



## The impact of transport policies on railroad intermodal freight competitiveness – The case of Belgium



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### ARTICLE INFO

#### Keywords:

Railroad intermodal transportation  
Terminal location  
Railroad modal split  
Transport policies

### ABSTRACT

This paper discusses the impact of three freight transport policies aiming to promote railroad intermodal transport in Europe, and examines the case of Belgium as a testing ground. These policies consist in subsidizing intermodal transport operations (such as in Belgium, to stimulate rail transport), internalizing external costs (as recommended by the European Union in order to foster cleaner modes), and adopting a system perspective when optimizing the location of inland intermodal terminals. The study proposes an innovative mixed integer intermodal freight location-allocation model based on hub-location theory and deals with non-linear transport costs in order to replicate economies of distance. Our analysis suggests that subsidizing has a significant impact on the volumes transported by intermodal transport, and, to a lesser extent, that optimizing terminal location increases the competitiveness of intermodal transport. On the other hand, according to our assumptions, internalizing external costs can negatively impact the promotion of intermodality. This finding indicates that innovative last-mile transports are needed in order to reduce the external impacts of drayage operations.

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### Introduction

Freight transport in Europe has grown by almost 40% over the last two decades while the number of truck movements has increased at an even higher rate. Ground freight is now the predominant option in Europe with market share in the EU27 growing from 73.7% in 2000 to 75.6% in 2011 (Eurostat). This comes from the greater flexibility and general economic competitiveness of the mode but partly also from the changes in production principles observed over the last decades. The freight context in Europe has shifted from heavy bulk cargo (e.g. steel and coal) to lighter cargo shipments involving smaller shipment size and more frequent freight services over longer distances. This shift has boosted road and air transport in Europe (Hesse and Rodrigue, 2004).

The present trend increases pressure on transport infrastructures and extends the negative impacts of transportation (e.g. emissions, noise, congestion, fuel consumption, economic losses). Consequently, in the current Transport White Paper, the European Union (EU) presents a roadmap for a more competitive and sustainable European transport system (COM, 2011). Concerning freight, one of the goals of the EU is to shift 30% of long-distance (over 300 km) road transport to more efficient modes, such as rail or water by 2030 and 50% by 2050.

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Containerizing cargo can be seen as an alternative option for the transport of lower volume flows, while offering the opportunity to consolidate goods and achieve economies of scale. In addition, as was pointed out by [Notteboom and Rodrigue \(2005\)](#), lack of space and congestion at seaport areas increases the relevance of inland intermodal terminals in the freight transport system in providing reliable connections and stimulating competition for distant hinterlands.

This situation has led to increasing interest in intermodal freight transport (i.e. the combination of at least two modes of transport without a change of loading unit, and where the long-haul mode is normally rail or inland waterways). This combination of modes is promoted by the EU as part of the solution to increase rail mode share and to foster more sustainable transport in Europe. Yet, despite the many advantages of this transport option and the various initiatives launched to increase intermodality, the share of intermodal transport in Europe remains limited – only about 5% of the total EU freight transport flows are made via intermodal routes ([Savy and Aubriot, 2005](#)). New transport policies are needed to change the European cargo paradigm and to increase this market share.

The potential markets for intermodal transport are large-flow routes over long distance. Small as they are, Belgium and the Netherlands still feature among the countries having the highest share of intermodal freight transport in Europe. According to Eurostat figures, road transport prevails in Belgium, with a market share of 66.3% (versus 77.4% in 2000) in terms of t-km. There are, however, increasing flows for rail (15.2% in 2011 versus 11.6% in 2000) and inland waterways (18.5% in 2011 versus 10.9% in 2000). Despite manifest improvement in Belgium, there remains ample spare capacity for these so-called alternative transport modes.

This paper, therefore, focuses on intermodal transport in Belgium and specifically on continental freight transport, considering road, rail and their combination. It analyzes the impact on freight transport of adopting three policies: subsidizing intermodal transport, internalizing external costs and adopting a system-wide perspective for strategically locating intermodal terminals. Subsidizing intermodal transport is a current practice in Belgium and internalizing external costs has been studied by the European Commission for several years. As to the third policy, we investigate the potential (in)efficiency of the fixed transport system with regard to the current location of the Belgian terminals. The hypothetical scenario tested here measures the gap between the current terminal locations and an optimal configuration.

For this analysis, a mixed integer-programming model is presented. The decisions to be made relate both to the location of railroad intermodal terminals in the network and to the allocation of freight flows between the modes with the view to minimize total transport costs. These can include direct operational costs, external costs and subsidies for intermodal operations. The model is based on the  $p$ -hub location problem. Most of mixed-integer linear programming formulations for the  $p$ -hub problem involve a large number of allocation decision variables representing the fraction of the total flow from and origin to destination node via two specific hubs. In network hub location problems with every origin and destination node as a candidate hub node, there are variables of size  $O(n^4)$  where  $n$  is the number of potential hub nodes. According to the survey made by [Farahani et al. \(2013\)](#), the models proposed by [Ernst and Krishnamoorthy \(1996, 1998\)](#) are the only one to use variables of size  $O(n^3)$ . The variables in their models treat the inter-hub transfers as a multi-commodity flow problem. Each commodity represents the traffic flow originating from a particular node. Their formulation decreases the problem size in number of variables by a factor  $n$ . As in [Ernst and Krishnamoorthy \(1998\)](#), these variables are also used in our model but with a relaxation of some traditional constraints in order to better reflect the reality of intermodal freight transport. To the best of our knowledge, this work is the first to use this formulation to address a real intermodal freight problem. In addition, it makes use of non-linear transport cost functions capturing the effect of economies of distance and reflecting the concept of economies of scale.

In what follows, we review some of the most relevant literature on intermodal freight transport and our own contribution (Section ‘Literature overview’); we present the case of Belgium (Section ‘Problem definition’), the methodology, the model proposed (Section ‘Methodology’), the results of our case study and the implication of the different policies tested (Section ‘Results’); and draw conclusions (Section ‘Conclusions’).

