Inland intermodal freight transport modelling

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1. INTRODUCTION

People and goods mobility is a key issue in the vitalization 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 globalization and to 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 EU of 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.

The EU needs to change transport paradigm in order to increase the efficiency of its transport system. New competitive transport patterns are required and should emerge. 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, rail-air (European Commission, 2011).

1.1. 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 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) by successive modes of transport without handling of the goods themselves when changing modes” (European Conference of Ministers of Transport, 1997). 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 goods' transition between the different modes of transport is usually done in an intermodal (or transhipment) terminal, where a change occurs between modes of travel or between transport networks.

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 highlighted in 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 of intermodal transport. Nevertheless, intermodal transport can benefit from the inherent advantages of each mode. 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 transhipments. 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 transhipment 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).

1.2. 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. In the specific segment for container handling, the port of Antwerp became in 2010 the second largest container port in Europe right behind the Port of Rotterdam (Eurostat). 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 transhipment, 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. 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 the Belgian government subsidies 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 optimization 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 subsidies to transport and transhipment operations. The last section is dedicated to the final conclusions of this work and to future research topics.

2. PROBLEM STATEMENT

The problem of locating freight terminals is not new in the literature. In fact, 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, he 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.

The previous works deal with different scales of intermodal freight, but all of them make use of factorial analysis of the costs. In this paper, the terminal location problem is defined at the strategic level of intermodal transport planning. Transportation and transhipment costs are defined according to composite costs formulas that take into account the different components of the cost (e.g., energy, salaries, maintenance, noise). In the next sections we explain how we estimated the flows, defined the potential locations of the transhipment terminal and the road and rail used to estimate the costs.

2.1. 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 transhipment 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).

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

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.

2.2. Belgium Road and Rail Networks

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).

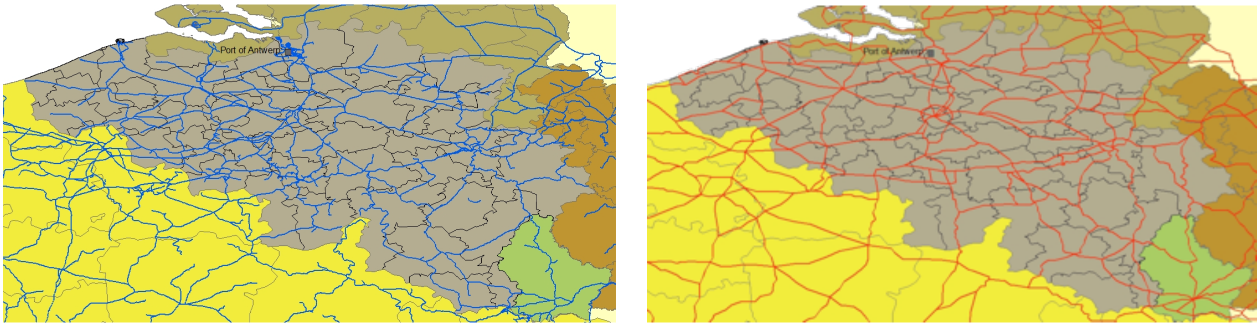

Figure 1 – Transportation networks: left – road network; right – rail network.

2.3. Potential Locations for Terminals

The set of potential locations for the terminals was selected assuming that the decisions can only regard locations inside Belgium. Thus, the transhipment terminals have to be located in nodes that belong to both, the road and the rail networks of Belgium.

3. OPTIMISATION MODEL

The location of transhipment terminals is defined as a discrete problem that locates terminals according to a set of possible locations, enabling the transhipment 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:

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

Subject to:

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

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

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

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

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

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

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

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 transhipment 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 transhipment 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 transhipment, 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 transhipment. 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 transhipment, implying that the freight transport is only made by road.

The constraint [2] indicates that no more than p transhipment terminals are going to be located. Constraint [3] guarantees that all the demand is satisfied (either with transhipment or without transhipment) 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 transhipment terminal (necessary capacity). Constraint [5] stipulates that transhipment is not possible, unless there is a transhipment terminal in k. Finally, constraints [6], [7] and [8] are standard non-negativity and integrality constraints.

3.1. Transport and Transhipment Costs

The road, rail and transhipment costs used in the model are based on the works of Daganzo (1999) and Janic (2007). 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:

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

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:

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

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:

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

where, $r_{ext}(W, q_t, d_{km})$ is the unitary rail transport external cost. This unitary cost includes costs of noise, local and global air pollution from energy consumption, accidents, and congestion.

5) Transhipment 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 transhipment operational cost.

6) Transhipment external cost:

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

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

4. 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.

