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Non Peer-reviewed author version

BRAEKERS, Kris; JANSSENS, Gerrit K. & CARIS, An (2009) Review on the comparison of external costs of intermodal transport and unimodal road transport. In: Proceedings of the BIVEC-GIBET Transportation Research Day 2009. p. 875-890..

Handle: http://hdl.handle.net/1942/10478

Review on the comparison of external costs of intermodal transport and unimodal road transport

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Abstract

Due to the continuous growth of freight transport, external costs caused by transport are rising. Road transport is the main contributor to these external costs. Alternative, more environmentally friendly transport modes, like barge and rail transport, often lack the opportunity to offer door-to-door transport services. Through the combination of several modes of transport, intermodal transport could provide a solution to overcome these issues. Combining barge or rail transport with road transport assures the flexibility which is needed to offer door-to-door services. Besides, intermodal transport is often assumed to be more environmentally friendly than unimodal road transport. Comparing the external costs from intermodal transport with those of unimodal road transport is however not straightforward. Intermodal transport involves several activities, which all have to be accounted for. Furthermore, external costs are very dependent on the situation in which they are caused and calculations are subject to large uncertainties.

This paper offers an overview on how external costs of intermodal transport and unimodal road transport may be compared. First, a brief review on the calculation and comparison of external costs of transport is given. Next, two key models for the comparison of intermodal transport and unimodal road transport are discussed. Finally, a sensitivity analysis is performed on the second model. Key parameters for increasing the competitiveness of intermodal transport regarding external costs, are determined.

KEYWORDS: external costs, intermodal transport, unimodal road transport, sensitivity analysis

1 Introduction

For several decennia, demand for freight transport is rising sharply. While the gross domestic product (GDP) in the EU-25 rose by 25% between 1995 and 2005, freight transport grew by 31%. The growth was the largest in road and sea transport, 38% and 35% respectively. (European Commission, 2007) This rise in freight transport has some important disadvantages. Congestion problems on European roads are rising, causing a decreasing flexibility of road transport. Furthermore, denser traffic flows augment the probability of accidents. Thirdly, and mainly, environmental concerns about climate change and air pollution are rising. A growing number of scientists is convinced that immediate action is necessary to counteract climate change and air pollution (European Commission, 2001). One of the main contributors to these environmental problems is the transportation sector, which accounts for 28% of total CO_2-emissions in the EU-25. Road transport is responsible for 84% of these emissions. (PACT, 2003)

According to Haezendonck en Coeck (2006), companies are confronted with a mobility paradox. On the one hand, customers are expecting shorter and more flexible delivery times. On the other hand, pressure from stakeholders and governments to reduce environmental harm is rising. Intermodal transport, through its combination of several modes of transport, could provide a solution to overcome this mobility paradox. By combining environmentally friendly transport modes, like transport by barge or rail, with flexible road transport, door-to-door transport services could be provided. Furthermore, intermodal transport is assumed to be more environmentally friendly than unimodal road transport. (Janic, 2008; Ricci, 2003; Ricci and Black, 2005; European Commission, 2006) As noted by Macharis and Van Mierlo (2006), calculating environmental effects of intermodal transport is rather complex. Intermodal transport invokes multiple activities, including pre- and post-haulage (PPH), transshipment and main haulage. All these activities have to be accounted for. Moreover, the authors indicate that making a comparison between the environmental effects of intermodal transport and unimodal road transport is difficult because of differences in environmental effects accounted for in past studies.

This paper focuses not only on the environmental aspects of freight transport, but takes a broader perspective by looking at the external costs of freight transport. INFRAS and IWW (1995, 2000, 2004) define external costs of transport as costs that result from the use of non-renewable resources which are not born by individual transporters. Examples of external costs are costs of air, noise, soil and water pollution, congestion, accidents, climate change, the use of space and the impediment of the view. Finally, external costs from up- and downstream activities may be considered. These include for example external costs caused by the electricity production for trains and costs of demolishing or recycling old vehicles.

The objective of this paper is to review how external costs of intermodal transport and unimodal road transport may be compared. It is shown that results from such a comparison are greatly influenced by the specific characteristics of the situation. Key parameters for increasing the competitiveness of intermodal transport regarding external costs are identified. First, section 2 looks at prevalent approaches for calculating external costs of transport. In section 3, research on the comparison of intermodal transport and unimodal road transport is reviewed. Two key models for the comparison of external costs of intermodal transport and unimodal road transport are discussed. Results of a sensitivity analysis conducted on the second model are presented in section 4. Finally, in section 5 conclusions are drawn and prospects for future research are given.

2 Calculation of external costs

Damages caused by external costs are generally not expressed in monetary values. In order to make a correct social-economic valuation and interpretation of the external costs, however, monetary values should be obtained. In this section several methods proposed in literature for the calculation of external costs are discussed. Next, this section draws attention on the difficulties and uncertainties concerning the calculation and comparison of external costs.

2.1 Bottom-up and top-down approaches

A first distinction in proposed methods may be made between a bottom-up approach and a top-down approach. Initially, the top-down approach, which results in average external costs, was most widely used. Total external costs of a geographical unit, for example a country, are estimated. Then, according to Dings and Sevenster (2002), Weinreich et al. (2000) and Van Wee et al. (2005), these costs are divided by a cost unit, like the total amount of vehicle kilometers traveled in the country, resulting in average costs per vehicle kilometer traveled. INFRAS and IWW (2000) and Daniels and Adamowicz (2000) note it is better to use the amount of ton-kilometers (tkm) instead of the amount of vehicle kilometers (vkm). Macharis and Van Mierlo (2006) on the other hand point at the limitations of the unit ton-kilometers. However, no alternative unit is given.

