transport work stemming	20%	15% / <b>13%</b>	34% / <b>32%</b>	53% / <b>50%</b>	72% / <b>69%</b>
from the consolidated flow in the	40%	10% / <b>6%</b>	28% / <b>23%</b>	47% / <b>41%</b>	65% / <b>59%</b>
centralised distribution system =	60%	5% / <b>1%</b>	22% / 15%	40% / <b>31%</b>	57% / <b>48%</b>
centralised distribution system –		0% / <b>-9%</b>	16% / <b>7%</b>	33% / <b>22%</b>	50% / <b>37%</b>

- Numbers with normal font = 80% fill-rate for the consolidated flow
- Numbers with bold font = 90% fill-rate for the consolidated flow

#### Decentralised distribution system:

- Two types of trucks have been used, one with a payload of 26 tonne (fill-rate 70%) and one with a payload of 8.5 tonne (fill-rate 50%). 95% of the transport work is handled by the larger of the two vehicles. CO<sub>2</sub>/tonne kilometres is set to 0.051 kg and 0.17 kg (NTM, 2007), thus resulting in an average of 0.057 kg CO<sub>2</sub>/tonne kilometre.

#### Centralised distribution system:

- Fill-rate improvements are only considered for the consolidated flow. For this flow truck with a payload of 26 tonne and a fill-rate of 80% or 90% has been applied, thus meaning that  $CO_2$ /tonne kilometre is set to 0.045 or 0.040 for this part of the distribution system (NTM, 2007).
- For distribution from the central warehouse to the end customer the same assumptions have been made as regards road freight in the decentralised distribution system. Hence, an average value of 0.057 kg CO<sub>2</sub>/tonne kilometre has been used.

Figure 5-4 below exemplifies the calculations presented above by illustrating how CO<sub>2</sub> emissions would be affected if a structural change that resulted in an increase in transport work by 40% simultaneously enables the shipper in question to improve its fill-rate for the consolidated flow. For instance, if the consolidated flow accounts for 60% of total transport work in the centralised distribution system and the shipper manages to achieve a fill-rate of 90% for the consolidated flow, then the overall increase in transport-related CO<sub>2</sub> emissions will only be 15% for the system as a whole (all other things being equal). What Figure 5-4 also helps to demonstrate is that the relative size of the consolidated flow, measured in terms of transport work, compared to transport work for the whole system, has a significant influence on the potential that this opportunity brings (cf. section 5.1.1 on intermodal rail-truck transport). That is, the greater the consolidated flow is compared to total transport work for the whole distribution system, the greater the potential is that a fill-rate improvement in this part of the distribution system will have a significant impact on the distribution system as a whole.

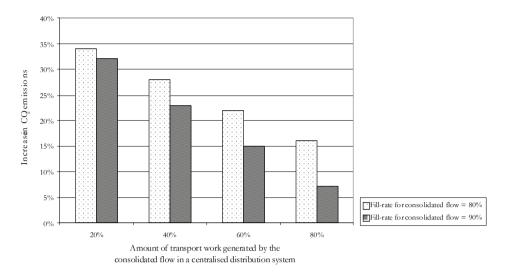


Figure 5-4: Example of how fill-rate improvements for the consolidated flow in a centralised distribution system can have a large effect for the system as a whole (based on a 40% increase in transport work due to the structural change)

Similar to the discussion with reference to change in mode of transport for the consolidated flow in a centralised distribution system, empirics in this dissertation indicate that it is possible for a shipper to achieve fill-rate improvements in the consolidated flow between the production unit and the central warehouse in this type of system. This is illustrated by ITT Flygt, where the company launched a fill-rate improvement programme subsequent to centralising the distribution system (Kohn, 2005). This undertaking revealed that the company was able to drastically improve on its fill-rate for the consolidated flow, whereas this type of improvement was not achieved for other parts of the distribution system. Hence, the character of the consolidated flow (evenly demand over time) serves as an enabler to achieve fill-rate improvements for a shipper.

On this topic it should also be noted that the only situation where a shipper can influence CO<sub>2</sub> emissions directly by means of a fill-rate improvement when procuring transport services externally, is when transport is handled as dedicated shipments. When transport is not handled as a dedicated service, a shipper is instead dependant on the fill-rate achieved by the transport provider throughout its transport network (*Kohn*, 2005). However, by consolidating its operations, a shipper can present the transport provider with an opportunity to improve the average fill-rate in its transport network, an issue that has not been included in the scope of this dissertation as it primarily focuses a shipper's distribution system.

The above discussion on potential reductions in transport-related CO<sub>2</sub> emissions owing to improved vehicle utilisation with regards to the consolidated flow in a centralised distribution system can be summarised as follows:

Given that the consolidated flow is of a dedicated nature from a shipper perspective it can enable an improvement in fill-rate that will lower the amount of transport-related  $CO_2$  emissions for this part of the system. The greater the consolidated flow is compared to total transport work, the greater the potential is that a reduction in  $CO_2$  emissions for this part of the distribution system will have a significant impact on the distribution system as a whole.

This confirms other studies that have shown how fill-rate improvements on laden trips will lower transport-related CO<sub>2</sub> emissions per amount of transport work (Blinge and Lumsden, 1996; International Maritime Organization, 2000; McKinnon, 2003; McKinnon, 2007). However, the analysis also makes a contribution to these studies as it, similar to the analysis on intermodal transport, illustrates the potential in CO<sub>2</sub> emission reductions at a system level that a fill-rate improvement for the consolidated flow provides.

#### 5.1.3 Fuel and energy efficiency

As discussed in the frame of reference this type of change refers to changes in, for example, driving behaviour and technology-related improvements. Given the perspective applied in this dissertation, these types of changes are not in the direct control of a shipper. Instead they are changes that a shipper can bring about by means of influence. Even though there is no empirical evidence in the appended manuscripts that suggests that the shippers in the case studies have executed this type of influence towards their transport service providers, the potential can still be analysed on a conceptual level by means of logical reasoning.

On the one hand, it can be acknowledged that since logistics-related activities should be managed centrally in a centralised distribution system (Abrahamsson, 1992; Fincke and Goffard, 1993; Norman, 1997; Christopher, 1998; Abrahamsson et al, 2003), this can affect a shipper's bargaining position towards its suppliers of transport services (Coyle et al, 2003; *Kohn, 2005*; Aronsson et al, 2008). The reason for this is that by consolidating all of the local markets in the distribution system, a shipper will have a larger portfolio or transport demand, to satisfy in a centralised distribution system vis-à-vis each subsidiary in a decentralised distribution system. Hence, by centralising the procurement of transport services, a shipper can also increase its bargaining position compared to its transport providers. Earlier studies (Abrahamsson, 1992; Coyle et al, 2003) as well as empirics presented in this dissertation (*Kohn, 2005*) indicate that such an improved position can enable a shipper to negotiate lower transport prices per amount of transport work. Analogous, a shipper should also be able to employ this power towards a

transport provider with regards to such issues as using fuels stemming from renewable resources or driver training. Similarly, a larger portfolio can by itself make the shipper a more attractive customer in the eyes of a transport provider. This will provide the shipper with reward power (cf. Kohn and Sandberg, 2006), which implies that a provider will try to live up to the environmental standards of a shipper in order to gain its business. As illustrated in the frame of reference, considerable improvements can be made with reference to CO<sub>2</sub> emissions per tonne kilometre with regards to such issues. Given the current environmental debate, transport service providers are well aware of the fact that there is a possibility to differentiate themselves from their competition by marketing themselves as a "green" transport provider. This is a behaviour that also relates to the use of power, more specifically non-coercive reward power (cf. Kohn and Sandberg, 2008). Hence, the question can be raised whether or not a shipper will need to impose such demands on its transport provider(s) in the future?

On the other hand, it must be recognised that when a distribution system is centralised, it is likely that a shipper will also turn to fewer and larger transport providers on the market (cf. *Kohn*, 2005) Owing to this, the shipper's dependence on the transport provider will increase (cf. Coyle et al, 2003), whereby the power relationship between the parties might be counterbalanced. If this is the scenario, it can prove difficult for shippers to pose such demands, as the countervailing power of the transport provider can be regarded as equal to or even greater compared to that of the shipper (cf. *Kohn and Sandberg, 2006*). This was the case with Stora Enso (*Kohn and Huge Brodin, 2008*), where one of the reasons why the company decided to abandon the old transport set-up with rail freight through Germany was because the rail companies were in a superior bargaining position that enabled them to demand high prices.

To summarise, the discussion pertaining to fuel and energy efficiency and potential reductions in transport-related CO<sub>2</sub> emissions suggests that:

Concentrating the procurement of transport services provides a shipper with an opportunity to pose greater demands with regards to environmental performance on behalf of the shipper's transport providers. Nevertheless, a shipper is simultaneously likely to approach providers that can provide a system-wide solution, which implies that these providers are likely to be larger companies than those approached by individual subsidiaries in a decentralised distribution system. Owing to this, the increased bargaining power might be counterbalanced by the bargaining power of a new and stronger provider.

This is all in line with earlier research that has argued that a shipper can reduce transport-related CO<sub>2</sub> emissions by posing demands on its transport providers (Wu and Dunn, 1995; Björklund, 2005), but it also contributes to this body of research by exemplifying how a shipper can improve its bargaining position by means of centralising the procurement of transport services. Benefits of

centralising the procurement of transport services has also been discussed in earlier research (Abrahamsson, 1992; Coyle et al, 2003), but not in a context of environmental improvements. However, as it has not been possible to quantify this potential in this study, the specific benefit of imposing stricter demands on transport providers needs further attention in future studies.

## 5.2 Analysis of interrelationships between a reduction in transportrelated CO<sub>2</sub> emissions and the provision of cost efficient customer service

In this, the second part of the analysis, interrelationships that exist between the analysed measures in the first part of the analysis and the provision of cost efficient customer service will be discussed. This part of the analysis has the same structure as the previous part, meaning that the analysis takes its starting point in the ratios (modal split, vehicle utilisation, and fuel and energy efficiency) and associated characteristics of a centralised distribution system (consolidated flow, emergency deliveries, and centralised management). Table 5-3 below illustrates the interrelationships that will be analysed with regards to each of the respective ratios and characteristics.

