RAIL-ROAD FREIGHT TRANSPORTATION – THE CASE STUDY OF BELGIUM

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ABSTRACT

The optimal location of intermodal terminals is a strategic decision problem for freight transport systems. Although this problem has already been study for some authors in the past, in those studies, transport costs per unit and kilometre are assumed as constant and no economies of scale are considered when travelled distance increases. The aim of this paper is to discuss the location of intermodal terminals in Belgium and the assignment of cargo from and to the Port of Antwerp to the inland intermodal freight network of Belgium, through the use of an optimisation model, in which costs are assessed with nonlinear cost functions. The model can be used to test the implications of adopting different transport cost policies, such as subsidising intermodal freight or internalising external costs in the transport costs. The case study of Belgium is used to illustrate how the model can be used to discuss the impacts of those policies. The results show that the model corroborates most of the locations of the existing major terminals in Belgium and it also evidences that the competitiveness of intermodal freight transport largely depends on the policy adopted.

Keywords: terminal location, rail-road modal split, intermodal transport, cost policies, transport costs.

INTRODUCTION

People and goods mobility is a key issue in the vitalisation of modern economies. An efficient transport system enables economic prosperity, supports regional cohesion, and improves the quality of life of the citizens. Conscientious of this, the European Union (EU) defined transport as a priority sector and the development of "a system that underpins European economic progress, enhances competitiveness and offers high quality mobility services while using resources more efficiently", as the paramount goal of European transport policy (European Commission, 2011).

In the late decades, due to the globalisation and to the EU enlargement, the movement of people and goods in EU has experienced a fast growth, which had a major positive contribute in the development of the European economy. However, along with the positive impacts, some negative aspects emerged, such as congestion, air pollution, noise and accidents. Furthermore, the increasing transport's dependence on fossil fuels contributes to the unsustainability of the today's transport patterns.

According to the EU Transport White Paper (European Commission, 2011), the transport sector is responsible for 5% of the EU gross domestic product (GDP) and provides more than 10 million jobs. For freight transport, the share of different modes is very unequal: 44% of goods are transported by road, 39% by short-sea shipping routes, 10% by rail, and 3% by inland waterways. This uneven distribution is even more evident for people's transport (largely car journeys): 81% of passengers travel by road, 6% by rail, and 8% by air.

Furthermore, the EU Transport White Paper also presents the European vision for a more competitive and sustainable transport system, including freight systems. As part of this vision, the EU aims to shift 30 percent of the long-distance (over 300 km) road freight to more efficient modes, such as rail or waterborne transport, by 2030. And for 2050, the goal is to shift half of the current road freight. To accomplish these goals, the transport infrastructure needs to be developed and readapted to the new challenges. Future priorities must focus on changing the freight and passengers transport from roads to less polluting modes, and integrating different modes in the most efficient travel chain (e.g. road-rail, sea-rail or rail-air).

Intermodal Freight Transport

Intermodal transport can be defined as the transport of people or goods, from its origin to its destination, involving more than one transport mode, and with the transfer from mode to mode being performed at an intermodal terminal (Crainic et al., 2007).

In terms of freight, intermodal freight transport is "the movement of goods in one and the same loading unit or vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes" (European Conference of Ministers of Transport, 2001). In practice, the major part of the journey is made by rail, inland waterways or sea, to benefit from economies of scale and to reduce the negative impacts of road; while, the beginning and the end of the journey benefit from the road transport flexibility. The transition of cargo between the different modes of transport is usually done in an intermodal (or transshipment) terminal, where a transfer occurs between modes/networks of transport.

Intermodal freight transport is currently a top issue on the agenda of public and private actors in the transport industry. In Europe, the combination of different transport modes has been seen as a potentially strong competitor to road transport and can be used as an alternative to unimodal transport.

On a large scale, intercontinental transport is already made by intermodal transport (road-sea-road or road-air-road). However, when it comes to inland freight transport, as it becomes clear from the statistics previously mentioned, road transport is still the predominant transport mode. Due to its flexibility, to its ability to guarantee fast and reliable door-to-door journeys, and just-in-time services, road transport continues to be a strong competitor to intermodal transport. Nevertheless, intermodal transport can benefit of the inherent advantages of each modes. For instance, the long-distance economies of rail can be combined with the flexibility of trucks to offer the shipper optimal service.

This capacity of intermodal transport enables the reduction of the transport costs per kilometre for medium-range distances. Janic (2007) shows that, for short distances, road transport is more competitive than intermodal transport, due to the additional cost of transshipments. Nevertheless, for distances of 600 to 900 km the intermodal transport costs become lower than the costs of road transport.

In summary, for shorter distances, the additional burden of transshipment costs in the intermodal transport limits its competitiveness. On the other hand, as the distances increase, and with high service frequencies of the main mode of the intermodal transport, the intermodal transport becomes an efficient alternative. In addition, intermodal transport is a much more worthwhile alternative in terms of environmental preservation. That is why intermodal freight transport has become an emerging research field in the last years, receiving an increasing interest from freight transport researchers (e.g., Macharis and Bontekoning, 2004; Bontekoning at al., 2004).

Intermodal Freight Transport in Belgium

Belgium is a country where intermodal transport solutions are observed. Its freight transport system heavily relies on the Port of Antwerp, one of the most important ports in the world. According to Eurostat[1], in 2010, in the specific segment for container handling, the Port of Antwerp became the second largest container port in Europe, right behind the Port of Rotterdam. One of its main advantages is its efficient hinterland connection. As part of the Benelux and halfway between Paris and the industrial Ruhr areas, the Port of Antwerp is located right in the heart of the European network of motorways, waterways and railways, being the ideal origin point for freight European distribution. It is a major freight transport hub in Europe, ensuring direct connections to all the large European centres of consumption and production.

For the last 30 years, the freight volume in the Port of Antwerp has strongly grown, mainly because of the versatility of the port. It offers a large variety of transport possibilities, beyond the regular process of transshipment, guaranteeing that it is always possible to find the best solution for any transport issue.

In terms of the inland, Belgium has the densest railway network in the world, with a total track length of around 3.500 kilometres; the length of its road network is 118.411 kilometres, while the length of its waterway network is about 1.523 kilometres.

