MODELLING A STRATEGIC TRANSPORT INTERCITY FREIGHT NETWORK INCLUDING EXTERNAL COSTS. A REAL APPLICATION

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ABSTRACT

A relevant issue for freight transport system interregional strategic modelling is to include external costs as part of a policy that supports the mechanisms for managing and pricing to achieve the social optimum. A freight transport model including external cost was developed and applied to the Colombian intercity intermodal strategic network. The model considers equilibrium between the phases of distribution and traffic assignment, in both national and interregional levels. Each link of the network includes internal costs: time and operation, and external costs: congestion, accidents, air pollution and CO_2 emissions.

For the calculation of marginal costs on the freight transport network two approaches were used. First, it is assumed that an additional unit of demand does not affect the equilibrium of the transport network, and then the marginal cost is estimated as the sum of marginal costs on the links of the shortest path. The second approach assumes that an additional unit of demand changes the network equilibrium and, consequently, the marginal costs are estimated by calculating the difference between the two equilibrium scenarios. Both approaches were applied on seven selected routes covering the most important freight transport corridors in Colombia.

We found that the methods produce the same results. Average external costs were rated equal to 0.014 US$/ton-km for highways, 0.000105 US$/ton-km for water transport and 0.0016 US$/ton-km for rails. In highways external costs are equivalent to 37% of internal costs, in railways 12% and in inland waterways they represent only 1%.

Keywords: Freight Transport Modelling, External Costs

INTRODUCTION

Transport cost is a relevant factor in a nation's economy. That is particularly true, considering that efficient freight transport promotes regional economies and boosts production. However, externalities such as congestion, air pollution and noise, increase with transport mode usage.

It is well know that total transport costs could be separated into internal and external. The former, also called private or direct costs, include costs that a user perceive directly such as operating costs, the opportunity cost of travel time, and tolls. External costs, also called social or indirect costs, refer to those that are borne by society as a whole, such as accident costs, costs of pollution, congestion costs imposed on other users, and costs of infrastructure use (Ozbay et al., 2007).

Given a graph *G(N,A)*, where *N* denotes the set of nodes, and *A* represents the set of links, the total cost on a link *ij* could be estimated as:

$$TC = PC_t + PC_{op} + E \tag{1}$$

Where PC_t is the private cost associated with the value of time, PC_{op} is the internal cost of operation, and *E* represents the costs of the externalities considered. These two items of private cost are analyzed in this study, as well as five components of external cost: congestion, accidents, air pollution, climate change and external cost of infrastructure; from them the total marginal costs are derived. Other costs associated to noise and the involvement of the landscape, which could represent about 10% of external costs (ISIS et al., 1998; INFRAS, 2004), have not been included.

Based on the previous considerations, this paper presents some results obtained from a detailed modelling of the Colombian multimodal freight transport network where transport external costs were incorporated. The results of a simulation of traffic flow over the Colombian interurban network in 2005 are outlined, and the estimates of the corresponding external costs for the analyzed modes are given as well.

Value of time and congestion

Most of the procedures used to solve the traffic assignment problem updating the cost function based on the performance of the links. Although different formulations have been suggested (Branston, 1976; Davidson, 1966; Spiess, 1990; National Research Council, 2000), BPR function of the Bureau of Public Roads (Traffic Assignment Manual; BPR, 1964) is one of the most used on the transport network. For a level of flow *Q*, PC_t could be estimated by using a BPR function as:

$$PC_t = Q \cdot VOT \cdot \frac{L}{V_0}\left[1 + \alpha\left(\frac{Q}{C}\right)^{\beta}\right] \tag{2}$$

Where VOT is the value of time, L the length of the link, C the capacity, V_o the speed at free flow and α and β are parameters. This cost is internalized by the users and therefore the average cost of travel time ACP_t can be expressed, for some level of flow Q, as follows:

$$ACP_t = VOT \cdot \frac{L}{V_0}\left[1+\alpha\left(\frac{Q}{C}\right)^{\beta}\right] \qquad (3)$$

It is commonly accepted that congestion also produces an externality; the best practice for its estimated cost is based on the relationship volume - delay, the value of time and elasticity of transport demand (Maibach *et al*., 2008). In this case, the total external cost of congestion is:

$$E_{cong} = Q \cdot \alpha \cdot \beta \cdot VOT \cdot \frac{L}{V_0} \cdot \left(\frac{Q}{C}\right)^{\beta} \qquad (4)$$

Internal operating cost

The internal operating costs are related to the cost of fuel, tolls and other costs charged by individuals, who should express the purpose of modelling in monetary units per unit distance (ISIS *et al*., 1998; Guo, 2007). It makes sense to work with empirical values of internal operating costs depending on the length L and the characteristics of link m, as follows:

$$PC_{op} = Q \cdot f(L,m) \qquad (5)$$

And consequently, the average cost of operation is calculated as:

$$APC_{op} = f(L;m) \qquad (6)$$

Cost of accidents

An adaptation of the model proposed by Lindberg (2002) was used, which even though it is not as complex as the model by Rizzi (2005), it allows a better specification than other proposed formulations (ISIS *et al*, 1998; Beuthe *et al*, 2002; DNP, 2003; FHWA, 2005; Ozbay *et al*, 2007). According to this model the total external cost of accidents E_{acc} is based on the number of accidents A, and certain variables such as both, the individual's willingness to pay a, and that of his/her relatives and friends b, and the external cost of the system which relates primarily with medical costs and social security system *c*.