The analysis of the results was divided in two parts:

1) Analysis of including external costs in the decision process;
2) Analysis of the impact of different levels of intermodal subsidies.

In the first part, the analysis is done only considering the real transport and transhipment costs. Two different scenarios are studied (with subsidies equal to zero):

1.1) Considering only the operational costs;

1.2) Considering both operational and external costs.

In the second part of the analysis, the subsidies given by the Belgium government to the intermodal freight transport are taken into account. 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 transhipment's operator (20€ / train car) and of a variable part, given to the rail transport's operator (0.4€ / km in rail). The Belgium government, given directories from the European Commission, is currently progressively reducing these subsidies. According to this, five more scenarios are studied:

2.1) Considering both transhipment and rail transport subsides;

2.2) Considering only the rail transport subsidy;

2.3) Considering only the transhipment subsidy;

2.4) Considering a 50% reduction of both subsidies;

2.5) Considering a 25% reduction of both subsidies.

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.

4.1. Cost Analysis Scenarios

For the first scenario, 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).

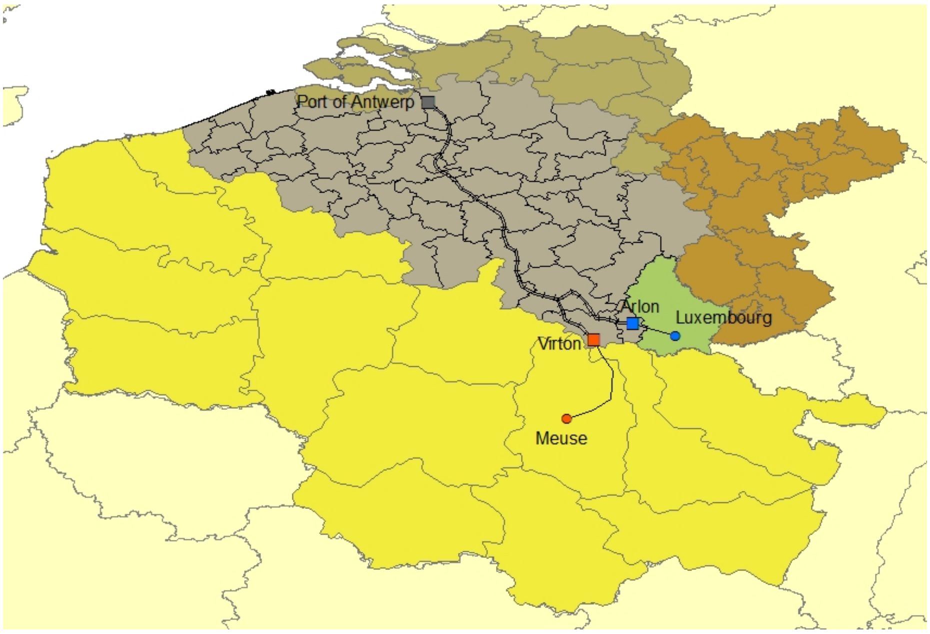

Figure 2 – Terminals location for the Scenario 1.1) Considering only the operational costs.

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).

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.

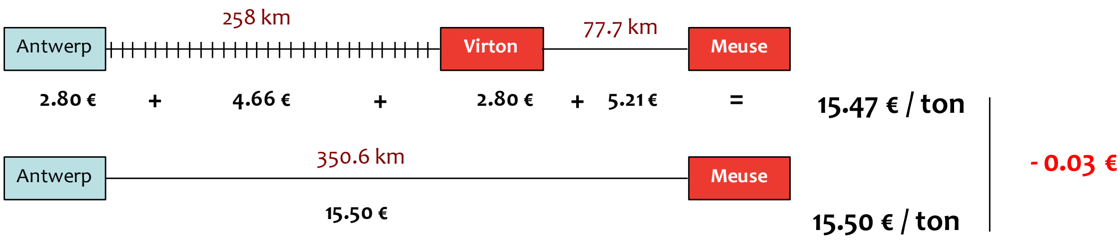

Figure 3 – Comparison of the total transport costs, between the Port of Antwerp and Meuse, for both intermodal and only-road solutions.