The calculation of external costs using the top-down approach has some important disadvantages. First of all, it is assumed that external costs are linear, which is not correct (Dings and Sevenster, 2002). Secondly, differences between locations and traffic conditions are not accounted for (Weinreich et al., 2000).

The bottom-up approach is more appropriate for the calculation of external costs due to transport. It follows a predefined structure in order to find the influence of transporting an additional ton-kilometer (Weinreich et al., 2000). The approach has the opportunity to account for differences in average speed, weight and energy consumption. The marginal external costs that result from this approach offer the information needed to measure the external costs caused by an additional specific transport activity. (Van Wee et al., 2005)

2.2 Resource and prevention approaches

INFRAS and IWW (2000) distinguish two approaches for the valuation of external costs. The resource approach is used to estimate damage costs, which are defined as the opportunity costs for the society suffering or repairing damages or losses of resources. The second approach is the prevention approach and is used to estimate avoidance costs. Avoidance costs are costs incurred to avoid damages referring to specific environmental targets, for example the costs of reducing CO_2-emissions by a certain percentage in order to avoid damages by these emissions. According to INFRAS and IWW (2000) the resource approach is the most appropriate method because real damages are valued. The prevention approach is considered as second best. It should only be used whenever the resource approach is not applicable. This is for example the case when calculating the external costs of climate change. Estimating damage costs of climate change is subject to large uncertainties due to the fact that local emissions have global effects which last for several generations. Therefore, using the resource approach is not feasible. (Weinreich et al., 2000)

2.3 The Impact Pathway Approach

In 1991, the European Commission founded the ExternE (Externalities of Energy) project under the Joule II Programme. The project had as objective to evaluate the external costs originating from the use of energy. Later, ExternE Transport has been started to evaluate the externalities of energy use in the transport sector. The main focus was on the calculation and valuation of external costs of air pollution. The methodology used was called the Impact Pathway Approach (IPA), a bottom-up approach for quantifying the emissions of energy related activities via a detailed chain approach. Besides the effects of emissions on the health of humans, the effects on crops and buildings were considered. (European Commission 1995; Krewitt, 2002) Currently the Impact Pathway Approach is stated to be the best available method for the calculation of external costs of air pollution due to transport. (Maibach et al., 2007). The Impact Pathway Approach is used to estimate damage costs, based on the resource approach described in section 2.2. The approach consists of four steps: emission modeling, dispersion modeling, quantifying impacts and economic valuation. For detailed information about the different steps of the Impact Pathway Approach, the reader is referred to European Commission (1995, 1998, 2005). An overview of state-of-the-art methods for the calculation of other external costs caused by transport is given by Maibach et al. (2007).

2.4 Difficulties and uncertainties

Several methods, sources of data and insights of several sciences, have to be combined when calculating external costs. This leads to considerable uncertainties and final values which are characterized by large ranges. (De Nocker et al., 2006; Kreutzberger et al., 2003) Next to these uncertainties, the calculation and comparison of external costs is subject to some difficulties. According to Kreutzberger et al. (2003) and Haezendonck and Coeck (2006) results for external costs are very method dependent. Van Lier and Macharis (2008) note that different studies often link the same externalities to other causes and outcomes. Besides, different assumptions are made. Therefore, the authors advise to use figures of a single research in order to preserve consistency and to avoid double counting.

Secondly, effects of one type of external costs on other types have to be accounted for. Kreutzberger et al. (2003) and Calthrop and Proost (1998) state that congestion not only causes external costs of congestion but also results in more emissions, more noise externalities and a higher probability of accidents. The consequence of accidents may however be smaller due to lower speed. These interrelationships should be addressed.

Furthermore, external costs are highly situation-dependent. Parameters like location, time of the day, vehicle characteristics and traffic situation have a great influence on the external costs of a transport activity. Firstly, external costs of a vehicle are strongly dependent on the geographical location of the road. Within densely populated urban areas, external costs from air pollution may be higher than in less populated inter-urban areas. External costs of noise may differ more than a factor 100, depending on the area where the noise is emitted (INFRAS and IWW, 2004). Secondly, time of the day (peak, non-peak, night) has an influence on external costs. Finally, external costs are dependent on vehicle characteristics and the traffic situation. According to Kreutzberger et al. (2003) external costs of an additional vehicle are dependent on the existing traffic intensity and average speed. External costs of noise are for example larger when the existing traffic level is lower. Load factor, vehicle characteristics and driving pattern may also influence external costs (Maibach et al., 2007). Macharis and Van Mierlo (2006) state that the energy use of a vehicle may differ by a factor ten, depending on the load factor and vehicle characteristics.

As a consequence of these difficulties, generalizing results from a study should be done with caution. Comparing external costs of intermodal transport and unimodal road transport on a general level is not straightforward. Ideally, each situation should be investigated separately.

3 Comparison of intermodal transport and unimodal road transport

The previous section summarized research on the way external costs of transport for all modes may be calculated. This section first discusses the results of studies comparing intermodal transport and unimodal road transport. For a detailed description, the reader is referred to Kreutzberger et al. (2003, 2006). Special attention is given to the RECORDIT[1] project. This project gives an extensive overview and comparison of external costs due to intermodal transport and unimodal road transport. In the remainder of the section, two key models for the comparison of external costs of intermodal transport and unimodal road transport are analyzed.

