

# Modelling the full costs of an intermodal and road freight transport network

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## Abstract

This paper develops a model for calculating comparable combined internal and external costs of intermodal and road freight transport networks. Internal costs consist of the operational-private costs borne by the transport and intermodal terminal operators, and the time costs of goods tied in transit. The external costs include the costs of the impacts of both networks on society and the environment such as local and global air pollution, congestion, noise pollution, and traffic accidents. The model is applied to the simplified configurations of both networks using the inputs from the European freight transport system. The objective is to investigate some effects of European Union policy, which aims to internalise the external costs of transport, on the prospective competition between two networks from a social perspective.

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## 1. Introduction

Intermodal freight transport provides transport for consolidated loads such as containers, swap-bodies and semi trailers by combining at least two modes (European Commission, 2002). In Europe, intermodal freight transport has frequently been seen as a potentially strong competitor to road transportation and to be environmentally friendlier in many contexts.<sup>1</sup> Its development to date, however, has not confirmed such expectations. For example, during 1990–1999, European intermodal freight transport grew steadily from an annual volume of about 119 to about 250 billion t–km<sup>2</sup> with an increase in its market share volumes from about 5%–9%.<sup>3</sup>

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<sup>1</sup> Efforts to promote intermodal freight transport have increased over the past two decades (Bontekoning et al., 2004; European Commission, 1999; European Conference of Ministers of Transport, 1998). Competitiveness of intermodal transport were investigated (European Commission, 2001a,b; Morlok et al., 1995).

<sup>2</sup> About 91% of this total was international. Rail carried about 20%, inland waterways 2%, and short-sea shipping 78% of the international traffic, while about 97% of the domestic traffic was carried out by rail and 3% by inland waterways.

<sup>3</sup> Freight transport in Europe was grew by an average annual rate of 2% during the period 1970–2001 and reached about 3000 billions t–km (tonne-kilometres) in 2001, of which about 44% was carried by road, 41% by coastal shipping, 8% by rail, and 4% by inland waterways.

This was mainly due to enhancement of operations in Trans-European corridors of 900–1000 km that carried about 10% of the tonnage. During the same period, in corridors of 200–600 km the share of intermodal transport was only about 2%, and 2%–3% in terms of the volumes of t–km and in tonnes, respectively. Since 1999 the market share has not really improved, mostly due to a low containerisation rate, deterioration in the quality of services of intermodal transport, and improvements in the efficiency and quality of road transport services (European Commission, 1999, 2000, 2001a, 2002; UIRR, 2000).

This paper analyses the internal and external costs of an intermodal and an equivalent road transport network to investigate European Union (EU) policies intended to internalise negative externalities.

## 2. The intermodal and road freight transport network

Analysis of the full costs of a given intermodal and equivalent road transport network requires an understanding of the network size, of the intensity of operations, of the technology in use, and of the internal and external costs of individual components of the system. Both networks are assumed of equivalent size in terms of the spatial coverage, number of nodes and the volumes of demand they serve. Fig. 1 shows a simplified scheme.

Network nodes are the origins and destinations of goods. They represent clusterings of manufacturing plants, warehouses, logistics centres and/or freight terminals located in shipper and receiver areas. The spatial concentrations shippers and recipients are divided into zones. Intermodal terminals are also nodes but only for the short-term storage and/or direct transferring of goods. Goods flows in both networks are consolidated to be by standardized units – containers, swap-bodies and semi-trailers.

Transport infrastructure provides the means for movement of the freight units. The nature of this infrastructure and the quality of service it offers depends on the volume of demand, the efficiency and effectiveness of the services, and the physical scale of the hardware.

Intermodal transport involves a number of stages: (i) collection in the originating zone and transportation by truck to the origin intermodal terminal located in the shipper area; (ii) transshipment at the origin intermodal terminal from truck to the trunk-haul, non-road transport mode (rail, inland waterways, air); (iii) line-haul transportation between the origin and destination intermodal terminals by the trunk-haul mode; (iv) transshipment at the destination intermodal terminal in the receiver area from the trunk-haul mode to