Its diversity and length of transport infrastructure, the importance of the Port of Antwerp, and its strategic location in Europe, make Belgium an ideal country for promoting intermodal transport. Despite the small area of the country, in the past years, the Belgian federal and regional governments introduced several measures for stimulating the intermodal transport market, even on short distances.

The aim of this paper is to develop an optimisation model to help finding if the intermodal freight transport (road-rail) can be competitive with road transport for a small country like Belgium. It is estimated that for distances lower than 600 kilometres, the rail-road transport

[1] ec.europa.**eu/eurostat**

has higher operational costs than truck-only (Daganzo, 1999). The proposed model will optimise the location of inland intermodal terminals and the allocation of cargo to the different modes of transport, according to the transport costs considered. We are also going to see if the strategic decision of choosing the intermodal terminals' location is an important and influent aspect for the competitiveness of the intermodal freight transport. Finally, the impacts that different cost policies have on the freight modal sharing and on the strategic location of these terminals will be analysed.

This paper is organized as follows. In the next section, the problem addressed is described. Then, the mathematical formulation of the optimisation model is presented. After that, results obtained from the application of the model to the Belgium case study are analysed and completed with a sensibility analysis on consideration of different cost policies. The last section is dedicated to the final conclusions of this work and to future research topics.

PROBLEM STATEMENT

Intermodal transport is getting a growing acceptance from policy makers, practitioners and academics as a valid transport alternative to tackle road congestion, environmental problems, and high transport dependence on fossil fuels. The use of rail or inland waterways in the long-haul can reduce transport costs and significantly mitigate the negative impacts associated with truck transport. However, due to the additional cost of transshipment, for short distances, road transport is more competitive than intermodal transport. This makes the case of a small country like Belgium a particular intriguing case study.

The problem of locating freight terminals is not new in the literature. According to Macharis and Bontekoning (2004), this is one of the strategic problems that need to be addressed with the development of operational research techniques. There were already some authors who have developed optimisation models to the road-rail terminal location decision problems. Actually, in the 1990's, Rutten (1995) presented a study in which the objective was to find terminal locations that could attract sufficient freight in order to run daily trains to and from the terminal. By adding terminals to the network, this author studied the effects on the performance of the existing terminals and on the overall intermodal network. Meinert et al. (1998) studied the potential benefits of locating a new terminal in a region that already had three rail terminals. The impact of this new terminal was analysed in terms of drayage length and time. Van Duin and Van Ham (1998) identified the optimal locations while incorporating the perspectives and objectives of shippers, terminal operators, agents, consignees and carriers. They developed a specific model for each level (strategic, tactical and operational), in which the different characteristics and particular goals related to each planning level were dealt with at the different level models.

Similar to the work presented in this paper, Groothedde and Tavasszy (1999) looked for the minimisation of the generalised and external transport costs in order to find the optimal location of intermodal road-rail terminals. They used the simulated annealing technique and, by adding the terminals to the network in a random way, they calculated the total generalised (from a user viewpoint) and external costs (from a system viewpoint), for each network configuration, in order to find the optimal locations. Arnold and Thomas (1999) chose the minimisation of total transport costs with the aim of finding an optimal location for intermodal road-rail terminals in Belgium, by using a linear programming model.

More recently, Arnold et al. (2004) proposed a linear integer model based on multicommodity fixed-charge network design to the location of freight terminals. The authors applied their approach to the Iberian Peninsula. Limbourg and Jourquin (2009) discussed the location of terminals in a European road-rail network. The main methodological contribution of this paper was the iterative procedure that the authors used, combining the results between the location problem and the multi-model assignment problem. In recent times, Alumur et al. (2012) proposed a location and network design problem, were transportation costs and travel times are jointly considered. The authors used the Turkish network as their case study.
In the above mentioned papers, marginal transport costs are assumed constant. Costs are usually calculated according to a constant cost per unit and kilometre travelled, not taking into account economies of scale when distances increase. In addition, these costs do not separately evaluate cost components, such as operational costs, time costs, or external effects costs, and thus are not suitable to test transport costs policies.
The main contribution of this paper is to propose a new intermodal freight location-allocation model using nonlinear cost functions. Transport and transshipment costs are defined according to composite costs formulas that take into account the different components of the cost (e.g., energy, salaries, maintenance, noise). The decisions variables are the location of the rail-road terminals and the flow pattern through the system either by road from the origin to destination or through rail-road terminals. This work also extends the existing literature by providing a sensibility analysis of the impact of different cost policies on the competitiveness of intermodal transport. The context of Belgium is used as a case study to discuss the implications of policies like the granting subsidies to intermodal freight transport operators (as the Belgian government currently does) and the internalisation of the external transport costs (a EU policy goal).
In the next sections we explain how we estimated the freight flows, how we defined the road and rail networks used to estimate the costs and the potential locations for the transshipment terminals.

Flows from and to the Port of Antwerp

This research focuses on the freight flows from and to the Port of Antwerp. It aims to determine the best location for intermodal transshipment terminals in Belgium. To accomplish this purpose, it was considered the in- and out-going flows of containerized goods between the Port of Antwerp and the provinces of Belgium, as well as the borders of the neighbouring countries (France, Germany, Luxembourg and Netherlands). The territory was divided according to the level 3 of the Nomenclature of Territorial Units for Statistics (NUTS).
Belgium is divided into three regions: Flemish Region (Flanders), Walloon Region (Wallonia) and Brussels-Capital Region. The first two, are subdivided into five provinces each. The ten provinces and the Brussels-Capital Region compose the eleven NUTS 2 level regions of Belgium. The Belgium provinces are further subdivided into arrondissements (44 arrondissements in total), which compose the NUTS 3 level regions of Belgium.
The freight demand data used for building the matrices of the demand flows with origin and destination in the Port of Antwerp was obtained from Worldnet database (Newton, 2009). The freight data from the Worldnet database is organized by NUTS 2 regions, refereed in

tonnes and by different type of commodities. In order to obtain the flows by NUTS 3 regions, it was necessary to disaggregate the data, using the population of each NUTS 3 zone as a proxy indicator for this disaggregation. In addition, given that the data refers to the year 2005, the demand data was extrapolated to 2010 by using the statistical information about the evolution of the number and tonnage of the containers in the Port of Antwerp (DGSIE, 2010; DGSIE, 2011). The final matrix comprises the freight movements from and to the Port of Antwerp and an analysis zone comprising Belgium NUTS 3 level regions, and the NUTS 3 level border regions from Germany, France, Luxembourg and Netherlands.

