PERGAMON

Transportation Research Part D 7 (2002) 285–301

TRANSPORTATION
RESEARCH
PART D

www.elsevier.com/locate/trd

External costs of the Belgian interurban freight traffic: a network analysis of their internalisation

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Abstract

The strong expansion of freight road transports throughout Europe is an important source of congestion and pollution, as well as a cause of many accidents. To solve this problem will require the conjunction of many different remedies. One element of solution would be the promotion and substitution of transportation modes with less negative effects. This paper is focused on this solution. It presents some results obtained from a detailed GIS modelling of the Belgian multimodal freight transport network inserted within the overall trans-European network. It outlines the results of a simulation of the flows over the Belgian network in 1995 which allows to estimate some of the costs of several external effects of freight transports: the costs of pollution, congestion, accidents, noise and road damages. This paper provides also the simulated impacts on modal choice of a marginal external cost internalisation, and an estimation of the corresponding external cost savings. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: External costs; Transportation costs; Freight transport; Networks; Simulation

1. Introduction and scope of the research

The strong expansion of freight road transports throughout Europe is an important source of congestion and pollution, as well as a cause of many accidents. It is most likely that this problem will only grow worse as it is expected that freight traffic will go on increasing over the coming years. This is not a problem which could be solved by recourse to a simple and unique solution, but which will require the conjunction of many different remedies. In some places a partial solution could be found in the building of enlarged infrastructures. However, spatial as well as

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PII: S1361-9209(01)00025-6

budgetary constraints severely limit this kind of solution. A better spatial distribution of human activities should be encouraged, and various regulatory devices could somewhat contain traffic expansion and its invasion to urban environment. Another partial solution would be the promotion of transportation modes which have lesser negative effects, i.e. rail and waterway, and their intermodal combination with road, in order to substitute these modes to the use of direct road transports. One way to achieve this substitution could be to set up a pricing policy that would include the external effects of each mode.

Our research is focused on this last solution. In this paper, we present some results obtained from a detailed modelling of the Belgian multimodal freight transport network within the overall trans-European network. We outline the results of a simulation of the flows over the Belgian interurban network in 1995, and give estimates of the corresponding pollution, congestion, noise and accidents costs as well as of the road damages by trucks. Secondly, we present the simulated impacts of a simple Pigovian internalisation of these costs into the users' costs. The reader should take note of the fact that the concept of external effects as it is applied in this paper encompasses all effects on other people and vehicles that result from individual decisions made without paying attention to the costs inflicted upon others. In particular, it includes the congestion cost imposed on other drivers, even though each driver is affected by congestion and takes it into account for its own driving decision.

This paper applies the NODUS virtual network methodology (Jourquin, 1995). It allows the minimisation of the total generalised cost of a transport task defined by an origins and destinations (O–D) matrix over a large virtual network in which each particular transport operation over the geographic network is represented by a specific virtual link. Thereby it assigns each flow to the least costly mode, means and routes and permits detailed analyses and simulation of modal choices and intermodal solutions. Compared to the usual GIS approaches, it is characterised by the fact that no exogenous modal split functions are imposed on the solution.

Thus, after this introduction, Section 2 briefly reviews the NODUS methodology. Then, Section 3 outlines the modelling of the Belgian freight network and presents the flow assignments and modal splits obtained for the year 1995 when only users' costs are taken into consideration. On this basis and using information from various sources, Section 4 gives cost estimates of the impacts of different types of pollution in 1995. Section 5 provides estimates of the cost of congestion by trucking on the road network through a computation of the time lost by trucks during peak hours. Section 6 presents an estimation of accidents costs, while Section 7 deals with the costs of noise and wear and tear of infrastructure, and discusses the consistency issue linked to the simultaneous use of the various external cost estimates. Section 8 presents the assignments and total external costs resulting from the marginal external cost internalisation into the users' costs. The total costs of these external effects in the two scenarios are also compared.

Some interesting observations and comments can be drawn from the results, which are useful information for the current debate on transport policy in Belgium and Europe. Nevertheless, it is worth keeping in mind that this model of a very large network is only a static one at the present time, even though it is possible, like in the present research, to approach an equilibrium solution through a set of iterations with changing parameters. However, it does not handle adequately the phenomenon of flows' spatial spread resulting from congestion (a topic of our ongoing research). Neither does it take into account the induced effects on the matrix of O–D that an internalisation of external costs should have. In this respect it is different from the models built for Belgium by

De Borger and Proost (1997), Mayeres et al. (1996) and Mayeres (1999) in which demands interact with transport cost within a macroeconomic framework and an 'optimal' equilibrium is obtained for both passengers and freight transportation. On the other hand, the latter models are not based on a network analysis and deal only with aggregate transport flows.

Note also that our definition of transport generalised costs remains somewhat incomplete, since we lack information on transport attributes like safety, reliability, frequency, scheduling and information which bear upon the choice of mode and means. However, this incompleteness is somewhat compensated for by the calibration of the model on detailed observed data. We acknowledge that some estimates of external effects are only tentative even though they are drawn from the best available sources and models. The reader should be aware that their definitions are influenced by the Belgian context, in particular with respect to the treatment of taxes, which cannot be set aside by the State to any specific purpose.

