INTERNAL AND EXTERNAL CO-LOADING OF OUTBOUND FLOWS TO INCREASE THE SUSTAINABILITY OF TRANSPORT: A CASE STUDY

T. van Lier, Vrije Universiteit Brussel (Vakgroep MOSI-Transport en Logistiek)

C. Macharis, Vrije Universiteit Brussel (vakgroep MOSI-Transport en Logistiek)

A. Caris, Universiteit Hasselt (IMOB)

H. Vrenken, Vrenken Transport & Economics

ABSTRACT

This paper calculates the potential for reducing internal and external transport costs for a company with three neighboring distribution centers (DC's), each specialized in a specific product category and each using a separate planning system. Most of the outbound flows are currently still transported by truck, with only a marginal portion transported by rail and Short Sea Shipping. Therefore, the potential of a more systematic bundling of the outbound freight flows out of the DCs, both internally within the company and externally with other shippers, is analyzed. Indeed, one way to achieve more sustainable logistics, besides implementing a further modal shift, is through supply chain collaboration. In this paper, two of the possible options for collaboration are investigated: horizontal internal collaboration across warehousing functions and horizontal external collaboration with a non-competitor. The first option looks at internal co-loading of the three product categories of the company by introducing cross-dock-operations on the EDC's premises with the objective to increase the fill level of the trailers/containers under current planning restrictions. To this purpose, a discrete event simulation is performed to evaluate a scenario where outbound product flows are brought together in a hypothetical crossdock located on site next to the three DC's. Both internal and external transport cost savings of the resulting freight bundling potential are calculated. The second option focuses on the potential of external co-loading with another non-competing, complementary shipper to further improve outbound operations. In order to assess the potential for horizontal logistic cooperation, a short overview of the academic literature in the field of cooperation in transport and logistics is provided.

Keywords: sustainable logistics, discrete event simulation, external costs, horizontal logistic cooperation

1. INTRODUCTION

Increasing the sustainability of corporate or public operations has gathered more and more attention in recent years, not in the least because of the growing public concern surrounding the harmful consequences of climate change due to greenhouse gas emissions. But also other nuisances, such as noise, accidents, visual intrusion, disturbances in the ecological system and pollution of air, soil and water, are increasingly being considered when analyzing the negative effects of all kinds of operations. For particular operations such as road transport of goods and people, specific additional nuisances such as congestion can be added to the list. A lot of these nuisances are imposed as a cost on society, leaving those responsible for the nuisance having to pay little or nothing. These nuisances and their cost in monetary terms are therefore called respectively external effects and external costs.[1] There are two main reasons why companies are increasingly paying attention to these external effects and looking for ways to reduce them. First, increased public awareness surrounding these external effects has made companies realize that corporate responsibility is an important marketing tool towards a rapidly growing group of concerned consumers. Secondly, the growing belief in society that polluters have to pay for the damages they have caused, combined with the economic principle that the internalization of external costs in the price of goods can avoid overconsumption of environmentally and socially harmful goods, has put external effects on the political agenda. On a European level, this is clearly reflected in the goals of the European Commission with regards to the internalization of external costs in the transport sector (European Commission, 2008 & European Commission, 2009a).[2] Since transport is a sector where, in contrast to most other sectors, external effects keep on increasing despite improved technology due to the large absolute growth in vehicle-kilometers (European Commission, 2009b), this sector is at the core of the Commission's efforts to internalize external costs in order to reduce the negative impact of externalities and achieve economic efficiency Through correct pricing of externalities for all modes and means of transport, transport operators and citizens will be able to identify among several transport alternatives what is best for the economy and the environment just by opting for the cheaper solution.[3] Many barriers, both scientifically and politically, still have to be taken down before a full internalization of all external costs for all modes will be realized, but the first initiatives are already being implemented, such as the inclusion of aviation in the European Union's Emission Trading Scheme from 2012 on.

This internalization policy thus presents a potential imminent transport cost increase for companies. However, luckily, there are often opportunities for companies to reduce both external and internal transport costs simultaneously by organizing their transport flows more

---

[1] For an overview of relevant studies regarding the definition and assessment of external costs, see section 4.

[2] The European Commission has since long recommended this policy of internalization in several strategy papers such as the Green Paper on fair and efficient pricing (1995), the White Paper on the overall transport strategy (Time to decide, 2001), it's midterm review (Keep Europe moving, 2006), the Greening transport package (2008) and most recently in the strategy and consultation document A Sustainable Future For Transport (2009). In 2010, The European Commission is expected to publish a new White Paper to outline the European Transport Policy for the next decade.

[3] As indicated by Verhoef (2000), Pigou in 1920 and Knight in 1924 were probably the first to argue that road users should be charged with their marginal external costs in order to obtain economic efficiency.

efficiently. Therefore, more and more companies are pro-actively looking for ways to increase both sustainability and profitability of transport operations.

This paper calculates the potential reduction of transport costs of an EDC (European Distribution Centre) by consolidating its outbound flows. The EDC, located in Flanders, is owned and operated by a global manufacturer and serves all types of clients in each of the European countries and adjacent regions. Most inbound traffic is transported by barge through a nearby trimodal intermodal terminal. Outbound traffic is mainly by road and involves only on a limited number of corridors railway or shortsea shipping in intermodal chains. Annually, over 15,000 trucks leave the premises of the EDC. The company has physically separated distribution systems for three product categories, all located on the same company site, but each using a separate planning system and with separate DC operations.

Warehousing operations of the company are thus centralized on a European level at the three DCs, implying lower warehousing costs, but higher transport costs. In this paper the potential of a more systematic bundling of the outbound freight flows out of the DCs, both internally within the company and externally with other shippers, is analyzed. Indeed, one way to achieve more sustainable logistics, besides implementing a further modal shift, is through supply chain collaboration.

Barratt (2004) presented a simple model to illustrate that there are a variety of forms of potential supply chain collaboration, which can be divided into two main categories or dimensions (Figure 1). One the one hand there is vertical collaboration, including collaboration with costumers, internally (across vertical functions) and with suppliers. On the other hand there is horizontal collaboration, including collaboration with competitors, internally (across horizontal functions) and with non-competitors (also called complementors).

In this paper, two of the options for collaboration shown in Figure 1 are investigated (indicated in grey): horizontal internal collaboration across warehousing functions and horizontal external collaboration with a non-competitor. The first option looks at internal co-loading of the three product categories of the company by introducing cross-dock-operations on the EDC's premises. The second option focuses on the potential of external co-loading with another non-competing, complementary shipper to further improve outbound operations. Co-loading is expected to increase the average fill levels of the trailers and containers and thus will reduce the number of trips. The internal co-loading is also expected to have effects on other parameters such as throughput time of trailers, standing time of trailers and capacity utilization of gates. In addition, the explicit goal of the company was to improve simultaneously not only operational and cost efficiency but also sustainability of logistic operations.