For the network representation, the demand at each NUTS 3 region was aggregated in a single generation node. The choice of these nodes was made according to the importance of cities and the existence of a rail platform. Thus, it will be considered 44 generation nodes in Belgium, 17 in Germany, 13 in France, 1 in Luxembourg and 9 in Netherlands (Tables 1 and 2).

There were also considered the movements between the Port of Antwerp and other European regions not considered in the analysis region. Thus, movements between North of Germany, Poland and Czech Republic were aggregated in a schematic node in Berlin; Spain and rest of France data was aggregated in the schematic node in Paris; the rest of Netherlands data aggregated in a node in Amsterdam; Switzerland and Italy aggregated in a node in Bern; and South of Germany, Austria, Hungary, Slovakia, Slovenia, Croatia, Bosnia and Herzegovina and Serbia and Montenegro data was aggregated in a schematic node in Vienna.

Table 1 – NUTS 3 nodes in Belgium.

COUNTRY	NUTS I		NUTS II		NUTS III	
Belgium	BE1	Brussels-Capital Region	BE10	Brussels-Capital	BE100	Brussels-Capital
	BE2	Flemish Region	BE21	Antwerp	BE211	Antwerp
					BE212	Mechelen
					BE213	Turnhout
			BE22	Limburg	BE221	Hasselt
					BE222	Maaseik
					BE223	Tongeren
			BE23	East Flanders	BE231	Aalst
					BE232	Dendermonde
					BE233	Eeklo
					BE234	Ghent
					BE235	Oudenaarde
					BE236	Sint-Niklaas
			BE24	Flemish Brabant	BE241	Halle-Vilvoorde
					BE242	Leuven
			BE25	West Flanders	BE251	Bruges
					BE252	Diksmuide
					BE253	Ypres
					BE254	Kortrijk
					BE255	Ostend
					BE256	Roeselare
					BE257	Tielt
					BE258	Veurne
	BE3	Walloon Region	BE31	Walloon Brabant	BE310	Nivelles
			BE32	Hainaut	BE321	Ath
					BE322	Charleroi
					BE323	Mons
					BE324	Mouscron
					BE325	Soignies
					BE326	Thuin
					BE327	Tournai
			BE33	Liège	BE331	Huy
					BE332	Liège
					BE334	Waremme
					BE335	Verviers (French Com.)
					BE336	Verviers (German Com.)
			BE34	Luxembourg	BE341	Arlon
					BE342	Bastogne
					BE343	Marche-en-Famenne
					BE344	Neufchâteau
					BE345	Virton
			BE35	Namur	BE351	Dinant
					BE352	Namur
					BE353	Philippeville

Table 2 – NUTS 3 nodes in Germany, France, Luxembourg, and Netherlands.

COUNTRY	NUTS I		NUTS II		NUTS III	
Germany	DEA	North Rhine-Westphalia	DEA2	Köln	DEA21	Aachen, Kreisfreie Stadt
					DEA22	Bonn, Kreisfreie Stadt
					DEA23	Köln, Kreisfreie Stadt
					DEA24	Leverkusen, Kreisfreie Stadt
					DEA25	Aachen, Kreis
					DEA26	Düren
					DEA27	Rhein-Erft-Kreis
					DEA28	Euskirchen
					DEA29	Heinsberg
					DEA30	Oberbergischer Kreis
					DEA31	Rheinisch-Bergischer Kreis
					DEA32	Rhein-Sieg-Kreis
	DEB	Rhineland-Palatinate	DEB2	Trier	DEB21	Trier, Kreisfreie Stadt
					DEB22	Bernkastel-Wittlich
					DEB23	Bitburg-Prüm
					DEB24	Daun
					DEB25	Trier-Saarburg
France	FR2	Bassin Parisien	FR21	Champagne-Ardenne	FR211	Ardennes
					FR212	Aube
					FR213	Marne
					FR214	Haute-Marne
			FR22	Picardie	FR221	Aisne
					FR222	Oise
					FR223	Somme
	FR3	Nord / Pas-de-Calaias	FR30	Nord / Pas-de-Calais	FR301	Nord
					FR302	Pas-de-Calais
	FR4	Est	FR41	Lorraine	FR411	Meurthe-et-Moselle
					FR412	Meuse
					FR413	Moselle
					FR414	Vosges
Luxembourg	LU0	Luxembourg	LU00	Luxembourg	LU000	Luxembourg
Netherlands	NL3	Western Netherlands	NL34	Zeeland	NL341	Zeelandic Flanders
					NL342	Overig Zeeland
	NL4	Southern Netherlands	NL41	North Brabant	NL411	West North Brabant
					NL412	Mid North Brabant
					NL413	North-East North Brabant
					NL414	South-East North Brabant
			NL42	Limburg	NL421	North Limburg
					NL422	Mid Limburg
					NL423	South Limburg

Belgium Road and Rail Networks

The transport network used has four components: i) the road network; ii) the rail network; iii) the set of generation nodes; and iv) the set of intermodal terminals.

To do the assignment of the demand flows to the intermodal transport system, the matrices of road and rail distances of Belgium networks are required. Both matrices were obtained from GIS data detained by the authors (Figure 1).