The total marginal cost of the accident regarding the volume of traffic Q is deduced from the total cost function, although a much more complex approach could be used if we introduce r as the risk of accidents and $1–\theta$ as the total cost of the accident which impose on other road users, in whose case:

$$r = \frac{A}{Q} \tag{7}$$

$$TC_{acc} = Qr\theta(a+b) + Qr\left[(1-\theta)(a+b)+c\right] \tag{8}$$

The two summands in equation (8) represent the internal and external costs, respectively. On the other hand, the marginal external social costs are then the derivatives of the respective total social costs minus the private marginal cost. The latter is given by (9) for accidents between vehicles, and the former by (10).

$$MPC_{acc} = r\theta(a+b) \tag{9}$$

$$MEC_{acc} = r(1-\theta)(a+b) + rc \tag{10}$$

Environmental costs

The environmental effects caused by transport are classified as air pollution, climate change, noise, impacts on nature and landscape, deterioration of water and soil, effects associated with electricity production and other effects such as visual pollution in cities (Bickel *et al*., 2006). This research examines only the costs of the first two above-mentioned environmental impacts: the cost of air pollution that has local impact and cost of climate change that has global effects.

Following the method of emission factors (EEA, 2001; Racero et al., 2006), the costs of air pollution on a given link for each pollutant emissions i AE_i are estimated as follows:

$$AE_i = Q(\gamma_i \cdot EF_i) \cdot L \tag{11}$$

where EF_i is an emission factor in grams per vehicle per kilometre and γ_i includes the monetary cost of pollution of each pollutant emission. The marginal cost is then derived from the total cost function as shown in (12):

$$MCE_i = \gamma_i \cdot EF_i \cdot L \tag{12}$$

The proposed formulation can alternatively be used individually to estimate the costs caused by the emission of carbon monoxide (CO), nitrogen oxides (NO_x) and sulfur dioxide (SO_2), retaining the same functional form and changing the FE and cost parameters for each pollutant.

Cost of infrastructure

It is common practice that the costs of infrastructure use are equivalent to the average cost of maintenance (Ozbay *et al*., 2007). We calculated the cost of infrastructure as an average cost based on the length (L) and number of lanes (N) representing each link.

$$CE_{inf} = f(L;N) \tag{13}$$

Since in this approach the cost is not a function of flow, the effect of the marginal cost of an additional vehicle cannot be calculated directly, so using the following relation (Ozbay *et al*., 2007) we can estimate it as:.

$$MCE_{infr} = f(L;N)\cdot\frac{t}{T} \tag{14}$$

Where t is the travel time of an additional vehicle and T is the time between each maintenance cycle.

METHODOLOGY

The research took as its starting point the strategic freight transport model developed by the UTMT (2008) in Colombia, which used the product approach to estimate demand for freight transport, following an adaptation of the classic model of the four steps.

Zoning and products

Zoning system considers 70 internal and 8 external areas. The external areas concentrate the freight movement that is attracted or produced in Venezuela, Ecuador, South America Atlantic, South America Pacific, Asia-Pacific, West Coast U.S., East Coast U.S. and Europa-Africa (Márquez, 2008).

A total of 34 groups of products were chosen for the analysis: fertilizer, oils and animal fats, products of the food industry, feed for animals, rice, sugar, banana, beer and fermented beverages, bio-fuels, coffee, coal, cement and plaster, ceramic products, petroleum products, ferronickel, flowers, fruits except banana, cattle and pigs, iron and steel, milk, vegetables, wood, corn, miscellaneous manufacturing , other flours, potato, paper and cardboard, parcels and consignments, crude oil, salt, soy, wheat and vegetables. These products represent about 83% of the freight in the country while the rest were included into the last group called “others”.

The demand model

Production and consumption, expressed in ton/day, in each zone i, were estimated with a specific model for each product group k by using zonal-based linear regression models. The trip distribution assumed in all cases gravitational models with impedance exponential type; in these models the generalized costs were obtained in the iterative process on the transport network.

On the other hand, the modal split was added to a multinomial Logit model, applied only in those product groups that were able to be transported by alternative transport modes.

Finally, a model for choosing the type of vehicle was introduced and the number of empty trucks using the approach suggested by Holguin-Veras and Thorsom (2003).

The supply model

The network for strategic modelling of freight transport in Colombia was built by selecting the main routes in the different transport modes, considering information of variable impedance, time and capacity required for the use of traffic assignment algorithms. The transport network characterized 27,469 km of roads, 11,257 km of navigable rivers and 2,192 km of rail.

In addition, a representative set of links was included connecting maritime international external areas and a set of centroid connectors to establish the connection with the internal areas. Formally, the network was defined as a graph $G(N,A)$ where N is the set of network nodes, including the centroids and A is the set of links of the network, including centroid connectors.

It was necessary to associate information about passenger demand with the network through preloads P that were added to the total freight flow Q in the traffic assignment phase and thereby obtain the total flow on each link Q_T.

$$Q_T = Q + P \tag{15}$$

Methodology for calculating marginal cost

The marginal costs on the transport network were calculated with two different methods: Equilibrium in Inertia and Equilibrium in Change.