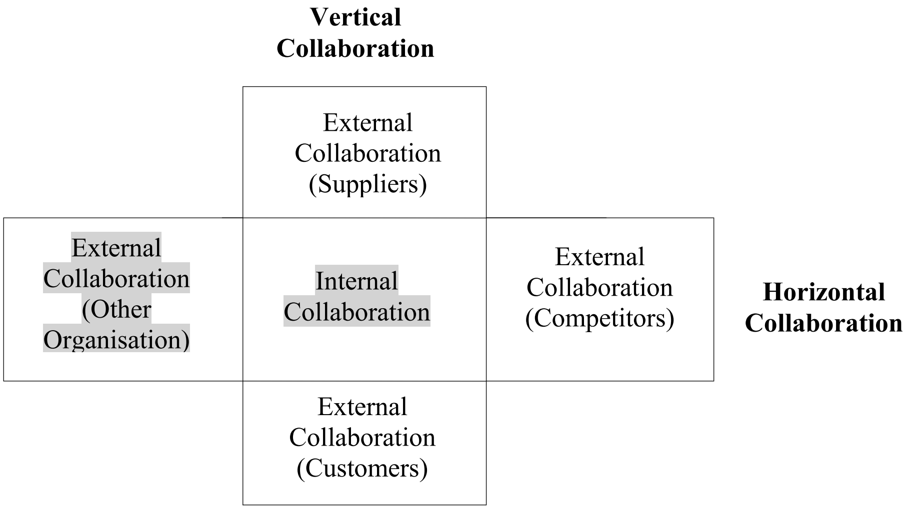

Figure 1: The scope of collaboration (Source: Barratt, 2004)

This paper has therefore three main parts. In a first part, the existing academic literature on horizontal cooperation in transport and logistics is shortly reviewed. In a second part of the paper, a new methodology is presented to quantify both potential internal and external cost reductions of a first collaboration option: internally co-loading outbound freight flows of neighbouring distribution centers. By calculating the internal and external cost impacts it becomes possible to assess both the cost-efficiency as well as the sustainability impact. This part will start with a description of the methodology used to evaluate the options. Subsequent sections will respectively tackle the discrete event simulation and the cost savings calculation of this first collaboration option. A final part of the paper looks at the potential of a second collaboration option under investigation: further horizontal logistic cooperation through external co-loading with a second non-competing shipper. This case-study will link the findings of the literature review on horizontal collaboration to provide suggestions on how to further work out such an horizontal external collaboration in practice. Overall conclusions are presented at the end of the paper..

2. LITERATURE REVIEW ON HORIZONTAL COOPERATION IN TRANSPORT AND LOGISTICS

Cruijssen, Cools and Dullaert (2007) identified fierce competition in global markets, the introduction of products with shorter life cycles and the heightened expectations of costumers as main drivers that forced shippers and Logistics Service Providers (LSPs) to invest in developing stronger and mutually beneficial relationships with each other. As seen in Figure 1 such cooperation can be vertical and/or horizontal. In this section, a brief literature review is given on horizontal cooperation, focusing on aspects that are relevant for the two types of collaboration identified in the model of Barratt (Figure 1) that are of interest to our research

purposes: horizontal internal collaboration and horizontal external collaboration with complementors in transport and logistics.[4]
In academic and professional literature horizontal cooperation between autonomous firms such as strategic alliances and joint ventures (as well as vertical cooperation in supply chains and lateral cooperation in supply networks) has received wide attention. When focusing however specifically on transport and logistics, horizontal cooperation seems to be only well documented for the maritime shipping and aviation industry, where respectively conferences (an alliance of multiple ocean carriers offering their services on a specific transport line against collective tariffs and identical service levels), and major alliances (such as Sky team, Star Aliance, Qualifier and One World) play a major role. However, literature on horizontal cooperation in logistics and transport on the landside, especially where operational consequences are concerned, is quite scarce, as concluded by Cruijssen, Dullaert & Fleuren (2007) in their broad literature review on this topic.[5] Although some of the opportunities, impediments and facilitators of horizontal cooperation in maritime shipping and aviation are shared with horizontal cooperation on the landside, the different playing fields make it difficult to extrapolate conclusions from one field to the other.[6]
The most relevant publications in the field of horizontal cooperation on the landside are discussed next. Caputo and Mininno (1996, 1998) looked at horizontal integration of logistics functions in the Italian grocery industry, focusing on various policies that competing companies can adopt to reduce total logistic costs, such as standardized pallets and cartons, multi-supplier warehouses, multi-distributor centers, co-ordinated routing, and joint outsourcing. Vos et al (2001) defined three types of synergy based on the scope of the cooperation: operational, coordination and network synergy. With operational synergy, only a single process or activity is involved, while with coordination synergy cooperation takes place across several activities and processes involved are harmonized. In network synergy, a complete logistics network is restructured by multiple partners. Hageback and Segerstedt (2004) studied joint transportation in a small and remote municipality in Northern Sweden. This *co-distribution* between some twenty companies in order to better fill incoming and outgoing trucks connecting Pajala with the economic center in the south of sweden was considered vital in order to stay competitive. However, even if possible cost saving were

---

[4] In literature, terms such as cooperation, collaboration, alliances and partnershipping are all used to refer to horizontal supply chain links, There exists a high level of ambiguity between the definitions and characteristics of these terms, making the boundaries between them vague. Due to this lack of a single, clear definition, the terms are often used interchangeably. Lambert et al (1999) define a real cooperation as *a tailored relationship based on mutual trust, openness, shared risk and shared rewards that yields a competitive advantage, resulting in business performance greater than would be achieved by firms individually*. The European Union (2001) defines horizontal cooperation as concerted practices between companies operating at the same level(s) in the market.

[5] It should be noted that Cruijssen, Dullaert & Fleuren (2007) focus on the definition of logistics horizontal cooperation as *cooperation between two or more firms that are active at the same level of the supply chain and perform a comparable logistics function on the landslide*. Much attention is therefore directed towards horizontal external collaboration between competitors. Nevertheless, many of the literature findings on this type of collaboration are also relevant for the two types of collaboration that we will focus on.

[6] Market power considerations and the probability of collusive actions are more prevalent in maritime shipping and aviation than in the more competitive landside transport sector. Also, in maritime shipping and aviation assets are more capital-intensive and average hauls are much longer. In addition, specifically for aviation, the preferential treatment of domestic airliners in the granting of traffic rights, which does not play a role in landside transport, is the dominant driver for horizontal cooperation in aviation (Cruijssen, Dullaert & Fleuren, 2007).

estimated by Hageback and Segerstedt to exceed 33 percent, unfamiliarity of the companies' managers with innovative logistic concepts and sometimes even with the logistics market in general caused important problems to launch co-distribution.