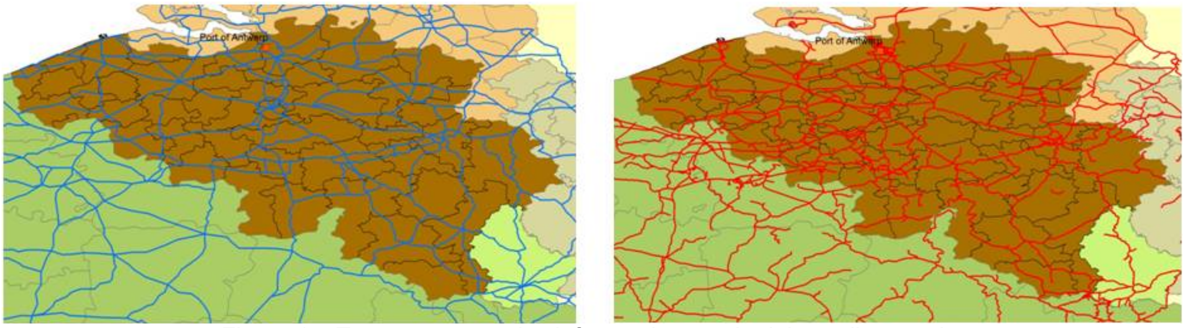

Figure 1 – Transport networks: left - road network; right - rail network.

Potential Locations for Terminals

According to the AGORA Intermodal Terminals database[2], Belgium has seven major intermodal terminals. The terminals are located in Antwerp (a group of terminals, including the Port of Antwerp), in Liège, in Genk (in the NUTS 3 region of Hassel), in Muizen (in the NUTS 3 region of Mechelen), in Charleroi, in Athus (in the NUTS 3 region of Virton), and in Mouscron. Other smaller terminals exist in Belgium, most of them located in the same NUTS 3 region of these seven major terminals (e.g., the terminal of Willebroek in the NUTS 3 region of Mechelen).
The set of potential locations for the terminals was selected assuming that the decisions can only regard locations inside Belgium. Thus, the transshipment terminals have to be located in nodes that belong to both, the road and the rail networks of Belgium.

OPTIMISATION MODEL

The location of transshipment terminals is defined as a discrete problem that locates terminals according to a set of possible locations, enabling the transshipment of goods from one transport network to another, in order to minimise the total transport costs.
In this paper, the generalised cost enclosed the price of transport and external costs, such as environmental impacts, congestion phenomena, and traffic accidents. Traffic flows, obtained from Worldnet, are assigned to the network according to the least-cost paths, while the modes of transport used between each OD pair are determined according to the costs of each mode. The possible locations for the intermodal terminals are limited to a set of locations in Belgium. It is assumed that the transport costs, both in road and rail, are symmetric.
The mathematical model proposed is an integer linear optimisation model that can be formulated as follows:

$$Min \sum_{j \in P} \sum_{k \in K} \left[h_{total} . x_j^k . \left(C_{kj} + T_k - S_k \right) \right] + \sum_{k \in K} \left[z_k . \left(R_k - S_r \right) \right] + + \sum_{j \in P} \left(h_{total} . w_j . C_j \right) \qquad [1]$$

[2] Available at http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/popups/archives/

Subject to:

$$\sum_{k \in K} y_k \leq p \qquad [2]$$

$$w_j + \sum_{k \in K} x_j^k = 1, \forall\, j \in P \qquad [3]$$

$$z_k = \sum_{j \in P} x_j^k . h_{total}, \forall\, k \in K \qquad [4]$$

$$x_j^k \leq y_k, \forall\, j \in P; k \in K \qquad [5]$$

$$y_k \in \{0,1\}, \forall\, k \in K \qquad [6]$$

$$w_j \in \{0,1\}, \forall\, j \in P \qquad [7]$$

$$x_j^k \geq 0, \forall\, j \in P;\ k \in K \qquad [8]$$

where P is the set of origin/destination nodes, to which is associated a certain flow (demand) from/to the Port of Antwerp; K is the set of potential locations for the transshipment terminals; h_{total} is the flow between the Port of Antwerp and the origin/destination node j, in both ways; C_{kj} is the road transport cost between terminal k and node j; T_k is the transshipment cost in the terminal k; R_k is the rail transport cost between the Port of Antwerp and the terminal k; C_j is the road transport cost between the node j and the Port of Antwerp; p is the number of terminals to locate; S_k is the subsidy given to the transshipment, by the Belgium government; S_r is the subsidy given to the rail transport, by the Belgium government; x_j^k, z_k, w_j and y_k are the decision variables, defined as:

$$y_k = \begin{cases} 1, if\ node\ k\ is\ a\ transshipment\ terminal \\ 0, \qquad otherwise; \end{cases}$$

$$x_j^k = \begin{cases} 1, if\ the\ flow\ from\ j\ to\ m\ is\ transshipped\ at\ terminal\ k \\ 0, \qquad otherwise; \end{cases}$$

$$w_j = \begin{cases} 1, if\ the\ flow\ from\ j\ to\ m\ is\ not\ transshipped \\ 0, \qquad otherwise; \end{cases}$$

$$z_k = capacity\ in\ terminal\ k.$$

The objective function [1] minimises the total transport cost associated to the flows between origin and destination nodes. The first and the second terms of the objective function represent the cost associated to the flows that have been transhipped one time, which means that the freight transport is made by the combination of rail and road. The first term is related to the road transport (between the terminal and the origin/destination node) and to the transshipment. The second term is related to the line-haul rail transport. The third term of the objective function is referred to the cost associated to the flows that do not suffer any transshipment, implying that the freight transport is only made by road.

The constraint [2] indicates that no more than p transshipment terminals are going to be located. Constraint [3] guarantees that all the demand is satisfied (either with transshipment or without transshipment) and that there is only one path between the Port of Antwerp and the node j, in both directions. Constraint [4] represents the total amount flows using the transshipment terminal (necessary capacity). Constraint [5] stipulates that transshipment is not possible, unless there is a transshipment terminal in k. Finally, constraints [6], [7] and [8] are standard non-negativity and integrality constraints.

Transport and Transshipment Costs

The road, rail and transshipment costs used in the model are based on the works of Daganzo (1999) and Janic (2007, 2008). The later author developed a model for calculating comparable combined internal (or operational) and external costs of intermodal and road freight transport networks. Internal costs are the operational-private costs supported by the transport and intermodal terminal operators, including different components such as personnel, fixed assets, energy, stock return, time, organisation costs and insurance, taxes and charges. External costs include the impacts of the networks on society and on the environment such as local and global air pollution, congestion, noise pollution, climate change and traffic accidents.