Table 5-3: Interrelationships focused in the second part of the analysis

Ratio	Characteristic	Interrelationships focused in the analysis			
		- Environment	- Cost	- Service	
Modal split	Consolidated flow	- Transport-related CO <sub>2</sub> emissions	- Inventory costs - Transportation costs	- Stock availability	
	Emergency deliveries	- Transport-related CO <sub>2</sub> emissions	- Transportation costs	- Stock availability	
	Centralised management	- Transport-related CO <sub>2</sub> emissions	- Transportation costs	- Lead-time (length and precision)	
Vehicle utilisation	Consolidated flow	- Transport-related CO <sub>2</sub> emissions	- Transportation costs	- N/A	
Fuel and energy source efficiency	Centralised management	- Transport-related CO <sub>2</sub> emissions	- Transportation costs	- N/A	

#### 5.2.1 Modal split

Similar to section 5.1.1, modal split will be analysed with regards to the three characteristics consolidated flow, emergency deliveries, and centralised management.

#### Consolidated flow

The analysis in section 5.1.1 pertaining to the characteristic of a consolidated flow in a centralised distribution system indicated that a shipper can substantially reduce transport-related CO<sub>2</sub> emissions for the whole distribution system if an intermodal rail-truck transport solution is

applied for this part of the distribution system. Even though this solution is advocated to be one possible way of breaking the current increase in transport-related CO<sub>2</sub> emissions (European Commission, 2000; EEA, 2007), it is not used to a great extent in industry. The argument that is made by shippers is that rail freight does not suffice with reference to current customer demands of relatively short and reliable lead-times, despite the fact that this solution can provide shippers with a cost advantage in terms of lower transportation costs (Flodén, 2007; Lammgård, 2007; Kohn, 2008). Hence, even though empirics in this dissertation illustrate that the consolidated flow that is created when a distribution system is centralised can enable a shipper to launch an intermodal transport solution, it is necessary to evaluate how such a change will affect the provision of cost efficient customer service. Based on the frame of reference, the analysis in section 5.1.1, and the empirics presented in the appended manuscripts, the following statements can be made:

- The consolidated flow in a centralised distribution system is a main contributor of both transport work and CO<sub>2</sub> emissions, given that all products need to be shipped via the central warehouse in such a system (Kohn, 2005).
- Transport costs with reference to regular deliveries are driven by the amount of transport work generated by the distribution system at hand (Abrahamsson and Aronsson, 1999).
- Service performance in terms of stock availability, lead-time, and lead-time precision is affected by the distance measured in time rather than geographical distance, where a centralised warehouse can provide a higher level of service with reference to the system as a whole compared to a decentralised distribution system with many local warehouses (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; Kohn, 2005).

When taking these statements into consideration simultaneously, it is possible to see that CO<sub>2</sub> emissions as well as transportation costs are driven by transport work. Service, in terms of stock availability, lead-time, and lead-time precision, on the other hand does not display the same evident link to transport work, as this is primarily driven by the system's structure (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999). Relating this to the interrelationships that were expected to exist between a reduction in transport-related CO<sub>2</sub> emissions and the provision of cost efficient customer service (see section 3.3.6), the following trade-off considerations appear if a shipper employs an intermodal rail-truck solution for the consolidated flow:

CO<sub>2</sub> emissions will decrease substantially since intermodal rail-truck transport emits less CO<sub>2</sub> compared to unimodal truck transport (Lenner, 1993; Christopher et al, 2007; Flodén; 2007; McKinnon, 2007; NTM, 2007).

- Transportation costs are expected to decrease between the production unit and the central warehouse as intermodal rail-truck transport is less costly than unimodal truck transport (Flodén, 2007; Kohn, 2008).
- The level of customer service in terms of lead-time and lead-time precision provided to the customer will stay at a constant given that safety stock levels are revised to compensate for the increase in lead-time and lower level of precision for the consolidated flow. Owing to this, inventory costs will increase, where this increase needs to be weighed against the positive gains in terms of transportation costs and CO<sub>2</sub> reductions (see sections 3.3.2-3.3.3 in the frame of reference)

With regards to the first of the considerations, the analysis in section 5.1.1 has illustrated the potential that a shipper has to reduce transport-related CO<sub>2</sub> emissions if a rail-truck intermodal transport solution is employed for the consolidated flow. Therefore this potential will not be discussed again here and the analysis will instead focus on how transportation costs and inventory costs are expected to be affected by this change in mode of transport.

Starting with how intermodal rail-truck transport affects transportation costs, this type of transport solution is argued to have a cost advantage compared to unimodal truck transport, in particular for longer distances (Blinge, 1995; Flodén, 2007; Kohn, 2008). This is also illustrated in Table 5-4 below, which illustrates how transportation costs and total cost of distribution are expected to be affected by this type of mode change for the consolidated flow when a distribution system is centralised. These calculations are based on cost estimates per tonne kilometre for unimodal truck transport and intermodal rail-truck transport respectively presented by Flodén (2007). In his study on the potential of employing intermodal rail-truck transport, Flodén concludes, through simulations, that on average the cost per tonne kilometre for intermodal rail-truck transport is less than half of unimodal truck transport (SEK 0.14 for intermodal transport vs. SEK 0.32 for unimodal truck transport 16). These are average cost estimates and consequently the difference between the two types of transport is expected to be lower in those instances where the rail part of the intermodal setup constitutes as smaller part and vice versa (Flodén, 2007). Even though these estimates are averages, they help to illustrate the cost incentive in using intermodal rail-truck transport compared to unimodal truck transport which is also pointed to in other research (e.g. Blinge, 1995; Flodén, 2007; Lammgård, 2007; Kohn, 2008)

<sup>&</sup>lt;sup>16</sup> It should be acknowledged that these figures correspond to the total cost per tonne kilometre of running these two types of transport solutions (including terminal handling costs and the like), i.e. the figures are valid for a provider of these services. For the purposes of this dissertation, however, it has been assumed that the mark-up (in %) is equal for both services, meaning that the cost ratio when comparing unimodal rail-truck transport with unimodal truck transport will remain the same.

As discussed earlier, the consolidated flow is likely to account for a substantial amount of total transport work in a centralised distribution system and this in turn implies that a shift to intermodal rail-truck transport for this part of the distribution system can also have a large effect on the transportation cost for the system as a whole. This is indicated by the figures within brackets in Table 5-4. Transportation costs are also considered to account for a large portion of total distribution costs. For instance, in the latest Establish Davis Benchmark, transportation costs accounted for 45% of total distribution costs in the USA and 44% of total distribution costs in Sweden (Establish, 2007). This in turn implies that a reduction in transportation costs will also have a large effect on the total cost of distribution, which is indicated by the figures without brackets. For instance, if total transport work increases by 40% due to centralisation and the consolidated that is created in the centralised distribution system accounts for 60% of total transport work, then total distribution costs would decrease by 3% for the whole of the distribution system compared to the situation in the decentralised distribution system, all other things being equal.

Table 5-4: Effect on transportation costs and total cost of distribution for the system as a whole if an intermodal rail-truck solution is applied for the consolidated flow when a distribution system is centralised

		Increase in transport work due to centralisation			
		20%	40%	60%	80%
Amount of transport work stemming from the consolidated flow in the centralised distribution system	20%	3% (7%)	11% (24%)	18% (42%)	26% (60%)
	40%	-3% (-7%)	4% (9%)	11% (24%)	17% (40%)
	60%	-9% (-21%)	-3% (-7%)	3% (6%)	8% (19%)
	80%	-15% (-34%)	-10% (-23%)	-5% (-12%)	0% (-1%)

- Numbers without brackets = total distribution costs
- Numbers within brackets = transportation costs
- Transportation costs are considered to account for 44% of total distribution costs in accordance with Swedish figures from Establish Davies Benchmark for 2007 (Establish, 2007).
- Only regular deliveries are considered.

#### Decentralised distribution system:

- All transport work has been assumed to be performed by means of unimodal road freight, where a cost of SEK 0.32/tonne kilometre has been applied in accordance with figures from Flodén (2007).

#### Centralised distribution system:

- Intermodal transport is only used for the consolidated flow. For this part of total transport work a cost of SEK 0.14/tonne kilometre has been applied in accordance with figures from Flodén (2007).
- For distribution from the central warehouse to the end customer the same assumptions have been made as regards road freight in the decentralised distribution system. Hence, a cost of SEK 0.32/tonne kilometre has been used.

Figure 5-5 below provides an example based on the calculations presented above, where the figure illustrates how transportation costs as well as total distribution costs are affected on a systems level if an intermodal rail-truck transport solution is applied for the consolidated flow when a distribution system is centralised, given that total transport work simultaneously increases by 40% due to centralisation. Relating to this, Abrahamsson and Aronsson (1999) argue that transportation costs are driven by the amount of transport work generated in distribution system. What the figure then helps to illustrate is that if the structural change increases transport work by 40% and thereby transportation costs (excluding economy of scale opportunities associated with centralised procurement of transport services), employing an intermodal transport solution for the consolidated flow can counterbalance this increase in transportation costs in those cases where the consolidated flow accounts for approximately 50% or more of total transport work.

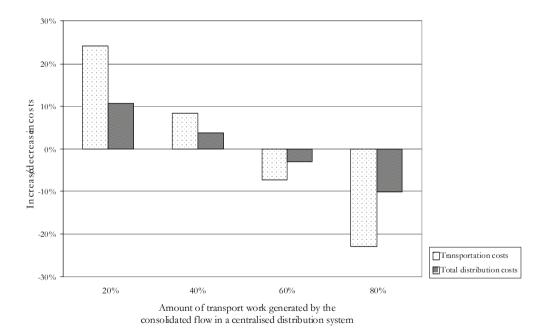


Figure 5-5: Example of how transportation costs and total distribution costs for the system as a whole are affected when transport work for the consolidated flow is transferred from unimodal truck transport to intermodal rail-truck transport in a centralised distribution system (based on a 40% increase in transport work due to the structural change)

Turning to inventory costs, Figure 5-6 below illustrates how the total cost of distribution is affected if safety stock levels need to be revised in order to guarantee that stock availability is not affected by longer and less precise lead-times caused by adopting an intermodal rail-truck transport solution for the consolidated flow. What this figure helps to illustrate is that even

though safety stock levels might need to be increased substantially, this does not affect total cost of distribution to the same degree. The reason for this is that inventory costs only constitute part of total distribution costs (approximately 11% in a Swedish context according to Establish Davis Benchmark (2007)) and that costs associated with adding safety stock in the central warehouse in turn only account for part of total inventory costs.