Cruijssen, Bräysy, Dullaert, Fleuren & Salomon (2007) discussed the concept of joint route planning through outsourcing and horizontal cooperation in order to attain larger economies of scale that help to cut down distribution costs. Joint route planning was found to be most beneficial in situations where there are a large number of shippers or LSPs of a uniform and not too large size, if order sizes are small compared to a standard truck's capacity, time windows are narrow, and inter-customer distances are large. Variation in order sizes did not seem to play an important role.

Cruijssen, Cools en Dullaert (2007) performed a large-scale survey on the potential benefits of and impediments for horizontal cooperation in Flanders. They concluded that LSPs strongly believed in the potential benefits of horizontal cooperation to increase their profitability or to improve the quality of their services, but finding a reliable party to lead the cooperation and constructing a fair allocation mechanism for the benefits were considered the most important impediments for such a cooperation.

Ergun, Kuyzu and Savelsbergh (2007) studied shipper consolidation in the context of collaborative logistics in the trucking industry. Their goal was to identify sets of lanes of multiple shippers that can be submitted to a carrier as a bundle rather than individually, in the hope that this results in more favorable rates. The authors focused on the simplest variant, which is static and involves only full truckloads. Consolidation of freight is also often proposed to reduce truck traffic in urban areas. Kawamura and Lu (2007) compared logistics costs with and without delivery consolidation in urban centers, under different sets of conditions that include population density, area size and truck weight regulation. Factory gate pricing (FGP) is an alternative approach to transport consolidation, as proposed by le Blanc et al. (2006). Under FGP, products are no longer delivered at the retailer distribution center, but collected by the retailer at the factory gates of the suppliers. The authors study asymmetric distribution networks in which supplier sites greatly outnumber retailer distribution centers. A case study is performed of a Dutch retail chain of slow moving dry grocery goods. This setting however differs from the type of distribution network studied in this paper.

In their literature review, Cruijssen, Dullaert en Fleuren (2007) listed the drivers, impediments and facilitators of horizontal cooperation in transport and logistics. The overall driving force behind such (and most other) cooperations is each participant's expectation of a positive net present value of the alliance project, as stated by Parkhe (1993). In a logistics context, so-called relational rents or synergies of cooperation can be "hard" (e.g. cost reductions) and "soft" (e.g. learning). Benefits of horizontal cooperation can be achieved through economies of scale (e.g. joint route planning) and economies of scope (e.g. warehousing company and transportation company jointly offering a one-stop shopping solution for a shipper). *Opportunities* that may trigger potential partners to engage in horizontal cooperation are lower costs and higher productivity, improved customer service and expanded market position. *Impediments* and threats for horizontal cooperation in transport and logistics are situated around partner selection (risk of opportunism), determining and dividing the gains (fair distribution of expected and unexpected costs and benefits), negotiation and coordination (relative bargaining power of partners), and information and communication technology (compatibility between required (order) data exchange and implemented ICT systems). In addition, managing or maintaining a horizontal cooperation involves many “soft” factors and requires *facilitators* since a transition to cooperation is often difficult because it involves changes in mindset, culture and behavior. Facilitators are categorized in four crucial groups: information sharing (proprietary information for a company’s own employees only versus shared information available to all participants in a cooperation), incentive alignment (providing a mechanism for realignment of the benefits and burdens with the purpose of internalizing the responsibility for the attainment of overall profitability to the individual participants), relationship management and contracts (level of mutuality, symmetry and strategic fit between partners, and “open” contract structure versus strict contract), and ICT (inter-company communication requirements and related costs) (Cruijssen, Dullaert & Fleuren, 2007)

Thus, there are several issues to agree on before a logistic cooperation can be used in practice. A key question to agree on is how the total cost or savings should be distributed among the participants. Incentive alignment is therefore, in addition to commitment and trust, a crucial facilitator in order for any cooperation to succeed, since multiple companies in a cooperation will always strive to optimize their own profit. Actions and decisions by one member of the cooperation will often result in costs or benefits to other participants as well, resulting in so-called spillovers, externalities or neighborhood effects as identified by Simatupang and Sridharan (2002). In a recent article, Frisk et al (2010) studied collaborative transportation planning in forestry in Sweden, where often several forest companies are operating in the same region but collaboration between two or more companies remained rare. Due to the large potential savings (often in the range 5–15%) there is however an increasing interest in collaborative planning. Frisk et al focused on a number of sharing mechanisms based on economic models including Shapley value, the nucleolus, separable and non-separable costs, shadow prices and volume weights and proposed a new allocation method called EPM (*Equal Profit Method)*, with the aim to share the overall cost/savings as equally as possible among the participants. In their study of a large application in southern Sweden with eight forest companies involved in a collaboration they concluded that better planning within each company could save about 5% and collaboration could increase this about another 9% to a total of 14%.

To conclude, although the academic and professional literature on horizontal cooperation in logistics is still in its infancy, there is an increasing interest in this topic. Moreover, some of the findings on other collaboration types provide useful insights in the two types of horizontal cooperation in logistics that will be investigated below.

3. INTERNAL HORIZONTAL COOPERATION

METHODOLOGY

The first collaborative option under investigation is internal co-loading within the company by bringing together the outbound product flows in a crossdock located on site next to the three DC’s in an attempt to increase the fill level of the trailers/containers. A discrete event simulation model is constructed to compare the hypothetical crossdock scenario with the current situation in order to determine the reduction in number of loading units necessary.

This simulation is carried out on the basis of a company data set covering outbound flows of all three DC's over a ten week period. The simulation results show the opportunities of bundling freight without changes in planning, since warehouse planning and operations are assumed to be given in both scenarios. So cut-off times for particular shipments, indicating the latest moment for trailers to be sealed and shipped, are considered inflexible. Based on the number of potentially avoidable loading units per destination, the effect of using a crossdock on both the internal and external transport cost components is calculated in order to assess both the commercial potential and the societal gain from freight co-loading. For the external transport cost savings, the external cost categories that are affected by a change in the number of loading units that need to be transported are identified. Focus is on short run marginal external costs, so that the relevant external transport cost categories in this particular case are air pollution, climate change, noise, accidents, congestion and part of up- and downstream processes (pre-combustion processes). By selecting scientifically validated indicators based on recent academic literature in the field of marginal external cost calculation for the relevant external cost categories related to road transport, short sea shipping and rail transport and by using a number of assumptions required to derive appropriate key cost figures for these external cost categories on trailer level, the external costs for both scenarios and the resulting savings due to the reduced number of loading units are calculated. In addition, the internal cost savings are estimated using a simplified rule of thumb based on internal company experience.

Secondly, the potential for horizontal logistic cooperation with a non-competing shipper, located some 50 km further, is investigated. In this particular case, potential for co-loading is analysed on two common international long distance destinations. The focus here is on the barriers for this type of horizontal logistic cooperation and possible business models and benefit sharing models that can be used to accommodate the start-up of a business case in practice.