1. Road transport operational cost:

$$C_{kj}^{op} = \left(Q_{kj} / (\lambda_j . M_j) \right) . c_{op}(d_{kj}) \qquad [9]$$

where, Q_{kj} is the demand flow between k and j; λ_j is the load factor of each vehicle (assumed to be equal to 0.85 for the general road transport, and 0.60 for the collection and distribution transport inside a NUTS 3 region where a terminal exists. In the later case, it was considered that the vehicles travel on average 12 km); M_j is the capacity of each vehicle (M_j = 2 TEU x 14.3 ton); and $c_{op}(d_{kj})$ is the unitary road transport operational cost expressed as a function of the road distance between k and j (d_{kj}).

2. Road transport external cost:

$$C_{kj}^{ext} = \left(Q_{kj} / (\lambda_j . M_j) \right) . c_{ext}(d_{kj}) \qquad [10]$$

where, $c_{ext}(d_{kj})$ is the unitary road transport external cost.

3. Rail transport operational cost:

$$R_k^{op} = \left(Q_k / q_t \right) . r_{op}(W, q_t, d_{km}) \qquad [11]$$

where, Q_k is the demand flow between the Port of Antwerp and k; q_t is the capacity of each train (q_t = 0.75 x 26 cars x 3 TEU x 14.3 ton, being 0.75 the load factor of the train); $r_{op}(W, q_t, d_{km})$ is the unitary rail transport operational cost expressed as a function of the train weight (W = 1550 ton – locomotive and 26 wagons), of the capacity of the train, q_t, and of the rail distance between the Port of Antwerp and k. This unitary cost includes costs of depreciation and maintenance of rolling stock, assembling/decomposing train cars, usage of train infrastructure, energy, and staff wages.

4. Rail transport external cost:

$$R_k^{ext} = \left(Q_k / q_t\right) . r_{ext}(W, q_t, l_{km}) \quad [12]$$

where, $r_{ext}(W, q_t, d_{km})$ is the unitary rail transport external cost.

5. Transshipment operational cost:

$$T_k^{op} = Q_k . (2 \times c_t^{op}) \quad [13]$$

where, Q_k is the demand flow between the Port of Antwerp and k; and c_t^{op} is the unitary transshipment operational cost.

6. Transshipment external cost:

$$T_k^{ext} = Q_k . (2 \times c_t^{ext}) \quad [14]$$

where, c_t^{ext} is the unitary transshipment external cost.

MODEL RESULTS

The model was applied to the case study of Belgium. For this case study, the maximum number of terminals to locate (parameter *p*) was assumed to be seven.
To study the implications of adopting different freight cost policies, the application to the case study was done according to three compositions of transport cost:

– Policy I: Only operational costs – a situation of free market, with no intervention from the government, where transport and intermodal terminal operators will minimise their direct costs of operation;

– Policy II: Operational and external costs – this situation is in line with EU policies that aim at internalising externalities of freight transport to strengthen the competitiveness of intermodal transport.

– Policy III: Operational costs and subsidies – this is the current situation in Belgium. According to Pekin et al. (2008), a subsidy scheme, which has been approved by the European Commission, has been implemented by the Belgium government, in order to provide financial support to the intermodal freight transport in Belgium. This subsidy is composed of a fixed part, given to the transshipment's operator (20€/train car) and of a variable part, given to the rail transport's operator (0.4€/km in rail).

The results obtained with the application of proposed terminal location optimisation model for the different policies are presented and discussed below. The location of the potential seven Belgium terminals, the total travel costs, and the best mode choice between each generation node and the Port of Antwerp will be used as reference for the analysis of the results.

Optimal Locations

The configuration of the intermodal freight transport system will depend on the number of terminals to locate. The tables presented below (Tables 3 and 4) summarise the locations of the terminals and the total, operational, external costs and subsidies for each one of the transport cost policies.

Table 3 – Summary of the locations of the terminals for the different transport cost policies.

Policies	Terminals
I	Arlon; Virton
II	Arlon; Virton
III	Arlon; Bilzen; Bütgenbach; Maaseik; Pepinster; Viesalm; Virton

From the Table 3, it can be observed that the terminals in Arlon and Virton are consistent solutions in all the policies. It is also possible to see that with subsidies (Policy III), the number of terminals located is higher.
Table 4 shows that the higher operational costs happen for the scenario where the subsidies are introduced (Policy III), whereas the higher external costs happen when these costs are not taken into account (Policy I). Lower operational costs happen in the Policy I, where only the operational costs are considered, while the lower external costs happen in the Policy III, where both subsidies are added.

Table 4 – Summary of the total, operational, external costs and subsidies for the different policies.

Policies	Total Costs (O.F.) [million €]	Operational Costs [€/tonne]	External Costs [€/tonne]	Subsidies [€/tonne]
I	624.3	19.382	3.859	---
II	748.5	19.389	3.851	---
III	745.3	19.473	3.816	0.149

Policy Analysis

For the first transport cost policy, as mentioned above, only the operational costs were considered. The resulting solution presents two intermodal terminals, one in Arlon and one in Virton (Figure 2). The estimated total transport costs for this solution are equal to 624.3 million €.
The terminal in Arlon will only address the freight flows from and to Luxembourg. Despite the existence of a terminal in Arlon, the freight flows from and to this NUTS 3 will be transported by road. The terminal in Virton will be used by its own demand flows and the demand flows from and to Meuse (France).