The Equilibrium in Inertia method is similar to the "Method A" used by Ozbay et al. (2007). It assumed that an additional unit of demand between OD pair does not affect the overall balance of the transport network equilibrium. In other words, the traffic network experiences an inertia state to reach a variation threshold of demand. In this case, the total marginal cost was calculated as well:

1. It is determined the shortest route between a given OD pair.

2. The Total Marginal Cost (*TMC*) is estimated for each link in the shortest path using the derivative of the function of total cost of that link.

3. The *TMC* of additional one unit of freight transport between a selected pair OD on the transport network is estimated as the sum of the marginal costs of the links on the shortest route.

The method Equilibrium in Change follows the "Method C" used by Ozbay et al., 2007). It assumes that one additional unit of demand for freight between an OD pair on the transmission system causes variation on the existing balance, which is reasonable as long as the amount of demand for additional cargo has passed the threshold hypothetically maintains the transmission system in a state of inertia. In this second approach the *TMC* was calculated as follows:

1. The total demand between a given OD pair is assigned to the network using the traffic assignment method of stochastic user equilibrium (SUE).

2. It is estimated the total cost of the transport network for the equilibrium condition achieved by the traffic assignment method used.

3. It is increased by 1% the demand for cargo between OD pair on the demand for original freight OD pair. This increased demand is reassigned to the network, and the total network costs are re-estimated.

4. *TMC* of the additional one unit to the entire network is estimated by computing the difference between the total cost of the transmission system with 1% increase in demand CT_1 and the cost of the transport network in the original equilibrium condition CT_0 and then dividing this difference by demand for extra cargo Δ_{OD} allocated, thus:

$$TMC = \frac{CT_1 - CT_0}{\Delta_{OD}} \tag{16}$$

Both methods were applied on selected routes as shown in Table 1. The calculation of *TMC* was experimenting with three *VOT* to incorporate into the analysis the effect of three different kinds of products: with low, average and high opportunity cost.

Table I – Selected Routes

No.	Origins	Destinations	Modes (km)		
			Roadway	Rail	River
1	Boyacá Noreste	Bogotá	256	301	-
2	Santander Suroeste	Cesar Sur	301	273	255
3	Cundinamarca Oeste	Atlántico Colombia	831	-	898
4	Bogotá	Magdalena Norte	959	970	-

5	Quindío	Valle del Cauca Oeste	306	344	-
6	Bogotá	Nariño Sureste	883	-	-
7	Antioquia Metro	Norte de Santander Sur	705	-	-

IMPLEMENTATION AND RESULTS

Parameter estimation

Parameters for congestion cost and value of time

According to Fowkes et al. (1989), willingness to pay for reducing a half-day trip is in a range from 5% to 30% of the fare. Considering averages freight fares in Colombia (Ministerio de Transporte, 2007; DANE, 2008), we finally found: 0.030 US$/hour/ton, 0.105 US$/hour/ton and 0.180 US$/hour/ton to represent low, medium and high opportunity cost, respectively.

We assumed an average speed of 17 km/h for the Magdalena river (Márquez, 2008). In the case of railways, speeds vary on the kind of terrain in a range between 25 and 50 km/h. With regard to BPR function parameters, the model used values of α and β for each of the modes studied, obtained from experiments under different conditions.

Operating cost parameters

For road links, the calculation of operating cost depends on the kind of terrain where it is; level, rolling or mountainous. Internal cost in other transport networks were estimated based on the relationship extracted from Litman (2002). For inland water transportation, the typical convoy consists of a tug and 6 barges (Márquez, 2008); on the other hand, for rail a typical locomotive train pulls 22 wagons.

Parameters of the cost of accidents

To estimate cost of accident, we used information supplied by Road Prevention Fund (Fondo de Prevención Vial, 2005). According to this statistics, accidents increased to 5.070 in interurban highways in 2005 (2.73% of total). We found from the same source that freight vehicles are involved in 5.35% of accidents. With the information, the parameter estimate of the risk of accident to freight vehicles in the roadway mode was 2.52×10^{-9}, with a fatal accident rate equal to 10.1%. Following the same analysis we estimated the risk of accident for inland waterway and rail, finding as values 3.61×10^{-11} and 1.48×10^{-11} with fatal accident rate of 20.8% and 60.5%, respectively.

The correct way to establish the value of statistical life (*VOSL*) for Colombia involves the development of a specific study to determine the willingness to pay for reducing the risk of accidents. However, since implementation of the study was beyond the scope of this research and considering that there were no references to the *VOSL* in the country, we decided to use the equivalent of €2,000,000 in 2005, that being assessed in terms of gross domestic product (GDP) per capita for Europe (OECE, 2006) found a value equivalent to 90 times the GDP per person. With this assumption, and giving that in 2005 the purchasing power parity per capita in Colombia was US$ 6,600 (Barrientos, 2009), *VOSL* for Colombia is US$ 683,100.

On the other hand, by maintaining the same proportions found in the QUITS project (ISIS et al., 1998) with respect to the VOSL in case of death, we estimated the VOSL for a serious accident at US$ 29,598 and for a fender-bender at US$ 2,911. Now, following recommendations from Beuthe et al. (2002), but emphasizing that each case study in particular for each mode and country should have its own values, we took an amount equal to 40% of the *VOSL* of the user to estimate the *VOSL* expressed by relatives and friends The external cost was calculated from the system as 10% of the value specified for each degree of severity, thus finding the sums of US$ 68,310 by fatal accidents, US$ 2,960 by injury accidents and US$ 291 by minor accidents.