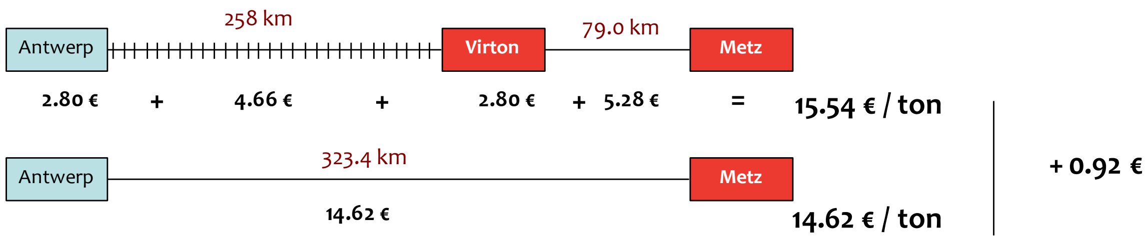

Figure 4 – Comparison of the total transport costs, between the Port of Antwerp and Metz, for both intermodal and only-road solutions.

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 this 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, as a function of the distance between the terminal and the generation node.

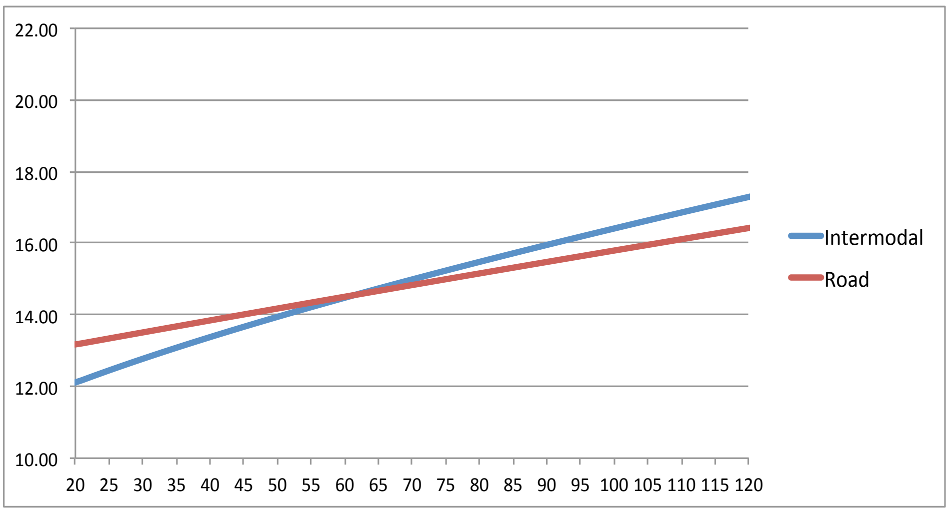

Figure 5 – Operational transport costs per ton (€/ton), by distance between the terminal and the origin/destination node (km).

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.

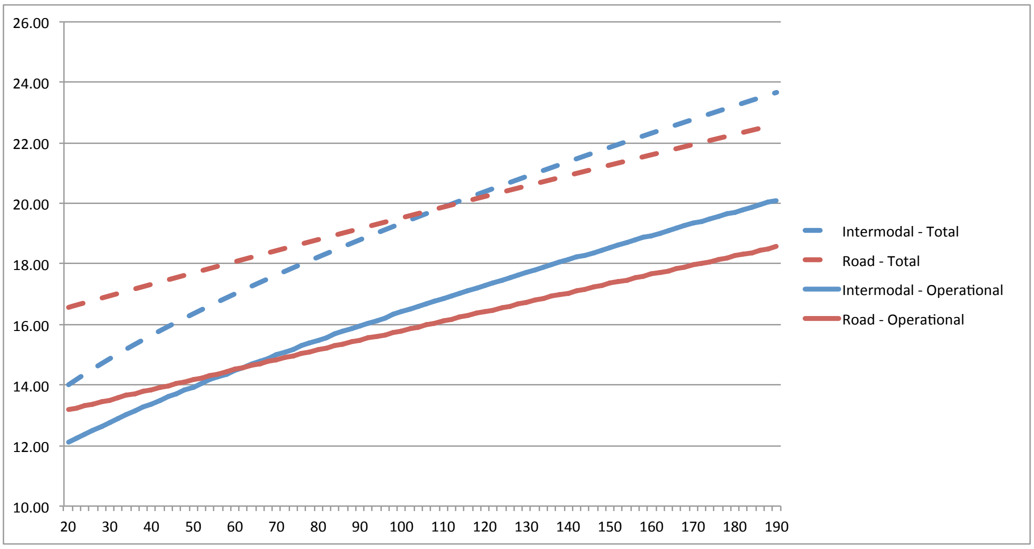

Figure 6– Total transport costs per ton (€/ton), by distance between the terminal and the origin/destination node (km).

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 scenario, 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 €.

4.2. Subsidies Scenarios

The second part of the results' analysis, as explained above, consists in integrating the Belgium government subsidies in total transport costs. The obtained results from the scenario 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 (Scenario 2.1).