3.1 Research on the comparison of intermodal transport and unimodal road transport

Kreutzberger et al. (2003, 2006) analyzed in total 17 different studies concerning external costs of transport. Their objective was to verify the assumption that the external costs of intermodal transport are less than those of unimodal road transport. They found that most studies confirm that this assumption is valid under most circumstances. Only three studies question it. According to Kreutzberger et al. (2003, 2006) these three studies only raise doubts because they use non-realistic data and draw biased conclusions. Therefore, Kreutzberger et al. (2003, 2006) conclude that intermodal transport causes significantly less external costs than unimodal road transport, unless a combination of unfavorable conditions takes place. Such unfavorable conditions include very large distances for pre- and post-haulage, the use of short trains and the location of terminals in the opposite direction of the main haulage, so that pre- and post-haulage cause a movement in the wrong direction.

The most elaborate analysis and comparison of the external costs of intermodal transport and unimodal road transport, is given by the RECORDIT project (Kreutzberger et al., 2003 and 2006). RECORDIT stands for REal COst Reduction of Door-to-door Intermodal Transport. The project was subsidized by the EU within the fifth Framework Programme during the period of 1998 to 2002. During the project a consistent approach was used to make a complete analysis of almost all external costs for different modes of transport. As a consequence, it is possible to compare the results of the different modes considered. Furthermore, the project enables a good comparison between intermodal transport and unimodal road transport. (Baccelli et al., 2001) In the RECORDIT project, three European corridors are analyzed. For each corridor, an intermodal and a unimodal road route are defined. For each route, external costs are calculated in detail. Results show a great advantage for intermodal transport over unimodal road transport. Especially accident costs are much less for intermodal transport compared to unimodal road transport (a reduction of 60 to 80%). Furthermore, external costs of transshipments appear to be very low and have no significant influence on the external costs of intermodal transport. (Baccelli et al., 2001)

[1] REal COst Reduction of Door-to-door Intermodal Transport

It can be concluded that intermodal transport usually causes less external costs than unimodal road transport. However, this is not true under all circumstances. The amount of external costs caused by intermodal transport is for example largely affected by the length of pre- and post-haulage. Furthermore, external costs of transport are very dependent on the situation, as shown in paragraph 2.4. Macharis and Van Mierlo (2006) distinguish two types of studies in their literature review. The first group of studies calculates the external costs of intermodal transport and unimodal road transport for a number of specific routes. These studies explicitly take into account the transshipment and pre- and post-haulage stages of intermodal transport. Moreover, they offer the opportunity to account for the specific conditions of the route and the transport modes used. Results are specific for a particular situation and cannot be generalized. The second group of studies calculates and compares the external costs caused by transport modes, without considering intermodal transport. The results indicate the average performance of these different modes, but do not allow for an immediate comparison of intermodal transport and unimodal road transport. (Macharis and Van Mierlo, 2006) Section 3.2 and 3.3 describe two models that try to overcome this gap between too specific and too general data.

3.2 Comparison according to the model of Macharis (2006)

A first model that can be used to overcome the gap between too specific and too general data, is proposed by Macharis and Van Mierlo (2006). The model indicates what the proportion of pre- and post-haulage to the main haulage of intermodal transport may be, so that intermodal transport is still more environmentally friendly than unimodal road transport. The following notation is used:

$$A \times MH + B \times PPH \leq B \times URT \qquad (1)$$

$$\frac{PPH}{MH} \leq \frac{URT}{MH} - \frac{A}{B} \qquad (2)$$

With:

A = external costs per ton-kilometer for main haulage (euro/tkm)

B = external costs per ton-kilometer for road transport (euro/tkm)

MH = distance of main haulage (km)

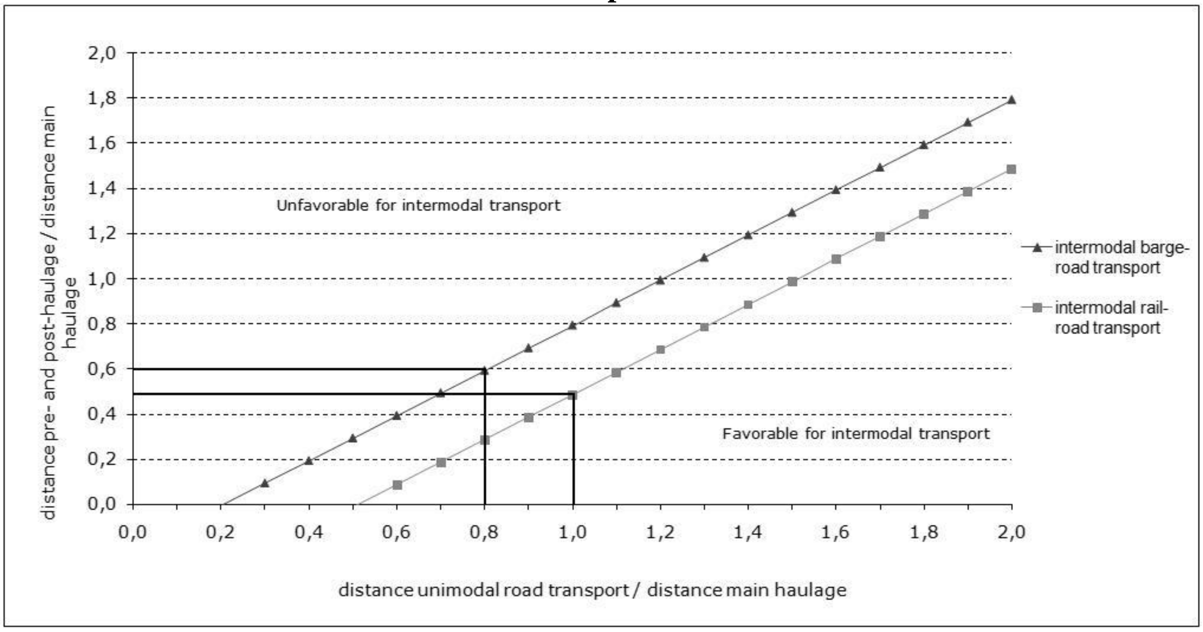
PPH = total distance of pre- and post-haulage (km)