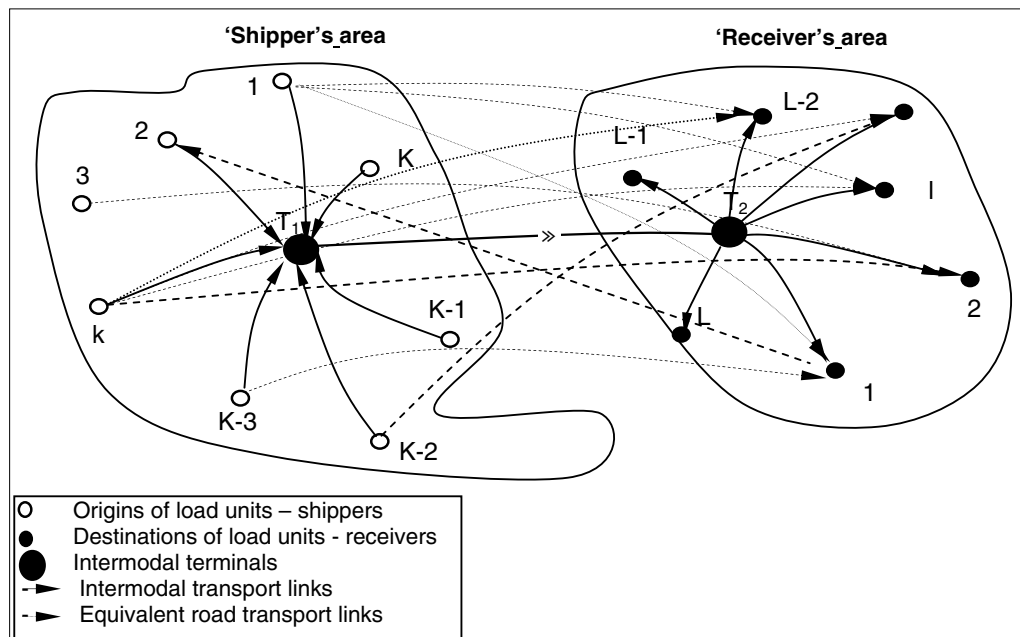


Fig. 1. Simplified scheme of an intermodal and road freight transport network.

trucks; (v) distribution from the destination intermodal terminal to the destination zone by truck (European Commission, 2000).

In the road transport network movement of loads between shippers and receivers is carried out directly by the same truck in three steps: collection in the origin zones; line-hauling from the border of the origin to the border of the destination zone; and distribution within the destination zones (Daganzo, 1999).

There are internal and external costs associated with a movement through an intermodal system and its equivalence by a road transport network. Internal costs comprise the operators' costs of moving units between shippers and receivers. The external costs are costs that networks impose on society, including environmental costs. Both categories of cost can be specified for each stage in the networks. They generally depend on the network nature, characterised by its location, distances and number of nodes; the intensity of activities in the network characterised its use; the efficiency of services, and the prices of inputs. Particularly relevant for external costs are the emission rates of pollutants and the number of accidents, and their impacts on society and the environment. In addition, network services can impose delays on other traffic by creating congestion.

### *2.1. Internal costs*

The collection, distribution, line hauling and transshipment of units moved within intermodal system determine the internal costs of the network. The cost of each component embraces the cost of ownership, insurance, repair and maintenance, labour, energy, taxes, and tolls/fees paid for using the network. The network infrastructure and mobile plant are assumed to be in place to serve a given volume of demand given the efficiency of the system. Thus, the costs of investment in any additional infrastructure and/or rolling stock are not taken into account.

The internal costs of an equivalent road transport network are analogous to those of the road part of the intermodal network plus the collection and delivery parts of the system. The internal costs directly associated with the particulars of a consignment, such as depreciation, maintenance, repair, and insurance costs, are not included because they are assumed to be borne by shippers or recipients (European Commission, 2001a,b; Levison et al., 1996).

### *2.2. External costs*

Because of a lack of full property right allocation, each step of the door-to-door delivery operation in either network generates burdens on society. If intensive and persistent, these burdens if not reflected in prices are considered as the external costs. As they are not internalised, the external costs are usually estimated indirectly using such methods as willingness-to-pay for avoiding, mitigating or controlling particular impacts. The external costs of both networks embrace the cost of damages by burdens such as the local and global air pollution, congestion, noise, and traffic accidents.

### *2.3. Intermodal network*

- **Air pollution**

Trucks carrying out collection and distribution usually burn diesel fuel and cause air pollution, the particular components of which can cause locally damage to surrounding buildings, green areas, and people's health. However, if deposited by weather in remote locations this air pollution can also have a wider impact. Air pollution from the main transport mode during the line haul between intermodal terminals depends on the type of energy used by mode. If aircraft, rail diesel engines, and/or diesel-powered ships (barges) are used the air pollution is direct. If electric energy is used, as by some railways, the air pollution is indirect, dependent on the composition of sources from which the electric energy is obtained. These are usually the remote power plants considered as the point sources of local air pollution. The air pollution generated by the operations of intermodal terminals is mainly indirect because the electric energy remote plants is used for the cranes transhipping the loads.

- Congestion

The trucks performing the collection and distribution of load units usually move in the densely urbanised and/or industrialised zones. They may experience congestion and the consequent private delays. However, they may also impose delays on other vehicles whose costs are counted as an externality. The inter-terminal transport mode is assumed to be free of congestion. Thus introducing new services does not cause shifting or rescheduling of existing ones and service-departures do not interfere and impose delays on each other. Loads are also assumed not to impose delay costs on each other while being handled in the intermodal terminals.

- Noise

Trucks involved in the collection and distribution of loads generate noise, which, if it exceeds tolerable limits causes annoyance and if it persistent can cause a decline productivity and have adverse health effects. Noise generated by line hauling between two intermodal terminals can have similar effect. Noise from the intermodal terminals is not considered since it is assumed to be just a part of ambient urban noise.