Since in the country there is not a tool of economic management of road safety we assumed that the one that causes the accident does not internalize any cost. Consequently, the marginal private cost of the accident who zero; that means a parameter θ equal to 0.

Environmental cost parameters

Estimations by Manzi et al. (2003) were taken as reference in order to calculate the emissions factors, as well as fuel consumption for road freight vehicles (Pérez, 2005).

In the case of inland waterway, a fuel consumption of 1.3 km/lt (Pardo, 2006) was found. The matching of these indicators with highway transport mode on flat ground resulted in the following FE for a typical convoy CO: 83.88 g/km, NOx: 4.14 g/km, SO_2: 0.65 g/km and CO_2: 276.92 g/km.

With regard to rail transport mode, we found that the rolling stock used fuel diesel and diesel-electric engines (MAVDT, 2008). Emissions of rail transport were estimated based on the amount of fuel burned, founding the following emission factor for a typical train: CO: 602.32 g/km, NO_x: 29.76 g/km, SO_2: 4.72 g/km and CO_2: 1988.48 g/km.

From estimations made by Byatt et al. (2006) an average of 85 US$/ton-$CO_2$ was found, this amount, taken as a initial reference, was high according to them because the review of the experience in Australia, the European Union, United States, Canada and New Zealand, had suggested lower values. Litman (2002) indicates that values in the order of 12.5 US$/ton-$CO_2$ should be used, although more recent studies have rates around 100 US$/ton-$CO_2$ (Brainard, 2009). Regarding the cost of other issues, a large variation of the proposed values was also found. At the end, after having reviewed various sources (Brainard, 2009; Munksgaard, 2007) we decided to adjust the values proposed by Litman (2002), especially in terms of cost CO_2, that was found undervalued in relation to other references.

Parameters of the cost of infrastructure

The calculation of the costs associated with road infrastructure taken as a basis for annual maintenance costs per mile shown in the official document CONPES 3085 (DNP, 2000), finds an average routine maintenance cost equal to 2.06×10^3 US$/km and periodic maintenance cost equal to 19.3×10^3 US$/ km. Intending to use a single marginal cost parameter for the entire network of road transport, an average speed was calculated and after applying the relationship proposed by Ozbay et al. (2007), a value of 0.01383 US$/pce/km was found, assuming that the other vehicles that use the infrastructure does not cause damage.

Following the same scheme of calculation, the rail transport mode value of 0.1115 US$/train type/km was found, which under operating conditions (Arias et al., 2007) is internalized by existing shareholders, which carried its own risk under the investments to expand and maintain the rail network concession that is in operation.

Moreover, we found that major maintenance projects in major river corridors, are aimed at controlling floods and sedimentation, maintenance of airworthiness and expansion of port infrastructure. Dredging, which allow you to retrieve the seaworthiness of the rivers, is not properly related to the use of infrastructure by the river boats, but is derived from transport and disposal of sediments that the fluvial dynamics causes. For this reason, we considered that the marginal damage caused to the infrastructure of a convoy-type effect can be dismissed without incur higher pricing errors, so for inland waterway transport, a null incremental cost of maintenance was assumed.

Applying the demand model

Applying the demand model propose by UTMT[1] (2008) resulted in a total exchange of 384.914 tons / day in all product groups studied, which represents the distribution volume of freight between all OD pairs internal and external trade. The fraction of demand for the study of externalities in the selected routes totalled 8.639 tons / day, as indicated in Table 2, which condenses the modelled demand on routes of interest.

Table 2 – Daily demand for freight transport in selected routes

Route	Origin *i*	Destination *j*	Freight *ij* (ton)	Freight *ji* (ton)	Total (ton)
1	Boyacá Noreste	Bogotá	1,877	0	1,877
2	Santander Suroeste	Cesar Sur	418	160	578
3	Cundinamarca Oeste	Atlántico Colombia	109	1	110
4	Bogotá	Magdalena Norte	332	3,276	3,608
5	Quindío	Valle del Cauca Oeste	106	161	267
6	Bogotá	Nariño Sureste	249	1,169	1,418

[1] The strategic model of freight transport in Colombia, including the cost of externalities was implemented in TRANSCAD ® 5.0 (Caliper Corporation, 2009)

7	Antioquia Metro	Norte de Santander Sur	478	303	781

Although OD pairs given in Table 2 relate only to internal areas, the calculation of the tonnage moved in certain routes included a portion of the volume of tons of foreign trade; as an example, in the case of Route 6 was added the tonnage being mobilized between Bogota and Ecuador, and Route 7 was added the weight of foreign trade goods between the Metropolitan Area of Medellin and Venezuela. A similar treatment was given to routes 3 and 5 which contain respectively the foreign trade demand mobilized through the ports of Barranquilla and Buenaventura.

Travel times in the equilibrium condition (Table 3) do not differ significantly with respect to the time of reference, especially for water transport due to the broad capabilities of the links. Particularly, the modelled travel times are not comparable with the actual operation times in this model, because it does not consider spent time in ports.