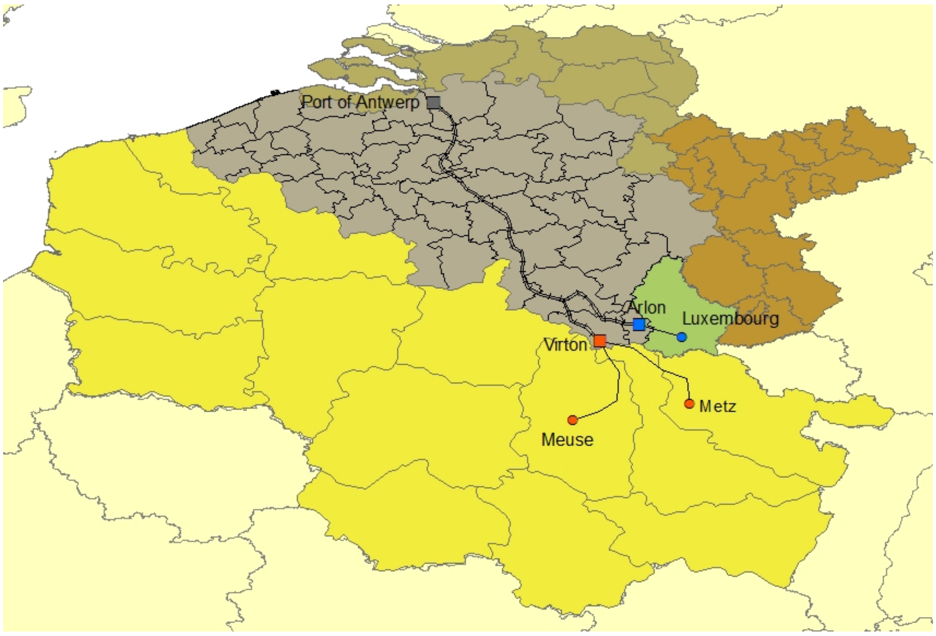

Figure 7 – Terminals location for the Scenario 1.2) Considering both operational and external costs.

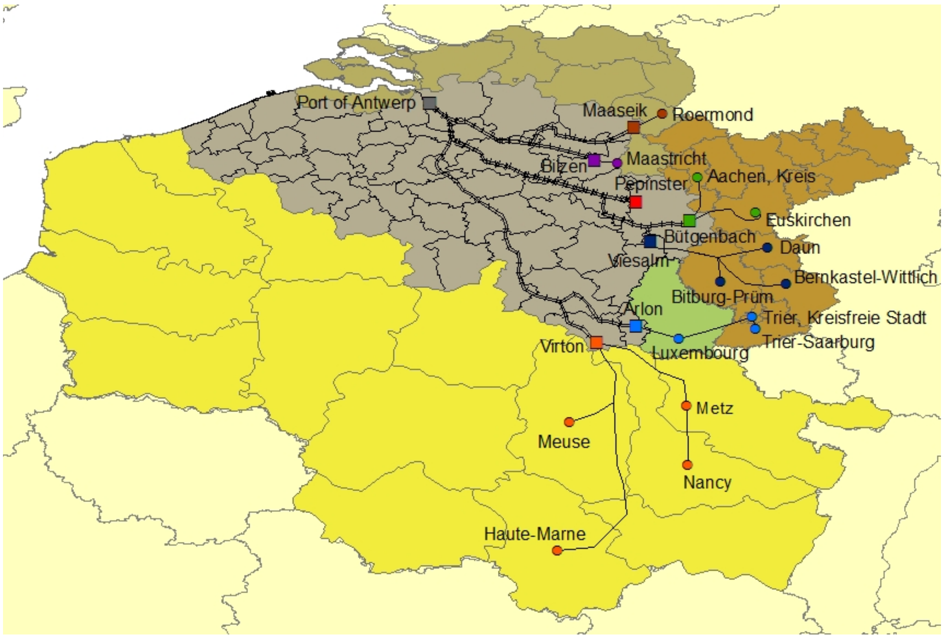

Figure 8 – Terminals location for the Scenario 2.1) Considering both transhipment and rail transport subsides.

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 transhipment costs.

For the scenario where it is considered a reduction of 50% of both subsidies, it is possible to observe that, as foreseeable, a less number of terminals are located and, consequently, less freight flows are addressed by the terminals (Figure 9). The total transport costs for this solution is 747.3 million €, only 0.16% lower than the solution for Scenario 2.1.