- Traffic accidents

Traffic accidents cause damage and property loss the network operators and third parties, in addition to the loss of life and injuries to the affected people. They are considered separately for each step and transport mode of the intermodal transport network due to the different frequency, character of occurrence, and consequences. Accidents at the intermodal terminals are not considered since are very rare events.

#### 2.4. Road network

The same categories of external costs and ways of their consideration are used for the three operational steps of the road transport network. Specifically, particular burdens, damages, and associated costs are considered regarding the use of diesel-powered trucks along the entire door-to-door distance.

### 3. Modelling full costs

Modelling the full costs of an intermodal and equivalent road transport network involves developing the model, collection of data, and the model application. Developing the model includes identification of the relevant variables and their relationships. The variables reflect the type and format of data needed for the model application. Data collection is particularly challenging.

External costs are estimated using a four-stage process, starting with the quantification of emissions/burdens and estimation of their spatial concentration, proceeding with an estimation of the prospective damages, and ending with putting monetary values on short and long-term damage. In both networks, data on the internal and external costs refer to particular parts (segments, actors) operating under different technical/technological, market, and environmental-spatial conditions. The results are then aggregated.

The model is based on a set of assumptions:

#### 3.1. Intermodal network

- Collection and distribution

- Vehicles of the same capacity and load factor collect and/or distribute load units in a given zone.
- Each vehicle makes a round trip of approximately the same length at a constant average speed.
- The collection step starts from the vehicle's initial position, which can be anywhere within the 'shipper' area and ends at the origin's intermodal terminal. The distribution step starts from the destination intermodal terminal where the vehicles may be stored in a pool and ends in the reception area at the last receiver.
- Headways between the arrivals and departures of the successive vehicles (and thus loads) at the origin and from the destination intermodal terminal, respectively, are approximately constant and independent of each other.

- Line-haul between two terminals

- Headways between successive departures of the main mode's vehicles between two intermodal terminals are constant, reflecting the practice of many non-road transport operators in Europe to schedule regular weekday services.

- The each inter-terminal vehicle has identical capacity irrespective of whether it is rail or road.
- The average speed and the anticipated delays of the main mode are constant and approximately equal.

### 3.2. Road network

- Trucks of similar capacity and load factor transport units between the origin and destination zones.
- Units are loaded onto each truck for exclusively one given pair of ‘zones’. The area, layout and distance between particular shippers and receivers in particular ‘zones’ crucially influence the length of vehicle tour distances. The vehicle speed is constant.
- The trucks move between the borders of particular pairs of the origin and destination zones along the same routes at a constant line-haul speed.

Based on these assumptions, the generic structure for calculating particular cost categories (internal, external) and cost type (transport, time, handling, type of externality) for particular steps of operation of the networks is developed:

- Internal cost:

$$\begin{aligned} \text{Transport cost} &= (\text{Frequency}) \times (\text{Cost per frequency}) \\ &= [(\text{Demand})/(\text{Load factor} \times \text{Vehicle capacity})] \times (\text{Cost per frequency}), \end{aligned} \quad (1)$$

$$\text{Time cost} = (\text{Demand}) \times (\text{Time}) \times (\text{Cost per unit of time per unit of demand}), \quad (2)$$

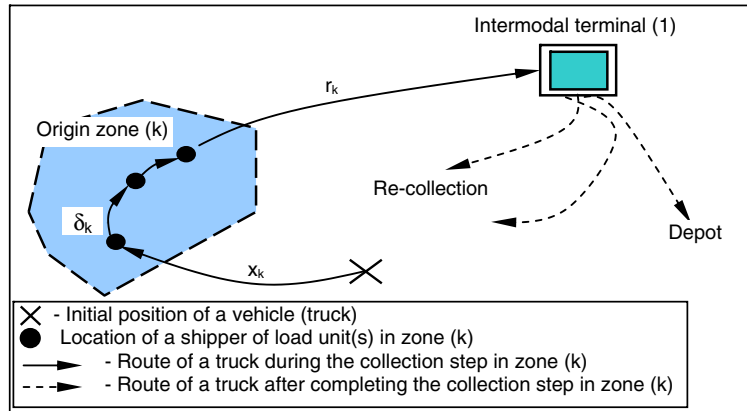
$$\text{Handling cost} = (\text{Demand}) \times (\text{Cost per unit of demand}). \quad (3)$$

- External cost:

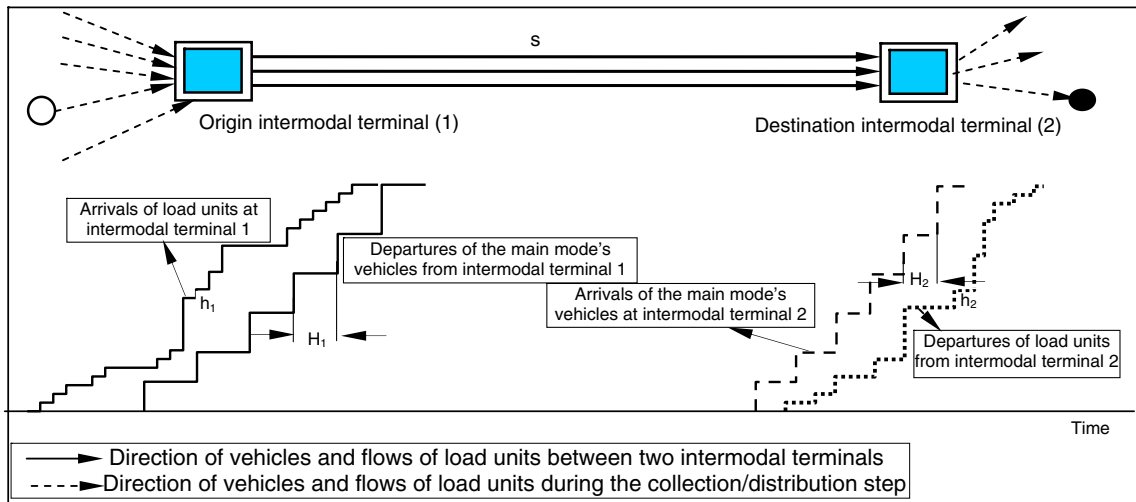
$$\begin{aligned} \text{External cost} &= (\text{Frequency}) \times (\text{External cost per frequency}) \\ &= [(\text{Demand})/(\text{Load factor} \times \text{Vehicle capacity})] \times (\text{External cost per frequency}). \end{aligned} \quad (4)$$

The variables in Eq. (1) are specific for particular steps in the intermodal network. In the collection and distribution step, ‘frequency’ relates to the number of vehicle runs needed to collect and/or distribute a given volume of units. In zone  $k$ , ‘frequency’  $f_k$  is proportional to the volume of units  $Q_k$  and inversely proportional to the product of truck capacity  $M_k$  and load factor  $\lambda_k$ . ‘Cost/frequency’ relates to the cost of individual truck types and is expressed in relation to distance of a trip as  $c_{ok}(d_k)$ . Distance  $d_k$  includes the segments between the vehicle’s initial position and the first stop  $x_k$ , the average distances between successive stops  $\delta_k$ , and the distance between the last stop and the intermodal terminal  $r_k$  (Fig. 2(a)). The reasoning for the trip frequencies and distances can also be applied to the distribution step (Fig. 2(c)). For the line hauling step,  $f$  is proportional to the volume of units in network  $Q$ , and inversely proportional to the product of the modular capacity of the inter-terminal mode its load factor (Fig. 2(b)). It is determined so as to minimise the internal and external costs for the transport operator and the time cost of loads while in the network (Daganzo, 1999). The internal and external cost per departure,  $c(w, s)$  and  $c_e(w, s)$ , depend on the vehicle weight  $w$  and the line-hauling distance  $s$ . The cost of time of loads at both intermodal terminals and line hauling step  $\alpha_{b1}$ ,  $\alpha_{b2}$ , and  $\alpha_{b1}$ , respectively, depends on the value of goods and the relevant discount rate. For the road transport network, the variables in the Eq. (1) have an analogous meaning, reflecting that trucks cover the entire door-to-door distance between ‘zones’  $k$  and  $l$ .

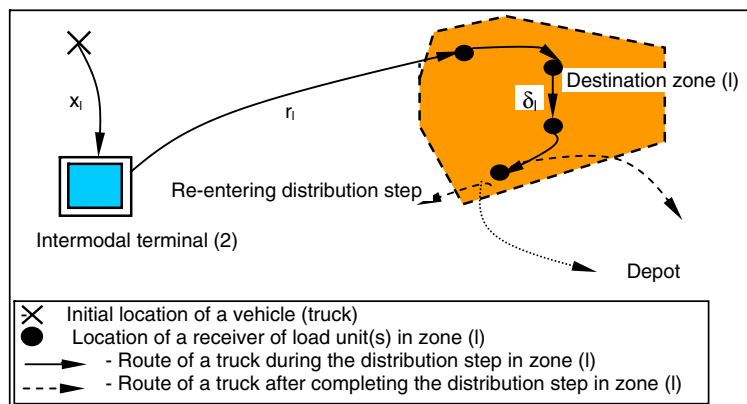
The variables in Eq. (2) have the following meaning: In the intermodal transport network the time cost in the collection step in zone  $k$  is proportional to the quantity of load units  $Q_k$ , the unit value of goods time  $\alpha_k$ , and the time of the vehicle tour  $t_k$ , which is proportional to the length of tour  $d_k$  and the average vehicle speed  $v_k$ . In the line-hauling step the time cost is proportional to the waiting and line haul time, and their unit costs. The line haul time is proportional to the distance  $s$  and anticipated delays  $D$  and inversely proportional to the vehicle speed  $v_s$ . The time cost is determined by optimizing the total costs of the line-hauling step with respect to the departure frequency of the main transport mode.



a) Collection in the 'shipper' area



b) Line haul between two intermodal terminals



c) Distribution in the 'receiver' area

Fig. 2. Simplified scheme of delivering load units in given intermodal transport network.