Table 3 – Travel times by mode of transport on the analyzed routes

Route	Description	Time (hours)		
		Roadway	River	Rail
1	Boyacá Noreste - Bogotá	5.12		11.53
2	Santander Suroeste - Cesar Sur	4.36	15.00	15.87
3	Cundinamarca Oeste - Atlántico Colombia	12.52	52.81	
4	Bogotá - Magdalena Norte	14.95		41.60
5	Quindío - Valle del Cauca Oeste	5.22		9.34
6	Bogotá - Nariño Sureste	22.14		
7	Antioquia Metro - Norte de Santander Sur	16.97		

The modelling with private costs of operation (Pérez, 2005; DANE, 2008; Litman, 2002) and travel times resulted in the delivery ratio are shown in Figure 1.

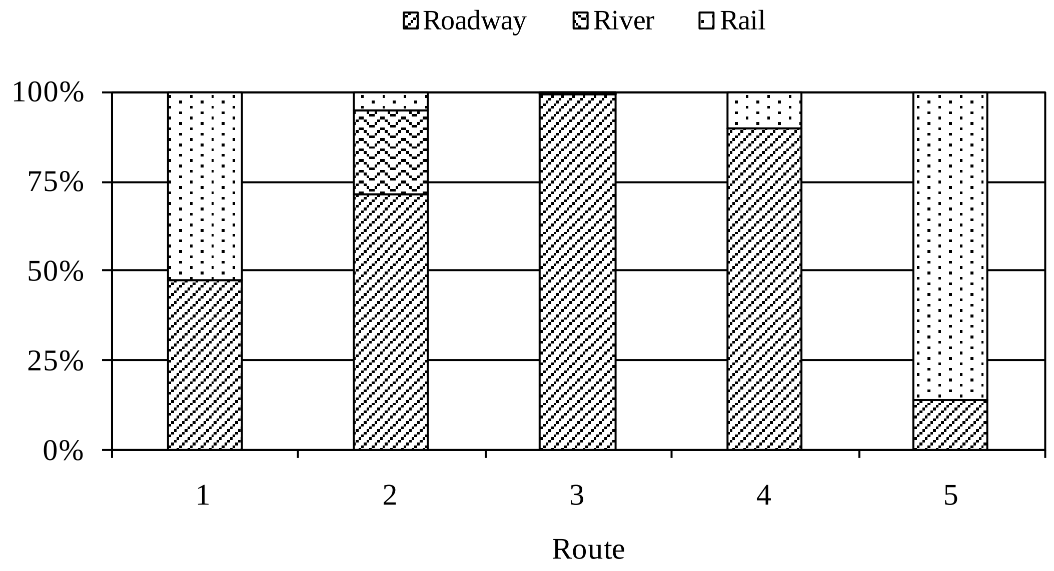

Figure 1 – Private cost of operation and travel times by mode and route

We found that share market of inland waterway transport is very low because it is heavily penalized for operating with travel times significantly greater than those of its competitors.

Internal costs

It were calculated the internal costs on each of the routes and transport modes initially using a VOT ratio equal to 0,11 US$/hour/ton (Fowkes et al., 1989; Ministerio de Transporte, 2007a; DANE, 2008), affected by the average number of tons mobilized by each transport unit equivalent.

In the case of road transport, we found that, on average, the cost of time is equal to 5% of total domestic cost considered (Table 4), which partly explains the predominance of this mode of transport in the country, given the freight opportunity costs, as well as its greater reliability in delivery times, therefore becoming more attractive.

Table 4 – Domestic costs of roadway

Route	Description	Internal cost (US$/pce)		
		Time	Operation	Total
1	Boyacá Noreste - Bogotá	2.96	50.05	53.01
2	Santander Suroeste - Cesar Sur	2.52	51.34	53.86
3	Cundinamarca Oeste - Atlántico Colombia	7.23	145.13	152.36
4	Bogotá - Magdalena Norte	8.63	170.65	179.28
5	Quindío - Valle del Cauca Oeste	3.02	55.59	58.61
6	Bogotá - Nariño Sureste	1.28	201.42	202.69
7	Antioquia Metro - Norte de Santander Sur	9.80	154.52	164.32

In contrast, as shown in Table 5, in inland waterway transport the domestic cost associated with time in a convoy rate is around 60% of the total domestic cost, and this may be reason why this alternative is mainly used in the movement of goods with low opportunity costs.

Table 5 – Internal costs of inland transport

Route	Description	Internal cost (US$/convoy)		
		Time	Operation	Total
2	Santander Suroeste - Cesar Sur	1,323.2	765.1	2,088.3
3	Cundinamarca Oeste - Atlántico Colombia	4,657.8	2,693.3	7,351.1

On the other hand, for rail transport was found that the value of time represents about 30% of the total domestic cost, as shown in Table 6. To compare the costs of the three modes, domestic cost per tonne for each mode and route was counted (Figure 2), finding that the domestic costs of roadway is 3.5 times larger than the internal costs of inland waterway transport.

Table 6 – Internal costs of rail transport

Route	Description	Internal costs (US$/train)		
		Time	Operation	Total

1	Boyacá Noreste - Bogotá	544.8	1,258.7	1,803.5
2	Santander Suroeste - Cesar Sur	749.7	1,141.0	1,890.7
4	Bogotá - Magdalena Norte	1,965.6	4,056.5	6,022.1
5	Quindío - Valle del Cauca Oeste	441.2	1,438.6	1,879.7

Additionally, we also was found that ratio between road and rail costs is 2.4 and the ratio between rail and water costs is 1.7.