2. The NODUS methodology

A thorough analysis of freight transportation on a network, with all its alternative solutions, requires a separate identification of every transport operation and its characteristics. In the NODUS network model, all the modes and means of transportation but also every operation of loading, unloading, transhipping between modes and transiting are identified and associated with a virtual link. A fictitious expanded multimodal network, or virtual network, is thus created. As this transformation is realised automatically by NODUS on the basis of the characteristics of the underlying geographical network, this software allows the convenient analysis of very large networks. In the present case, there are about 12,000 nodes and 17,000 geographical links to start with, but the virtual network is made of 265,000 virtual links.

Appropriate cost functions are attached to each virtual link defined by a specific transport operation. Altogether, the costs included in the modelling have three components: the costs directly related to the vehicles and their crew, the handling costs, and the inventory cost of the goods during transport. Obviously, the costs of the successive operations must be added, the cost of every moving operation being proportional to distance. These costs are estimated on the basis of the crew wages, fuel price, maintenance and insurance costs, vehicles' capital annuity and speed as well as the value of the transported goods. Then, given an O–D matrix, it is possible to minimise the corresponding total (generalised) cost of transportation with respect to, simultaneously, the choices of modes, means and routes, intermodal combinations being included in the choice set. The reader will find more detailed explanations in Jourquin (1995), Jourquin and Beuthe (1996) and the TERMINET Report (1998).

The flow assignments are made on the basis of the 'all or nothing' principle. It implies the strong hypothesis that there should not be any capacity constraint on a link, a hypothesis that is difficult to maintain all over the network. This problem is solved to some extent by a careful calibration of the network, as explained in the following section. The resulting assignments can be taken as estimates of transport demand for the different modes and means under two hypotheses: that the shippers are actually minimising the generalised cost of transportation, and that the (unknown) carriers' tariffs bear a close relationship with the operating transport cost, at least at the margin for 'contestable' transports. Both hypotheses can be debated. Even though they can be accepted as good approximation, it is still necessary to calibrate the model before proceeding further, in order to take into account some elements that could not be included in the cost functions for lack of information: safety, reliability, information and other services characterising the different transport solutions. Note that the average load factors in the cost functions take into account the trips made by empty vehicles.

3. The simulation of reference

The first step of the research is to set up an accurate model of the existing interurban freight flows inside and through Belgium in 1995, this year being the most recent one for which sufficient data are available for setting up the model. This 'reference scenario' was built up in three steps:

1. Surveys of shippers and freight traffic observations were used, along with aggregated published statistical data, to create point-to-point O–D matrices for each mode and for the 10 chapters of NST-R commodities. Over the Belgian territory the origins and destinations were defined at the level of the communal entity. For the neighbouring zones Nuts 3 regional data were taken, and Nuts 2 data elsewhere in Europe. These aggregate data of imports, exports and transit flows over the Belgian territory were spread among specific points of origin and destination by a Monte Carlo procedure. Two matrices for the empty light and heavy truck flows and another one for the cars and small commercial vehicles were also built up. The network definition for each commodity included a number of restrictions: along the railways and waterways, loading and unloading operations were not allowed for all commodities at some nodes, and the handling of block trains or single wagon operations was forbidden at some stations.
2. All these matrices were then assigned mode per mode over the corresponding network and the aggregated estimated flows were compared to truck counts observed along the roads, railways and waterways. [1] Speeds on some links could also be adjusted in order to obtain a better fit between some computed and observed flows, particularly in the periphery of large cities. This fitting of the network allowed us to account to some extent for the traffic spread over the network resulting from the congestion.
3. In the last stage the matrices relative to each freight transportation mode were merged to obtain 10 aggregated matrices corresponding to the different groups of commodities. They were used to assign the transport flows simultaneously to the modes, means and routes through generalised cost minimisation. Finally, the cost functions were calibrated in order to obtain a better fit with the observed global modal-splits.

As indicated above, the model assigns the flows not only to modes, but also to transportation means. In this application, the model performed rather well in identifying the types of boats used (300, 600, 1350 and 2000 t or more) on the basis of their different cost functions, the capacity of each inland waterway and the exclusions mentioned above. Likewise, the information about

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[1] The matrices of empty truck flows and cars and small commercial vehicles were assigned on the basis of the shortest distance. Obviously, these matrices are not aggregated at stage 3 with the other matrices of tonnes transported. However, they will be used later on to compute flows of vehicles.