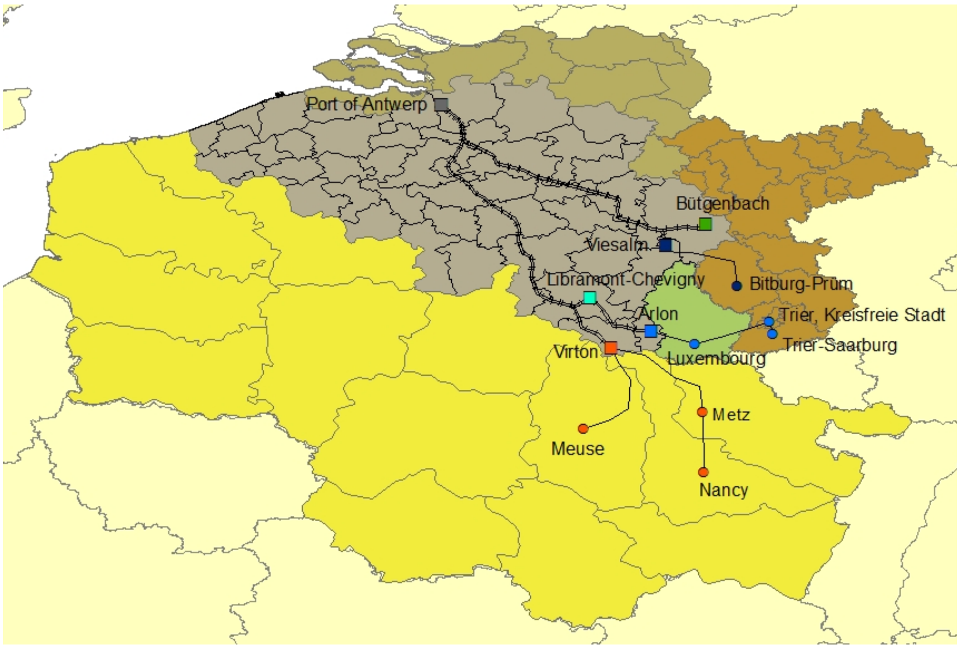

Figure 9 – Terminals location for the Scenario 2.4) Considering a 50% reduction of both subsidies.

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 studied scenarios.

Table 3 – Summary of the locations of the terminals, for the different scenarios.

Scenarios	Terminals
1.1	Arlon; Virton
1.2	Arlon; Virton
2.1	Arlon; Bilzen; Bütgenbach; Maaseik; Pepinster; Viesalm; Virton
2.2	Arlon; Bütgenbach; Libramont-Chevigny; Maaseik; Pepinster; Viesalm; Virton
2.3	Arlon; Bütgenbach; Libramont-Chevigny; Virton
2.4	Arlon; Bütgenbach; Libramont-Chevigny; Viesalm; Virton
2.5	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 scenarios. It is also possible to see that with subsidies, the number of terminals located is higher.

Table 4 shows that the higher operational costs happen for the scenario where the subsidies are introduced (Scenario 2.1), whereas the higher external costs happen when these costs are not taken into account (Scenario 1.1). Lower operational costs happen in the Scenario 1.1, where only the operational costs are considered, while the lower external costs happen in the scenario 2.1, where both subsidies are added.

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

Scenarios	Total Costs (O.F.) [million €]	Operational Costs [€/tonne]	External Costs [€/tonne]	Subsidies [€/tonne]
1.1	624.3	19.382	3.859	---
1.2	748.5	19.389	3.851	---
2.1	745.3	19.473	3.816	0.149
2.2	746.1	19.439	3.828	0.101
2.3	748.2	19.393	3.848	0.011
2.4	747.3	19.409	3.839	0.048
2.5	746.4	19.43	3.831	0.086

5. CONCLUSIONS

This paper proposes an optimisation model for the location of intermodal terminals in an inland intermodal freight transport system. The intermodal freight transport system of Belgium was used as a reference case study for this work.

The obtained results enable the drawing of some conclusions. The location of the intermodal terminals is an important issue for intermodal freight transport competitiveness. A catchment area can be defined around each transhipment 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, when rail transport or transhipment costs are subsidised by the government the external costs decrease and the competiveness of intermodal transport increases. 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 transhipment 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.

Despite the applicability of the proposed model, this work is still at an initial stage and will surely be improved. There are some aspects that were not taken into account, which probably could have influenced the results obtained with the model. This is the case of the terminals construction costs. Perhaps by considering the costs of having a new terminal, the results would not show the neighbouring terminals in Arlon and Virton at the same time. Also the waterway movements in Belgium were not taken into account, which may influence the results, since the waterways are a transport mode often used to do the freight journeys inside Belgium.

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.

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