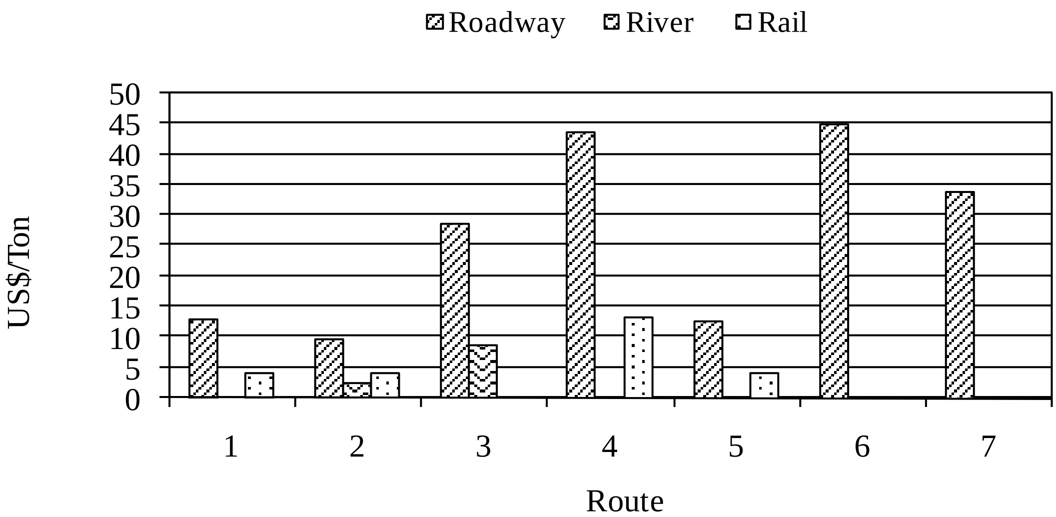

Figure 2 – Comparison of domestic costs by mode and route

Finally, we gathered a cost indicator for each of the modes of transport, finding that: 0.04 US$/ton/km for road, 0.01 US$/ton/km for inland waterway and 0.013 US$/ton/km for rail.

External costs

No difference was found between the results from the two methodologies used for calculating marginal costs for transport demand. Additional 1%, used in application of the method Equilibrium State of Change was not enough to cause the expected variation on the existing balance. This event can be explained in general as it failed to show congestion in networks.

In the case of road transport, the weight of the preloads on demand caused by passenger vehicles, which in average represents 50% of total equivalent vehicles not allowed to prove the expected impact of the additional demand for cargo transport. In the other two modes, although they were not used pre-loaded, no variation was found because none of them are alternative links to cover the selected routes, regardless of the conditions of congestion registered.

The results obtained for road (Table 7), draw attention to the prevalence in the impacts of environmental external cost when is compared with the other analyzed components of external cost. We found that, in the case of road, environmental external costs represent about 94% of total external costs.

Table 7 – External costs for road transport

Route	External cost (US$/pce)			
	Congestion	Accidents	Environmental	Total
1	1.1660	0.1490	18.8425	20.1575
2	0.9925	0.1750	17.5260	18.6935
3	2.8475	0.4830	49.1275	52.4580
4	3.4010	0.5575	61.0195	64.9780
5	1.1885	0.1780	23.1875	24.5540
6	5.0365	0.5130	76.2540	81.8035
7	3.8610	0.4100	59.3005	63.5715

We also found that, for road transport, cost of the accidents is the minor component since it fails to represent even 1% on the total external cost, which is reasonable since accidents are a phenomenon greater importance in urban areas. Table 8 summarizes the external costs of inland waterway transport. It does not register external costs associated with congestion and the social costs of accidents are irrelevant, the whole burden of indirect costs is on the environmental impact assessment, represented by the costs of emissions.

Table 8 – External costs of inland waterway transport

Route	External cost (US$/convoy)			
	Congestion	Accident	Environmental	Total
2	0	0,000	22.6865	22.6895
3	0	0,0003	79.8610	79.8613

In the rail transport mode (Table 9) we found that the external environmental cost is the most important of all, representing just over 87% of the total external costs, followed by the external cost of congestion to 12%. This latter cost is particularly high and perceived explained. First, by the way the links were penalized representing the passage through the seasons, and second, by the low capacity of railway links that feeds the BPR function.

Table 9 – External costs of rail transport

Route	External cost (US$/train)			
	Congestion	Accident	Environmental	Total
1	25.12	0.01	192.55	217.68
2	34.58	0.01	174.54	209.12
3	90.64	0.02	620.53	711.19
4	20.34	0.01	220.06	240.41

Figure 3 was developed to compare the external costs by mode and route, in this case it was necessary to use a logarithmic scale to represent the external cost per tonne and that the amounts of the mode of road transport are significantly increased the costs obtained in other modes.