Table 1
Comparison of 1995 statistics and assigned flows over the network (tonnage market shares)[a]

Group	1995 Statistics			Assigned flows		
	% Water	% Rail	% Road	% Water	% Rail	% Road
0–9	11.28	8.99	79.73	11.06	9.05	79.89
0	7.18	2.24	90.58	7.56	1.67	90.77
1	5.06	2.44	92.7	5.61	2.13	92.26
2	25.33	43.51	31.16	25.11	43.81	31.08
3	28.65	6.23	65.12	28.89	9.08	62.03
4	25.06	49.07	25.87	18.66	50.24	31.10
5	7.44	26.22	66.34	7.32	26.77	65.91
6	15.37	1.74	82.89	15.44	1.33	83.23
7	23.70	5.25	71.05	24.09	5.39	70.52
8	8.00	6.56	85.44	7.85	6.05	86.10
9	0.53	11.40	88.07	0.88	11.35	87.77

[a] 0: Agricultural products and animals. 1: Food; 2: Solid fuel; 3: Petroleum products; 4: Iron ore and scrap; 5: Metallurgic products; 6: Minerals and building materials; 7: Fertilisers; 8: Chemical products; 9: Diverse products.

exclusions and cost functions included in the model allowed satisfactory assignments between block trains and traditional trains. Unfortunately, the use of different cost functions for light and heavy trucks (7 and 40 t, respectively) did not lead to correct choices between these two means. Actually, both types of trucks are used on long and short distances according to the size of the shipments but no information was available about shipment sizes. We solved this problem by splitting the total tonne-flows assigned to road transportation between small and large trucks on the basis of external available information about their use over various trip distances.

The detailed comparison made in Table 1 between the modal shares assigned by the model and those according to the 1995 statistics of 'observed' modal choices shows how well the model performed.

Another way to assess the model performance is to compute the coefficient of correlation between the observed flows and those assigned by the multimodal model. We obtained values of 0.92 for the waterways, 0.86 for the railways, and 0.87 and 0.93, respectively, for the small and large trucks. Fig. 1 gives a view of the network and freight flows over the Belgian territory.

As mentioned, the calibration of the model was made with respect to available information in tonnes transported. Once this calibration was completed, it was possible to compute the corresponding t-km per commodity group and mode. These results are given in Table 2 for flows over only the Belgian territory.

4. Measures of pollutants' effects and costs [2]

The methodology applied to assess the pollutants' effects on health in Belgium follows the line drawn by Mayeres et al. (1996), which combines the results obtained in various researches. In the

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[2] On this problem the reader will find abundant information in the ExternE Report (1997) of the European Commission (DG12), and in the publications by De Borger et al. (1996a,b).

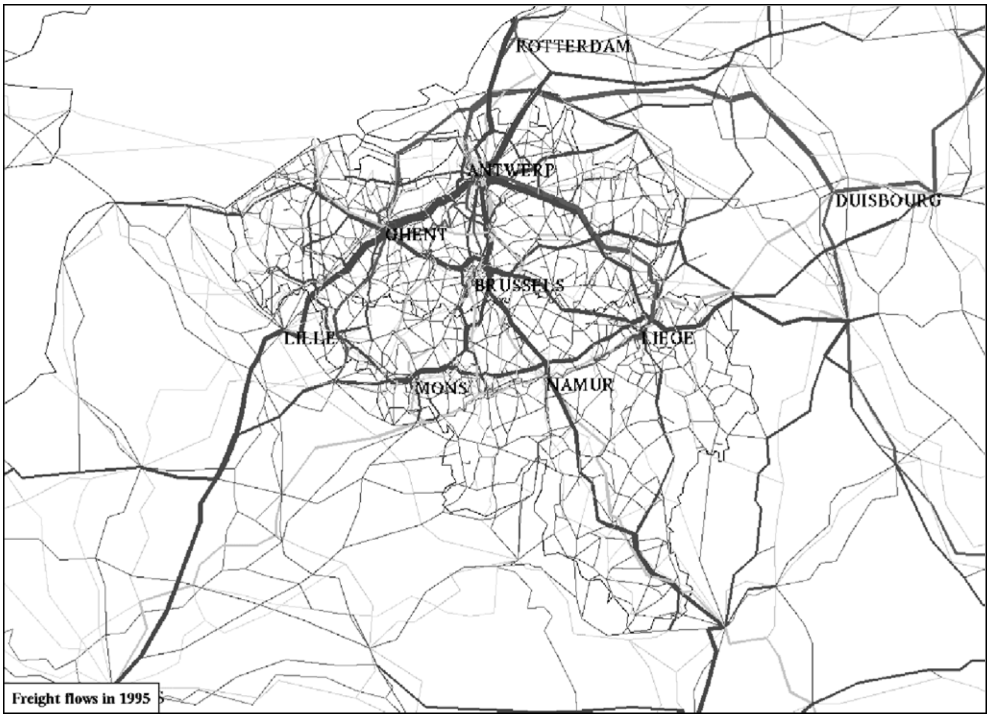

Fig. 1. An illustration of the flows assigned on the Belgian freight network.

Table 2
Freight transport modal splits and t-km as assigned in Belgium

NSTR	1995						
	Road		Waterway		Railway		Total
	Millions t-km	%	Millions t-km	%	Millions t-km	%	Millions t-km
0	3793	92	190	5	117	3	4100
1	4779	91	243	5	204	4	5226
2	368	20	458	26	958	54	1784
3	1417	52	797	29	535	19	2749
4	315	15	469	23	1288	62	2072
5	2385	58	257	6	1468	36	4110
6	7170	73	2398	24	283	3	9851
7	696	64	281	26	105	10	1087
8	3677	83	369	8	403	9	4449
9	6753	77	123	2	1865	21	8741
Total	31,355	71	5584	13	7227	16	44,166

Source: Own computation.

present state of information, though, we can only take into consideration the effects of the concentration of particles PM_{10} and of troposphoric O_3 (ozone) which are caused by some pollutants: VOC, NO_x and SO_2.