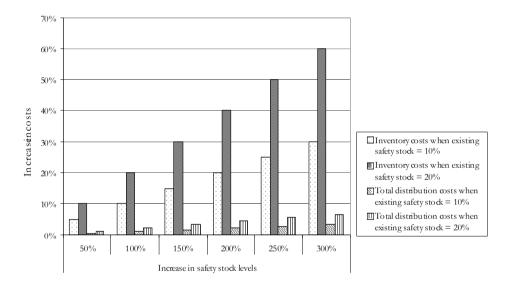


Figure 5-6: Example of how inventory costs and total distribution costs increase for the system as a whole owing to an increase in safety stock levels in order to warrant an unchanged level of stock availability when transport work for the consolidated flow is transferred from unimodal truck transport to intermodal rail-truck transport in a centralised distribution system

The discussion above indicates that if a shipper desires to keep the level of service constant, with regards to stock availability, when employing an intermodal transport solution for the consolidated flow, then the shipper needs to consider trade-offs between on the one hand a reduction in transport-related CO<sub>2</sub> emissions and transportation costs and on the other hand an increase in inventory costs. The reason for this is that even though intermodal rail-truck transport is recognised to both reduce CO<sub>2</sub> emissions and transportation costs compared to unimodal truck transport, this will come at the expense of longer and less precise lead-times. In this trade-off consideration it is important to recognise that inventory costs constitute a smaller portion of total distribution costs compared to transportation costs (11% vs. 44% according to Establish Davis Benchmark (2007)). This implies that for every Swedish krona or Euro it is possible to reduce transportation costs by employing an intermodal rail-truck transport solution, a shipper can increase inventory costs by a factor of four. For example, if transport work is increased by

40% due to centralisation and the consolidated that is created in the centralised distribution system accounts for 60% of total transport work, then safety stock levels can be increased to the extent that inventory costs can increase by as much as 28%, since such a change in mode of transport for the consolidated flow would render a 7% decrease in transportation costs (see Table 5-4).

Based on the preceding discussion, the analysis on the interrelationship between a reduction in transport-related CO<sub>2</sub> emissions and the provision of cost efficient customer service with reference to intermodal rail-truck transport for the consolidated flow can be summarised as follows:

Employing an intermodal rail-truck transport solution for the consolidated flow in a centralised distribution system not only provides a shipper with an opportunity to reduce transport-related  $CO_2$  emissions, but it also offers an opportunity to reduce transportation costs as this transport solution is less costly than unimodal truck transport. This positive aspect of intermodal rail-truck transport needs to be weighed against longer and less precise lead-times in the consolidated flow, whereby safety stock levels may need to be increased so as to warrant an unchanged stock availability towards the customer. Hence, there is a trade-off between on the one hand a reduction in transport-related  $CO_2$  emissions and transportation costs and on the other hand increased inventory carrying costs (assuming an unchanged degree of stock availability).

This confirms earlier research that has pointed to the common trade-off in using intermodal rail-truck transport, namely that of lower transportation costs and less CO<sub>2</sub> emissions vs. lower degree of service in terms of longer and less precise lead-times (Flodén, 2007; Lammgård, 2007). Earlier research on intermodal transport has shown that in those cases where the cost criterion is emphasised, shippers will tend to favour the use of intermodal transport (Tsamboulas and Kapros, 2000). This is also supported by empirics in this dissertation, where all of the three cases in *Kohn (2008)* display this pattern. However, the analysis in this dissertation also illustrates how a shipper can achieve substantial savings in transportation costs for the distribution system as a whole by only employing an intermodal transport solution for the consolidated flow that is created in a centralised distribution system.

Even though earlier research has posed and answered the question why shippers use intermodal transport (e.g. cost advantage), less attention has been devoted to providing an understanding of how shippers employ this type of transport solution in their logistics systems. This dissertation provides insights on this issue. For instance, a common denominator among the cases in *Kohn* (2008) is that all of the three shippers only use intermodal transport in those parts of their systems where they know it is going to function without substantial complications. All of the three companies operate the intermodal transport solutions on the Swedish market and this

implies that they do not have to concern themselves with issues such as different standards regarding width on the railway tracks or the fact that at current state it is not possible to procure an intermodal rail-truck transport service that, for instance, supports a shipper's pan-European logistics operations.

The analysis also make a contribution to Flodén's (2007) recent study, where he argues that one way of convincing shippers to use intermodal transport to a greater extent compared to today would be to put forward the argument that transportation costs can be used to compensate for longer and less precise lead-times. This dissertation identifies an area where the savings in transportation costs can be used, namely in terms of increasing safety stock levels so as to compensate for the lower degree of service in terms of longer and less precise lead-times for inbound transport to a central warehouse. Here it must be recognised that this conclusion assumes a centralised distribution system, where the central warehouse(s) has consolidated inbound flows.

#### **Emergency deliveries**

With regards to emergency deliveries, the discussion in the framework revealed that the interrelationship discussion will centre on transport-related CO<sub>2</sub> emissions and transportation costs. The reason for this being that a fundamental principle of centralising a distribution system is that it should improve the level of customer service, measured in terms of stock availability, order lead-time, and lead-time precision (Abrahamsson, 1992; Fincke and Goffard, 1993; Abrahamsson and Aronsson, 1999; *Kohn, 2005*). Owing to this there will be less of a need for emergency deliveries in a centralised distribution system compared to that of a decentralised system and this is also one of the reasons why transportation costs need not increase when a distribution system is centralised despite of the fact that transport work for the system increases (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; *Kohn, 2005*; Schenker Consulting, 2007). The other reason why transportation costs are argued not to increase is connected to achieving economies of scale in the procurement of transport services (Abrahamsson, 1992; Christopher, 1998; Coyle et al, 2003), an issue that will be discussed further later on in the analysis.

Referring back to the analysis pertaining to emergency deliveries in section 5.1.1, it was illustrated how the discussed change in mode of transport will have a positive effect on transport-related CO<sub>2</sub> emissions as a slower mode of transport incurs less CO<sub>2</sub> emissions compared to that of a faster mode of transport (Lenner, 1993; Christopher et al, 2007; McKinnon, 2007; NTM, 2007). The effect of this change is however dependant on how transport work is manifested. Based on this it can be maintained that the improvement in stock availability, that is an outcome of a shipper centralising its distribution system, is expected to have a positive effect on transport-

related  $CO_2$  emissions as well as transportation costs (see Figure 5-7). Nevertheless, it should be recognised that there is a need to make a distinction with reference to how emergency deliveries affect transport-related  $CO_2$  emissions in a shipper's distribution system vis-à-vis how they affect the cost of transport for the same system. This implies that the cost structure for transport must not necessarily be equal to the structure that reflects the amount of  $CO_2$  emissions incurred by regular deliveries and emergency deliveries. This is illustrated by the case of ITT Flygt, where transport work stemming from emergency deliveries constituted less than half of a per cent in the decentralised distribution system. Owing to this the decrease in emergency deliveries did not have any significant effect on transport-related  $CO_2$  emissions even though the reduction in emergency deliveries was one of three reasons why the company was able to keep transportation costs at more or less a constant even though transport work was increased (*Kohn, 2005*).

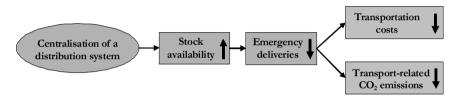


Figure 5-7: Illustration of how transport-related CO<sub>2</sub> emissions are connected to the provision of cost efficient customer service in a shipper's centralised distribution system with reference to emergency deliveries

Based on this, the analysis regarding emergency deliveries can be summarised as follows:

Improved stock availability has a positive effect on both transportation costs and transport-related  $CO_2$  emissions since the improved availability enables a shift in mode of transport for part of total transport work. However, there is a need to make a distinction with reference to how transportations costs and  $CO_2$  emissions caused by emergency deliveries are affected by the structural change. That is to say, transportation costs and  $CO_2$  emissions associated with emergency deliveries must not necessarily decrease to the same extent when a distribution system is centralised.

Earlier research has contented that there is a need to differentiate between transportation costs for regular deliveries and emergency deliveries (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999). The results presented here make a contribution in that they illustrate that it is also important to recognise this logic when considering transport-related CO<sub>2</sub> emissions. The argument has been put forward that transportation costs and CO<sub>2</sub> emissions need not be affected in the same manner and there is a need for further research on this issue so as to identify in what cases they are affected in the same manner and in what cases they are not, since this issue has not been explored within the scope of the research presented here.

#### Centralised management

With regards to centralised management and change in mode of transport, the analysis in section 5.1.1 illustrated how the conditions of a specific structural change will determine whether a change in mode of transport for regular deliveries will increase or decrease the amount of transport-related CO<sub>2</sub> emissions. It was also argued that it is more likely that CO<sub>2</sub> emissions stemming from transport would increase when a shipper centralises its distribution system and employs a standard transport solution for regular deliveries, all other thing being equal.