DISCRETE EVENT SIMULATION OF CURRENT AND FUTURE OPERATIONS

To analyze the operations in the shipping department of the company, a discrete event simulation methodology is applied. A simulation model is set up to calculate performance measures in the current and consolidation scenario. In the consolidation scenario the simulation model recombines load orders of various DCs in a single loading unit, based on a number of predefined rules. Results of the consolidation scenario are then compared with the outputs of simulating the current situation.

In a discrete event system, one or more phenomena of interest change value or *state* at discrete points in time. These points in time are moments at which an *event* occurs. An event is defined as an instantaneous occurrence that may change the state of the system. Customers arrive from an external input source and queue for handling by a service mechanism. The customers or entities in our discrete event simulation model are load orders arriving from the warehouse into the shipping department of each DC. The arrival of load orders from the warehouse serves as an input for the simulation model of the shipping department. The arrival time depends on the warehouse planning and operations and is assumed to be given. In the simulation model the load orders queue for handling at the gates. Load orders consist of boxes in various sizes, which may be palletized or not. The service delivered by the resources or gates is the loading of boxes or pallets onto loading units, which may be containers or trailers. Examples of state variables in this discrete event system are the status of the gates (idle or busy), the number of load orders waiting in a queue for handling at a gate or the time of arrival of a load order in a queue for handling at a gate. Events are the arrival of a load order in the shipping department or the completion of service of a load order at a gate. With this methodology, opportunities for consolidating freight from the three different distribution centres are identified through simulation of current and future operations. In the current situation the shipping department of each DC is operating independently (Figure 2).

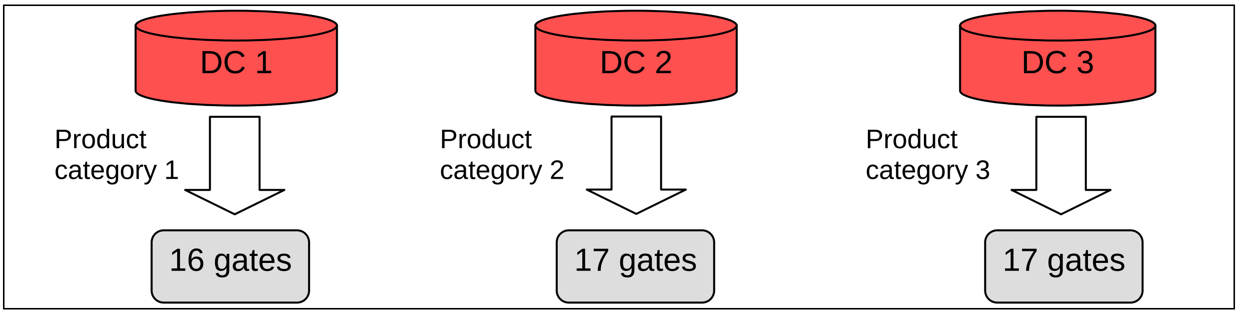

Figure 2 – Current scenario (Source: own format)

Figure 3 represents the future scenario in which load orders from the three DC's are consolidated at a crossdock. The objective of the case study analysis is to quantify potential benefits of consolidating freight from the three DC's to joint hub destinations. The objective of the simulation analysis was to investigate whether it is interesting to consolidate load from the three DC's or not. No assumptions were made on the operational implementation of the crossdock. In the future scenario the crossdock is a fictitious location on the current company premisses where the three flows of the warehouses would arrive jointly, so that load orders with the same destination may be grouped in one trailer, taking into account certain operational constraints, such as customs regulations, load unit compatibility and existing cut-off times of load orders.[7]
To perform the simulation analysis, a data set of load orders in the three DC's for a period of 10 weeks in the last quarter of 2008 is applied.

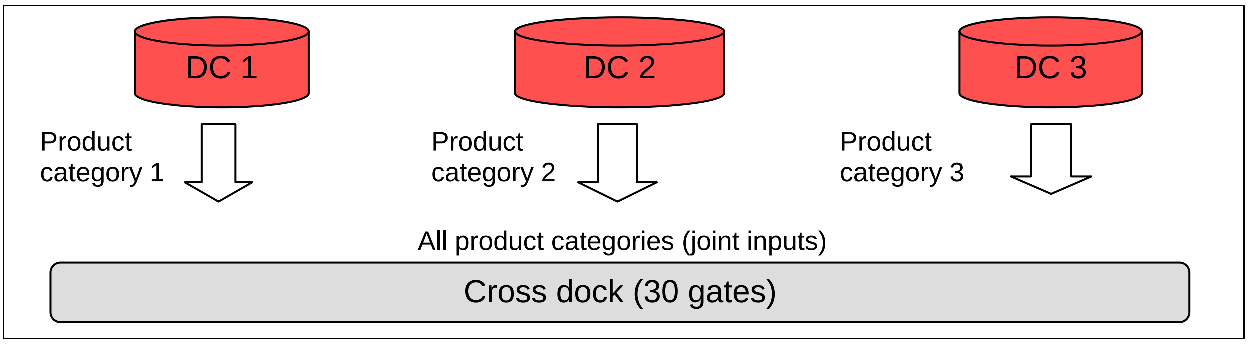

Figure 3 – Crossdock scenario (Source: own format)

[7] The exact location of the potential cross-dock was not investigated in this study, but given the fact that room for expansion is available at the company premises, directly connecting the three DCs to the crossdock via fixed internal transport systems such as conveyor belts and/or roll conveyors is, at least technically, feasible.

The following conclusions are drawn from the simulation results. First, the organization of a crossdock may lead to a reduction in average and maximum standing time of trailers. The standing time depends on the warehouse planning and operations. Considerable time often passes between the arrival in shipping of the first and last load order destined for the same trailer. Time lags also occur between the arrival of the first and last carton of a single load order. However, through consolidation a significant reduction in throughput time and standing time of trailers might already be realized.

Second, simulation results show that the available gates were used at full capacity during only a limited period per day. Capacity gains could be realized through a shift to non peak periods. The assumptions made in the crossdock scenario about the number of available gates, namely thirty, sufficed to deliver the same service level in shipping.

The third performance measure to evaluate the crossdock scenario is the fill rate of trailers or containers. In the crossdock scenario load orders from the three DC's destined for the same hub destination are bundled (if allowed by the operational constraints), leading to a higher fill rate. The crossdock scenario leads to an increase of 4.76% in the average fill rate over all load orders in all three DC’s. Fill rates in a particular DC were found to be lower than in the other two DC’s, offering opportunities for bundling freight. The percentage of trailers filled less than half reduced to 23% in the crossdock scenario instead of 34% in the current scenario. The crossdock also offers the opportunity to increase the fill rate of trailers containing pallets.

Finally, the simulation of the crossdock scenario calculated the reduction in number of trailers necessary over the observed period, showing the opportunities of bundling freight without changes in planning. Since in both scenarios the warehouse planning and operations are assumed to be given and serve as an input for the simulation model, this implies that the different cut-off times of load orders for the different product categories coming from the related DC’s need to be respected, which severely restricts the freight bundling opportunities between different DC’s. The analysis indicated that under these circumstances the overall number of trailers could nevertheless still be reduced by 7.8%. Further improvements in performance measures would require the introduction of smart planning rules aimed at taking maximum advantage of consolidation opportunities.