## Literature overview

As an emerging research area, intermodal freight transportation, has gained growing research interest over the last two decades (see [Caris et al. 2008, 2013](#) for a review on this). As yet, several authors have addressed the strategic planning of these multimodal systems, mostly through developing operational research techniques ([Macharis and Bontekoning, 2004](#)). [Rutten \(1995\)](#) was one of the first to address this issue. His study aimed to define terminal locations likely to generate sufficient freight demand in order to operate daily trains to and from the terminal. [van Duin and van Ham \(2001\)](#) identified the optimal locations while incorporating the perspectives and objectives of different stakeholders, and developed a specific model for each decision level (strategic, tactical and operational).

More recently, a substantial number of analytical works addressing intermodal transport issues have appeared. Among these, [Arnold et al. \(2004\)](#) used an integer-programming model and heuristics to locate railroad terminals by minimizing the total transportation cost. Assuming the unit transport costs and transshipment costs to be constant and applying the proposed methodology to the Iberian Peninsula, they concluded that modal share is very sensitive to the relative costs notwithstanding the fact that these have little impact on the location of terminals. [Limbourg and Jourquin \(2009\)](#) discussed the location of terminals in a European road-rail network. Their main methodological contribution was the iterative procedure used in combining the results of both the location and the multi-model assignment problems. The concept of market area

and the shape of this area around intermodal terminals were discussed on year later by the same authors (Limbourg and Jourquin, 2010). Ishfaq and Sox (2011) and Alumur et al. (2012) proposed to introduce travel time constraints in the intermodal freight location-allocation. The latter analyzed the trade-off between cost efficient routes and transport time constraints with the Turkish network data set, modelling the competition between ground and air transport.

As intermodal networks are combinations of their respective modal networks, the hub network has emerged as the most suitable solution for intermodal transport network (Bookbinder and Fox, 1998). Woxenius (2007) discusses various designs of transport system on their operational character and their application into passenger, freight and rail freight transport, and then apply to intermodal freight transport. Kreutzberger (2006, 2008, 2010) also considers bundling strategies from different perspectives. In the literature relating to the network hub location problem, the economies of scale due to flow consolidation between hubs are typically incorporated by discounting the inter-hub connection cost by a fixed discount factor (Alumur and Kara, 2008). The same holds for the literature on intermodal transport systems. In the aforementioned works, the economies of scale are also represented through the use of a fixed discount factor for rail or air transport costs, i.e. the authors considered flow-independent functions. Other authors, such as Racunica and Wynter (2005) and Ishfaq and Sox (2010) account for economies of scale by using a non-linear concave cost function. In both works, the optimization model is kept linear by adopting piecewise linear functions to approximate these non-linear functions. Nonetheless, they both proposed heuristics solution methods to tackle the optimization models.

The present work makes a step forward by considering economies of distance and by including external costs (i.e. noise, congestion, air pollution, energy consumption, accidents) in the estimation of total transport costs. Economies of distance reflect the fact that unit transport costs are inversely proportional to the distance travelled. They play a central role on the competitiveness of intermodal transport in the sense that economies of distance are usually more effective for the inter-terminal modes than for road transport (Janic, 2007). While the effects of economies of distance have as yet not been addressed in the intermodal freight design problem, we do it here by adopting the non-increasing non-linear cost functions proposed by Janic (2008). Economies of scale are indirectly considered in the formulation of the road and rail cost functions – e.g. by assuming a standard load factor per mode in order to represent flows consolidation and by computing rail costs based on a normal frequency of five trains per week running between terminals. With these assumptions, the linearity of the optimization model is kept and can be solved up to optimality within reasonable time (less than 10 min).

The main motives to promote intermodal freight transport in the EU are to reduce excessive external costs. Beuthe et al. (2002) use simulations of freight traffic over the Belgian road, rail and inland waterways networks. They study the external effects of interurban freight transport for 10 different categories of goods. The results of the simulation suggested that a road pricing policy, following an internalisation strategy, could be very effective in shifting road flows to rail and inland waterways. Based on a GIS location analysis model, Macharis et al. (2010) compare the impact on railroad and barge-road intermodal market share of fuel price increases and of external costs internalization. They conclude that the market areas of intermodal terminals only expand in proportion with fuel prices. When fuel price increases are small, the intermodal option is less interesting, given the increase on pre- and post-haulage prices and marginal benefits on the long haul. The authors briefly describe the internalization of external costs but suggest that the impact of such a policy would be larger than the scenario of doubling fuel prices. To our knowledge, though, the present research is the first to address external costs in the intermodal freight location-allocation optimization problem and to discuss the implications of adopting different policies on the operations of the freight system (i.e. location of the terminals, amount of subsidies and operational costs).

Besides, whereas most of the papers presented in the literature deal either with aggregated data or with the context of a closed country, we propose a case study based on disaggregated data and extend the regional scope of the Belgian context by considering the existence of terminals at neighbouring countries and of flows generated in other European countries.

## Problem definition

The case of Belgium is used to illustrate the applicability of the proposed location-allocation model and to discuss the implications of adopting different cost policies. The description of the case study and the tested policy scenarios are provided in the following sections.

### Freight transportation in Belgium

Belgium has a strategic location within Europe. Being part of Benelux and lying halfway between Paris and the industrial Ruhr area, the country is located at the heart of the European production system and has one of the densest road and railway networks in the world. Its freight transportation system heavily relies on the Port of Antwerp, the second largest container port in Europe, right behind the Port of Rotterdam. Belgium also has two smaller container ports, those of Zeebrugge and Ghent. According to their annual reports, the three ports altogether handled 11,884 thousand TEUs (20-foot equivalent units) in 2011. The Port of Antwerp was responsible for 73% of this traffic while that of Zeebrugge transhipped around 18%. Railroad traffic is just a part of these volumes (e.g. 34% in the case of the Port of Antwerp<sup>1</sup>).

<sup>1</sup> [www.portofantwerp.com](http://www.portofantwerp.com).



Fig. 1. Spatial disaggregation of Belgium and Neighbouring NUTS 3 units.