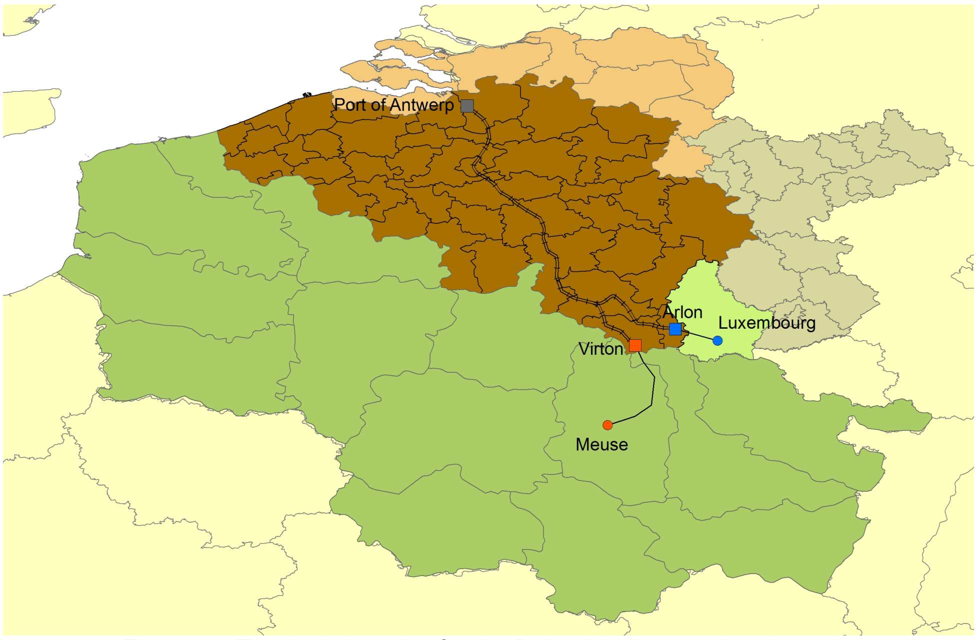

Figure 2 – Terminals location for the Policy I (only operational costs).

By the observation of these results, it is worth wondering why the terminal in Virton addresses only the flows from and to Meuse and does not address the flows from Metz, the NUTS 3 region neighbouring of Meuse. To answer to this question, we calculated the transport costs between these two NUTS 3 regions and the Port of Antwerp (Figures 3 and 4).

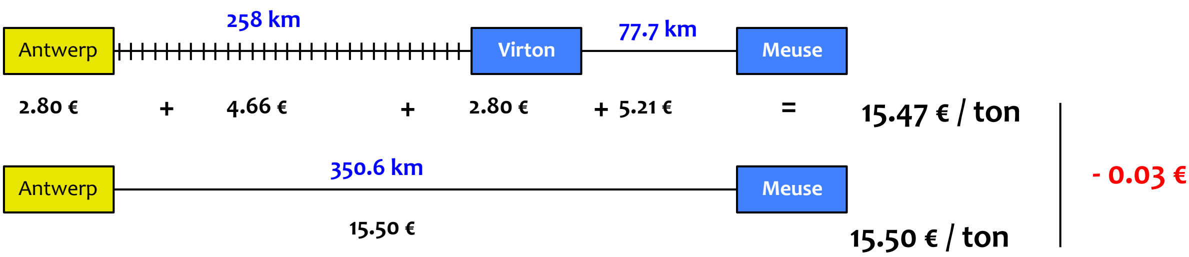

Figure 3 – Comparison of the transport costs between the Port of Antwerp and Meuse.

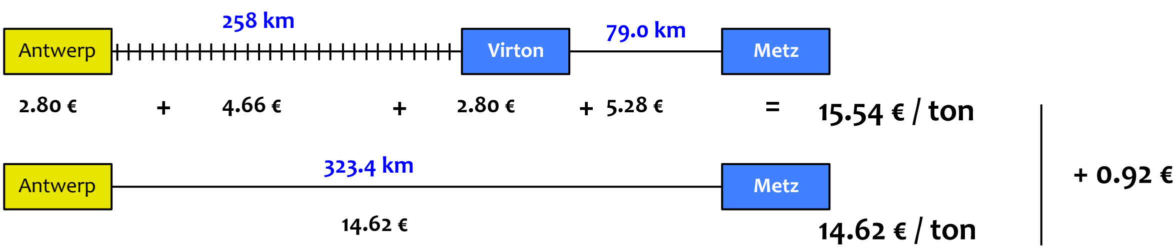

Figure 4 – Comparison of the transport costs between the Port of Antwerp and Metz.

As it is possible to observe from the previous figures, the goods' transport between the Port of Antwerp and Meuse is 0.03 euro less expensive if the intermodal solution is used. On the other hand, if the same comparison is made for the goods' transport between the Port of Antwerp and Metz, the conclusion is that the truck-only solution is the less expensive solution, being almost 1 euro cheaper than the intermodal solution.

Therefore, and after these results, it can be assumed that there is a market area around each intermodal terminal, defined with a specific radius, which represents the distance between the terminal and the freight generation node. From that radius on, the intermodal transport solution is not a worthwhile solution. This means that intermodal transport can only be used if the distance between the terminal and the origin/destination node is inside the catchment area of the terminal, stressing the importance of correctly deciding the location of intermodal terminals.

Based on the terminal located in Virton, lets analyse into detail the case where, from a given freight generation node, we have two options: to transport our goods to a terminal located at 260 km from the Port of Antwerp; or to transport our goods only by road, assuming a distance to the Port of Antwerp equal to 260 km, plus the road distance between our node and the terminal. Figure 5 shows the evolution of the operational costs, per ton, from the Port of Antwerp to the destination/origin of the goods, as a function of the distance between the terminal and the generation node.

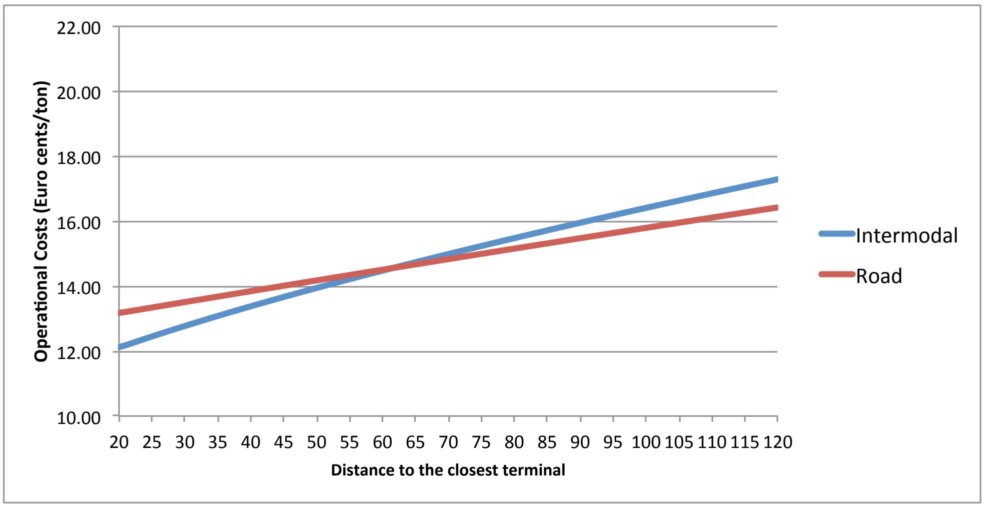

Figure 5 – Operational transport costs per ton as a function of the distance between terminal and the origin/destination node.