Relating this to the provision of cost efficient customer service, the frame of reference as well as empirics in the dissertation (cf. Kohn, 2008) has helped to illustrate that there is a basic trade-off between the speed and cost of a specific mode of transport. In generic terms, this trade-off states that whereas faster modes of transport enhance the level of service in a distribution system, measured in terms of lead-time (length and precision), they do so at the expense of higher costs and vice versa. Furthermore, it can be argued that a shipper will tend to find a transport solution that provides the lowest transportation cost given a certain level of customer service in terms of length and variations in lead-time, where many shippers' distribution systems in Europe are currently designed so as to guarantee lead-times from the central warehouse to the customer of 24-72 hours. Using the words of Hesse and Rodrigue (2004), this has in many cases led to a modal adaptation, where road transport is by many shippers considered the only viable alternative for regular transport, as airfreight is in many cases considered too expensive and the other modes of transport are considered to slow and unreliable to satisfy this lead-time demand. As such, it could be argued that it is the current desire of shippers to find a transport solution that offers them a high degree of customer service (short and precise lead-times) to a low cost that is at odds with finding transport solutions that are more environmentally friendly. This is also illustrated by the fact that road freight constitutes almost 80% of total freight volumes in the EU-15 countries (EEA, 2007).

This development reflects the fact that shippers have the same quality requirements on intermodal rail-truck transport as they have on unimodal truck transport (cf. Ludvigsen, 1999). This is also emphasised in the cases of ITT Flygt (Kohn, 2005; Kohn and Huge Brodin, 2008) and KappAhl (Kohn, 2008). With regards to ITT Flygt, the inferior performance in terms of longer and less precise lead-times is one of the main reasons why the company has opted to use unimodal truck transport instead of intermodal rail-truck transport for the consolidated flow between its production unit and central warehouse. In the case of KappAhl, the company uses intermodal rail-truck transport, but only in those parts of the distribution system where this transport solution is at par with the lead-time performance of unimodal truck transport. The increased use of road freight in part also reflects how the field of logistics management has evolved over the last couple of decades, from a pure cost focus to more of a service focus (cf.

Tsamboulas and Kapros, 2000). It can therefore be claimed that it is the current focus on short and reliable lead-times that is at odds with shippers employing a slower and more environmentally (CO<sub>2</sub>) friendly mode of transport, as highlighted by Rodrigue et al (2001):

"In logistics, time is often the essence. By reducing the time of flows, the speed of the distribution system is increased, and consequently, its efficiency. This is achieved by using the most polluting and least energy efficient transportation modes. The significant increase of air freight and trucking is partially the result of time constraints imposed by logistical activities."

(Rodrigue et al, 2001, p 5)

To conclude this discussion, the following summary can be made:

When a distribution system is centralised, the average distance between a shipper's warehouse and its customers will increase. In order to be able to provide the customers with timely deliveries (short and reliable lead-times) despite of the increase in distance, a shipper will adopt an equally fast or a faster mode of transport.

This analysis highlights the basic trade-off between transport-related CO<sub>2</sub> emissions and service (length and precision in lead-time) discussed in earlier research (Wu and Dunn, 1995; Rodrigue et al, 2001). Similar to Flodén (2007), it highlights that it is shippers' current emphasis on short and precise lead-times that needs to be compensated or balanced by other aspects, since this focus is hindering the employment of slower modes of transport, which are both more cost and CO<sub>2</sub> efficient. However, this trade-off consideration is complex and the question can be raised whether it is the responsibility of shippers to change their strategic focus or modify their distribution systems in order to enable the use of less polluting modes of transport or whether it is the customers' responsibility to decrease current lead-time demands?

#### 5.2.2 Vehicle utilisation

The first part of the analysis illustrated how the consolidated flow in a centralised distribution system can enable a shipper to decrease the amount of transport-related CO<sub>2</sub> emissions due to fill-rate improvements with reference to this part of the distribution system. When considering how these improvements affect the provision of cost efficient customer service, the frame of reference discussed how this type of improvement provides a good example of when financial and environmental gains can coincide without jeopardising the provision of customer service (McKinnon, 2003; 2007).

This is also illustrated by empirics in this dissertation (Kohn, 2005), which demonstrate how an improvement in fill-rate for laden trips with reference to the consolidated flow will reduce the

total number of trips (cf. Wu and Dunn, 1995). This in turn results in a reduction in overall fuel consumption, which will have a positive effect on transport-related CO<sub>2</sub> emissions as well as transportation costs. On the same note, the case of Stora Enso (Kohn and Huge Brodin, 2008) complements the case of ITT Flygt, as it illustrates how the consolidated flow has enabled the shipper in question to achieve fill-rate improvements for the consolidated flow without jeopardising the provision of cost efficient customer service. This is achieved thanks to the fact that goods are consolidated, which enables the shipper to improve the fill-rate for single shipments at the same time as the frequency in shipments is kept high (once every day in both cases).

This decrease in transportation costs will also have a positive effect on total distribution costs. This is exemplified by Figure 5-8, which illustrates how transportation costs and total distribution costs decrease owing to an improvement in fill-rate from 70% to 80% for the consolidated flow in a centralised distribution system.

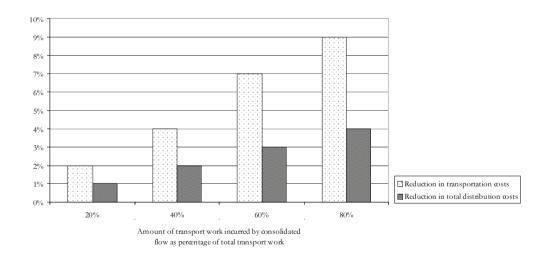


Figure 5-8: Illustration of how much an improvement in fill-rate from 70% to 80% can affect transportation costs and total distribution costs depending on the magnitude of the consolidated flow<sup>17</sup>

<sup>&</sup>lt;sup>17</sup> This calculation is based on the following four assumptions: First, a truck with a payload of 26 tonne has been used for road freight between the production unit and the central warehouse (consolidated flow), as this is a dedicated flow (cf. *Kohn*, 2005). CO<sub>2</sub>/tonne kilometre is set to 0.051 kg when the fill-rate is 70% and 0.045 kg when the fill-rate is 80% for this flow including fuel production life cycle (NTM, 2007). Second, for distribution from the central warehouse to the end customer, two types of trucks have been used. These have a payload of 26 tonne (fill-rate 70%) and payload of 8.5 tonne (fill-rate 50%), where 95% of the transport work is handled by the larger of the two vehicles. The 95/5 split between the two truck types is based on data from Wincanton with reference to how this transport provider's network is configured (see *Kohn*, 2005). CO<sub>2</sub>/tonne kilometres is set to 0.051 kg and 0.17 kg respectively (NTM, 2007), which corresponds to values provided by Wincanton for its transport network. Third, transport-related CO<sub>2</sub> emissions and transportation costs are considered to be affected in the same manner due to a

Based on the discussion above, the analysis as regards vehicle utilisation and the interrelationship between a reduction in transport-related CO<sub>2</sub> emissions and the provision of cost efficient customer service is summarised as follows:

Provided that the volumes in the consolidated flow are large enough to warrant a high frequency in deliveries in this part of the distribution system, an improvement in fill-rate for the consolidated flow in a centralised distribution system will lead to a reduction in transport-related  $CO_2$  emissions and transportation costs without impeding the provision of customer service

This confirms earlier research (Blinge and Lumsden, 1996; McKinnon, 2003; McKinnon, 2007) as it demonstrates how an improvement in fill-rate will have a positive effect on both transport-related CO<sub>2</sub> emissions and transportation costs. However, it also extends this research by illustrating how the consolidated flow that is created when a distribution system is centralised is an enabler for achieving this type of improvement.

#### 5.2.3 Fuel and energy efficiency

It has been argued that centralising a distribution system, provides a shipper with an opportunity to reduce its transport-related CO<sub>2</sub> emissions by virtue of an improved bargaining position vis-àvis its transport providers (Kohn, 2005; Aronsson et al, 2008). Even though changes with reference to fuel and energy efficiency are not considered to have a negative impact on the customer service provided by a shipper's distribution system, they are recognised as having a potential negative impact on transportation costs (Blinge and Lumsden, 1996). What needs to be considered is the reaction on behalf of the transport provider, if a shipper increases its demands with regards to, for instance, using cleaner fuel types. By centralising its procurement of transport services a shipper does not only increase its bargaining position, but rather the shipper simultaneously becomes more dependant on the transport provider and its transport network, if a single souring approach is applied by the shipper in question (Coyle et al, 2003). Therefore, demands from a shipper with regards to fuel and energy efficiency improvements may lead the transport provider to try to push the costs for such improvements to the shipper by means of higher transport prices. If the provider is successful in this attempt, then it can be argued that a reduction in transport-related CO2 emissions achieved through increased demands on carriers can have a negative impact on the cost of transportation in the long run. This also gives raise to the question whether shippers are willing to pay for such indirect improvements, since costs associated with transport are often listed as a primary decision variable when choosing a carrier (Lammgård, 2007). However, if a shipper cannot demand an improved environmental

fill-rate improvement. Fourth, it has been assumed that transportation costs constitute 44% of total distribution costs (Establish Davis Benchmark, 2007).

performance on behalf of its transport provider(s) without jeopardising the price of transport, then it can be questioned whether or not the shipper in question has a bargaining advantage visà-vis its provider(s). This indicates that it is important for a shipper to fully understand the power relationship between itself and its provider(s), especially considering that the use of power will have a significant influence on how future relations between the parties will develop (cf. Kohn and Sandberg, 2006).

Relating this to the discussion on changes in logistics systems in section 3.1, it is also a question of whether demands on transport providers with regards to fuel and energy efficiency are most likely to come from shippers or from policy-makers and the like. It can be argued that to date, this type of demand has primarily come from other stakeholders than shippers (i.e. through laws and regulations by means of, for example, Euro standards for truck engines). Nevertheless, if we are to come to terms with the runaway increase in CO<sub>2</sub> emissions, this type of issue needs to be simultaneously addressed by businesses (Hart, 1997; SOU, 2001; Fromlet, 2002; Östlund et al, 2003; Sperling, 2006). On this note, this dissertation illustrates how a shipper by means of centralising its procurement of transport services is likely to be in a better position to impose demands with regards to these issues than if the procurement of transport services is decentralised.

To summarise, the discussion and analysis pertaining to fuel and energy efficiency and a trade-off between reductions in transport-related CO<sub>2</sub> emissions and transportation costs indicates that:

Concentrating the procurement of transport services provides a shipper with an opportunity to pose greater demands on transport providers with regards to environmental performance. Nevertheless, shippers need to evaluate this opportunity closely as it might be associated with increased transportation costs. The reason for this being that these types of improvements can be very costly for the transport providers, whereby this cost might be transferred to the shipper in the form of higher prices. This indicates that it is essential for a shipper to fully understand the power relationship between itself and its transport provider(s).