URT = distance of unimodal road transport (km)

When parameters A and B are substituted by their respective values in expression (1) or (2), one can examine for which distances of pre- and post-haulage, main haulage and unimodal road transport, intermodal transport is more environmentally friendly than unimodal road transport. Intermodal transport is more environmentally friendly when the inequality holds. Based on expression (2), Macharis and Van Mierlo (2006) illustrated and analyzed their model by drawing two graphs, one for intermodal transport by barge and one for intermodal transport by railway. Macharis and Van Mierlo (2006) based their analysis on data for parameters A and B representing costs of air pollution and climate change.

In this paper we take a broader perspective by not only looking at environmental costs but at all types of external costs. The analysis is redone with data for parameters A and B that represent total external costs per ton-kilometer. The external costs of road transport, represented by parameter B, are assumed to be 24.12 euro/1000tkm, while the external costs of main haulage of intermodal transport, represented by parameter A, are assumed to be 12.35 euro/1000tkm for railway transport and 5.0 euro/1000tkm for barge transport (European Commission, 2002). Results are graphically shown in figure 1.

Figure 1: Comparison of the external costs of intermodal transport and unimodal road transport



All points underneath the straight lines of figure 1 represent points for which the external costs of intermodal transport will be less than those of unimodal road transport. For intermodal barge-road transport one can for example conclude the following: when the distance of unimodal road transport is 80% of the distance of main haulage of the intermodal transport by barge, the total pre- and post-haulage distance must be 60% or less of the main haulage distance, in order that intermodal transport will perform better than unimodal road transport. For intermodal rail-road transport figure 1 shows that when the distances of the unimodal road transport and the main haulage are the same, total pre- and post-haulage distance may be about 50% of the main haulage distance.

The model proposed by Macharis and Van Mierlo (2006) offers a great simplicity of computation and interpretation. A possible disadvantage is that in no way specific conditions concerning the route or means of transport may be taken into account.

3.3 Comparison according to the model of Janic (2007)

A second model for the comparison of the external costs of intermodal transport and unimodal road transport is proposed by Janic (2007). The author aims to compare both types of transport by their internal and total costs. Internal costs include private operational costs and time costs of goods in the network. Total costs are the sum of internal and external costs, where external costs consist of costs from air pollution, congestion, noise pollution and accidents. This paper focuses only on the external costs of transport and uses the proposed model to calculate and compare these costs.

Janic (2007) considers a transport network which consists of two geographically separated areas, a shipping and a receiving area. In each area, several nodes represent places of respectively shipping and receiving. In both areas an intermodal terminal is situated. Throughout the network, goods are transported by means of standardized loading units like containers or swap bodies. An intermodal transport activity consists of five stages: pre-haulage, transshipment, main haulage by train, transshipment and post-haulage. A unimodal road transport activity consists of three stages: a collection tour, transport from one area to the other and a distribution tour. No transshipment is needed. (Janic, 2007)

The following assumptions related to the calculation of external costs are made by Janic (2007):

- Unimodal road transport is carried out by trucks of equal capacity and load factor.
- In unimodal road transport, trucks are loaded with goods of a single shipping area and destined for a single receiving area. As a consequence, the whole transport is carried out by the same truck.
- Pre- and post-haulage in intermodal transport is carried out by trucks of equal capacity and load factor. The capacity and load factor may however differ from those applied in unimodal road transport.
- The distance of each pre- and post-haulage route is the same. Furthermore, the route and distance are assumed to be the same as the collection and distribution tour of a unimodal road transport.
- External costs of noise pollution and accidents at intermodal terminals are not considered.
- Each train has the same capacity and load factor.
- Transport by railway is free of congestion.

According to Janic (2007) the external costs of intermodal transport and unimodal road transport can be calculated by the expressions in appendix. The appendix gives also an overview of parameters and values used. Janic (2007) does not provide elaborate computational results in his paper. Results for the internal and total costs are shown graphically. Results for the external costs separately are not available. In order to calculate the external costs according to the expressions and data from Janic (2007), additional assumptions about the missing values of some parameters in appendix have to be made. First, as in the original article, the total net weight of the goods to be transported is fixed at 3510 ton and the total distance of the unimodal road transport (d_{kl}) is varied from 300 to 1300 km in steps of a 100 km. Next, the distance of main haulage of intermodal transport, denoted by s, needs to be determined. It is assumed that the intermodal terminals are located centrally in the shipping and receiving area. This means that the distance of the main haulage of intermodal transport is on average the same as the total distance of unimodal road transport reduced by the distance of the collection and distribution route. Because it was already assumed that the distances of the collection and distribution routes are equal to the distance of pre- and post-haulage (d_k), the distance of the main haulage of intermodal transport can be described as:

$$s = d_{kl} - 2 \times d_k \tag{3}$$

Third, based on the expressions used by Janic (2007), it is assumed that parameters Q_k and Q_{kl} are equal and can be interpreted as the number of fully loaded container equivalents to be transported. They are calculated by dividing the net weight of goods to be transported by the net weight of a loaded container, as is shown by expression (4).