Despite Belgium's small surface area, intermodal freight has an important role in the country's freight transportation system. Over the past years, the Belgian federal and regional governments introduced several measures to stimulate the intermodal transportation market, even on short distances. For instance, the Belgian Government provides subsidies for this type of transportation with the view to increase the modal share of intermodal rail transportation. In 2006–2007, the Belgian Government granted an annual subsidy of 30 million euros to the intermodal operators in Belgium (Pekin et al., 2008). Financial support, though, has gradually been reduced over the last years. For 2014, the total value of subsidies is estimated at 15 million euros.

#### Definition of the inputs

The demand data used in this study was obtained from Carreira et al. (2012). Only containerized rail and road traffic flows were included in the demand dataset for this study. The original 2005 database was extrapolated to 2010 based on aggregated flow values available from Eurostat and from Belgian ports' annual outlooks. This database is structured according to second-level Nomenclature of Territorial Units for Statistics (NUTS).<sup>2</sup> Afterwards, the NUTS 2 demand flows were disaggregated to a NUTS 3 level within Belgium and the neighbouring regions. The number of companies of productive sectors located in those regions was assumed as a proxy indicator for this disaggregation. In total, the studied area was divided in 44 Belgian NUTS 3 regions, and 40 foreign NUTS 3 regions, including 17 regions in Germany, 13 in France, one in Luxembourg, and nine in the Netherlands (Fig. 1). The demand at each of these regions was concentrated on a single generation node. The choice of these nodes was made according to the importance of the cities in the NUTS 3 region and the existence of a rail platform nearby.

In order to cover the large part of the freight flow movements with other countries in Europe, eight artificial generation nodes were also included in the analysis:

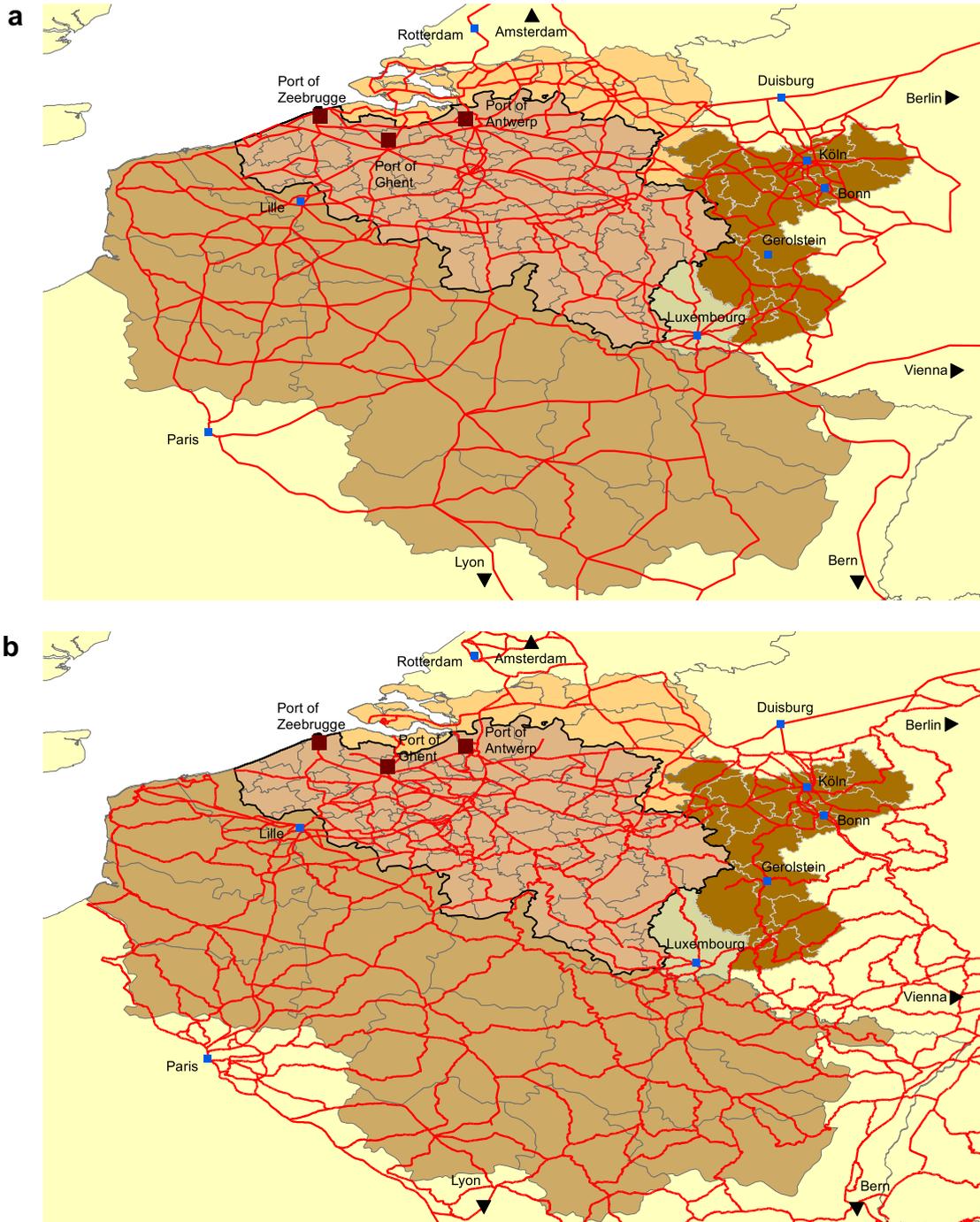
- Rotterdam, representing the port of Rotterdam and the South of the Netherlands;
- Amsterdam, representing the rest of the Netherlands;
- Duisburg, representing the Ruhr region in Germany;
- Vienna, representing the South of Germany, Austria, Hungary, Slovakia and the Balkans;
- Berlin, representing the rest of Germany;
- Bern, representing Switzerland;

<sup>2</sup> The NUTS is a European geographic designation for referencing the administrative divisions of countries. This is a three-level hierarchical classification that provides a single uniform breakdown of territorial units for the production of regional statistics for the EU. In Belgium, the NUTS 3 regions correspond to the *arrondissements* while NUTS 2 correspond to the provinces.