Whereas earlier research has argued that a shipper can reduce transportation costs by procuring transport services centrally and also concentrating the supplier base for the whole of the distribution system to one or a couple of transport providers (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; Coyle et al, 2003), the research presented in this dissertation indicates that this concentration of procurement can also enable a shipper to pose greater demands with regards to measures relating to fuel and energy efficiency. However, the empirics presented in this dissertation do not give an indication of how the interrelationship between transportation costs and shipper induced CO<sub>2</sub> improvements on behalf of the transport provider will manifest itself. Hence, there is a need to explore this interrelationship further in future research.

## 5.3 A discussion on the configuration of a centralised distribution system and its connection to transport work

The analysis performed in sections 5.1 and 5.2 has focused on measures a shipper can employ in order to reduce transport-related CO<sub>2</sub> emissions per tonne kilometre when a distribution system is centralised and how such measures affect the provision of cost efficient customer service. However, it should be recognised that whether centralising a distribution system will lead to an increase or decrease in transport-related CO<sub>2</sub> emissions is, on the one hand, dependant on how much transport work is increased due to the structural change and, on the other hand, how much it is possible to reduce CO<sub>2</sub> emissions per tonne kilometre by employing one or more of the measures discussed throughout the dissertation.

Even though there is consensus among researchers with regards to the fact that transport work will increase when a distribution system is centralised, there is nevertheless a lack of studies illustrating how large this increase will be. This is also the reason why the numerical analysis in sections 5.1 and 5.2, based on *Kohn (2005)* and Schenker Consulting (2007), has assumed an increase in overall transport work in the span of 20% to 80% (also see introduction in section 5.1). This section will therefore turn the attention to how centralisation affects the amount of transport work generated by a distribution system. Hence, the following discussion will not centre on whether or not this type of structural change will lead to an increase in transport work. Instead, this section aims to illustrate how different system configurations can lead to different outcomes, with reference to the amount of transport work that is generated by a distribution system. This is because the change in transport work is an important aspect of structural change, since this provides the baseline against which a shipper can reduce (or increase) transport-related CO<sub>2</sub> emissions.

Throughout the dissertation, it has been assumed that when a distribution system is centralised, regional/local warehouses are abandoned for a solution that is based on one central warehouse. However, the concept of centralised distribution does in itself not stipulate that there should be only one central warehouse. Instead, it is advocated that a shipper should use as few warehouses as possible given the lead-time demands posed by the customers (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999). This is also illustrated in *Kohn (2008)*, where Carlsberg Sweden, for instance, has decided to use two central warehouses for its distribution of beverages in Sweden. Similarly, Sandvik Coromant decided to use two central warehouses when the company centralised its distribution system (Abrahamsson, 1992). This point is also illustrated by McKinnon (1998), who demonstrates that a distribution system will have varying number of distribution centres/warehouses depending on the value density of the product that is distributed. In his article he illustrates, amongst other things, that the greater the value density of

a product is, the fewer the number of distribution centres will be. In line with this, the subsequent discussion will illustrate how two different system configurations can affect the amount of transport work generated by a distribution system quite significantly.

For the purpose of illustrating how the system configuration can affect the amount of transport work generated by the system, we will return to the case of ITT Flygt once more. The reason for this is that it is possible to illustrate how transport work is affected if one central warehouse is substituted for two central warehouses in this case. This will be discussed below. However, the reader is also advised to read the case description, analysis, and calculation procedure presented in the licentiate thesis (*Kohn, 2005*) in order to better understand this discussion.

As illustrated by the case study, ITT Flygt's decision to centralise its distribution system for the western European market led to an increase in transport work by 34% (*Kohn, 2005*, p 83). Figure 5-9 below stems from the licentiate thesis and it illustrates how the increase is transport work is divided amongst the eight markets/countries.

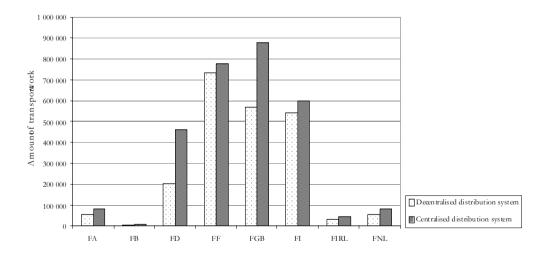


Figure 5-9: Amount of tonne kilometres generated by the two distribution systems with reference to the eight analysed markets (*Kohn, 2005, p 83*)

This figure helps to illustrate two things. First, it illustrates how most of the overall increase in transport work can be attributed to four of the markets; France, Germany, Great Britain, and Italy. Second, it illustrates how most of this increase is attributed to two of these markets, namely Germany and Great Britain. In fact, these two markets accounted for approximately 75% of the

total increase in transport work<sup>18</sup>, where transport work for the German market increased by 128% and by 54% for the British market (*Kohn, 2005*, pp 82-89). The reason for this increase in transport work is an increase in average length of haul for these two markets, as illustrated by Figure 5-10.

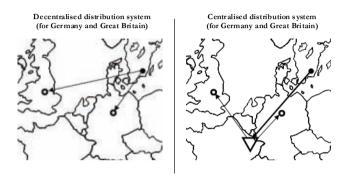


Figure 5-10: Illustration of how the average length of haul has increased for the German and British markets due to the structural change (based on Kohn, 2005, p 83)

With regards to these figures, it would be interesting to know how transport work would be affected if the products for these two markets were distributed from a central warehouse that would be located closer to these two markets than the current central warehouse in Metz, France. As it so happens, it is possible to find such an opportunity within ITT Flygt's current distribution system. After the company had launched its distribution centre in Metz for the western European market, it also launched a second distribution centre. This distribution centre is located by the company's main production unit in Lindås, Sweden, and it has the task of serving the rest of the world with products. For instance, this warehouse supplies the rest of the European market, i.e. the Nordic region as well as the eastern parts of Europe.

In line with this, an analysis has been made with regards to how transport work would be affected if the German and British markets were to be supplied from this central warehouse instead of that in Metz, France. This situation is illustrated in Figure 5-11, which, in generic terms, compares the current distribution system with such a conceptual set-up. If the two markets in question would be supplied by the warehouse in Sweden instead of the warehouse in France, then ITT Flygt's centralisation for the eight western European markets would only have rendered an increase in transport work by 11% instead of the experienced increase by 34%. The

<sup>18</sup> The overall increase in transport work due to the structural change amounted to approximately 742,000 tonne kilometres, out of which approximately 567,000 tonne kilometres was attributed to the German and British markets.

<sup>&</sup>lt;sup>19</sup> In order to arrive at this figure, it has been assumed that products to Germany are shipped using the same route as in the decentralised distribution system. This would imply that transport work with regards to the German market

reason for this substantial change is that these two markets constitute a large part of total sales for the company, with regards to the eight markets studied in the licentiate thesis<sup>20</sup>.

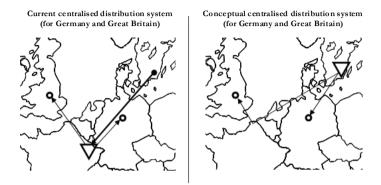


Figure 5-11: Comparison of today's distribution system and a conceptual distribution system where the German and the British markets are supplied by the central warehouse in Lindås, Sweden

Albeit that the above discussion is of a conceptual character, it helps to illustrate how the configuration of a distribution system and the number of warehouses employed, can greatly affect the amount of transport work generated by a distribution system. This discussion has also left out constraining factors for accomplishing such a change (e.g. space constraints in the Lindås warehouse). However, with regards to the analysis in sections 5.1 and 5.2, it should be acknowledged that by adopting a configuration that leads to a lower increase in transport work, a shipper is in a better position to counterbalance the increase in transport-related CO<sub>2</sub> emissions inflicted by the increase in transport work. This can be achieved by employing the measures that reduce transport-related CO<sub>2</sub> emissions per amount of transport work that have been discussed and analysed throughout this dissertation. Hence, if shippers are to come to terms with the current transport situation, an understanding of how to best configure a distribution system, in terms of nodes and links, is of paramount importance. This is because there is a close link between transport work and CO<sub>2</sub> emissions. However, since the discussion above has only addressed the issue on a conceptual level, there is a need to address this issue further in future research.

would not increase due to the structural change (from decentralised to centralised), since the products would be shipped using the same routing in both the decentralised distribution system and the conceptual centralised distribution system. With regards to the British market, it has been assumed that the products would be shipped using a route similar to that which ITT Flygt used for its special express transport solution for the British market prior to centralising its distribution system. This solution implied that the products to the British market were shipped by means of road freight via France and the channel tunnel. This is described further on pp 62-63 in the licentiate thesis (*Kohn, 2005*). However, the exact routings that serve as a basis for the calculations may not be revealed due to confidentiality reasons.

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<sup>&</sup>lt;sup>20</sup> Exact figures on this issue can not be revealed due to confidentiality reasons.

# 6 CONCLUSIONS, CONTRIBUTIONS, AND FUTURE RESEARCH

This chapter discusses and summarises how the research presented in this dissertation contributes to the body of knowledge in logistics by addressing the overall purpose that was stated in section 1.3:

■ To explain how a shipper, through various measures, can reduce transport-related CO₂ emissions when centralising a distribution system and how this affects the provision of cost efficient customer service

The chapter starts by discussing the conclusions of this research. This is followed by a discussion about the theoretical contribution as well as the managerial implications of the research. Subsequently, some avenues for future research are discussed.

#### 6.1 Conclusions

One of the more important logistics-related industry trends over the last couple of decades has been that of shippers centralising their distribution systems. The quintessence of this structural change is that the physical structure of the distribution system and management of the same is centralised. Even though this type of structural change can take many forms, this dissertation has assumed that the structural change implies that a shipper changes from a system with local warehouses in each country/region to a system with one central warehouse supplying customers with direct deliveries in each of the same countries/regions (see Figure 6-1). This type of change has enabled shippers to cut logistics costs by 25-30% while at the same time, customer service has been improved (Abrahamsson, 1992; Abrahamsson and Aronsson, 1999; Abrahamsson et al, 2003).