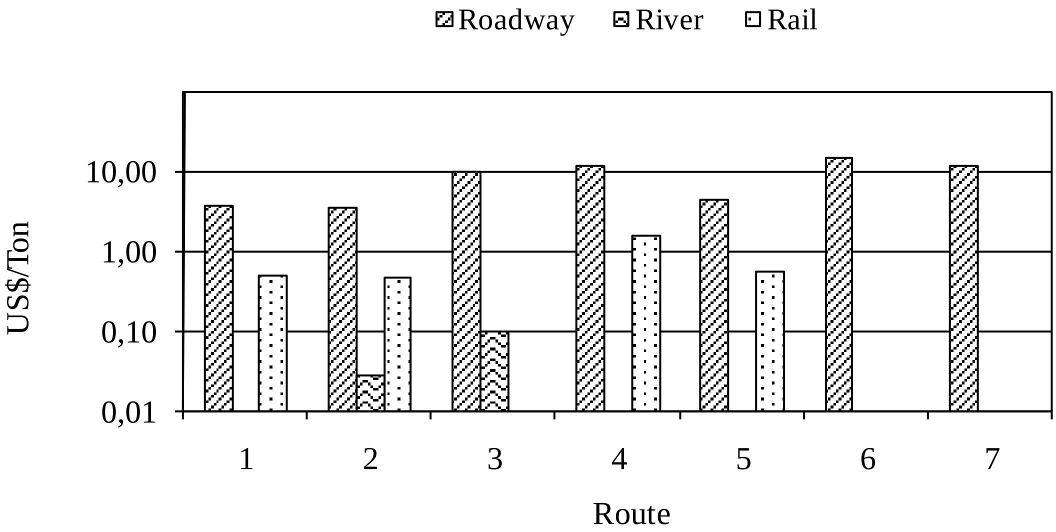

Figure 3 – Comparison of external costs by mode and route

A comparison of external costs between different transport modes resulted in a ratio of 1 to 110 of the external costs of road with regard to inland waterway transport, and 1 to 8 of road with respect to rail transport mode. A ratio of 1 to 17 was obtained, in the only comparable route between modes of inland waterways and rail.

Finally, an average rate of external costs for each mode of transport was obtained, finding that: 0.014 US$ / ton / km for road, 0.0001 US$ / ton / km in inland waterway transport and 0.0016 US$ / ton / km in the case of rail transport.

So, in the mode of road transport external costs are equivalent to 37% of domestic costs valued, in the rail transport mode they reach an amount equivalent to 12% and inland waterway transport they represent only something higher than 1%.

Sensitivity of external costs to change the *VOT*

The calculation of *TMC* was evaluated with three *VOT*, in order to incorporate the effect of three different product types into analysis: one with a low opportunity cost, one with medium and opportunity cost another with high opportunity cost.

Similar to other transport modes , the results for road transport mode (Table 10) were not encouraging due mainly to the specification of demand model (UTMT, 2008) which envisaged a single modal model whose variables are the perceived monetary: cost and travel time. That is, this model alone could not reproduce directly changes in modal split due to changes in the *VOT*. To do so, changing the partition model parameters in response to the mobilization of goods with varying degrees of opportunity cost, would be required; which was not included in the scope of the research.

Table 10 – External costs of road transport mode with variations of VOT

Route	Description	External cost (US$/ton)

		Low	Medium	High
1	Boyacá Noreste - Bogotá	3,514	3,665	3,816
2	Santander Suroeste - Cesar Sur	3,270	3,399	3,527
3	Cundinamarca Oeste - Atlántico Colombia	9,168	9,538	9,907
4	Bogotá - Magdalena Norte	11,373	11,814	12,255
5	Quindío - Valle del Cauca Oeste	4,310	4,465	4,618
6	Bogotá - Nariño Sureste	14,220	14,874	15,526
7	Antioquia Metro - Norte de Santander Sur	11,057	11,559	12,059

Simulation of internalisation

Initially, 50% internalization of external costs of environmental impacts of road transport mode was simulated by introducing a proportional increase in operating costs per route, as shown in Table 11.

Table 11 – Simulated operating costs for highway transport

Route	Description	Cost simulation (US$/pce)		
		Time	Operation	Total
1	Boyacá Noreste - Bogotá	2,960	59,468	62,428
2	Santander Suroeste - Cesar Sur	2,519	60,103	62,622
3	Cundinamarca Oeste - Atlántico Colombia	7,229	169,693	176,922
4	Bogotá - Magdalena Norte	8,634	201,159	209,792
5	Quindío - Valle del Cauca Oeste	3,018	67,183	70,201
6	Bogotá - Nariño Sureste	12,785	239,543	252,328
7	Antioquia Metro - Norte de Santander Sur	9,801	184,173	193,974

This simulation represented the increased costs of operating the highway transport mode at rates ranging from 16% to 20% depending on the characteristics of each route, finding the new modal split shown in Figure 4.

Many other experiments can be simulated with the model. It proved to be very sensitive to changes in the perceived costs incurred, as shown in Figure 5 which represents changes in road market share for route 1, assuming different levels of internalization of environmental costs.