Table 3
Losses per gram of emitted pollutant (mECU 1995)

	Emissions of					
	PM_{10}	NO_x	VOC	SO_2	CO	CO_2
Effect on health						
Concentration de PM_{10}	88.745	8.061	1.606	100.005	–	–
Concentration de O_3	–	5.537	1.419	–	–	–
Effect on global warming	–	–	–	–	0.009	0.006
Effect on vegetation	–	1.167	–	1.834	–	–
Total for 1 gm of emitted pollutant	88.745	14.765	3.026	101.839	0.009	0.006

Source: ExternE Report (1997) and Mayeres et al. (1996).

Following Small and Kazimi (1995), the effects on the number of deaths of the concentration of PM_{10}, resulting from direct emission as well as from emissions of VOC, NO_x and SO_2, can be obtained by linking the concentration of particles in the air to the emissions of pollutants. These are functions of the t-km produced by the different modes. The health effects are then obtained by applying the relevant mortality rate on the concentration and multiplying by the population concerned. To compute the monetary value of the total effect of 1 gm of PM_{10}, we applied therefore the following formula: loss per gram of pollutant = (concentration per gram of pollutant) × (population) × (mortality rate) × (value of life). With a mortality rate of 0.66 per one hundred thousands, and a value of life estimated at 4,452,841 ECUs in 1995, [3] we obtained a loss of 84.5 mECU per gram of emitted PM_{10}, 1.5 per gram of VOC, 7.6 per gram of NO_x, and 95.4 per gram of SO_x. [4]

As less information was available on the effects of concentration of particles on the number of diseases, we borrowed simply from Hall et al. (1992) and Krupnick and Portney (1991) the following estimates adjusted in ECUs of 1995: 4.17 mECU per gram of PM_{10}, 0.06 per gram of VOC, 0.36 per gram of NO_x and 4.52 per gram of SO_x.

The effects on health of concentration of tropospheric ozone (O_3) could be analysed in more detail. In effect, gathering the results of various specific studies, the ExternE Report (1997) gives a set of dose–response coefficients linking the number of deaths and different types of diseases to concentration of ozone caused by emissions of VOC. [5] This report also gives estimates of the medical costs of each disease. This information can be used to compute the loss resulting from 1 gm of pollutant which amounts to 1.419 mECU. Note that effects of the traffic production of ozone in Belgium on the population of neighbouring countries are included in the computation. [6]

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[3] This is a (1995 adjusted) value provided by Mayeres et al. (1996). They used the statistical value of life of the ExternE report (final report published in 1997), an average computed from a number of European stated preference studies. However, following Jones-Lee (1990), they added the value of life for relatives, the loss of output, plus the medical and police costs, and subtracted the 'gain' of consumption.

[4] mECU = 1 ECU/1000. Since January 1st, 1999, the ECU has been renamed EURO.

[5] The relation between concentration of O_3 and emissions has been analysed by Simpson (1992).

[6] The international effects, computed with (marginal) coefficients provided by Simpson (1992), are equal to 11 times the Belgian effects. It may be that the use of these marginal coefficients leads to an overestimation.

Table 4
Average emissions of pollutants by the three freight transport modes (grams per t-km)

	Emissions of					
	PM	NO_x	VOC	SO_2	CO	CO_2
Truck	0.039	0.647	0.089	0.045	0.174	53.703
Rail	0.006	0.140	0.016	0.021	0.027	19.422
Boat	0.020	0.232	0.009	0.041	0.098	44.097

Source: TRENEN report (1995) for boats, COST 319 (1999) for trucks and diesel trains, and RIMV report (1998) for electrical trains.

As no information appears to be available on the link between NO_x emission and concentration of ozone, we used the result of the empirical analysis [7] by the ExternE project to obtain a loss of 5.537 mECU per gram of NO_x. This value includes also the international effects. There are also some other effects on health but the lack of data does not allow to take them into consideration.

Emissions of CO and CO_2 release some carbon (C) which affect global warming, SO_2 and NO_x emissions have a negative impact on cereal harvests, while SO_2 damages the forests. For these effects we used estimates provided by Mayeres et al. (1996) which are based on results from Fankhauser (1995), ExternE Report (1997) and Nilsson (1991). Expressed in 1995 ECU, the losses from CO and CO_2 emissions are valued, respectively, at 0.009 and 0.006 mECU per gram; the loss from NO_x amounts to 1.167 mECU per gram and the one from SO_2 at 1.834 mECU. The results of all these computations are summarised in Table 3, while the emissions of the various pollutants in grams per t-km in 1995 are given in Table 4 for the different modes.

The computations of road transport emissions are based on the work of Hickman (1997) in the COST 319 (1999) report. It provides a relation between emissions and mean speed of trucks for computing the emissions of light and heavy trucks. The TRENEN report (1995) provides average boat emissions. For our detailed computations, we adjusted those for each category of boat on the basis of their fuel consumption. For rail freight transport, average emissions were found in the RIMV report (1998) for electrical trains, and in Jorgensen and Sorenson (1997) for diesel trains. [8] The numbers presented in Table 4 are mean values obtained from the repartition between the different means.