For a long time it has been argued that this change is unfavourable from an environmental perspective as it increases the total amount of transport work generated by a distribution system (Wu and Dunn, 1995, Rodrigue et al, 2001; McKinnon, 2003; Croxton and Zinn, 2005). More recent research has come to question this view and this research indicates that even though this type of structural change causes an increase in overall transport work in a shipper's distribution system, it simultaneously provides the shipper in question with a number of new opportunities to reduce transport-related CO<sub>2</sub> emissions, i.e. opportunities that were not existent prior to the structural change (Aronsson and Huge Brodin, 2006).

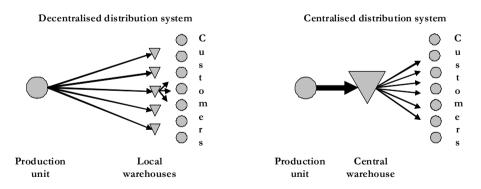


Figure 6-1: Generic illustration of a decentralised and a centralised distribution system, as applied in this dissertation (adapted from Abrahamsson, 1992, p 2)

In accordance with the discussion above, a shipper needs to understand which factors cause an increase in transport-related CO<sub>2</sub> emissions when a distribution system is centralised and which factors that decrease the amount of transport-related CO<sub>2</sub> emissions. However, there has been a

lack of guidance available for shippers on this issue, as environmental issues, in general, have received little attention within the logistics community. With regards to this issue, Table 6-1 below presents a classification of measures that lead to an increase and decrease respectively of transport-related CO<sub>2</sub> when a distribution is centralised. This classification is based on the analysis in chapter 5 and the subsequent sections will present this dissertation's conclusions with regards to each of these measures. For those measures that lead to an increase in transport-related CO<sub>2</sub> emissions, the conclusions will centre on what a shipper can do in order to minimise the increase. The conclusions will also address how each of the measures is interrelated to the provision of cost efficient customer service.

Table 6-1: Classification of measures that increase and decrease transport-related CO<sub>2</sub> emissions when a distribution system is centralised

Measures that increase	Measures that decrease		
transport-related CO <sub>2</sub> emissions	transport-related CO <sub>2</sub> emissions		
- Reducing the number of warehouses	- Employing a slower mode of transport		
- Employing a faster mode of transport	for regular deliveries		
for regular deliveries	- Employing intermodal rail-truck		
	transport for the consolidated flow		
	- Improving the fill-rate for laden trips in		
	the consolidated flow (unimodal truck		
	transport)		
	- Reducing the number of emergency		
	deliveries		
	- Imposing stricter environmental		
	demands on transport providers		

#### Reducing the number of warehouses

A first measure that increases transport-related CO<sub>2</sub> emissions when a distribution system is centralised concerns how the physical structure of the distribution is changed in terms of nodes and links. Here it should be acknowledged that as the number of warehouses (i.e. nodes) in a distribution system is reduced, this generally increases the total number of kilometres travelled (cf. Rodrigue et al, 2001; McKinnon, 2003; Croxton and Zinn, 2005).

With regards to this issue, this dissertation illustrates how the increase in transport work can vary when a distribution system is centralised, depending on how the distribution system is configured in terms of nodes and links. Furthermore, it should be acknowledged that even though this type of structural change (i.e. centralisation) will lead to an increase in transport work, a shipper should aim to minimise this increase by identifying a configuration that leads to as small an increase in transport work as possible. This is imperative as there is a close link between transport work and CO<sub>2</sub> emissions. On this issue, this dissertation has illustrated how a shipper can drastically reduce the increase in transport work caused by centralising a distribution system by

employing two central warehouses instead of one. On this topic, empirics illustrate how a shipper that experienced an increase in transport work by more than 30% upon centralising its distribution to one central warehouse, could instead achieve an increase of just over 10% if two central warehouses as opposed to one were to be employed.

Based on this, it can be argued that a centralised distribution system that is designed so as to consider the effect transport-related CO<sub>2</sub> emissions will on contain warehouses/distribution centres than advocated by Abrahamsson (1992). A distribution system with e.g. 2-4 warehouses/distribution centres and centralised management instead of 10-30 local warehouses and local management, will render a substantial reduction in logistics-related cost. The potential will not be as large as the 25-30% cost reductions advocated by Abrahamsson, since employing one or a few extra warehouses/distribution centres will lead to higher inventory carrying cost, warehousing costs, and administrative costs. However, by virtue of having more warehouses/distribution centres, such a "CO2 considerate" centralised distribution system can render lower transport-related CO2 emissions and transportation costs as it generates less transport work. To summarise, this dissertation concludes that:

A shipper that seeks to centralise its distribution system in order to achieve economies of scale in its logistics operations, but aims to do so in a CO<sub>2</sub> efficient manner, should aim to identify the number of nodes that minimises the overall increase in transport work.

#### Employing a faster/slower mode of transport for regular deliveries

The second measure that has been discussed and analysed in this dissertation concerns how a shipper seeks to adapt a preferred mode of transport for regular deliveries when a distribution system is centralised. As indicated by the heading, this dissertation indicates that this can either imply a shift to a faster mode of transport or a slower mode of transport.

On this issue, earlier research has argued that centralising a distribution system is associated with a modal shift towards faster and more polluting modes of transport (cf. Rodrigue et al, 2001; Hesse and Rodrigue, 2004). This dissertation in part confirms this view and the results indicate that this adaptation in mode of transport is attributable to two aspects of how centralised distribution is applied by shippers. The first aspect concerns how shippers not only centralises the physical structure of the distribution system, but also management of the same. In a decentralised distribution system, each subsidiary will typically decide on its own mode of transport. However, as management is centralised, a shipper will seek to employ a standard or preferred mode of transport for the distribution system as a whole, which in most cases will be road transport. The second aspect relates to shippers measuring the distance between its warehouse(s) and its customer(s) in terms of lead time rather than geographical distance, whereby

a shipper should seek to minimise the number of warehouses in a distribution system with regards to the lead time demands of its customers (cf. Abrahamsson, 1992; Abrahamsson et al, 1998). These two aspects combined help to explain why road freight, today, is the preferred transport alternative among shippers and why almost 80% of all goods transport in the EU-15 countries is performed by means of road freight (EEA, 2007). That is, when shippers increase the geographical distance between their warehouse(s) and their customer(s) at the same time as demand on lead times increase, shippers need to employ a mode of transport that is both reliable and cost efficient, and currently road freight is the alternative that best fulfils these demands. This, together with the measure discussed in the previous section (i.e. reducing the number of warehouses), can be argued to be central to the argumentation in earlier research on logistics and the environment, which has argued that centralising a distribution system will lead to an increase in transport-related CO<sub>2</sub> emissions.

However, by centralising management of the distribution system, it is also possible for a shipper to take a more holistic approach to its transport situation compared to the situation in a decentralised distribution system. This is illustrated by empirics in this dissertation, which indicate that a shipper that centrally manages all of its shipments can employ a slower mode of transport, e.g. rail, in those parts of its distribution system where lead-time demands allow such a shift. Based on this discussion and the analysis in chapter 5, this dissertation concludes that:

A shipper that seeks to manage transport in a more CO<sub>2</sub> efficient manner in a centralised distribution should aim at identifying those parts of the distribution system where it is possible to shift to a slower mode of transport (in addition to the consolidated flow, which is discussed below), given customer demands on short and reliable lead-times. Such a shift in mode of transport will also provide a shipper with a potential to reduce its transportation costs in these parts of the distribution system, as slower modes of transport on average come with a cost incentive.

#### Employing an intermodal rail-truck transport solution for the consolidated flow

A characteristic trait or feature of a centralised distribution system is that of a consolidated flow between a shipper's production unit and central warehouse (also see Figure 6-2). The results of this dissertation indicate that this flow, which is created when a distribution system is centralised, can enable a shipper to employ an intermodal rail-truck transport solution for this part of the distribution system.

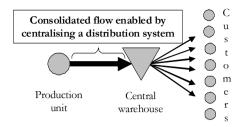


Figure 6-2: Illustration of the consolidated flow that is created when a distribution system is centralised

In order to evaluate the potential that this opportunity brings with regards to a reduction in transport-related CO<sub>2</sub> emissions, a shipper needs to weigh the size of the consolidated flow, measured in terms of transport work, against total transport work for the whole distribution system. It can nevertheless be concluded that the more of total transport work that stems from the consolidated flow, the greater the potential for a reduction in transport-related CO<sub>2</sub> emissions per tonne kilometres is. The analysis also indicates that even though centralising a distribution system will increase the amount of transport work generated by the system, employing an intermodal rail-truck transport solution for the consolidated flow can counterbalance this increase and even lead to a net decrease in transport-related CO<sub>2</sub> emissions. The reason why this measure can outweigh the increase in transport work is attributable to the greater performance of rail freight compared to road freight with regards to transport-related CO<sub>2</sub> emissions per tonne kilometre.

Even though employing an intermodal rail-truck transport solution can enable a shipper to significantly reduce transport-related CO<sub>2</sub> emissions, this type of solution is not greatly employed by shippers in Europe. A primary reason for this is the inferior performance with regards to length and precision in lead-times for this type of solution compared to unimodal road freight (Flodén, 2007; Lammgård, 2007). In light of this argument, this dissertation indicates that the consolidated flow in a centralised distribution system presents an attractive option, as this flow is of an internal character, serving the purpose of providing the central warehouse with replenishment orders. However, a shipper will potentially need to increase safety stock levels for the central warehouse in order to ensure that any uncertainties in lead-time for the flow between the production unit and the central warehouse do not affect the level of stock availability offered by the distribution system. The analysis also indicates that the increase in inventory carrying costs that is associated with such a change can be compensated for by a decrease in transportation costs attained in the consolidated flow, as intermodal rail-truck transport comes with a cost incentive compared to unimodal truck transport. Based on the discussion above and the analysis in chapter 5, this dissertation concludes that:

- By employing an intermodal rail-truck transport solution for the consolidated flow that is created when a distribution system is centralised, a shipper can counterbalance the increase in transport-related CO<sub>2</sub> emissions. Employing this measure for the consolidated flow can even enable a shipper to decrease the amount of transport-related CO<sub>2</sub> emissions generated by the system despite of an increase in overall transport work.
- Employing intermodal rail-truck transport for the consolidated flow in a centralised distribution system will also provide a shipper with an opportunity to reduce transportation costs, as this transport solution is less costly than unimodal truck transport. Nevertheless, this positive aspect of intermodal rail-truck transport needs to be weighed against longer and less precise lead-times in the consolidated flow, whereby safety stock levels may need to be increased in order to warrant an unchanged stock availability towards the customer.