$$Q_k = Q_{kl} = \frac{3510 \text{ ton}}{12 \text{ ton/TEU}} = 292.5\,\text{TEU} \quad (4)$$

Finally, as evidenced by the expressions for $C_{\text{int}(2)}$ and $C_{\text{int}(3)}$ in appendix, parameter Q should be equal to the total net weight of the goods to be transported, namely 3510 ton.

Based on the preceding assumptions and the expressions in appendix, the external costs of intermodal transport and unimodal road transport are calculated. An overview of the results for all door-to-door distances is shown in table 1. The first column shows the door-to-door distances. Columns two to four show the external costs of respectively pre-haulage (or post-haulage), the terminals and main haulage. Column five shows the total external costs of intermodal transport while column six shows those of unimodal road transport.

Table 1: External costs based on model of Janic (2007)

d_{kl} (km)	$C_{\text{int}(1)}$ (euro)	$C_{\text{int}(2)}$ (euro)	$C_{\text{int}(3)}$ (euro)	C_{int} (euro)	C_{roed} (euro)
300	10483.69	385.40	3751.56	25104.35	14515.48
400	10483.69	385.40	4285.15	25637.93	16173.67
500	10483.69	385.40	4709.02	26061.80	17589.22
600	10483.69	385.40	5066.38	26419.17	18837.30
700	10483.69	385.40	5378.35	26731.14	19961.39
800	10483.69	385.40	5657.02	27009.81	20989.19
900	10483.69	385.40	5910.03	27262.81	21939.62
1000	10483.69	385.40	6142.54	27495.33	22826.21
1100	10483.69	385.40	6358.26	27711.04	23659.06
1200	10483.69	385.40	6559.89	27912.68	24445.90
1300	10483.69	385.40	6749.54	28102.32	25192.81
1901	10483.69	385.40	7709.35	29062.13	29062.38

As appears from table 1, for all the door-to-door distances (300 to 1300 km) the external costs of intermodal transport are higher than those of unimodal road transport. The difference between the external costs declines with an increasing door-to-door distance. For a door-to-door distance of 1901 km, the external costs of intermodal transport and unimodal road transport are approximately equal. When the door-to-door distance increases further, intermodal transport performs better than unimodal road transport. These results are rather surprising, as was thought that intermodal transport would cause less external costs than unimodal road transport for far smaller distances. Furthermore, it seems that the external costs caused at the intermodal terminals represent only a small portion (1.54% to 1.37% for d_{kl} from 300 to 1300 km) of the total external costs of intermodal transport. This confirms the findings of Baccelli et al. (2001) based on the results of the RECORDIT project.

Reasons why the external costs of intermodal transport are higher than those of unimodal road transport for door-to-door distances up to 1900 km, may be derived from the data used. First, load factors of trucks during pre- and post-haulage (0.6) and trains during main haulage

(0.75) are less than the load factor of trucks during unimodal road transport (0.85). Of greater importance is the fact that distance-dependent external costs are applied. As a consequence, the external costs per vehicle kilometer of road transport decrease with increasing distance. For example, for a door-to-door distance of 300 km, the external costs of pre- and post-haulage are 0.86 euro/vkm, while the external costs of unimodal road transport are 0.28 euro/vkm. When the same external costs per vehicle kilometer are used for pre- and post-haulage and unimodal road transport, the results of table 1 change considerably. For example, with external costs per vehicle kilometer of 0.2812 euro/vkm, intermodal transport already causes less external costs than unimodal road transport for a door-to-door distance of 215 km.

While the use of distance-dependent external costs has a large effect on the results, in literature no other source was found using external costs of transport varying with traveled distance. Some authors do make a distinction concerning external costs between transport in and around cities and transport outside cities, on highways. The external costs of the former are consistently higher than those of the latter. A reason for that is the density of population, which is far higher in cities than outside. As a consequence, more people are affected by air and noise pollution during transport in and around cities than outside cities. Furthermore, in urban areas it is harder to maintain a constant speed than on highways, resulting in higher external costs in the former case. (De Nocker et al., 2006) Maibach et al. (2007) state that within a single country external costs of one truck kilometer during peak hours in an urban area may be five times higher than external costs of an interurban truck kilometer during non-peak hours by the same vehicle.

The fact that the external costs per vehicle kilometer are higher for pre- and post-haulage than for unimodal road transport, may therefore partially be justified by making the following assumptions: pre- and post-haulage of intermodal transport and the collection and distribution route of unimodal road transport are situated in and around cities, while road transport between the shipping and receiving area takes place on highways between cities. These assumptions, though, do not explain why the external costs per vehicle kilometer keep decreasing with increasing distance.