It is important to underline that all the computed costs of illnesses not inducing death are based on market prices and costs: cost of medicines, ambulance, hospital, and medical services. A willingness to pay estimate is only used for the value of life in case of death.

On the basis of these two tables, we obtain that, in 1995, the total cost of pollution produced per t-km by interurban road transport was equal to 18.2 mECU, while it amounted, respectively, to 5 and 9.8 mECU for the rail and waterway transports. From the total t-km flows obtained from the reference simulation, the total losses can be estimated at 571 millions ECU for road transports, 36 millions for railways and 54.8 millions for inland waterway transports.

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[7] On an electrical plant in Lauffen (Germany).

[8] These are indirect emissions from electricity production by a power plant. See also the COST 319 report.

5. The cost of congestion

A policy of social marginal cost pricing can also be used for solving some of the traffic congestion. Admittedly, congestion as such is not an environmental externality in the strict sense, since its effect on transport cost is taken into account by the carriers and included in the assignment model via the lower speed of transport it induces. However, it is a source of inefficiency of the transport system that one may wish to attenuate by an appropriate road pricing, which would integrate the marginal congestion cost that the driving of a truck on a road inflicts upon other vehicles. In this way, the carriers would have to take account not only of the congestion cost they support but also of the cost they inflict upon other carriers.

As briefly explained in Section 1, the general methodology applied in this paper is a static one, which does not analyse the flows' impact on the costs of a link use and the resulting spread of the traffic over different routes like in a spatial equilibrium model. We hope that further developments of the methodology will allow in the near future a rigorous handling of this problem over a network as large as the present one. Note, however, that the congestion spatial effect of spreading flows over the network has been de facto taken into account to some extent at the calibration stage of the reference simulation. It remains, nevertheless, that road traffic is slowed down during the peak hours so that there is a loss of time, which induces additional labour and fleet cost as well as an additional opportunity cost for the transported goods.

From the calibrated cost functions, the overall cost of time can be estimated at a weighted average of 34.36 ECU per vehicle-hour in 1995, to which corresponds a cost of 23.7 mECU per t-km. It includes all the costs linked to the operation of a truck (labour, fuel, insurance, maintenance and vehicle cost) plus the inventory cost of the goods transported which varies with the value of the commodities and the loading of the vehicles. [9]

There are also a few problems of capacity on some links of the rail network, but it can be argued that at least part of the corresponding cost is internalised in the railway operations. In any case, we do not have enough information at this stage to tackle this problem, and its unravelling would require a thorough analysis of the railway operations system with an altogether different methodology. On the other hand, there is no congestion to speak of on the Belgian waterways, except at a few locks. The small corresponding cost is not included in the present analysis.

The computation of the time lost through congestion on roads was made in the following way. The speeds on a road during peak hours and outside peak hours are computed by using a flow-speed relation [10] applied to the respective flows. [11] The difference between these speeds translates into a loss of time for trucks travelling along this road during peak hours. This loss is then multiplied by the truck flows and the value of time for each group of commodity. The total loss is the sum of the losses on all the main roads of the network and for all commodities. In 1995, it

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[9] The value of time varies between empty or loaded and light or heavy trucks.

[10] Formula recommended in the COBA manual (1996) and calibrated for Belgium by STRATEC. On average, there are 5 h of peak in Belgium. It is assumed that there is no congestion outside the peak hours. For lack of sufficient data congestion costs were analysed only on the main roads of the network. The private car and small commercial vehicle flows were taken into account for these computations.

[11] The flow during one peak hour is estimated as 0.136 of the daily flow on average. This number is obtained from observations of the 30th highest hourly flows.

amounted to 743 millions ECU. This estimation does not include the cost of time lost by private cars and small commercial vehicles. On the basis of the 60 billions vehicle-km [12] estimated by the Institut Belge de la Sécurité Routière (IBSR, 1998) for these vehicles in 1995, their congestion cost can be tentatively estimated at 2.9 billions ECU. [13]

6. The external costs of accidents

For estimating the external costs of accidents, we followed Jansson's approach (Jansson, 1994) which distinguishes two kinds of accidents: those between two vehicles and those between vehicles and pedestrians or cyclists. Thus, Jansson defines the total social cost for accidents between vehicles as

$$\mathrm{CST}_m = (a + b + c)rF = (a + b + c)AX,$$

and the total social cost for accidents between vehicles and pedestrians or cyclists as

$$\mathrm{CST}_p = (a + b + c)sM,$$

where a is the willingness to pay for cancelling the risk of an accident for the user, b is the same willingness but for the closest relations, c is the 'cold blood' cost per vehicle made of the costs of police, ambulance, etc.; F is the traffic flow, X is the number of accidents between vehicles, A is the average number of vehicles in an accident, and M is the total number of km by pedestrians and cyclists; finally, the risks of accidents are $r = (XA)/F$, and $s = X/M$. The marginal external social costs are then the derivatives of the respective total social costs minus the private marginal cost. The latter is equal to $r(a + b)$ for accidents between vehicles, but is assumed to be zero for the other accidents. [14]

The risk ratios in Table 5 have been computed on the basis of the Belgian statistics of accidents involving a truck in 1995, provided by the INS (1995) and the Belgian railways (SNCB, 1995), and the number of t-km by train and trucks estimated by the reference simulation presented in Section 3. Accidents are very few on the waterways and there were none in 1995.