- Lyon, representing Italy and the South of France;
- Paris, representing Spain and the rest of the North and West of France.

Flows from and to these artificial nodes were divided into road and rail flows, according to the mode used as indicated in the original database. In our model, these flows cannot change mode before arriving at or departing from our study area.

On the supply side, we considered the transport networks available at Eurostat (for details, see [Carreira et al., 2012](#)). Both rail and road networks were used to compute travel distances between each pair of generation nodes or intermodal terminals ([Fig. 2](#)). For this calculation, the shortest paths in distance were used. For the sake of simplicity, the Belgian inland waterway system is not considered in this study.



**Fig. 2.** The reference intermodal network (a) Road network, (b) Rail network.

The two networks were linked at special nodes representing the intermodal terminals. According to AGORA Intermodal Terminals database, besides the terminals associated with the three seaports, Belgium has six major hinterland terminals: in Liège, in Genk (NUTS 3 region of Hasselt), in Muizen (NUTS 3 region of Mechelen), in Charleroi, in Athus (NUTS 3 region of Virton), and in Mouscron. Beside these, we also considered non-Belgian terminals located in the vicinity of the Belgium border. Namely, we included the terminals located in Luxembourg; Bonn, Köln, Gerolstein, and Duisburg in Germany; and Lille in France. (The French terminal is located very close to the Belgian border and is a major competitor of the Belgian terminal of Mouscron).

### Proposed scenarios

To study the implications of adopting different freight cost policies in the Belgian context, we suggest analyzing four scenarios:

- Scenario 0 is the reference case. It represents the current situation, with the existing Belgian terminals and the subsidies provided by the Belgian government;
- Scenario 1 considers the situation where subsidies are no longer provided and takes the six existing terminals in account. This scenario allows us to assess the impact of subsidies.
- Scenario 2 considers the case of a changeable location for the six Belgian terminals. It takes subsidies into account and the fact that the railroad terminals can be located at the generation centre of any NUTS 3 region in Belgium. This scenario allows us to analyze potential fixed transport system inefficiency given the current terminal locations in Belgium.
- Scenario 3 is in line with EU goals and considers the case where external costs are added to operational costs and subsidies. It takes the current terminal locations into account.

The demand for each scenario was assumed to be equal. This means that in our study it was not considered the impact of each policy in the total demand of freight flows.

### Methodology

To study the impact of the different transport policies, a location-allocation intermodal freight model is presented. In this model, terminals can be pre-defined (transforming the model into an allocation model) or their location can be part of the decision process. In the latter case, a set of potential locations is provided. The allocation of flows between modes and to each terminal will depend on the competitiveness of the two transport options – only road or intermodal. In this paper, it is assumed that most of the cargo does not have a high value and does not involve perishable goods. Thus, the allocation is done by comparing transport costs in the two options.

In this paper, the road, rail and transshipment costs used in the model are based on the works of Daganzo (1999) and Janic (2007, 2008). The latter developed a model for calculating comparable combined operational (or internal) and external costs of intermodal and road freight transportation networks. Operational costs are the operational-private costs supported by the transportation and intermodal terminal operators, including different components such as personnel, energy, and stock depreciation and maintenance, and rail infrastructure charges. External costs include the impacts of the networks on society and on the environment and consist in local and global air pollution, congestion, noise pollution, and traffic accidents.

### Cost functions

#### Road transportation operational cost

$$C_{jk}^o = \frac{D_{jk}c^o(d_{jk})}{\lambda_j M_j} \quad (1)$$

where,  $D_{jk}$  is the demand flow between  $j$  and  $k$ ;  $c^o$  is the unitary road transportation operational cost, expressed as a function of the road distance,  $d_{jk}$ , between  $j$  and  $k$ ;  $\lambda_j$  is the load factor of each vehicle (for the Belgian case study, this factor is assumed to be equal to 0.85 for the long-haul road transportation, and 0.60 for the collection and distribution transportation inside a NUTS 3 region where a terminal exists. In the latter case, it was considered that the vehicles travel, on average, 12 km); and  $M_j$  is the capacity of each vehicle ( $M_j = 2 \text{ TEU} \times 12 \text{ tonnes}$ ).

Using a regression analysis, Janic (2007) determined that  $c^o(d_{jk}) = 5.4563d_{jk}^{-0.2773}$  in €/vehicle·km. Thus, in terms of €/t·km, the long-haul operational road transportation cost for travelling from node  $i$  to node  $k$  is  $C_{ik}^o = \frac{5.4563}{0.85 \times 2 \times 12} d_{jk}^{-0.2773} = 0.2675d_{ik}^{-0.2773}$  and the collection/distribution operational road transportation cost for travelling from node  $i$  to terminal  $k$  is  $C_{ij}^{o'} = \frac{5.4563}{0.60 \times 2 \times 12} d_{jk}^{-0.2773} = 0.3789d_{ij}^{-0.2773}$ .

### Road transportation external cost

$$C_{jk}^e = \frac{D_{jk}C^e(d_{jk})}{\lambda_j M_j} \quad (2)$$

where,  $C^e(d_{jk}) = 9.884d_{jk}^{-0.6235}$  in €/vehicle.km is the unitary road transportation external cost determined by Janic (2007). Similarly to the previous section, in terms of €/t.km, the long-haul external road transportation cost for travelling from node  $j$  to node  $k$  is  $C_{jk}^e = 0.4845d_{jk}^{-0.6235}$  and the collection/distribution external road transportation cost for travelling from node  $j$  to terminal  $k$  is  $C_{jk}^{e'} = 0.6864d_{jk}^{-0.6235}$ .