#### Improving the fill-rate for laden trips in the consolidated flow

Another measure that will positively affect transport-related CO<sub>2</sub> emissions per tonne kilometre is that of improving the fill-rate for laden trips in the consolidated flow. The analysis indicates that the greater the size of the consolidated flow is (measured in transport work) compared to total transport work for the whole distribution system, the greater the potential is that a fill-rate improvement in this part of the distribution system will have a significant impact on the distribution system as a whole (cf. potential for intermodal rail-truck transport).

However, this measure and the measure of employing intermodal rail-truck transport are mutually exclusive, since a shipper can only employ either of them. The analysis indicates that he potential with regards to change in mode of transport for the consolidated flow is larger compared to the potential that is associated with fill-rate improvements for this same flow. Furthermore, the analysis indicates that the latter form of improvement does not impose a trade-off for a shipper provided that the volumes in the consolidated flow are substantial enough not to jeopardise the delivery service from the central warehouse. Instead, it is illustrated how this type of measure is a good example of when environmental improvements and financial gains can coincide, since an improvement in fill-rate for the consolidated flow in a centralised distribution system will lead to a reduction in transport-related  $CO_2$  emissions and transportation costs without impeding the provision of customer service. Based on this, it can be concluded that:

By means of improving the fill-rate for laden trips in the consolidated flow in a centralised distribution system, a shipper can simultaneously reduce transport-related CO<sub>2</sub> emissions and transportation costs without impeding the level of customer service provided by the system. Therefore, a shipper that seeks to manage its centralised distribution system in a more environmentally conscious manner and cannot employ an intermodal rail-truck transport solution for the consolidated flow should instead seek to employ this measure.

#### Reducing the number of emergency deliveries

The fourth measure that this dissertation has identified to reduce transport-related  $CO_2$  emissions concerns how centralising a distribution system affects the amount of emergency deliveries generated by the system in question. By changing the structure of a distribution system from that of a decentralised character to that of a centralised character, a shipper will reduce its need for emergency deliveries as stock availability is improved in the latter type of system (cf. Abrahamsson, 1992; Abrahamsson and Aronsson, 1999). This in turn implies that part of total transport work that was handled as emergency deliveries in the decentralised distribution system are handled as regular deliveries in the centralised system, thus generally implying a shift in mode of transport from a faster to a slower mode. This change in mode of transport has a positive effect on  $CO_2$  emissions, where the analysis has indicated that the effect of this shift is dependant on three features of the structural change in question;

- (i) the overall increase in transport work,
- (ii) amount of transport work that stems from emergency deliveries prior to the structural change, and
- (iii) decrease in the amount of emergency deliveries.

With regards to these three aspects, the analysis in chapter 5 indicates that when emergency deliveries constitute a small amount of total transport work prior to the structural change, then centralising a distribution system will not lead to any substantial reductions in CO<sub>2</sub> emissions for the distribution system as a whole. The analysis in chapter 5 also provides numerical assessments for when a reduction in transport-related CO<sub>2</sub> emissions stemming from emergency deliveries can outweigh the increase in transport-related CO<sub>2</sub> emissions caused by an increase in overall transport work due to the structural change.

With regards to the interrelationship with the provision of cost efficient service, the analysis illustrates how this relationship is reversed. It is the improved level of stock availability provided by a centralised distribution system compared to a decentralised distribution system that can enable a shipper to reduce the amount of emergency deliveries. In addition to reducing the amount of transport-related CO<sub>2</sub> emissions generated by a distribution system, this shift will also reduce a shipper's transportation costs associated with emergency deliveries. To summarise, this dissertation concludes that:

• The improvement in stock availability enabled through centralising a distribution system and the associated decreased need for emergency deliveries will have a positive effect on both transportation costs and transport-related CO<sub>2</sub> emissions, as the improved availability enables a shift in mode of transport from a faster to a slower mode of transport for part of the transport work generated by the distribution system.

#### Imposing stricter environmental demands on transport providers

With regards to the fifth and final measure that can reduce transport-related CO<sub>2</sub> emissions, this dissertation indicates that centralising a distribution system can enable a shipper to increase its demands on transport providers with regards to technology-related improvements (e.g. type of fuel and engine) and driver education. The reason for this is that by centralising how the distribution system is managed, a shipper's procurement of transport services will become less fragmented and more concentrated. Owing to this, a shipper can improve its bargaining position vis-à-vis its transport provider(s), where this power advantage can be used to demand environmental improvements on behalf of its transport provider(s). Based on this line of reasoning, it is concluded that:

 A shipper that seeks to lower its transport-related CO<sub>2</sub> emissions when centralising its distribution system, should aim to leverage its improved bargaining position by employing stricter environmental demands.

#### 6.1.1 Striving towards a more CO<sub>2</sub> efficient form of centralisation

This dissertation has advocated that it is necessary to employ a more holistic approach to the issue centralised distribution and its environmental effects. More specifically, the dissertation argues that it is necessary to consider how this type of structural change can simultaneously enable a shipper to employ measures that reduce transport-related CO<sub>2</sub> emissions per tonne kilometre. This is also illustrated in Figure 6-3, which aims to illustrate two things.

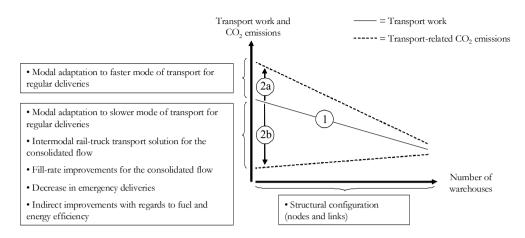


Figure 6-3: Illustration of how transport work and CO<sub>2</sub> emissions are affected in different ways with regards to the studied measures when a distribution system is centralised

Firstly, it illustrates how the increase in transport work can vary when a distribution system is centralised, depending on how the distribution system is configured in terms of nodes and links (indicated by number 1 in the figure). With regards to the structural configuration, a shipper that seeks to centralise its distribution system in a more  $CO_2$  efficient manner will adopt more central warehouses than that advocated by Abrahamsson (1992), who states that a shipper should seek to minimise the number of warehouses in relation to customer lead-time requirements. Adding one or a few warehouses in relation to this "time-based optimised distribution system" will allow a shipper to obtain most of the potential cost savings associated with centralising a distribution system at the same time as it is possible to minimise the increase in transport work and associated  $CO_2$  emissions.

Secondly, the figure illustrates which of the respective measures that have been discussed in this dissertation lead to an increase or a decrease respectively, with regards to  $CO_2$  emissions per tonne kilometre. This is indicated by the bullet points listed adjacent to the numbers 2a and 2b in the figure. On the one hand it must be acknowledged that by centralising a distribution system, a shipper is likely to adopt a faster mode of transport for regular deliveries (cf. Rodrigue et al, 2001; Hesse and Rodrigue, 2004). Such a change will lead to a larger increase in  $CO_2$  emissions compared to transport work (2a). On the other hand it should be acknowledged that by centralising its distribution system, a shipper is provided with an opportunity to employ measures that reduce the amount of  $CO_2$  emissions per tonne kilometre (2b), measures that are not possible to employ in a decentralised distribution system with an array of independent logistics solutions throughout the system.

A prerequisite for employing these measures is that the shipper needs to have an overview of its entire distribution system and a systems approach. Compared to a centralised distribution system, this is more difficult to achieve in a decentralised distribution system with many regional/local distribution systems. Therefore, a holistic approach is of paramount importance for a shipper that wishes to come to terms with the issue of transport and the environment. A holistic approach in this case refers to a shipper considering how the structural change on the one hand affects the amount of transport work generated by the distribution system and on the other hand how the structural change creates new opportunities for a shipper to employ measures that reduce the amount of transport-related CO<sub>2</sub> emissions. In addition to reducing transport-related CO<sub>2</sub> emissions, some of these measures come with a cost incentive. By employing such measures, a shipper can come to compensate for the potential loss in economies of scale caused by employing a structural configuration that seeks to minimise CO<sub>2</sub> emissions rather than to maximise economies of scale.

To conclude, a shipper that is able to (i) indentify a structural configuration that minimises the increase in transport work and to (ii) employ one or multiple of the measures that reduce transport-related CO<sub>2</sub> emissions per amount of transport work (see Figure 6-3), can be argued to be well and truly on the way towards accomplishing a more CO<sub>2</sub> efficient form of centralisation.

#### 6.2 Theoretical contribution

The dissertation makes two distinct contributions to the research area of logistics management. First, the dissertation makes a contribution to research on logistics and the environment, an area where it has been argued that there is a lack of empirical studies which analyse the environmental consequences of various logistics strategies (Abukhader and Jönson, 2004a/b; Aronsson and Huge Brodin, 2006). Centralised distribution is an example of such a strategy, and the dissertation makes a contribution as it studies this type of structural change from a shipper perspective. This study has focused how a shipper's centralisation affects the ratios of transport intensity, modal split, vehicle utilisation, and fuel and energy efficiency simultaneously, whereby it can be argued that more of a holistic or systems approach to a shipper centralising its distribution system (cf. Aronsson and Huge Brodin, 2006) has been applied compared to earlier research. In so doing, the dissertation has demonstrated that it is not only relevant to consider how transport work is affected by a structural change, but also how this structural change simultaneously affects a shipper's opportunity to employ measures that reduce the amount of CO<sub>2</sub> emissions per tonne kilometre. As such, the research presented here complements and extends earlier research into logistics and the environment (Wu and Dunn, 1995; Rodrigue et al, 2001; McKinnon 2003; McKinnon, 2007) by demonstrating how a structural change in a shipper's distribution system, in effect, can facilitate other changes within the system that may or may not outweigh the overall increase in transport work induced by the structural change. The dissertation also extends earlier studies on the environmental effects of structural changes (Aronsson and Huge Brodin, 2006; Schenker Consulting, 2007), as it provides calculations with regards to some of the identified measures so as to identify the effect a specific measure has.