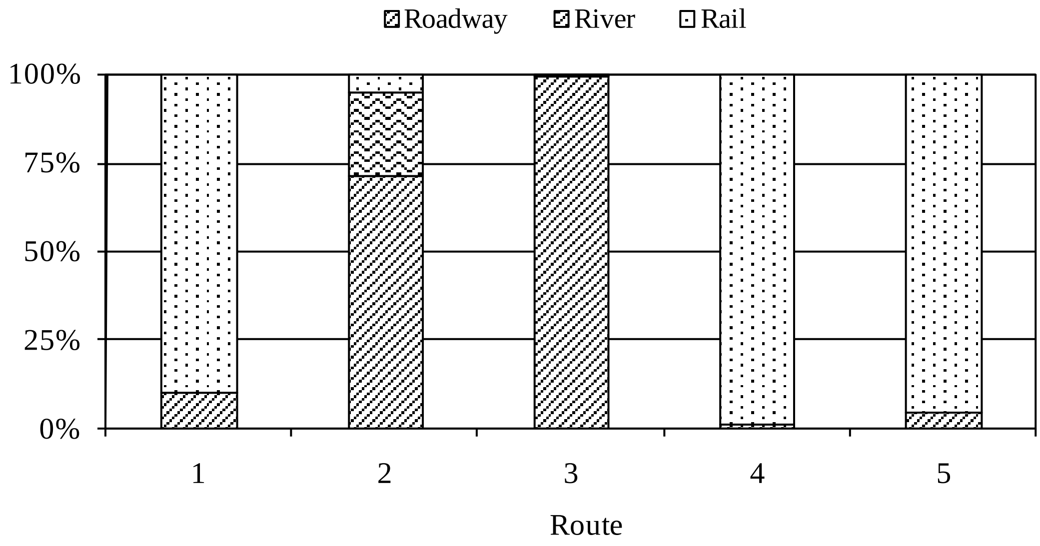

Figure – Modal internalizing environmental costs

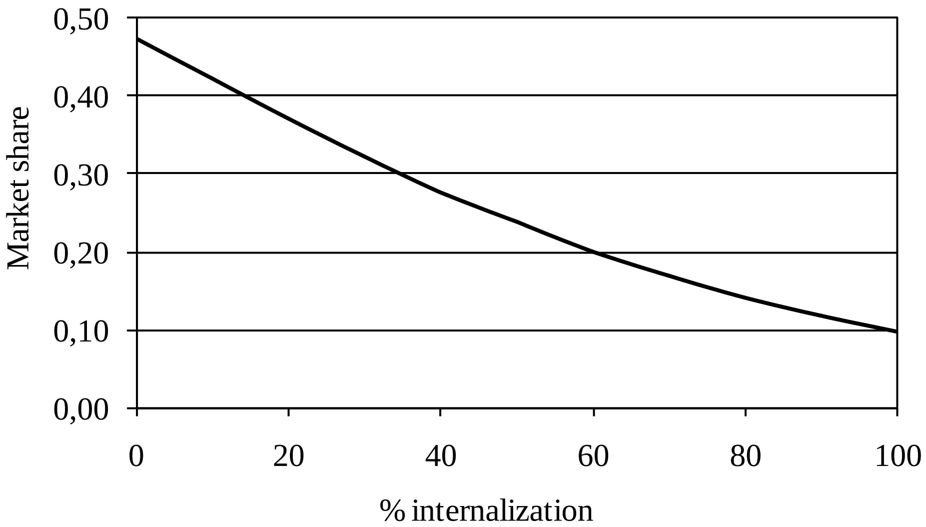

Figure 5 – Market share of Route 1 in the highway mode

CONCLUSIONS

The model theory used in this research is relatively simple and easy to understand because it follows the sequential approach of balance between the phases of distribution and traffic assignment, but presented as an important constraint that the freight generation phase is inelastic to changes on the network

The marginal costs on the transport network were obtained very simply by adding marginal costs on the shortest path in each case studied, following the methodology called "balance in a state of inertia", whose fundamental assumption is that the network equilibrium was not affected by an additional unit of demand between the OD pair. The second proposed method, identified as "equilibrium state of change" which was based on different assumptions, whereby a percentage change in demand caused changes in the network equilibrium, gave the same results as the first method because the additional amount of freight demand did not exceed the threshold that keeps the hypothesized transport network in equilibrium inertia. We can say then, that in those cases where no congestion occurs in large networks, the two methods are equivalent, being advisable to use primarily, given their great simplicity and ease of implementation, even without the help of specialized software transport modelling.

The internal cost estimate did not include the calculation of fixed costs, represented especially in vehicle ownership costs, so the correct interpretation of the results should bear this fact, especially when it comes to making comparisons with respect to the other costs. Despite this, the costs obtained are now a good approximation of the true costs, especially with respect to amounts of external costs.

Specifically in calculating the external cost of accidents, although national statistics may be incomplete, the estimated risk of accident is subordinated to the real conditions of operation modes of transport in the country, but the estimate of the VOSL along with the other costs that derive from them was made based on foreign experiences that may differ from reality in Colombia. Notwithstanding the above, as the external cost of the accident is not decisive in interregional freight transport, a difference of 50% in the estimate of the VOSL would produce only a 2% change in total external costs.

In general, we found that average external costs were rated equal to 0.014 US$/ton-km for highways, 0.000105 US$/ton-km for water transport and 0.0016 US$/ton-km for rails. In highways, external costs are equivalent to 37% of internal costs. In railways, they represent 12% and in inland waterways they are only 1%. As a relevant fact, authorities have not implemented policies to subsidize inland waterways, but there are diesel subventions for lorries..

Although the results presented here apply specifically to the Colombian scenario, the methodological approach and the general results are transferable to other contexts, especially in the case of developing countries.

This research has some limitations due to lack of information, so some data was transferred from previous research. Based on this analysis, several lines of future research have been identified including determination of basic parameters for the analysis: emission factors for freight vehicles on major road corridors in the country, willingness to pay for the mitigation of environmental impacts caused by freight transport, quantifying the impact of freight vehicles on the damage the road infrastructure, the value accidents. On the other hand, it is relevant to analyse the implementations of policies with the purpose to internalize external cost and their impacts.

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