In the road transport network, the time cost (Eq. (2)) refers to transportation of load units between zones  $k$  and  $l$ . It is proportional to the quantity of load units  $Q_{kl}$ , the unit value of goods time  $\alpha_{b/kl}$ , and the time

Table 1  
Components of the full costs of given intermodal and equivalent road freight transport network

	Intermodal network		Road network
	Collection/distribution <sup>a</sup>	Line-haul <sup>b</sup>	Collection/distribution/line-haul
1. Transport (internal) cost	$C_{1/k} = (Q_k/\lambda_k M_k) c_{ok}(d_k)$ (1a)	$C_{1/t/\min} = \sqrt{2}/2c(w, s) \left[ \frac{QT(\alpha_{b1} + \alpha_{b2})}{c(w, s) + c_e(w, s)} \right]^{0.5}$ (1b)	$C_{1/kl} = (Q_{kl}/\lambda_{kl} M_{kl}) c_{o/kl}(d_{kl})$ (1c)
2. Time cost	$C_{2/k} = Q_k \alpha_{bk} t_k$ (2a)	$C_{2/t/\min} + C_{2/t} = \sqrt{2}/2 \left[ \frac{QT[c(w, s) + c_e(w, s)]}{(\alpha_{b1} + \alpha_{b2})} \right]^{0.5} + Q\alpha_b(s/v_s + D)$ (2b)	$C_{2/kl} = Q_{kl} \alpha_{b/kl} (d_{kl}/v_{kl} + D_{kl} + 2t_{s/kl})$ (2c)
3. Handling cost	$C_{3/k} = Q_k t_{hk} c_{hk}$ (3a)	$C_{3/t} = Q(c_{h1} + c_{h2})$ (3b)	$C_{3/kl} = 2Q_{kl} t_{h/kl} c_{h/kl}$ (3c)
4. External costs	$C_{4/k} = (Q_k/\lambda_k M_k) c_{ek}(d_k)$ (4a)	$C_{4/t} + C_{5/t/\min} = Q(c_{e1} + c_{e2}) + \sqrt{2}/2c_e(w, s) \left[ \frac{QT(\alpha_{b1} + \alpha_{b2})}{c(w, s) + c_e(w, s)} \right]^{0.5}$ (4b)	$C_{4/kl} = (Q_{kl}/\lambda_{kl} M_{kl}) c_{e/kl}(d_{kl})$ (4c)
Sub-total	$C_c = \sum_{i=1}^4 \sum_{k=1}^K C_{i/k}$ (5a)	$C_{T/\min} = \sum_{i=1}^6 C_{i/t}$ (5b)	$C_{T/kl} = \sum_{i=1}^4 C_{i/kl}$ (5c)
Total	$C_{I/FULL} = C_c + C_{T/\min} + C_d$ (6)		$C_{R/FULL} = \sum_{i=1}^4 \sum_{k,l=1}^{K,L} C_{i/kl}$ (7)

<sup>a</sup> The analogous expressions are used for calculating the sub-total cost  $C_d$  for the distribution step.

<sup>b</sup> Daganzo (1999).

between zones  $T_{kl}$ . This time depends on the distance  $s_{kl}$ , the average vehicle speed  $v_{kl}$ , the anticipated delay  $d_{kl}$ , and the time of stopping to pick-up/deliver the load units in each zone  $t_{s/kl}$ .

In Eq. (3), for the intermodal transport network, the handling cost for the collection within zone  $k$  is proportional to the quantity of load units  $Q_k$ , unit handling time and cost  $t_{hk}$  and  $c_{hk}$ , respectively. This cost is analogous for the distribution step in zone  $l$ . In the line-hauling step, the handling cost is proportional to the total quantity of load units in the network  $Q$  and the unit handling cost at both intermodal terminals;  $c_{h1}$  and  $c_{h2}$ , respectively. For the road transport network handling cost refers to the zones  $k$  and  $l$  and are analogous to those in the collection and distribution step of the intermodal transport network.

Variables in Eq. (4) have the following meanings. In the intermodal transport network, the external cost in the collection step in zone  $k$  is proportional to the frequency of trips  $f_k$  dependent on the quantity of load units  $Q_k$ , the vehicle capacity and load factor  $M_k$  and  $\lambda_k$ , respectively, and the aggregate external cost per trip  $c_{ek}(d_k)$ . For a given vehicle type this cost depends on the distance  $d_k$  and costs of the individual burdens. the external cost is analogous for the distribution step in 'zone'  $l$ . In the line-hauling step, the external costs are proportional to the total quantity of load units  $Q$ , the unit aggregate external cost of each intermodal terminal  $c_{e1}$  and  $c_{e2}$ , and the unit aggregate external cost of each departure-service  $c_e(w, s)$ .