It is possible to observe that there is a boundary around 60/70 km, from which the only-road transport starts to become a less expensive solution. This means that the catchment area of the terminals is around 60/70 km (in the opposite direction of the Port of Antwerp).

Then, we propose to analyse what could be the impact of adding external cost in the analysis costs. In this case, it is possible to verify the catchment area is extended (Figure 6 – dashed curves). The new boundary is around 110/120 km away from the intermodal terminal, which is approximately 50 km more than if only the operational costs are considered.

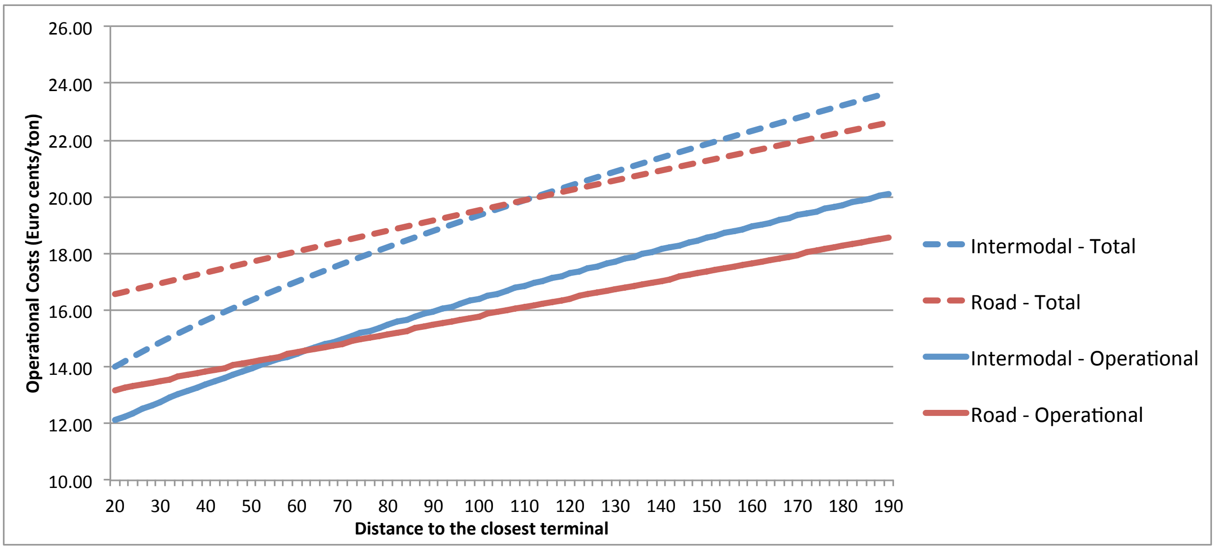

Figure 6 – Transport costs per ton as a function of the distance between the terminal and the origin/destination node.

It can be then assumed that, by considering the external costs in the analysis, intermodal transport becomes more competitive. This conclusion is confirmed by the obtained results for the next transport cost policy, where the analysis was made considering both the operational and the external costs (Figure 7). In this case, the results show that in addition to addressing the freight flows from and to Meuse, the terminal in Virton is also going to be used by the demand flows from and to Metz. The total transport costs for this solution is equal to 748.5 million €.

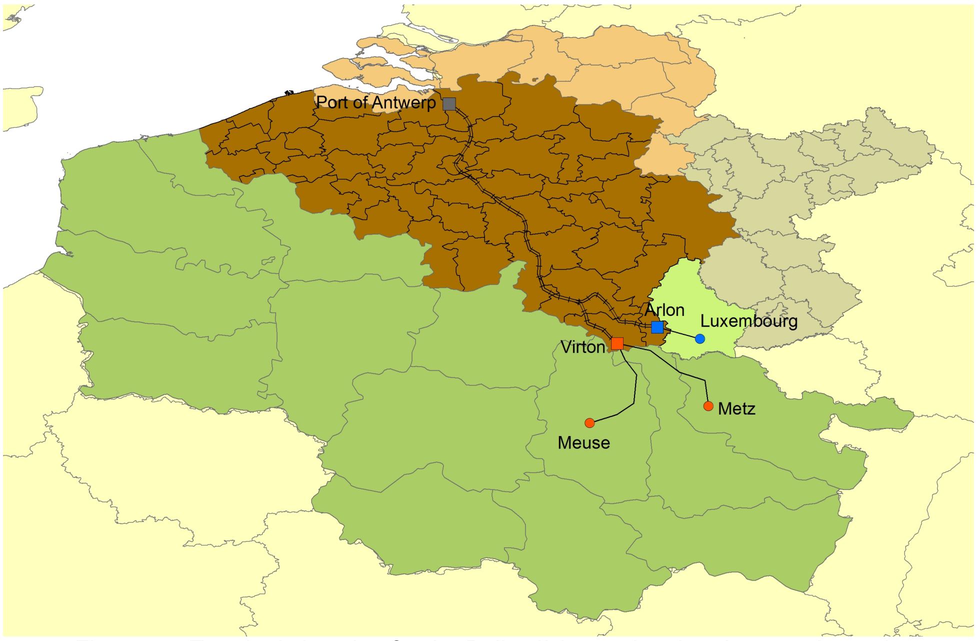

Figure 7 – Terminals location for the Policy II (operational and external costs).

The third and final transport policy, as explained above, consists in integrating the Belgium government subsidies. The obtained results from this policy, considering the subsidies values discussed in Pekin et al. (2008), are represented in Figure 8.