As is shown in this section, the model proposed by Janic (2007) may be applied to calculate and compare the external costs of intermodal transport and unimodal road transport. The model of Janic (2007) offers the opportunity to adapt several parameters, like load factors, train length and distances, to the situation under consideration. Ideally other parameters affecting the external costs should be taken into account as well. These parameters include for example the time of transport (peak, non-peak or night), vehicle characteristics and location characteristics, like population density and speed limits. Finally, while in this paper the model is only used to analyze intermodal road-rail transport, an analogous analysis can be made for intermodal road-barge transport.

4 Sensitivity analysis

While the results in the previous section are not as positive for intermodal transport as initially expected, these results represent only a single possible situation. As was mentioned before, external costs of transport are very dependent on the situation in which they are caused. This section describes a sensitivity analysis that is performed on the model to investigate other possible situations. This sensitivity analysis may also be applied to identify key parameters for increasing the competitiveness of intermodal transport regarding external costs.

The sensitivity analysis is performed on six parameters, as is shown in table 2. Three parameters are concerned with pre- and post-haulage (1, 2, 3) and two with main haulage of intermodal transport (4, 5). The last parameter is concerned with unimodal road transport (6). For each parameter, several values expected to increase the competitiveness of intermodal transport are considered. Because results for the original scenario were more negative than expected, only a single worse value for each parameter is considered. The original values are underlined.

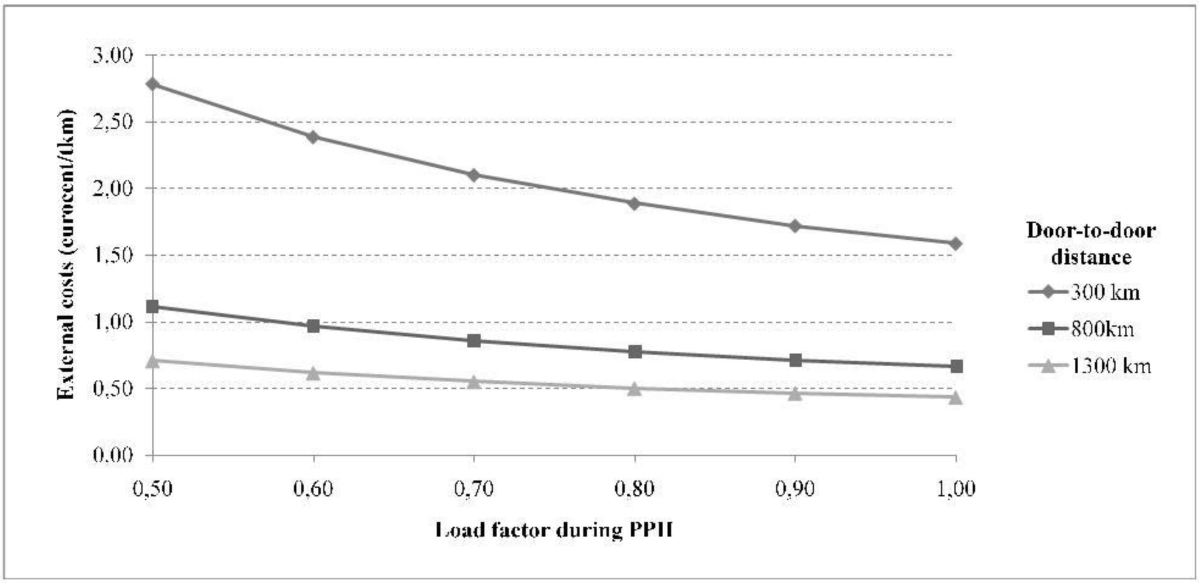
Results of the sensitivity analysis are shown in table 2. For each value of the six parameters the corresponding break-even distance is presented. The break-even distance is defined as the door-to-door distance for which the external costs of intermodal transport and unimodal road transport are equal (1901 km in the original case). It appears that for the parameters concerning pre- and post-haulage a relatively small change in a parameter value has a significant effect on the break-even distance. For example, increasing the load factor during pre- and post-haulage from 0.6 to 0.7 results in a reduction of the break-even distance of 617 km (from 1901 to 1284 km). A change in the load factor during unimodal road transport has a similar effect. For the parameters concerning main haulage of intermodal transport, the effect on the break-even distance is smaller.

Table 2: Results of the sensitivity analysis

Parameter 1: Load factor during PPH						
Value	0.5	<u>0.6</u>	0.7	0.8	0.9	1.0
Break-even distance (km)	3018	1901	1284	912	672	509
Parameter 2: External costs per vehicle kilometer during PPH						
Value (euro/vkm)	0.46	0.56	0.66	0.76	<u>0.86</u>	0.96
Break-even distance (km)	373	632	967	1388	1901	2510
Parameter 3: Distance of PPH						
Value (km)	10	20	30	40	<u>50</u>	60
Break-even distance (km)	426	809	1179	1543	1901	2255
Parameter 4: Flatcars per train						
Value	23	<u>26</u>	29	32	35	38
Break-even distance (km)	1945	1901	1864	1833	1806	1782
Parameter 5: Load factor during main haulage						
Value	0.65	<u>0.75</u>	0.85	0.95	/	/
Break-even distance (km)	1990	1901	1833	1779	/	/
Parameter 6: Load factor during unimodal road transport						
Value	0.45	0.55	0.65	0.75	<u>0.85</u>	0.95
Break-even distance (km)	224	435	758	1231	1901	2824

More detailed results for the first parameter, the load factor during pre- and post-haulage, are shown in figure 2. The figure displays the evolution of external costs per ton-kilometer of intermodal transport for three door-to-door distances when the load factor during pre- and post-haulage changes. For a given load factor, external costs per ton-kilometer are higher when door-to-door distance is smaller because the share of high cost pre- and post-haulage distance is larger. As can be seen in figure 2, external costs per ton-kilometer decrease with increasing load factor for all door-to-door distances. The effect is larger for smaller door-to-door distances, again because of the larger share of pre- and post-haulage costs in the total external costs of intermodal transport.