In the road transport network the variables in the Eq. (4) are analogous to those in the collection and distribution step of the intermodal transport network but again applied to the door-to-door distance between 'zones'  $k$  and  $l$ .

The detailed analytical expressions for particular cost components of both networks are given in Table 1 (Daganzo, 1999; Janic et al., 1999). The analytical procedure of optimizing frequency of the main transport mode between two intermodal terminals in the intermodal transport network, which minimizes the full costs, can be found in the reference literature (Daganzo, 1999). Dividing the total costs (5(a)–(c)), (6) and (7) in Table 1 by the volume of demand and distance gives the average internal, external and full costs per unit of the network output–t–km, which is useful for their comparison.

#### 4. Application of the model

The model is applied to a simplified European intermodal rail-truck and equivalent road freight transport network making use of European Union data.

- Load units, time cost and operating time of the networks

Both networks deliver units of 20 feet or about 6 m (a TEU or 20 feet equivalent unit) as is common in Europe. Each unit has an average gross weight of 14.3 metric tonnes (12 tonnes of goods plus 2.3 tonnes of tare) (European Commission, 2001a). The unit cost of time per units in each step is taken to be  $\alpha_b = \text{€}0.028 \text{ h–tonne}$ .<sup>4</sup> The network operational time is  $T = 120 \text{ h}$ , i.e., five weekdays.

- Road collection, distribution and line-hauling

In each zone of the networks, the average length of trip and speed of each vehicle (assuming one stop during collection and distribution) step taken as  $d = 50 \text{ km}$  and  $u = 35 \text{ km/h}$ . On the road network the average vehicle speed between origin and destination zones, is  $v = 60 \text{ km/h}$ . Vehicle operating costs, based on the full vehicle load equivalent of two 20 foot load units, is estimated to be  $\text{€}5.46d^{-0.278}$  vehicle-km. The load factor is taken as  $\lambda = 0.85$ . The same method is used for calculating the vehicle operational costs during the collection and distribution step of the intermodal transport network. The average load factor is  $\lambda = 0.60$ . In both networks, vehicle costs already include handling costs. From the same European Commission (2001a,b) sources, the externalities comprising the local and global air pollution, congestion, noise pollution, and traffic accidents are determined as  $\text{€}9.88d^{-0.624}$  vehicle-km. The headways between the arrivals and departures of load units at/from both intermodal terminals during the collection and distribution step,  $h_1$  and  $h_2$ , respectively, are assumed to be zero.

<sup>4</sup> The average value of ten chapters of goods groups including the load units transported by the road and rail-truck intermodal transport between particular EU member states is estimated to be 2.08 €/kg. The total discount rate is taken to be 12%, which gives the time cost  $\alpha_b$  equal to:  $\alpha_b = (\text{€}2.08 \text{ kg} \cdot 14300 \text{ kg} \cdot 0.12) / (8760 \text{ h} \cdot 14.3 \text{ tonnes}) = \text{€}0.028 \text{ h–tonne}$  (European Commission, 2002).



- Rail line-hauling: The trains operating between two intermodal terminals consist of 26 flatcars. Each car ( $m$ ) weighs about 24 tonnes, that together with the weight of the engine of about 100 tonnes gives the weight ( $W$ ) of an empty train of 724 tonnes. The capacity of each car is equivalent to three TEU, i.e., 42.9 metric tonnes. With an average load factor per train of  $\lambda = 0.75$ , the load ( $Q$ ) per train is equal to 837 tonnes. The gross weight ( $w$ ) of the train is thus equal to 1560 metric tonnes. The average train speed and average anticipated delay are  $v_s = 40$  km/h and  $D = 0.5$  h, respectively (UIRR, 2000). The train’s internal-operating cost is estimated, from the assumptions our, to be  $\text{€}0.58 (ws)^{0.74}$ . The train’s external cost resulting from local and global air pollution, noise, and traffic accidents are estimated to be  $\text{€}0.57 (ws)^{0.6894}$  train.
- Intermodal terminals: The handling cost of a load unit at each intermodal terminal includes only the transshipment cost of  $\text{€}40$  per load that gives a unit handling cost of  $\text{€}2.8$  tonne (Ballis and Golias, 2002; European Commission, 2001b). The external cost of the intermodal terminals includes only the cost of local and global air pollution imposed by the production of electricity for moving cranes used for transshipment of load units as follows:  $\text{€}0.0549$  tonne (European Commission, 2001a).

The results are shown in Figs. 3 and 4, and Tables 2 and 3. For the purpose of the sensitivity analysis, the length of hauling distance (i.e., the length of door-to-door distance), and the volume of demand–load units are varied in both networks as parameters. Specifically, the demand is varied using the increments equivalent to the single loaded train (837 tonnes).

Fig. 4 illustrates the dependence of the average internal and full cost of both networks on the length of door-to-door distance. The volume of demand–load units corresponds to the loads of five trains per week, i.e., one train per day, as the benchmarking case. Such train frequency is the most common in many trans-European intermodal markets–corridors (European Commission, 2000, 2001a, 2001b; UIRR, 2000).