### Rail transportation operational cost

$$R_{jk}^o = \frac{D_{jk}}{q_t} r^o(W, l_{jk}) \quad (3)$$

where,  $q_t$  is the capacity of each train ( $q_t = 0.75 \times 26 \text{ cars} \times 3 \text{ TEU} \times 12 \text{ tonnes}$ , being 0.75 the load factor of the train) and  $r^o$  is the unitary rail transportation operational cost expressed in €/train, according to Janic (2008). The operational costs are a function of the gross weight of the train ( $W$ ) and the rail distance between terminals  $j$  and  $k$  ( $l_{jk}$ ). For the case study, the operational cost was computed assuming a commercial speed of 60 km/h and a train weight of one locomotive and 26 wagons (resulting in a  $W$  equal to 1550 tonnes). Based on these assumptions, the rail operational cost can be computed according to the following non-linear expression of distance:

$$R_{jk}^o = 0.59325 + 0.01900l_{jk} + 0.001804 \left( \frac{l_{jk}}{\ln(l_{jk})} \right) \quad (4)$$

In this expression, rail operational costs are in €/t. Note that contrarily to Janic (2007), the transshipment costs are not considered in the operational rail transportation cost. This is handled separately in our model.

### Rail transportation external cost

$$R_{jk}^e = \frac{D_{jk}}{q_t} r^e(W, l_{jk}) \quad (5)$$

where,  $r^e$  is the unitary rail transportation external cost expressed in €/train. As for the case of operational costs, we have excluded the external costs for transshipment from these unitary external costs. The external rail transportation costs for travelling from terminal  $j$  to terminal  $k$  in €/t is thus given by:

$$R_{jk}^e = 0.001696l_{jk} + 0.0015 \left( \frac{l_{jk}}{\ln(l_{jk})} \right) \quad (6)$$

### Transshipment operational costs

The operational costs of transshipping cargo at terminal  $j$  ( $T_j^o$ ) were considered to be equal to 2.8 €/t.

### Transshipment external costs

The external cost of transshipping cargo at terminal  $j$  ( $T_j^e$ ) were considered to be equal to 0.0549 €/t.

### The government subsidies

The subsidies in the model are divided into two parts:

- a fixed subsidy for intermodal transport handling costs ( $\tilde{T}_{jk}$ )
- and a variable subsidy for rail transportation as a function of distance travelled ( $\tilde{R}_{jk}$ ).

In the case of Belgium, according to the act C-2009/14189, a fixed subsidy of 1.5385 €/t is given to all the flows between Belgian terminals  $j$  and  $k$  and a variable subsidy of 0.00978 €/t.km is provided to all rail movements between Belgian terminals distanced at least by 51 km. For the case of inter-port movements (e.g., between Antwerp and Zeebrugge) these two subsidies need to be divided by two.

### Location-allocation model formulation

In hub-and-spoke networks, the goods are transported from their origin to a hub, from this hub to a second one, and from there to their final destination. The inter-hub links consolidate the total flows coming from the origin hub (or any of its

connected nodes) to the destination hub (or any of its connected nodes). The hub-and-spoke design problem implies to find the hub locations, to allocate the non-hub nodes to the hubs and to assign the flows on the network to minimize the total transportation cost. In the standard multiple-hub network problem, there are no capacity constraints at the hubs and no fixed cost to locate a hub. Moreover, three constraints are traditionally identified: it is assumed that (i) all the hubs are connected directly to each other; (ii) there is no direct connection between non-hub nodes; and (iii) the non-hub nodes are connected to a single hub. These assumptions, however, are not valid in the case of long-range freight transportation where hubs represent the terminals. Hence, these three constraints are relaxed and thus the number of possible routes is increased. Our mathematical model therefore better reflects the reality since it allows partial inter-hub connections by rail, direct connections by road between demand nodes, and a demand node to be assigned to more than one terminal. There are no capacity restrictions.

Sets

$N$	node set consisting of $n$ demand nodes, indexed by $i, m \in \{1, \dots, n\}$
$H$	existing and potential terminal (hub) set, ( $H \subseteq N$ ) consisting of $h$ nodes, indexed by $j, k \in \{1, \dots, h\}$
These sets are divided into various subsets:	
$N_0$	set of port nodes, existing terminals in Belgium
$N_1$	set of demand nodes inside Belgium, potential terminals
$N_2$	set of demand nodes outside Belgium
$N_3$	set of railroad terminals located outside Belgium
$N_4$	set of demand nodes representing the cargo entering or exiting the Belgian network by rail

Thus  $N = N_0 \cup N_1 \cup N_2 \cup N_3 \cup N_4$  and  $H = N_0 \cup N_1 \cup N_3 \cup N_4$

Parameters

$p$	number of terminals to locate inside Belgium
$l_{jk}$	rail distance between terminal $j$ and terminal $k$
$d_{im}$	road distance between demand nodes $i$ and $m$
$D_{im}$	cargo demand from demand node $i$ to demand node $m$ (in tonnes)
$e$	=1 if the external costs are to be considered 0 otherwise
$s$	=1 if the subsidies are to be considered 0 otherwise

Decision variables

$y_k=1$	if a terminal is located at $k, \forall k \in N_1$ 0 otherwise
$W_{im}$	road flows from demand origin $i$ and destination $m, \forall i, m \in N$
$X_{jk}^i$	flows from node $i$ firstly routed through origin terminal $j$ and then through destination terminal $k, \forall i \in N, \forall j, k \in H$
$Q_{km}^i$	flows from origin $i$ to destination $m$ that are routed through destination terminal in $k, \forall i, m \in N, \forall k \in H$

A schematic representation of the distances and flows variables, with a specific case of  $Q_{km}^i$  routing through origin terminal  $j$ , are represented in Fig. 3.