CALCULATION OF EXTERNAL AND INTERNAL TRANSPORT COSTS

The discrete event simulation shows that freight co-loading between the three DC’s reduces the amount of trailers that needs to be shipped. Less trailers on the move implies less external and internal transport costs. In this section, the external cost savings due to the reduced number of trailers in the crossdock scenario simulation are calculated, in order to determine the societal gain of co-loading between the DC’s on the company site. For the relevant external cost categories key figures per trailer-kilometer are calculated based on available figures in literature and validated assumptions. Since some of the outbound flows involve intermodal transport using rail or short sea shipping, also the external costs of these modes need to be taken into account. Next to this external cost gain, there is obviously also an internal cost gain for the company. Internal cost saving, and thus the commercial potential of co-loading, is estimated here using a simplified rule of thumb and serves more to give an indication of the cost saving potential rather than a detailed calculation.

What is there to gain for society?

In literature, distinction is made between following external costs of transport (Infras/IWW, 2004):

- Accidents;
- Noise;
- Air pollution;
- Climate change;
- Congestion[8];
- Nature (disturbance of ecosystems) & landscape (visual infringements)
- Additional costs in urban areas (space availability & separation effects);
- Up- and downstream processes

Regarding the external costs of road transport, an important distinction is made between "intra-sectoral externalities" and "inter-sectoral externalities" (Verhoef, 2000). Intra-sectoral externalities are, like congestion and part of the external accident costs, imposed upon one another by road users. Inter-sectoral externalities are, like environmental externalities, noise annoyance and another part of the external accident costs, imposed upon society at large. It is sometimes argued that intra-sectoral externalities such as congestion are not an externality since it is almost entirely internal to the road transport sector. As however Verhoefen (2000) states, for a correct welfare analysis, the relevant level of disaggregation is the individual level, so that at least from a welfare economic point of view both intra-sectoral and inter-sectoral externalities are Pareto-relevant. Congestion will therefore be included in the analysis.

Since the impact of additional units of transported goods via road, inland waterway/SSS or rail will be calculated, marginal rather than average external costs are considered. Distinction should further be made between short and long run marginal external costs. Short run marginal costs are related to an additional vehicle entering the (existing) system and consider only variable costs (i.e. costs depending on traffic volume such as air pollution, climate change, noise, accidents, congestion and the short run part of up- and downstreamprocesses), neglecting fixed costs to run the system or additional costs for possible network improvements in the longer run. Long run marginal costs are considering future system enlargements due to increased traffic volume (Maibach et al, 2008). Focus in this case study is on short run marginal costs, excluding long run externalities such as nature and landscape, separation and space scarcity in urban areas and the long run part of up- and downstream processes, since adjustments to the transport infrastructure are not considered in this study.

Calculation of the relevant external costs in this specific case is based on the best practices in the field of marginal external cost assessment currently described in scientific literature.[9] Although there is growing consensus on the main methodological issues, there remain many uncertainties when performing such an external cost assessment in practice (Maibach et al.,

[8] In the case of congestion, an additional road infrastructure user will only take into account the time loss and other costs (such as additional wear and tear of the car and higher fuel consumption) suffered by himself as a result of congestion (internal cost), not the time loss and other costs imposed by him on all the other transport users as a result of his additional participation in traffic (external cost).

[9] Note that we calculate the impact of additional units of transported goods via road or inland waterway, which means that we are interested in marginal rather than average external costs.

2008).[10] Numerous studies have shown that marginal external costs of transport activities depend strongly on parameters such as fuel type, location (urban, interurban, rural), driving conditions (peak, off-peak, night) and vehicle characteristics (EURO standards) (Panis en Mayeres, 2006). As a result, the external cost of one truck-kilometer in urban areas during peak traffic can be up to five times higher than the cost of an off-peak inter-urban kilometer of the same vehicle (Maibach et al., 2008). Since the IMPACT study (Maibach et al., 2008) provides a recent summary of the best practices for taking into account the different external cost categories and selects the most relevant studies and key figures in a European context, it was considered most appropriate for our research, especially since it takes the above remarks related to differentiation into consideration. Moreover, the IMPACT study provides the basis for the recently recommended key figures for future internalization schemes as proposed by the European Commission (European Commission, 2008). However, since the IMPACT study expresses key figures for the different external cost categories per vehicle-kilometer, figures had to be recalculated on trailer level for SSS and rail. Using company validated assumptions regarding EURO-class of trucks, average weight of trucks, average load of trailers, network types, congestion levels, percentage day and night traffic, number of wagons and type of traction for trains, and type and size for ships, external cost figures for the three transport modes under consideration could be calculated, taken into account as much as possible the different parameters influencing marginal external costs as provided in the IMPACT study.

Table 1 provides an overview of the resulting key figures per trailer-km calculated for the six relevant external cost categories and for the three prevailing modes of transport namely road, short sea shipping (SSS) and rail.

Table 1 – Short run marginal external cost figures in €/trailer-km (Source: own calculations based on IMPACT 2008 figures)

IMPACT 2008	TOTAL in €/trailerkm				
€/ vkm	Road	SSS	Rail (Electric)	Rail (Diesel)	
ACCIDENTS	0.03604	0	0.00200	0.00200	Rail 0.08 €/train-km
NOISE	0.01700	0	0.01210	0.01210	
AIR POLLUTION	0.03998	0.02315	0.00343	0.09946	SSS 4.63 €/ship-km
CLIMATE CHANGE	0.01520	0.00210	0.00768	0.00865	SSS 0.42 €/ship-km
UP & DOWNSTREAM	0.0178	0.00200	0	0	SSS 0.40 €/ship-km
CONGESTION	0.4758	0	0	0	
TOTAL	0.6018	0.0273	0.0252	0.1222	
TOTAL - Congestion	0.1260	0.0273	0.0252	0.1222	

[10] For an overview on the assessment of external costs, see also int.al. INFRAS/IWW (2000 and 2004), ExternE, EC (2005), EX-TREMIS, TRT (2007), Forkenbrock (2001), Witboek EC (2001) en revision EC (2006), Mauch, Banfi en Rothengatter (1995), Maddison et al.(1996), Kreutzberger., Macharis en Woxenius (2006), Macharis and Van Mierlo (2006).

Expressed in €/1000vkm, the figures in Table 1 indicate that for this particular case truck road transport has an external cost of 601.80€/1000trailer-km including congestion and 126,00€/1000trailer-km excluding congestion, compared to 27.30€/1000trailer-km for Short Sea Shipping, 25.20€/1000trailer-km for electric rail and 122.20€/1000trailer-km for diesel rail. Immediately, some important conclusions can be drawn:

- Truck road transport causes the highest external costs, but rail transport using diesel traction is only slightly behind when congestion is excluded.
- Rail transport using electric traction and short sea shipping are least polluting.
- Congestion is the most important marginal external cost category for road transport and makes this transport mode by far the least sustainable.
- The difference between the external costs of electric and diesel traction are mainly attributable to air pollution.