The average internal cost decrease more than proportionally as the door-to-door distance increases in both networks, indicating the existence of economies of distance. With the intermodal transport network the internal cost decreases at a higher rate, equalise with the costs of its road network counterpart at a distance of about 900 km and become increasingly lower afterwards. This indicates that intermodal transport is currently

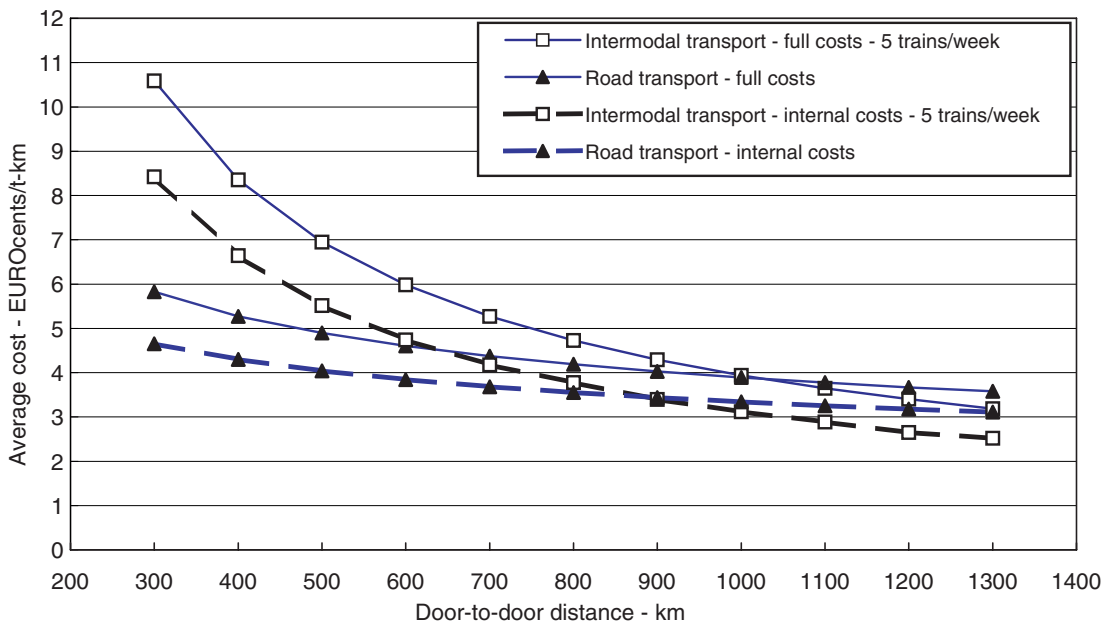


Fig. 3. Dependence of the average external, internal and full costs of given intermodal and road transport network on the door-to-door distance.

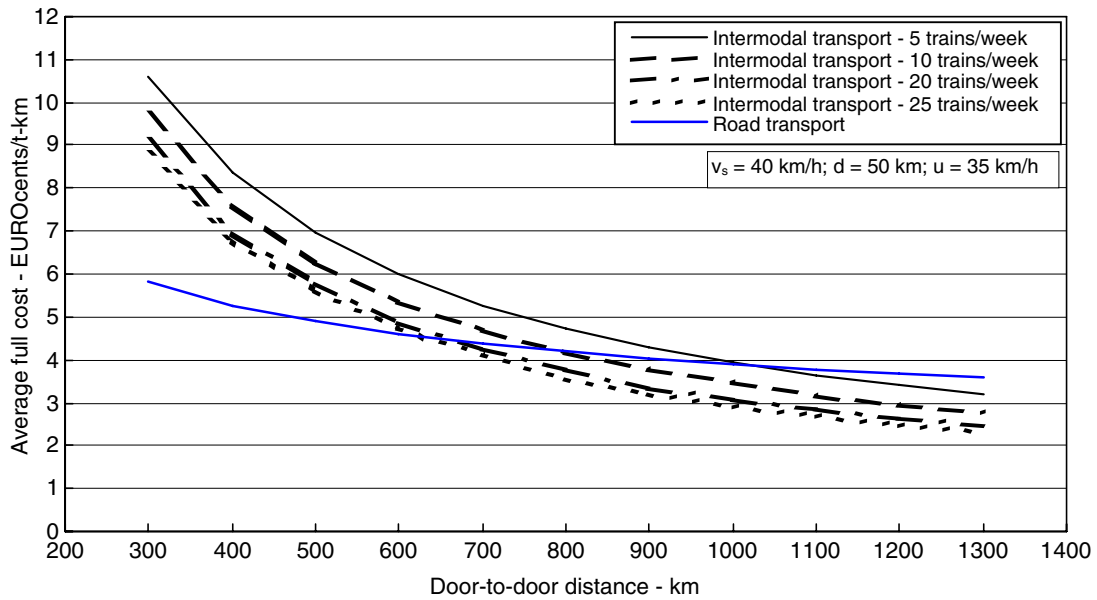


Fig. 4. Dependence of the average full costs of the intermodal and road networks on the volume of units and door-to-door distances.