Table 6 presents the estimated values of the parameters a, b and c in 1995. They are based on various sources given in footnotes. Damages to vehicles are not taken as external nor those medical costs which are covered by insurance. Table 7 gives the resulting estimates of the marginal external costs. As a consequence of the assumptions made and/or of the methods used, these marginal costs are equal to average costs, except in the case of accidents involving pedestrians or

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[12] Our estimation of 743 millions ECU concerns only traffic on motorways and four-lane roads, while the amount for light vehicles relates to motorways and national roads, some of which do not have four lanes.

[13] For computing this amount, 41% of vehicle-km were taken as trips to work, 14% were business travels, and 45% were leisure trips (Boniver and Thiry, 1994). The cost of time for these three categories was taken as, respectively, 4.315, 28.2 and 3.6 ECU per hour (Hansen, 1999). It was assumed that, during congestion hours, time loss per vehicle-km by small vehicles was equal to the loss by trucks, as computed on the network.

[14] The marginal social costs can be shown to depend on the risk elasticities with respect to traffic flows. Like Jansson (1994), we assumed that the elasticity relating to accidents between vehicles was zero, while the other one was taken as 0.5. As a consequence, the average cost is equal to marginal cost for accidents between vehicles, but is twice the marginal cost in the other case.

Table 5
Accident risk ratios per t-km

	Between vehicles involving a truck	Between a truck and cyclists or pedestrians	Between a train and a vehicle
Fatal	3.34914×10^{-9}	1.12387×10^{-9}	4.2536×10^{-10}
Serious	1.97907×10^{-8}	3.14413×10^{-9}	7.97551×10^{-10}
Light	6.31316×10^{-8}	6.90807×10^{-9}	1.83437×10^{-9}

Source: Statistical data from INS (1995) and SNCB (1995).

Table 6
Monetary values of *a*, *b*, and *c* (ECU, 1995)

	a	*b*	*c*
Fatal	3,099,921[a]	1,239,968[b]	112,952[c]
Serious	294,492[d]	117,796	271,594[e]
Light	0[f]	0	564[g]

[a] Statistical value of life from the ExternE Report (1997).
[b] 40% of the statistical value of life according to Jones-Lee (1990).
[c] Output loss + police and medical costs consumption 'gain', according to De Borger and Proost (1997).
[d] Willingness to pay against a fatal accident multiplied by 0.095 according to O'Reilly et al. (1994).
[e] Income loss + police and medicasl costs, De Borger and Proost (1997).
[f] No reliable data were found.
[g] Estimate from the British Department of Transportation given by Newbery (1998), adjusted for 1995.

Table 7
Marginal external costs of accidents per t-km in mEcus

	Between vehicles and involving a truck	Between a truck and cyclists or pedestrians	Between a vehicle and a train
Fatal	0.0378	2.502	1.894
Serious	5.375	1.075	0.545
Light	0.036	0.002	0.001

Source: Own computation.

cyclists where the relevant marginal costs are half the average costs as indicated before. Aggregating these estimates, we obtain an average external cost of road accidents of 12.95 mECU per t-km, while the average external costs of rail accidents are equal to 2.44 mECU per t-km. These estimates lead to a total external cost of road accidents which amounts to 406 millions ECU in 1995, while the cost of rail accidents amounts to 17.5 millions ECU.

7. The cost of noise and roads' 'wear and tear'

The cost of noise can be estimated either through a statistical analysis linking the rents paid with different characteristics of housing, i.e. the so-called hedonic price method, or by costing the reparative expenditures (double glazing, etc.). In the present research we use estimates which are averages of various studies relying on either of these approaches (OCDE, 1997). They amount to 6.6 mECU per t-km for road traffic, and 3.1 mECU per t-km for rail traffic. The noise impact of inland waterways transports is taken as zero. On this basis, we obtained a total cost of 208,51 millions ECU for the noise produced by trucking, and of only 22,403 millions for the railway.

The cost of damages caused to the roads by trucking must be included as external costs, because no taxes are set for specific purposes in Belgium. Hence, fuel taxes cannot be considered as a specific payment for the maintenance of roads. Note also that roads are built for a maximum loading charge, which is practically never controlled... These costs have been estimated by the method proposed by Newbery (1998). Damages are taken as a function $N(W/8.2)^4$ of the number of axles (N) and of an axle load (W). In the present research, it is possible to estimate separately the damages caused by, on the one hand, the loaded and unloaded heavy trucks of 40 t and, on the other hand, the loaded and unloaded light trucks of 10 t at most. For the loaded trucks, these damages amount to 51.043 mECU per vehicle-km for the heavy trucks and 4.4436 mECU for the light trucks; for the unloaded trucks, they amount, respectively, to 0.0415 and 0.02635 mECU per vehicle-km. The weighted average damage per t-km is equal to 1.4494 mECU. In 1995, the total damages caused by trucking can be valued at 63,982 millions ECU.