Congestion costs for road account for no less than 79% of total external costs in these calculations. Since the external congestion costs of road transport depend highly on the location, time and vehicle type, there are significant case specific differences. However, it seemed useful to compare the calculated figures with specific external cost figures for road transport to be found in literature to see if the order of magnitude of these congestion costs was confirmed. A study by De Ceuster (2004) shows the values for the marginal external costs and taxes for a heavy duty diesel truck for Flanders over the period 1991-2002. In 2002 total marginal external costs amounted to 52.18€/100 km, with a high and increasing proportion of congestion costs over the years, accounting for 73.87% of total short term marginal external costs in 2002. Taking into account that congestion levels in Flanders still show an increasing trend (Maerivoet & Yperman, 2008) and a large proportion of trailer-km under consideration are transported on Flemish roads, our findings seem to be in line with these values. It is also worthwile to note that the other external cost categories in this study remained stable or gradually decreased between 1991 and 2002 due to technological advancements (e.g. EURO-norm evolution for road vehicles) (De Ceuster, 2004).

A comparison of the number of trailers in the current and the crossdock scenario based on the outbound data set of all 3 DC's for the selected 10-weeks period in the 4th quarter of 2008 indicated that there were approximately 231 trailer movements less when working with a crossdock. On an existing total of 2,966 trailer movements in the 10-week period under investigation, this implies a reduction of trailer movements with 7.8 percent. These 231 avoided trailer movements were calculated taking into account certain assumptions and restrictions that were imposed in modeling the crossdock scenario such as no export bundling, no direct drops bundling, only allowing realistic consolidator blocks and respecting existing planning. Especially this last element severely restricts the internal bundling potential, since respective cut-of times of shipments related to the different DCs had to be respected. Using the key figures from Table 1 and the corresponding trajectories of the avoided 231 trailer movements, it was then possible to calculate the avoided external costs through co-loading via a crossdock. It is however important to note that concerning the trajectories, only the distance between the company and the line haul hub was taken into account, since beyond that hub the company has no or very limited control on the consolidation possibilities. Indeed, consolidation from that point on is a matter of concern for the logistics service provider. This explains the relatively low amount of trailer-km and the fact that a large proportion of trailer-km is transported on Flemish roads. It should therefore

be stressed that resulting figures give the external cost savings under the assumption that load consolidation in the line haul hub of the logistic service provider is not influenced by the change in fill rate of the trailers leaving the DC's and arriving in the line haul hub.
Results of the calculations are shown in Table 2. From this we can conclude that the crossdock scenario results in an external cost saving over the three DCS of 15,672€ excluding congestion and 72,241€ including congestion for the selected ten week period. Applying a linear projection, the external cost saving potential on a yearly basis can be estimated, namely 52/10*72,241 = 375,653€. However, this does not take into account the seasonal variations in warehousing activity and should therefore only be regarded as a very rough estimate.

Table 2 - Summary of external transport cost savings (in €) (Source: own calculations)

External cost category	Savings in simulation period	Estimated savings per year	Savings as % of total
Air pollution	5,336	27,747	7.4%
Climate change	1,860	9,672	2,6%
Noise	2,021	10,510	2,8%
Accidents	4,285	22,282	5,9%
Congestion	56,569	294,159	78,3%
Up- and downstream	2,170	11,284	3,0%
Total	72,241	375,653	100%

Since no co-loading on intermodal rail trajectories occurred based on the simulation results and restrictions imposed on consolidator blocks, there was no need to make the distinction between rail or diesel traction to calculate the external cost gains.[11] A small amount of co-loading occured on trailer movements using intermodal trajectories with short sea shipping, but the share of short sea shipping accounted only for 686 € in external cost savings or 1% of total external cost savings (short sea shipping is assumed to generate no external noise, accident and congestion costs). Looking at the amount of truck-kilometers avoided in the 10-week period, there were 118,898 trailer-kilometers avoided in road transport and 25,180 trailer-kilometers avoided in short-sea shipping. So in trailer-kilometers avoided, short-sea shipping accounts for 17.5%, but due to the lack of marginal external accident and congestion costs in short sea shipping this accounts only for a small portion of avoided external costs. On a yearly basis, the amount of truck-kilometers avoided become respectively 618,367 trailer-kilometers in road transport and 130,936 trailer-kilometer in short-sea shipping. Again, these yearly figures do not take into account the seasonal variations in warehousing activity and can therefore only be regarded as very rough estimates.

And what is in it for the company wallet?

Besides the external cost savings due to a reduced number of trailers, this reduction also has an impact on internal transport costs. Every truck that can be avoided through co-loading between different DC's implies a direct cost saving. A simple rule of thumb was used in order to roughly estimate this internal cost saving.[12] It was assumed that regardless of the

[11] The difference between electric and diesel traction would however be significant when calculating total external costs on all intermodal rail outbound trajectories, as indicated in Table 1.
[12] Due to confidentiality reasons, transport cost figures for this company could not be provided.

transport mode, a variable cost of 1€ per travelled km had to be taken into account. In addition, a fixed cost of 200€ per trip was added. For train or ferry (SSS) an additional fare of 300€ was considered. Applying these rules to the 231 trailers avoided and their respective trajectory to the first consolidator hub in the crossdock scenario resulted in an internal cost saving of around 200,000€. Applying the same linear projection as with the external cost savings, resulted in the yearly internal cost saving potential: 52/10*200,000 = 1,040,000€. Again, the remarks concerning the seasonal variations in warehousing activity still stand. Also here, focus is on trajectories where the company can influence bundling and calculations are based on the assumption that warehouse planning with existing cut-off times for the three different product categories is respected.

4. EXTERNAL HORIZONTAL COOPERATION: CO-LOADING WITH THIRD SHIPPER'S CARGO

Besides the potential for internal bundling freight within the company, also the potential for operational synergy through external horizontal logistic cooperation with another shipper is investigated. Additional potential gains from co-loading of cargo are explored by virtually combining cargo flows flows of the two shippers.. A critical selection criterion for the second shipper has been that his shipments should be mainly heavy cargo, and therefore complementary with the shipments of the first shipper. Semi-trailers of the first shipper when loaded up to their cubic volume capacity typically carry a load weight of less than 7 tons, thus leaving much of its weight capacity unused. Co-loading with a partner with heavy weight cargo and spare cubic volume capacity can bring substantial savings of semitrailer movements.

The selected shipper is a global player active in industrial machinery parts and typically carries over 20 tons in one vehicle, while leaving two thirds of the cubic volume capacity unused. Since the second shipper is active in a totally different sector, this type of collaboration falls in the category of external horizontal collaboration with a complementor, as indicated in the model of Barratt (2004) (See Figure 1). The distance between the DC's of the partner shippers is about 50 km and both shippers serve all regions of Europe from these DC's. Both shippers channel all of their cargo through national DC's, operated by their logistic service providers in these countries. Co-loading opportunities are explored for two distant destination regions: Turkey and Spain.