Objective function

$$\begin{aligned} & \min \sum_{i \in N} \sum_{m \in N} d_{im} \cdot (C_{im}^o + C_{im}^e \cdot e) \cdot W_{im} \\ & + \sum_{i \in N_0} (T_i^o + T_i^e \cdot e) \cdot W_{im} + \sum_{m \in N_0} (T_m^o + T_m^e \cdot e) \cdot W_{im} \\ & + \sum_{i \in N} \sum_{j \in H} \sum_{k \neq j \in H} [d_{ij} \cdot (C_{ij}^o + C_{ij}^e \cdot e) + T_j^o + T_j^e \cdot e] \cdot X_{jk}^i \\ & + \sum_{i \in N} \left[ \sum_{j \in H} \sum_{k \neq j \in H} (R_{jk}^o + R_{jk}^e \cdot e) \cdot X_{jk}^i - s \cdot \sum_{j \in N_0 \cup N_1} \sum_{k \in N_0 \cup N_1} (\tilde{R}_{jk} \cdot l_{jk} + \tilde{T}_{jk}) \cdot X_{jk}^i \right] \\ & + \sum_{i \in N} \sum_{k \in H} \sum_{m \in N} [d_{km} \cdot (C_{km}^o + C_{km}^e \cdot e) + T_k^o + T_k^e \cdot e] \cdot Q_{km}^i \end{aligned}$$

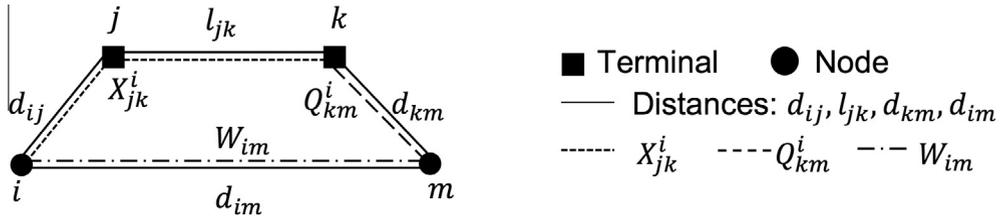


Fig. 3. Distance and flow notations.

The objective function consists in minimizing the total transportation cost. This represents the perspective of the shippers, who have to pay the operational costs and can be subject to subsidies or penalizations to compensate for the external impacts of their activity. The main decisions addressed by the formulation are the location of railroad terminals and the flow pattern through the network either by road from origin to destination or through railroad terminals. The flows are assigned to the multimodal network under the assumption of the ‘all-or-nothing’ principle. The first sum of the objective function corresponds to the transportation costs of road flows; the second and third sums correspond to the transshipment costs at the ports between sea and road; the third line is the sum of the pre-haulage costs of moving containers between an origin node and the railroad terminal to which the node is assigned; the fourth line is the inter-terminal rail costs; and the last line represents the post-haulage costs, between the railroad terminal and the destination node. The model assumes that railroad flows between any pair of nodes  $i$  and  $j$  will pass through two different terminals.

Subject to

$$\sum_{k \in N_1} y_k = p \tag{7}$$

$$y_k = 1 \quad \forall k \in N_0 \cup N_3 \cup N_4 \tag{8}$$

$$D_{im} = W_{im} + \sum_{k \in H} Q_{km}^i \quad \forall i, m \in N \tag{9}$$

$$\sum_{m \in N} D_{im} = \sum_{m \in N} W_{im} + \sum_{j, k \in H} X_{jk}^i \quad \forall i \in N \tag{10}$$

$$\sum_{i \in N_4} (W_{ij} + W_{ji}) = 0 \quad \forall j \in N \tag{11}$$

$$\sum_{k \in H} X_{jk}^i \leq y_j \sum_{m \in N} D_{im} \quad \forall i \in N, \forall j \in H \tag{12}$$

$$\sum_{j \in H} X_{jk}^i \leq y_k \sum_{m \in N} D_{im} \quad \forall i \in N, \quad \forall k \in H \tag{13}$$

$$\sum_{j \in H} X_{jk}^i = \sum_{m \in N} Q_{km}^i \quad \forall i \in N, \forall k \in H \tag{14}$$

$$y_k \in \{0, 1\} \quad \forall k \in H \tag{15}$$

$$W_{im} \geq 0 \quad \forall i, m \in N \tag{16}$$

$$X_{jk}^i \geq 0 \quad \forall i \in N, \forall j, k \in H \tag{17}$$

$$Q_{km}^i \geq 0 \quad \forall i, m \in N, \forall k \in H \tag{18}$$

Constraint (6) ensures that  $p$  terminals have to be located and constraints (7) that the existing terminals are opened. Constraints (8) stipulate that demand between each origin  $i$  destination  $m$  pair must be satisfied. Constraints (9) state that the flows must leave origin node by road or by railroad. Constraints (10) ensure that no road flows are generated at the demand nodes representing the cargo entering or exiting our study area by rail. Constraints (11) and (12) indicate that transshipment is not possible unless there is a terminal. Constraints (13) ensure flow conservation. Finally, constraints (14) describe that  $y_k$  is binary, and constraints (15)–(17) are non-negativity constraints.

### Results

This section presents and discusses the results obtained from applying the proposed terminal location-allocation optimization model for the different policy scenarios.

### Scenario 0 – reference case

The reference scenario regards the current situation in Belgium. According to this scenario, it is estimated that in the modelled network there is a total operational cost (road, rail and transshipment) of almost 2,000 million euros (Table 1). Note that pre- and post-haulage flows take into account the international flows while pre- and post-haulage for Belgium flows only consider the domestic flows. The estimated external costs are around 416 million euros and the Belgian government is providing 17.4 million euros in subsidies to the intermodal system in Belgium. The rail flows represent 12.1% of the flows in the network whereas for flow in Belgium this market share is 25.4%.

When analyzing the flows at the terminals, the Belgian terminals tranship almost 20 million tonnes per year (including inland terminals and the terminals at the ports). These flows only represent transshipments to and from the inland railroad transport system. As expected, the Port of Antwerp handles the largest percentage of flows – almost 10.8 million tonnes (Table 2). On the inland side, the most relevant terminals are Hasselt (with 1.9 million tonnes), Virton and Liège (both with around 1.5 million tonnes). In this strategic analysis, the Mouscron terminal is highly affected by the existence of a terminal in Lille and does not handle more than 230 thousand tonnes per year. The market areas of the six Belgian terminals are presented in Fig. 4. The minimum weekly number of trains between the Belgian terminals was estimated assuming the maximum capacity of a train (load factor equal to 1) with 26 cars and 3 TEU in each car (Fig. 5). The Belgian seaports were clustered in a single origin or destination point for train services, given their proximity and the current practice of freight rail operators in Belgium. In total, a minimum of 73 train services would be needed to transport the rail flows. The most significant OD pair is between the seaports and Hasselt terminal. In addition to the train services to and from the ports, 12 train services would be needed to transport goods between inland terminals.