Table 8 gathers all the costs for the different categories of external effects as computed on the basis of the reference 1995 simulation. However, one may legitimately question whether the summing of all these separately estimated costs does not lead to an overestimation of the social costs. Several comments can be made to clarify this issue. Firstly, many of these cost estimates are based on market prices and costs rather than on willingness to pay estimates derived from partial equilibrium exercises: the cost of accidents and illnesses (medicines, ambulance and hospital costs), the cost of congestion (fuel, wages, etc.), wear and tear (cost of repairs), noise (double glazing and differential rent). These estimates can be added without fear of overestimation. One could even argue that they may lead to some underestimation, since they cannot account for all the costs of these negative effects. Secondly, the costs of accidents with fatal outcome and pollution induced deaths are estimated from the same willingness to pay estimate of individual value of life, which is multiplied by the rates of mortality induced, respectively, by accidents and pollution. The addition of these two rates does not seem to involve any overestimation of the total costs. Moreover, even though the external cost coefficients per t-km are applied to the total

Table 8
Total external costs in 1995 (millions ECU)

	Road	Waterway	Railway
Congestion[a]	743.08	–	–
Pollution	570.742	54.807	36.324
Accidents	406.1	–	17.55
Noise	208.51	–	22.403
Wear and tear	63.982	–	–
Total	2123		
Energy consumption[b]	1.2×10^{11}	2.2×10^9	4.3×10^9

Source: Own computation.

[a] Excluding light vehicles costs.

[b] Millions of joules.

Table 9
Marginal external costs per t-km (ECU)

	Road	Rail	Inland waterways
Pollutants	0.01820	0.00503	0.00981
Congestion	0.02108	–	–
Accidents	0.00937	0.00243	–
Noise	0.00665	0.00310	–
Wear and tear	0.00204	–	–
Total	0.05734	0.01056	0.00981

Source: Own computation.

transport flows, it is clear that the losses from accidents, illnesses and other effects do not affect everyone but are incurred to a large extent by different people. Altogether, even though we remain aware of the many approximations which were needed to obtain these results, we submit that such an assessment of freight transport 'externalities' provides useful estimates of neglected losses which should be taken into account to adjust a country Gross Domestic Product value to a more realistic level.

8. Simulation of an internalisation of external costs

The simulation aims at computing the effects on modal splits and external effects that a pricing policy according to the social marginal cost of transports would have. This pricing is here applied to all traffic without distinction between peak and non-peak periods. It is based on an adjustment of the transport costs per t-km according to each mode marginal external cost as computed above, i.e. contribution to pollution, congestion cost, accidents external cost, noise cost and unpaid road damages by trucking.

For each particular commodity a specific marginal cost of congestion was introduced which takes into account the different values of the transported commodities and the different loads transported by light and heavy trucks. As to the wear and tear cost, it was introduced as a weighted average of the cost of the different categories of trucks (light, heavy, loaded, unloaded). Beforehand, the cost per t-km of road transports was reduced by 13.2% to exclude the effect of indirect fuel taxes on costs, while the cost of inland waterways transports was reduced by 12.07%. No such adjustment was applied to rail cost. [15]

Table 9 summarises the marginal external costs introduced in the simulation. Note that the congestion cost given in this table is an average number for all the traffic, since this cost is a function of the flow speed, which varies with the flow level on each segment of the network. For a

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[15] These percentages are based on numbers given in De Borger and Proost (1997). Note that their computations of taxes and subsidies of rail transport in Belgium would have led to a positive adjustment of cost per t/km before inclusion of their external costs. As we were uncertain about this issue, we chose not to apply this adjustment. This implies that there may be a bias in favour of rail in our simulation. In any case, remember also that some other additional external costs should probably be included in such a simulation.

Table 10
Freight Modal Splits upon Internalisation in Belgium

NSTR	Road		Water		Rail		Total
	Millions t-km	%	Millions t-km	%	Millions t-km	%	Millions t-km
0	2974	75	541	14	456	11	3971
1	3807	77	723	15	397	8	4927
2	298	17	441	25	1004	58	1743
3	1153	44	979	37	492	19	2624
4	246	12	568	28	1201	60	2015
5	1227	31	522	13	2187	56	3936
6	5630	59	3275	34	678	7	9583
7	556	53	300	29	195	18	1051
8	2387	60	889	22	708	18	3984
9	4776	56	745	9	3007	35	8528
Total	23,054	54	8983	21	10,326	24	42,363

Source: Own computation.

given simulation step, the values of this marginal cost are fixed at the flow levels of the initial situation. Hence, it is necessary, in principle, to iterate through several simulations with adjusted congestion costs, up to the point where the computed flows reach a satisfactory equilibrium. In the present case, two iterations were sufficient. For the first step, the (average) marginal cost of congestion was fixed at 0.02958, while, in the second step, it was reduced to 0.02108 (the figure given in Table 9).