Table 2

The structure of the full costs of given intermodal transport network<sup>a</sup>

	Door-to-door distance (km)					
	300	500	700	900	1100	1300
<i>The cost component</i>	<i>Share (%)</i>					
• Rail + terminal externalities	6	7	7	7	8	8
• Rail internal-operational	12	13	14	15	16	17
• Terminal internal-operational	17	16	15	14	13	13
• Rail line-hauling + terminal time	17	20	22	24	25	25
<i>Sub-total</i>	52	56	58	60	62	63
• Road externalities	15	14	13	13	12	12
• Road internal-operational	33	30	29	27	26	25
• Road time	0	0	0	0	0	0
<i>Sub-total</i>	48	44	42	40	38	37
Total	100	100	100	100	100	100

<sup>a</sup> The volume of demand–load units corresponds to the load of 5 trains/week as the benchmark case.

Table 3

The structure of full costs of given road transport network

	Door-to-door distance (km)					
	300	500	700	900	1100	1300
<i>The cost component</i>	<i>Share (%)</i>					
• Road internal-operational	79	82	83	84	85	86
• Road time	1	1	1	1	1	1
• Road externalities	20	17	16	15	14	13
Total	100	100	100	100	100	100

the competitive alternative to the long-haul road transport beyond the above-mentioned break-even distance in some trans-European corridors–markets.

The relationship between the average internal costs of both networks may partially explain the current split between the two modes in Europe. The operational cost of road transport is lower than the operational cost of the intermodal transport network over short, medium and even some long-distances markets, which, in combination with other market and regulatory factors leads to lower prices. This attracts more of voluminous and price sensitive commodities over such distances (about 90% up to 600 km).

For both networks, the sum of their internal and external costs also decreases more than proportionally as door-to-door distances increase. The rate of decrease is again higher in the intermodal transport network suggesting a break-even distance of about 1050 km. This is longer than for the operational costs. Since the volume of demand around these distances is generally low, basing prices on the higher full costs may affect the already low, although still price-sensitive, demand thus making conditions under which intermodal transport can gain a higher market shares even more complex. This raises questions about the efficiency of EU policies that expects internalising externalities to strengthen the market position of intermodal transport. Table 2 shows the structure of the full costs of the intermodal transport network.

As the door-to-door distance increases, the share of the rail/terminal-related external costs increase and the share of the road-related external costs decrease. The share of the road external costs is about twice that of the rail-terminal related external costs. Consequently, the road operational steps at both ends of the intermodal network contribute considerably to its external costs (about 40–50%).

In the absolute terms, the relatively constant shares of the rail and terminal internal costs are comparable to the shares of road internal costs decreasing with increasing door-to-door distance. The shares of the time costs increase in the rail-terminal case and appear negligible in both road operational steps. Consequently, increasing the door-to-door distance by about 1000 km (i.e., from 300 to 1300 km), increases the shares of the main mode generally from 52% to 67% and decreases the share of the road mode from 48% to 37% (Table 3).

Increasing the door-to-door distance increases the share of internal costs from about 80%–86%, the share of the external costs decreases from 20% to 13%, while the share of time costs remains almost negligible.

Fig. 4 shows the influence on the average full costs of changing the volume of units and door-to-door distance in both networks. These costs of the road transport network are constant and those of the intermodal transport network decrease as the volume of units increases. This diminishing of full costs reduces the break-even distance for the intermodal network. For example, if demand increases from 5 trains a week to 10, the break-even distance will shorten from about 1050 km to 800 km. If the demand increase is from 10 to 20 trains a week, the break-even distance will decrease further to 650 km. Consequently, intermodal transport could enhance its competitiveness by increasing service frequencies of the main mode on the shorter distance services.

## 5. Conclusions

The paper developed a model for calculating the full costs of a given intermodal and road freight transport networks. The model is applied to simplified configurations of intermodal rail-truck and equivalent road transport networks in Europe. The results show that the full costs of both networks decrease more than proportionally as door-to-door distance increases; suggesting economies of distance. For the intermodal transport network, the average full costs decrease at a decreasing rate as the quantity of loads rises indicating economies of scale; in the road transport network they are constant.

Full and the internal costs decrease more rapidly with increasing distance in the intermodal case rather than in the road transport network. Consequently, the costs of both networks equalised at a break-even distance – shorter for the internal measure and longer for full costs. Since the full costs of intermodal transport decrease and the those of road transport remain constant as the volume of loads increases, the break-even distance shortens at a decreasing rate.

Despite caveats inevitable in such estimations, the results offer some insight into EU policies aimed at internalising transport externalities. If the full costs are to be used as the main basis for pricing, the break-even distance will increase for intermodal transport and thus push the it to compete in longer distance markets, with increasingly diminishing demand. However, intermodal transport can neutralise the effects of the higher prices associated with internalising by increasing the service frequencies in medium-distance markets (around 600–900 km) to meet the large demand there.

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