It is relevant to notice that the existence of a parallel inland waterway transport system in Belgium could influence the results obtained. For instance, given the presence of inland ports in Hasselt, Liège and Mechelen, barge option could be a lower-cost option for part of the cargo transhipped in these terminals. Nevertheless, in general, the obtained results are consistent with the current situation in Belgium. For instance, the existent terminal at Athus (Virton region) has a daily flow of approximately 320 TEU containers (equivalent to the 1.4 million tonnes per year obtained with the model) and, as resulted from the model, it offers six weekly trains to Belgian seaports. In addition, the value of subsidies is coherent with the range of annual subsidies provided by the Belgian government between 2006 and 2014.

### Scenario 1 – no subsidies considered

Cutting off Belgian government subsidies to intermodal operators results in a small increase in total road flows (around 1.0%) and a reduction of almost 9.0% in total rail flows (Table 1). The reduction of rail flows is more significant in Belgium, where the rail market share strongly decreases to 9.2% (a reduction of 16.2% as compared with the reference scenario). The total operation costs slightly decrease, meaning that in the reference scenario the cargo from some OD pairs were shipped by intermodal transport despite their higher operational costs. On the other hand, the external costs barely increased.

The Belgian road flows increase by 8.6%, despite a sharp decrease of pre- and post-haulage road flows in the intermodal system. Consequently, the rail flows in Belgium decrease by 67.7% and the flows in Belgian terminals decrease to less than two thirds of their initial value. On the other hand, the neighbouring terminals experience an increase on cargo flows. This reflects a loss of competitiveness for the Belgian terminals. It is estimated that, without subsidies, the Belgian terminals

**Table 1**  
Cost and flows indicators for the different scenarios. The values in brackets represent the variation with regard to the reference situation, Scenario 0.

Indicator	Scenario 0	Scenario 1		Scenario 2		Scenario 3	
Operational cost (10 <sup>6</sup> Euros)	1925.41	1919.20	−(0.32%)	1924.72	−(0.04%)	1923.33	−(0.11%)
External cost (10 <sup>6</sup> Euros)	416.13	416.43	(0.07%)	414.94	−(0.29%)	415.52	−(0.15%)
Subsidies (10 <sup>6</sup> Euros)	17.41	–		21.62	(24.21%)	15.19	−(12.74%)
Total road flows (10 <sup>6</sup> t-km)	35939.75	36314.60	(1.04%)	35768.49	−(0.48%)	35964.10	(0.07%)
Belgian road flows (10 <sup>6</sup> t-km)	2630.19	2857.31	(8.64%)	2538.39	−(3.49%)	2644.28	(0.54%)
Pre-haulage in Belgium (10 <sup>6</sup> t-km)	106.38	44.14	−(58.50%)	117.07	(10.05%)	100.12	−(5.88%)
Post-haulage in Belgium (10 <sup>6</sup> t-km)	126.80	23.66	−(81.34%)	139.75	(10.22%)	99.94	−(21.18%)
Pre- and Post-haulage for Belgium flows (10 <sup>6</sup> t-km)	86.62	32.81	−(62.12%)	93.34	(7.77%)	81.75	−(5.62%)
Export road flows (10 <sup>6</sup> t-km)	12704.11	12753.98	(0.39%)	12666.93	−(0.29%)	12694.28	−(0.08%)
Import road flows (10 <sup>6</sup> t-km)	13349.74	13425.03	(0.56%)	13309.97	−(0.30%)	13363.35	(0.10%)
Transit road flows (10 <sup>6</sup> t-km)	7255.71	7278.27	(0.31%)	7253.19	−(0.03%)	7262.18	(0.09%)
Total rail flows (10 <sup>6</sup> t-km)	4925.68	4482.89	−(8.99%)	5097.56	(3.49%)	4889.11	−(0.74%)
Belgian rail flows (10 <sup>6</sup> t-km)	893.78	288.59	−(67.71%)	1076.98	(20.50%)	755.93	−(15.42%)
Export rail flows (10 <sup>6</sup> t-km)	1313.15	1475.55	(12.37%)	1297.16	−(1.22%)	1413.73	(7.66%)
Import rail flows (10 <sup>6</sup> t-km)	1818.52	1818.52	(0.00%)	1795.29	−(1.28%)	1818.71	(0.01%)
Transit rail flows (10 <sup>6</sup> t-km)	900.24	900.24	(0.00%)	928.13	(3.10%)	900.73	(0.06%)
Total flows in Belgian terminals (10 <sup>3</sup> t)	19721.16	12083.85	−(38.73%)	22800.24	(15.61%)	18963.27	−(3.84%)
Total flows in neighbouring terminals (10 <sup>3</sup> t)	6670.61	7249.26	(8.67%)	6657.52	−(0.20%)	7028.95	(5.37%)

**Table 2**

Rail flows at inland terminals and seaports (in 10<sup>3</sup> tonnes). The values in brackets represent the variation with regard to the reference situation, Scenario 0.

Terminal	Scenario 0	Scenario 1		Scenario 2		Scenario 3	
Port of Antwerp	10779.5	8286.9	–(23.12%)	12196.0	(13.14%)	10813.3	(0.31%)
Port of Ghent	1399.0	893.3	–(36.15%)	1581.9	(13.08%)	1332.3	–(4.77%)
Port of Zeebrugge	1467.3	827.8	–(43.58%)	1495.0	(1.89%)	1382.5	–(5.78%)
Mechelen	339.4	123.8	–(63.53%)	–	–	329.9	–(2.81%)
Hasselt	1903.8	218.5	–(88.52%)	1811.4	–(4.85%)	1806.1	–(5.13%)
Charleroi	571.7	405.4	–(29.08%)	565.6	–(1.06%)	549.2	–(3.93%)
Mouscron	228.5	56.2	–(75.41%)	–	–	185.8	–(18.67%)
Liège	1549.5	824.7	–(46.78%)	1454.5	–(6.13%)	1529.5	–(1.29%)
Virton	1482.6	447.4	–(69.83%)	–	–	1034.5	–(30.22%)
Maaseik	–	–	–	1246.8	(80.23%) <sup>a</sup>	–	–
Leuven	–	–	–	863.0	–	–	–
Arlon	–	–	–	1585.8	–	–	–