First test of compatibility concerns lead times. In the case under investigation, there are differences in lead times between the shippers, but they are not far apart of each other. For traffic to Turkey, the partner shipper uses an intermediate stop in a DC in Germany, where cargo is combined with cargo from other origin regions. This improves load rates on the long stretch between Germany and Turkey. With current service schedules the stopping time in this German DC is nearly a day. Compared to direct shipping, routing through this intermediate DC adds 12 hours of lead time to Turkey. The service levels to Spain of both shippers are comparable and impacts co-loading has on current lead times of either shippers will be only marginal, even if the time needed for the extra cross-dockings is considered.

There are solutions to avoid the time losses to Turkey. First, if the envisaged co-loading provides sufficient additional cargo, this DC may be circumvented because in the new situation the trailers to Turkey will be filled close to their maximum capacities. Alternatively, there is room for rescheduling the services from the German DC to Turkey in a way that time losses are reduced. The overall time loss in theory can even go below zero because cross-docking avoids obligatory night resting time of truck drivers.

Co-loading implies additional process time, because of the extra (un)loading and co-loading processes and because certain extra distances need to be covered in order to call at both of the shipper's DC's on both ends of the transport movement. On the selected corridors, this additional time appeared to be marginal.

A second test of compatibility concerns demand characteristics. Both shippers provided demand in tons and m3 per day, but the assignment of cargo to vehicle was only given for one shipper and needed assumptions on cargo assignment rules for the other. The results of the analysis show that in the long-haul to Turkey a reduction of about 15% in movements can be achieved. On top of this 15% there is much co-loading potential unused, due to a lacking demand of heavy weight cargo on this relation. E.g. doubling of heavy freight would rise savings to 23%.

The savings to Spain are between 10% and 20%, depending on the assumptions on the assignemen of cargo to vehicles. Savings would be close to 20% if the promised daily frequency is kept so all cargo is delivered according to the promised A-B lead time. This assumption implies low average truck loads (i.e. low efficiency) in the basis situation. Alternatively, if postponing of deliveries is allowed and today's cargo can be combined with next-day's cargo, the average truck load in the basis situation is higher and the potential reduction lower. Because of the existing economic crisis, the overall level of demand was significantly lower than average. It can be argued that under normal economic circumstances the efficiency before co-loading is higher than today and savings of co-loading therefore will more likely be close to 10% on this relation. This level of savings is far lower than cargo to Turkey because the average weight of the co-loaded cargo for Spain appeared to be far lower.

To conclude, there is a match of demand on both relations, but this match is not very good yet. To become more attractive, particularly the share of heavy cargo in total demand would have to increase. It is important also to envisage that the savings in transport cost will be partly offset by extra costs elsewhere in the logistic chain. These are related to cross-docking in the origin and national DC's, to inefficiencies of transport outside of the long-haul stretch between the European and national DC's and to cost of integrating the chains. The costs (or investments) related to integrating the chains will follow from common labelling, chain management, cargo insurance, procedures, communication and the like. A real example of additional costs in the logistic process is in the packaging. Today, one of the shippers fills one trailer with many hundreds of small loose cartons, which makes (un-)loading of semi-trailers time consuming. In the current situation with barely constraints in the loading of these semi-trailers this process is appropriate. In the situation of co-loading with third party cargo the handling of these loose cartons will add too much to (un-)loading and cross-docking time and therefore will cause extra costs and extra lead time. Therefore it will be necessary to introduce packaging devices that can contain many of the smaller boxes.

As already highlighted in the literature review on horizontal cooperation, an important issue in co-loading is that the shippers come to an agreement upon how the benefits of co-loading are shared. These benefits include those of saving logistic costs, but also a quantification of the improved levels of services (frequency, lead time) and the reduced impacts on society are benefits, if the shippers subscribe these social objectives. Two overall alternative models by which benefits are shared exist: a model based on activity based costing (ABC) and a model based on sharing system benefits. The first method implies a far reaching integration of business process control and is well suited once both parties are convinced of the benefits of co-loading and decide on integration of their networks. The second method is most appropriate in a pilot phase and as long as the extent of cooperation is limited, because this method is more simple in its implementation and more focused on identifying and sharing the costs and benefits of the system's change.

Two alternative business models for co-loading are proposed that can be used in the short term, e.g. in a pilot phase. In the first, one shipper will start using the services of the logistic service provider of the partner shipper which then will assign joint cargo to its trucks for the long-haul transport service. This implies that the current logistic service providers of one shipper will not be used anymore for the long-haul part of the distribution channel, but still will distribute from DC's to final clients. The second model is a joint tendering of all distribution services by the two shippers on a corridor. Joint tendering may include sharing the national DC's in the destination countries and even continuing the co-loading in the further distribution within the destination countries. This second model will also provide savings in the final legs and it will give equal positions to either of the shippers. The first model may be needed if rearrangement of contracts with logistic service providers is not appropriate on the short-term.

6. CONCLUSIONS

This paper calculated the potential of a more systematic bundling of outbound freight flows out of three DCs by applying supply chain collaboration. Two of the possible options for collaboration were investigated: horizontal internal collaboration across warehousing functions and horizontal external collaboration with a non-competitor. The first option looked at internal co-loading of the three product categories of the company by introducing cross-dock-operations on the EDC's premises with the objective to increase the fill level of the trailers/containers under current planning restrictions. By applying discrete event simulation, a scenario where outbound product flows were brought together in a crossdock located on site next to three surrounding DC's was compared to the current situation where each DC ships outbound flows separately. Both internal and external transport cost savings of the resulting freight bundling potential were then calculated based on the number of trailers avoided in the simulation. This new methodology was applied on a specific business case.

The following key messages summarize the findings from this case study. First, gates in the shipping department of the DC's are only used for a limited period per day at full capacity. Capacity utilization may be improved by a shift in workload to non-peak periods. Second, the crossdock scenario leads to an improvement in performance measures. The average fill rate increases with 5% and there is clearly an opportunity to increase the fill rate of trailers containing pallets. Moreover, only 23% instead of 34% of trailers is filled less than half in the crossdock scenario. A reduction in average and maximum standing time of trailers is observed and the number of trailers used over a period of ten weeks reduces with 8%.

Therefore, true opportunities for co-loading exist with no changes made to current restrictions in planning. These opportunities may therefore further increase by changing the warehouse planning process. In both scenarios the warehouse planning and operations, including cut-of times, are different for the three DC's and are assumed to be given. They serve as a fixed input for the simulation model. Further improvements in performance measures would therefore be possible with the introduction of smart planning rules aimed at taking maximum advantage of consolidation opportunities. Third, external and internal transport cost reductions are possible but also remain limited without process changes. Estimating the potential of smart planning on internal and external cost savings fell outside the scope of this current study, but is an interesting track for further research.