Table 10 gives the t-km results of the final simulation, per mode and per category of commodities. Before commenting on these results, it is appropriate to note that this simulation, like the previous reference simulation, is based on fixed O–D matrices. It implies that the results do not take into account any effect of competitive price adjustments that the carriers might very well consider after the inclusion of external costs into their pricing. Thus, no longer term induced demand effect is included. Also, note that it is assumed that a similar pricing policy is adopted by the neighbouring countries, so that there is no skirting effect of Belgium by foreign traffic.

Comparing the global modal splits of Table 10 to those of the reference simulation in Table 2, we see that this internalisation has induced a strong shift from road transport (down from 71% to 54%) to rail transport (up from 16% to 21%) and an even stronger shift to inland waterway (from 13% to 24%). This global shift is not affecting all the categories of commodities in the same way. The strongest shifts affect the steel products (5) and diverse manufactured goods (9) from road mainly towards rail, and the chemical products (8) towards waterways. Another strong shift can be seen in transports of agricultural products (cat.0), which are switched rather evenly towards rail and waterways. Also, note that the switching away from road transports for petroleum products (3) and iron ore and scrap (4) benefits exclusively to inland waterways transports. These results are naturally functions of the demand elasticities specific to each commodity group. For an additional insight into the modelling, the reader may want to inspect the detailed estimates of direct and cross-elasticities which have been derived from the same transport model by Beuthe et al. (2001).

Table 11 gives the external costs corresponding to the results of this simulation. It is seen that the total cost of pollution under this scenario of internalisation amounts to 560 millions ECU, i.e.

Table 11
Total external costs with internalisation

Total external costs (millions ECU)			
	Road	Water	Rail
Congestion	412.827	/	/
Pollution	419.654	88.166	51.943
Accidents	298.600	/	25.075
Noise	153.313	/	32.013
Wear and tear	46.396	/	/
Total	1528		
Energy consumption[a]	9×10^{10}	3.5×10^{9}	6.1×10^{9}

Source: Own computation.

[a] Millions of joules.

102 millions less than before, a 15.4% decrease. The congestion cost decreases even more from 743 to 413 millions, a 44% decrease resulting from a 26% decrease of trucking. This more-than-proportional decrease is the consequence of lesser flows in peak hours, hence of higher speed on less congested roads. The other external costs decrease also by significant percentages: there is a 24% decrease in losses from accidents, a 20% decrease in losses from noise, and a 27% decrease in losses from wear and tear. Table 11 also gives the new figures of energy consumption by the three modes. They correspond to a 21% decrease of total consumption.

9. Conclusions

This fairly detailed analysis of the external effects of interurban freight transports provides an estimation of the main social costs they impose on the population. They include health and production losses caused by pollution, time lost on congested roads, life and health losses through accidents plus the additional costs not covered by insurance, nuisance value of noise and road damages unpaid by truckers. They amounted to more than 2 billions ECU in 1995. The results of the simulation internalising the corresponding marginal external costs suggest that a road pricing policy integrating these factors could be very effective in limiting road congestion, overall pollution as well as the other external effects. Altogether, the external cost savings would amount to about 500 millions ECU. Needless to say, however, that it would not be feasible for Belgium to pursue such a policy in isolation, but that it could be applied only in the framework of a concerted common policy of all European countries. This is what was assumed in the above simulation.

From a methodological point of view, this particular network approach allows to model with full details every operation by the different modes and means on every segment of the network. Thus, it can take into account the particular circumstances affecting transport on a specific link. This advantage was well illustrated by the valuation of congestion costs which were obtained from the grand sum of all the congestion costs computed separately on every segment of the network. The distinction made between heavy and light trucks as well as between the different commodities allowed also to reach more precise estimates of wear and tear damages.

As acknowledged in Section 1, this model is still a static one which cannot as yet compute a multimodal spatial equilibrium solution spreading traffic over several routes in case of congestion. This is a difficult task to achieve with a network as large as the one modelled in this research, but we presently try to solve this problem. For the time being, the phenomenon of traffic spreading is only handled at the calibration stage of the model. Furthermore, the induced effects on the transport demands that an internalisation of external effects could have brought about are not taken into account. If reliable information is available on transport demand functions for the different categories of commodities and on competitive adjustments by the different modes, these induced effects could also be handled in the framework of an equilibrium model.

Another topic worth pursuing is the valuation of transport services' relative qualities per commodity group and its explicit inclusion into the generalised cost. As its stands now, these important factors in the mode/means choice, like safety, reliability, information, frequency and scheduling, are only indirectly introduced in the model by the calibration of the network and the cost functions. To the extent that such quality differences may dampen somewhat the effects of cost variations, the computed modal shifts and external cost savings could very well be somewhat overestimated.

Acknowledgements

This research was partly funded by the Services Fédéraux des Affaires Scientifiques, Techniques et Culturelles (SSTC, Belgium). The basic O–D matrices used in this research have been built up by the consultant STRATEC S.A. in the framework of a joint research contract with the Ministère de l'Equipement et des Transports de la Région Wallonne. We are grateful to B. De Borger (UFSIA), Ch. Koul à Ndjang'Ha (GTM), and, in particular, to I. Mayeres (KUL) for their kind help in the gathering of information on external effects and costs. We also thank two referees for their useful critical comments. All remaining errors are only ours.

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