Figure 2: External costs of intermodal transport for different load factors during PPH



The sensitivity analysis confirms the fact that small changes of the situation under consideration can yield considerable differences in the results, as was already mentioned in section 2.4. From the analysis appears that changing a parameter concerning pre- and post-haulage has more effect than changing a parameter of main haulage. This is caused by the large share of pre- and post-haulage costs in total costs of intermodal transport. It has to be noted that this is partly due to the use of distance-dependent external costs for road transport. However, when constant external costs are used for road transport, pre- and post-haulage costs would still have a large share in the total external costs because road transport causes significantly higher external costs than transport by rail (or barge) over the same distance.

5 Conclusions and future research prospects

Promoting intermodal transport is often regarded as an interesting option to decrease external costs from transport while maintaining the flexibility to offer door-to-door transport services. This paper confirms that comparing the external costs of intermodal transport and unimodal road transport is not straightforward. The calculation of external costs is subject to several difficulties and uncertainties. External costs due to transport are very situation-dependent which complicates comparisons on a general level.

Two key models which may be used to overcome the gap between too general and too specific data are discussed. While the first model offers great simplicity of computation and interpretation, the second model offers a deeper insight into the different parameters involved when calculating external costs of transport. A sensitivity analysis on the second model shows that small changes in a parameter can have a large effect on the results. For intermodal transport, results seem to be more sensitive to changes in parameters of pre- and post-haulage than changes in parameters of main haulage.

Future research should focus on the validation of the distance-dependent external costs used in the second model. Besides, other parameters, like vehicle characteristics, could be included. Finally, the external costs of intermodal road-barge transport may be analyzed by the model.

Appendix: formulas, symbols and values used by Janic (2007)

External costs of intermodal transport			
Symbol	**Value/Formula**	**Unit**	**Explanation**
$C_{\text{int}(1)}$	$\frac{Q_k}{\lambda_k \times M_k} \times c_{e/k}(d_k)$	euro	External costs of a pre- or post-haulage
Q_k		TEU	Fully loaded container equivalents pre- or post-hauled in zone k
λ_k	0.60	-	Load factor of trucks in zone k
M_k	2	TEU	Truck capacity in zone k
$c_{e/k}(d_k)$	$9.88 \times d_k^{-0.624} \times d_k$	euro	External costs per trip in zone k
d_k	50	km	Distance of PPH in zone k
$C_{\text{int}(2)}$	$Q \times (c_{e1} + c_{e2})$	euro	External costs caused at the terminals
Q		ton	Net weight of the transported goods
c_{e1}	0.0549	euro/ton	External costs at shipping terminal
c_{e2}	0.0549	euro/ton	External costs at receiving terminal
$C_{\text{int}(3)}$	$\sqrt{2}/2 \times c_e(w,s) \times \left[\frac{Q \times T \times (\alpha_{b1} + \alpha_{b2})}{c(w,s) + c_e(w,s)}\right]^{0.5}$	euro	External costs of main haulage
$c_e(w,s)$	$0.57 \times (w \times s)^{0.6894}$	euro	External costs per train trip
$c(w,s)$	$0.58 \times (w \times s)^{0.74}$	euro	Internal costs per train trip
w	1560.55	ton	Total weight of a loaded train
s		km	Distance of main haulage
Q		ton	Net weight of the transported goods
T	120	hours	Network operational time
α_{b1}	0.028	euro/ton $\times$ hour	Time costs of goods in shipping terminal
α_{b2}	0.028	euro/ton $\times$ hour	Time costs of goods in receiving terminal
C_{int}	$2 \times C_{\text{int}(1)} + C_{\text{int}(2)} + C_{\text{int}(3)}$	euro	Total external costs of intermodal transport

External costs of unimodal road transport			
Symbol	**Value/Formula**	**Unit**	**Explanation**
C_{road}	$\frac{Q_{kl}}{\lambda_{kl} \times M_{kl}} \times c_{e/kl}(d_{kl})$	euro	Total external costs of unimodal road transport
Q_{kl}		TEU	Fully loaded container equivalents transported from zone k to l
λ_{kl}	0.85	-	Load factor of trucks from zone k to l
M_{kl}	2	TEU	Truck capacity from zone k to l
$c_{e/kl}(d_{kl})$	$9.88 \times d_{kl}^{-0.624} \times d_{kl}$	euro	External costs per trip from zone k to l
d_{kl}		km	Door-to-door distance from zone k to l

Other data		
Explanation	**Value**	**Unit**
Number of trains per week (operational time of 120 hours)	5	trains/week
Number of flatcars per train	26	flatcars
Weight of an empty flatcar	24	ton
Weight of a locomotive	100	ton
Weight of an empty train	(26 × 24) + 100 = 724	ton
Load factor of a train	0.75	-
Capacity of a flatcar	3	TEU
Net weight of a fully loaded TEU-container	12	ton/TEU
Net weight of a train load	12 × 26 × 3 × 0.75 = 702	ton
Net weight of transported goods	702 × 5 = 3510	ton

Source: Janic, 2007

References

Baccelli, O. et al. (2001) *Deliverable 4: External cost calculation for selected corridors*. European research project RECORDIT. (http://www.recordit.org/deliverables/deliv4.pdf)

Calthrop, E. and Proost, S. (1998) Road Transport Externalities. *Environmental and Resource Economics* 11(3-4), 335-348.