Second, the dissertation contributes to earlier research on how structural changes to a distribution system will affect the system's performance. Whereas earlier research has predominantly focused on how this type of structural change has affected the provision of cost efficient customer service in a shipper's distribution system (e.g. Coyle et al, 1988; Abrahamsson, 1992; Abrahamsson and Aronsson, 1999), this study has incorporated an environmental dimension to the discussion. More specifically, the study has examined the interrelationships that exist between a reduction in transport-related  $CO_2$  emissions and the provision of cost efficient customer service. In this way, the dissertation answers the call made in earlier research, which is that environmental issues need to be considered in conjunction with cost and service issues rather than separately (Wu and Dunn, 1995; Beamon, 1999; Skjoett-Larsen, 2000).

### 6.3 Managerial implications

This dissertation suggests that transport-related CO<sub>2</sub> emissions need not increase when a distribution system is centralised, despite of an increase in transport work. Nevertheless, it should be acknowledged that all of the discussed measures that reduce transport-related CO<sub>2</sub> emissions (see Table 6-1) do not demand an equal amount of effort from a shipper in order to become materialised. This implies that it is more likely to see shippers employ those measures that require the least effort compared to those that require greater effort. Effort in this case refers to the amount of resources (e.g. personnel, time, and money) a shipper needs to devote to employ a measure as well as whether the measure can be achieved solely through intra-company actions or whether there is also a need to include other stakeholders outside the company boundaries. Another aspect that needs to be considered is that shippers are more likely to implement measures that reduce the amount of transport-related CO<sub>2</sub> emissions without jeopardising the provision of cost efficient customer service. With regards to this, the following paragraphs will discuss the five measures listed above that reduce the amount of CO<sub>2</sub> emissions per tonne kilometre in order to evaluate the feasibility in shippers employing them.

With regards to reducing the amount of emergency deliveries and improving the fill-rate for shipments in the consolidated flow, these are examples of measures that require a relatively small amount of effort on behalf of a shipper. One of the fundamental principles with centralised distribution is that it allows a shipper to reduce system wide inventories while simultaneously improving stock availability to the customer (cf. Abrahamsson, 1992), thus reducing the need for emergency deliveries. Hence, a shipper that centralises its distribution is expected to achieve a decrease in transport-related CO<sub>2</sub> emission stemming from emergency deliveries. As

demonstrated by empirics in this dissertation (*Kohn, 2005; Kohn and Huge Brodin, 2008; Kohn, 2008*) and also other research (Aronsson and Huge Brodin, 2006), centralising a distribution system implies that shipment flows are consolidated between a production unit and a central warehouse. The character of such consolidated flows is an enabler for accomplishing fill-rate improvements in this part of the distribution system. Similar to a reduction in emergency deliveries, this is a measure that a shipper is able to realize without any significant efforts. In addition, both of these measures are examples of measures where a shipper can lower the amount of transport-related CO<sub>2</sub> emissions without jeopardising the provision of cost efficient customer service. On the contrary, this study suggests that if a shipper employs these measures, this will simultaneously reduce the shipper's transportation costs.

In contrast, the remaining three measures (i.e. achieving improvements in fuel and energy efficiency, modal adaptation to a slower mode of transport, and employing intermodal rail-truck transport for the consolidated flow) require more efforts on behalf of a shipper in order to become materialised. With regards to improvements in fuel and energy efficiency, this is considered more demanding for a shipper to achieve than the measures discussed above since this dissertation is limited to a situation where a shipper procures its transport services from an external provider. Owing to this, a shipper can only achieve improvements of this kind indirectly by means of posing more strict environmental demands when procuring transport services. Even though a shipper can improve its bargaining position towards its supplier(s) of transport services by centralising a distribution system, this must not necessarily imply that a shipper can induce changes relating to fuel and energy efficiency on behalf of a transport provider. For one thing, many of the improvements associated with fuel and energy efficiency are costly, whereby the question of who is supposed to pay for these investments will be raised (also see sections 5.1.3 and 5.2.3). In addition, there are currently no clear laws and regulations from policy-makers indicating what type of technology that will be supported in the future. The argument can be made that the technology is already there, but transport providers are afraid to make the wrong investment. However, without knowing which technology/technologies<sup>21</sup> that will come out on top, transport providers are given little incentive to invest in new technology already today. This argument is also applicable in the situation where a shipper operates its own fleet of transport vehicles instead of procuring these services externally, since then the issue of investing in the right technology is shifted from the transport provider to the shipper.

The final two measures (modal adaptation to slower mode of transport and employing intermodal rail-truck transport in the consolidated flow) are related to one another. These two measures are examples of measures that do not only require large efforts but also require

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<sup>&</sup>lt;sup>21</sup> For example, Volvo Trucks has presented no less than seven different trucks that are all powered by seven different types of renewable fuels (Volvo, 2007).

comprehensive understanding of the trade-offs associated with employing this type of transport solution, as illustrated earlier in the dissertation (see section 5.2.1). Nevertheless, this dissertation has illustrated how intermodal transport (in this case combining rail-truck transport) can drastically reduce a shipper's transport-related CO<sub>2</sub> emissions without jeopardising the provision of cost efficient customer service. Nevertheless, in order to attain this potential, a shipper is not only dependant on its own decisions and actions. A shipper also needs to consider external factors to the distribution system in question. For example, a shipper will be dependant on an actor providing this type of transport service at competitive prices and performance. To date, it can be argued that providers of intermodal rail-truck transport solutions have not fully been able to achieve this. An evidence of this fact is examples of shippers that decide to run their own intermodal operation<sup>22</sup>. Nevertheless, it should be recognised that this is a very complex issue and providers of intermodal rail-truck transport services also work under a form of constraint. For instance, they need to deal with issues such as different width on the railways, different signalling systems throughout Europe, and passenger traffic being prioritised over goods transport. These are just some examples of obstacles that intermodal rail-truck providers need to handle, which unimodal truck transport providers need not to worry about. This highlights the complexity that is inherent in using intermodal rail-truck transport. This in combination with increasing demands on short and reliable lead-times also helps to explain why the portion of rail freight has steadily decreased over the last couple of decades. Hence, if policy-makers wish to increase the share of intermodal rail-truck transport for goods shipment in Europe, there is a need from a policy perspective to form an understanding of the basis upon which shippers make their decisions regarding the physical structure and management of their logistics systems and supply chains. This is an area that needs further development if we are to come to terms with increasing transport-related CO<sub>2</sub> emissions within Europe.

## 6.4 Suggestions for future research

This dissertation has focused on one type of structural change in a shipper's logistics system, namely that of centralising a distribution system. There are additional logistics strategies that are considered disadvantageous from an environmental perspective even though they support the provision of cost efficient customer service, for example the application of just-in-time and sourcing from low cost countries (cf. McKinnon, 2003; Abukhader and Jönsson, 2004a/b)). Therefore, these strategies (and other) provide an avenue for further research, which could help fill the lack of empirical studies on the environmental effects of various logistics strategies.

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<sup>&</sup>lt;sup>22</sup> This is exemplified by empirics in this dissertation. Another recent example outside the scope of this dissertation is Volvo Logistics, which earlier this year announced that it will launch a new intermodal rail-truck transport system in cooperation with DB Schenker. The aim is to transfer 40% of the north-going long-haul freight traffic from mainland Europe to Sweden to this new system, which is called Viking Rail. Volvo Logistics calculates that it will be possible to reduce transportation costs by 5%, which will be used to compensate for, at times, inferior performance (Dahllöf, 2008; Niklasson, 2008).

Given the current focus on environmental issues and the increased public debate, it can be argued that we have begun to witness a change in consumer awareness and behaviour. Terms such as "food miles" are increasing in popularity and there seems to be a consensus that we at times may need to re-evaluate from where we buy our products. Will this mean that companies will need to go back to less geographically dispersed logistics systems? An interesting option could be to go "glocal", that is to be global but also local. Within the logistics community it has for a long time been advocated that physical goods should be substituted for information (e.g. Christopher, 1998) and from an environmental viewpoint, such solutions could be expected to be very fruitful. If a logistics system could be controlled and managed centrally, whereas the physical production and stockholding was to be handled on a more local or regional scale, then it might be possible to find solutions that provide customers with cost efficient service at the same time as goods are transported over shorter distances.

The research presented in this dissertation as well as closely related empirical research on the environmental implications of structural changes in logistics systems (e.g. Aronsson and Huge Brodin, 2006) could also serve as a basis for a survey with regards to what measures (if any) shippers employ in their logistics systems to reduce their transport-related CO<sub>2</sub> emissions as well as which measures they believe to have the greatest impact on the CO<sub>2</sub> performance of their logistics system. Do shippers, for example, even recognise and understand the extent to which the number of warehouses in a distribution system affects the amount of transport work and transport-related CO<sub>2</sub> emissions generated by the system at hand?

Last but not least, the issue of increasing emissions is so complex that if we are to come to terms with the current situation we need address the issue from multiple perspectives concurrently. The environment is an area for which public policy-makers, company managers (providers and shippers), and private consumers need to take responsibility together. Relating to this, it can be recognised that different stakeholders make different trade-offs with regards to economic or financial issues and the environment. Therefore, there is a need to form a better understanding of the trade-offs various stakeholders make in order to facilitate an increased use of more environmentally friendly transport solutions without impeding the provision of cost efficient customer service. An example of such a study could be to compare the conditions under which shippers can employ rail freight/intermodal rail-truck transport within the EU and the USA.

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