Additionally, the potential for horizontal logistic cooperation with another, non-competing shipper was analyzed for this specific business case. It was concluded that there is substantial potential for reducing the number of truck movements if the light cargo of the shipper is co-loaded with heavy cargo of a third shipper. Transport costs reductions will be high if both shippers enter high cargo volumes into the system. However, savings in transport costs need to offset additional costs related to additional cross-docking and logistic integration.

REFERENCES

Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. Supply Chain Management: An International Journal, Vol. 9, 1, 30-42.

Caputo. M. and V. Mininno (1996). Internal, vertical and horizontal logistics integration in Italian grocery distribution. International Journal of Physical Distribution and Logistics Management, Vol. 26, 9, 64-90.

Caputo. M. and V. Mininno (1998). Configurations for logistics co-ordination. A survey of Italian grocery firms. International Journal of Physical Distribution and Logistics Management, Vol. 28, 5, 349-376.

Cruijssen, F., W. Dullaert and H. Fleuren (2007). Horizontal cooperation in transport and logistics: a literature review. Transportation Journal, Vol. 46, 3, 22-39.

Cruijssen, F., M. Cools and W. Dullaert (2007). Horizontal cooperation in logistics: opportunities and impediments. Transportation Research E: Logistics and Transportation Review, Vol. 43, 2, 129-142.

Cruijssen, F., O. Bräysy, W. Dullaert, H. Fleuren, and M. Salomon (2007). Joint route planning under varying market conditions. International Journal of Physical Distribution & Logistics Management, Vol. 37, 4,. 287-304.

De Ceuster, G. (2004). Internalisering van externe kosten van wegverkeer in Vlaanderen. Study performed for Vlaamse Milieumaatschappij, MIRA, Transport & Mobility Leuven, Leuven (in Dutch).

Ergun, O., G. Kuyzu and M. Savelsbergh (2007). Shipper collaboration. Computers & Operations Research, Vol. 34, 1551-1560.

European Commission (2005). “ExternE": Methodology 2005 update Report. 2nd edition,

European Commission (2008). Greening Transport Package. DG Energy & Transport, Luxembourg

European Commission (2009a). A Sustainable Future For Transport. DG Energy & Transport, Luxembourg

European Commission (2009b). Statistical Pocketbook 2009: EU Energy and Transport in Figures. DG Energy & Transport, Luxembourg

European Union (2001). Commission notice: guidelines on the applicability of Article 81 of the EC Treaty to horizontal cooperation agreements (2001/C 3/02).

Forkenbrock, D.J. (2001) Comparison of external costs of rail and truck freight transportation. Transportation Research Part A: Logistics and Transportation Review 35, 321-337.

Hageback. C. and A. Segerstedt (2004). The need for co-distribution in rural areas - a study of Pajala in Sweden. International Journal of Production Economics, Vol.89, 2, 153-163.

HEATCO (2005). Bickel, P. et al., Developing Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO), Deliverable 2: State-of-the-art in project assessment, Stutgartt, 2005

INFRAS/IWW (2000). Maibach, M., S. Banfi, C. Doll, W. Rothengatter, P. Schenkel, N. Sieber and J. Zuber. External Costs of Transport: Accident, Environmental and Congestions Costs in Western Europe. Karlsruhe/Zürich/Paris: the International Union of Railways (UIC)

INFRAS/IWW (2004). Schreyer, C., M. Maibach, W. Rothengatter, C. Doll, C. Schneider and D. Schmedding. External Costs of Transport: update study. Karlsruhe/Zürich/Paris: the International Union of Railways (UIC)

Kawamura, K. and Y. Lu (2007). Evaluation of delivery consolidation in U.S. urban areas with logistics cost analysis. Transportation Research Record: Journal of the Transportation Research Board, No. 2008, Transportation Research Board of the National Academies, Washington, D.C., 34-42.

Kreutzberger, E., C. Macharis. and J. Woxenius (2006). Intermodal versus unimodal road freight transport - a review of comparisons of the external costs. In: B. Jourquin, P. Rietveld, and K. Westin (Eds.), Transporation Economics: Towards Better Performance Systems. Routledge

Lambert, D., M. Emmelhainz. and J. Gardner (1999). Building successful logistics partnerships. Journal of Business Logistics. Vol. 20, 1, pp. 165-181.

le Blanc, H.M., F. Cruijssen, H.A. Fleuren and M.B.M. de Koster (2006). Factory gate pricing: an analysis of the Dutch retail distribution. European Journal of Operational Research 174, 1950-1967.

Macharis, C. and J. Van Mierlo, (2006). Intermodaal vervoer: Milieuvriendelijker ook in de toekomst? Tijdschrift Vervoerswetenschap, 42^{e} jaar, 1, 8-11 (in Dutch).

Maddison, D., D. Pearce, O. Johansson, E. Calthrop, T. Litman and E. Verhoef (1996). Bleuprint 5: The True Costs of Road Transport. Earthsan, London, p. 239.

Maerivoet, S. and I. Yperman (2008) Analyse van de Verkeerscongestie in België. Transport & Mobility Leuven, Rapport 07.15, Leuven (in Dutch).

Maibach, M., C. Schreyer, D. Sutter (INFRAS), H. P. Van Essen, B. H. Boon, R. Smokers, A. Schroten (CE Delft), C. Doll (Fraunhofer Gesellschaft-ISI), B. Pawlowska, M. Bak (University of Gdansk) (2008) Handbook on Estimation of External Cost in the Transport Sector. Internalisation Measures and Policies for All external Cost of

Transport (IMPACT), Version 1.1., European Commission DG TREN, Delft, CE, The Netherlands.

Mauch, S.P., S. Banfi, and W. Rothengatter (1995). External effects of transport, International Union of Railways : Paris

Panis, L. I. & I. Mayeres (2006). Externe kosten van personenvervoer" in: Despontin, M. en Macharis, C. (eds.) Mobiliteit en (groot)stedenbeleid. 27ste Vlaams Wetenschappelijk Economisch congres, 19 en 20 oktober 2006, Brussel, 417-446 (in Dutch).

Parkhe, A., (1993). Strategic alliance structuring: a game theoretic and transaction cost examination of interfirm cooperation. The Academy of Management Journal, Vol. 36, 4, 794–829.

Simatupang, T. and R. Sridharan (2002). The collaborative supply chain. International Journal of Logistics Management, Vol. 13, 1, 15-30.

Verhoef, E. T. (2000). The implementation of marginal external cost pricing in road transport. Long run vs short run and first best vs second best. Papers in Regional Science, Vol. 79, 3, 307-332.

Vos, B., M. Iding, M. Rustenburg, and C. Ruijgrok (2003). Synergievoordelen in Logistieke NETwerken (SYLONET) - deel 1. TNO Inro report 033N08832001 (in Dutch).