Daniels, R. and Adamowicz, V. (2000) Environmental valuation. In: Hensher, D. A. and Button, K.J. (eds.) *Handbook of Transport Modelling*, Elsevier Science, Oxford.

De Nocker, L., Int Panis, L. and Mayeres, I. (2006) De externe kosten van personenvervoer. In: Despotin, M. and Macharis, C. (eds.) *Mobiliteit en grootstedenbeleid – 27e Vlaams Wetenschappelijk Economisch Congres,* VUB Press, Brussels.

Dings, J. and Sevenster, M. (2002) *De werkelijke kosten van verkeer. Overzicht van externe kosten en de relatie met prijsbeleid.* CE Delft, Delft.

European Commission (1995) *Externalities of Energy – ExternE Project. Volume 2: Methodology*. European Commission, DGXII, Science, Research and Development, Office for Official Publications of the European Communities, Luxemburg.

European Commission (1998) *Externalities of Energy - ExternE Project. Methodology Update 1998*. European Commission, DGXII, Science, Research and Development. Office for Official Publications of the European Communities, Luxemburg.

European Commission (2001) *White paper - European transport policy for 2010: time to decide*. Office for Official Publications of the European Communities, Luxemburg.

European Commission (2002) *Proposal for a regulation of the European Parliament and of the Council on the granting of Community financial assistance to improve the environmental performance of the freight transport system.* Office for Official Publications of the European Communities, Luxemburg.

European Commission (2005) *Externalities of Energy - ExternE Project. Methodology Update 2005.* European Commission, DGXII, Science, Research and Development. Office for Official Publications of the European Communities, Luxemburg.

European Commission (2006) *Keep Europe moving - Sustainable mobility for our continent - Mid-term review of the European Commission's 2001 Transport White paper*. Office for Official Publications of the European Communities, Luxemburg.

European Commission (2007) *Panorama of transport.* Office for Official Publications of the European Communities, Luxemburg.

Haezendonck, E. and Coeck, C. (2006) Externe kosten van goederentransport in Vlaanderen: de impact van het hinterlandtransport van containers via zeehavens. In: Despotin, M. and Macharis, C. (eds.) *Mobiliteit en grootstedenbeleid – 27e Vlaams Wetenschappelijk Economisch Congres,* VUB Press, Brussels.

INFRAS and IWW (1995) *External costs of transport.* UIC. Karlsruhe/Zürich/Paris.

INFRAS and IWW (2000) *External costs of transport – Accident, environmental and congestion costs in Western Europe.* UIC. Zürich/Karlsruhe.

INFRAS and IWW (2004) *External costs of transport – Update Study.* UIC. Zürich/Karlsruhe.

Janic, M. (2007) Modelling the full costs of an intermodal and road freight transport network. *Transportation Research Part D: Transport and Environment* 12(1), 33-44.

Janic, M. (2008) An assessment of the performance of the European long intermodal freight trains (LIFTS). *Transportation Research Part A: Policy and Practice* 42(10), 1326-1339.

Kreutzberger, E. et al. (2003) *Is intermodal freight transport more environmentally friendly than all-road freight transport? A review.* Presented at Nectar Conference No. 7, Umeå, June 13-15.

Kreutzberger, E., Macharis, C. and Woxenius, J. (2006) Intermodal versus unimodal road freight transport - a review of comparisons of the external costs. In: Jourquin, B., Rietveld, P. and Westin, K. (eds.) *Transportation economics - Towards better performing transport networks,* Routledge, New York.

Krewitt, W. (2002) External costs of energy - Do the answers match the questions? Looking back at 10 years of ExternE. *Energy Policy* 30(10), 839-848.

Macharis, C. and Van Mierlo, J. (2006) Intermodaal vervoer: Milieuvriendelijk ook in de toekomst? *Tijdschrift voor Vervoerswetenschappen* 42(1), 8-11.

Maibach, M. et al. (2007) *Handbook on estimation of external costs in the transport sector.* Produced within the study Internalisation Measures and Policies for All external Cost of Transport (IMPACT), European Commission DG TREN, Delft.

Ricci, A. (2003) Pricing of intermodal transport. Lessons learned from RECORDIT. *Journal of Transport and Infrastructure Research* 3(4), 351-370.

Ricci, A. and Black, I. (2005) The Social Costs of Intermodal Freight Transport. *Research in Transportation Economics* 14, 245-285.

PACT (2003) *Combined transport – CO_2 reduction.* UIRR – Nestear – SGKV – Lugmair.

Van Lier, T. and Macharis, C. (2008) *Berekenen van de impact van de externe effecten van een binnenhaven.* Presented at Vervoerslogistieke werkdagen 2008, Deurne (the Netherlands), November 13.

Van Wee, B., Janse, P. and Van Den Brink, R. (2005) Comparing energy use and environmental performance of land transport modes. *Transport Reviews* 25(1), 3-24.

Weinreich, S. et al. (2000) *Deliverable 1: Accounting framework.* European research project RECORDIT. (http://www.recordit.org/deliverables/deliv1.pdf)