As it is possible to observe, with the addition of the subsidies, the intermodal network expands and there are a higher number of terminals located (equal to the maximum number of terminals considered, seven). The solution presents terminals in Maaseik, Bilzen, Pepinster, Bütgenbach, Arlon, Viesalm and Virton. The terminal in Maaseik is used by the demand flows of Roermond (Netherlands); the terminal in Bilzen addresses the freight flows from and to Maastricht (Netherlands); the terminal in Pepinster only addresses its own demand flows; the terminal in Bütgenbach is used by its own containers and the containers from and to Aachen, Kreis and Euskirchen (both in Germany); the terminal in Arlon addresses the flows from and to Arlon, Luxembourg, Trier, Kreisfreie Stadt and Trier-Saarburg (the last two in Germnay); the terminal in Viesalm is used by the freight flows from and to Viesalm, Daun, Bernkastel-Wittlich and Bitburg-Prüm (the last three in Germany); finally, the terminal in Virton addresses the demand flows from and to Virton, Meuse, Metz, Nancy and Haute-Marne (all in France). The total transport costs for this solution is equal to 745.3 million €, 0.43% lower than in the previous solution (Policy II).

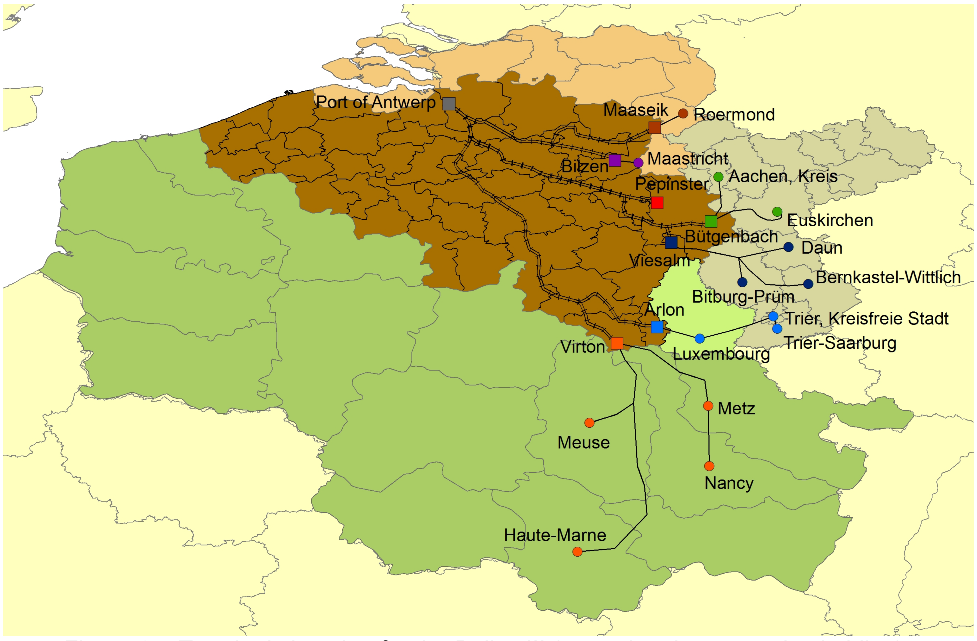

Figure 8 – Terminals location for the Policy III (operational costs and subsidies).

It is also possible to see that the terminals are all located in the east side of Belgium, which can be explained by the higher distances between the Port of Antwerp and these NUTS 3 regions. This evidences the idea that intermodal transport is only competitive when the rail line-haul is long enough to counterbalance the transshipment costs.

CONCLUSIONS

This paper proposes an optimisation model for the location of intermodal terminals in an inland intermodal freight transport system, using nonlinear cost functions to assess transport and transshipment costs. The intermodal freight transport system of Belgium was used as a reference case study for this work, in order to illustrate the capability of the model to analyse the implications of transport costs policies, such as the subsidising intermodal freight transport operators (as the Belgian government currently does) and the internalising of transport external cost (a EU policy goal).

The obtained results validate the adopted methodology and, in particular, the proposed model and enable the drawing of some conclusions. The location of the intermodal terminals is an important issue for intermodal freight transport competitiveness. The model got very similar results to the currently existing situation in Belgium, in terms of the chosen locations for the terminals. A catchment area can be defined around each transshipment terminal, which represents the distance between the terminal and the origin/destination node, from which on the intermodal transport solution becomes not worthwhile. This catchment area increases if the external costs are included in the decision process.

The results also show that, for a small country as Belgium, if the real expected transport costs are considered, road transport is the transport mode chosen to do the majority of the freight journeys. However, the competitiveness of intermodal transport increases when rail transport or transshipment costs are subsidised by the government, as it was possible to observe by the different policies tested. Like this, the intermodal freight transport can become very competitive, even for short distances inside Belgium. It is worth noting that almost all the terminals proposed in the solutions obtained, cover the demand flows from the border countries of Belgium, especially from Germany and France. This means that, despite of the small area of the country, due to its location, Belgium is a very promising candidate to promoting intermodal transport. The transshipment terminals located in Belgium enable the response to the demand flows from large economy and industry centres in Europe. This indicates that, perhaps, the EU should at a certain level, support the subsidies given by the Belgium government.

Although policies involving the subsidising of intermodal transport largely increase the competitiveness of intermodal transport and the volume of freight that migrates to rail, the inclusion of externalities in the total cost of transport does not seem to have a big impact in the competitiveness of intermodal transport.

These results are part of ongoing research. We are currently improving this work. For instance, in terms of the demand, in future works we will take into account the inclusion of the freight flows from the other seaports of Belgium (Zeebrugge and Ghent). Also, it will be added to the demand data the flows between the different NUTS 3 regions of Belgium, which do not have origin or destination in the maritime ports. Other important innovation will be to consider that part of the international cargo will arrive in Belgium by train. This can be done in part by including in the model some of the foreign terminals located next to the Belgium border. This work can also be improved by considering inland waterways, which in practice influence the location of some rail-road terminals, and by taking into account the railway lines capacity, which is a relevant aspect, given the current reduced available capacity in Central Europe railway lines.

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