<sup>a</sup> Comparison with flows in Mechelen, Mouscron and Virton terminals for Scenario 0.

would lose around 3.0% of their flows to neighbouring terminals. The rest were intermodal flows generated by the existence of subsidies. The most affected terminals are those of Hasselt and Mouscron with flow reductions of almost 90% and 75%, respectively (Table 2). In the first case, the loss of flows is due to the fact that without subsidies it is no longer cheaper to send cargo by rail to the Port of Antwerp. In the latter case, road becomes more competitive for flows to and from the ports of Ghent and Zeebrugge. As a result of this, there is a significant reduction of the minimum number of trains per week between inland terminals and the three seaports – the maximum number of trains is now between Liège and the ports, with eight trains per week. No cargo flows exist between inland intermodal terminals.

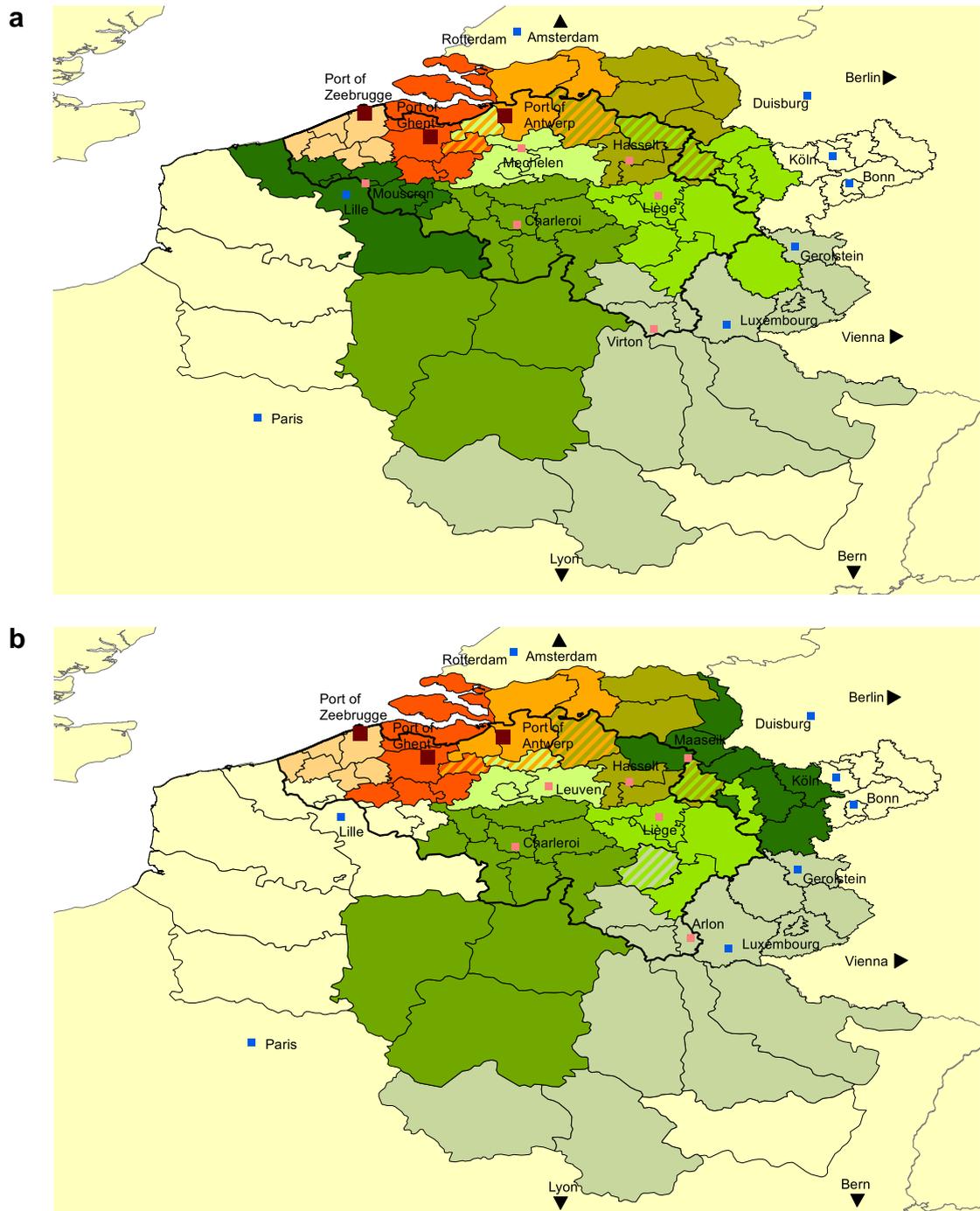
#### Scenario 2 – optimal terminal locations

When the location of the terminals is changeable the Mechelen and Mouscron terminals are replaced by those of Leuven and Maaseik, which are both located in the eastern part of the country. In addition, a terminal in Arlon replaces the existing terminal in the neighbouring NUTS 3 region of Virton. As a result of these new locations, there is a small decrease on road flows and an increase of almost 3.5% on rail flows (Table 1). The operational costs hardly vary and the total external costs are reduced by almost 0.3%. Nevertheless, the total value of subsidies increases by 24.2%. When comparing this solution with the references scenario, the total costs in the entire network modelled (the objective function) only come down 0.26%. This suggests that the location of the current set of railroad terminals in Belgium is not too far from optimal.

Despite this conclusion, the results in terms of modal share are largely affected by the new location of the terminals. Looking only at the results for Belgium, the impacts are expressed at a larger scale: the rail flows increase by 20.5% and the road flows are reduced by 3.5%. The pre- and post-haulage road transport flows increased by more than 10%. The market share of rail increased to 29.8%. This is the result of some new medium-haul markets in Belgium that become attractive markets for intermodal transport as a consequence of the new terminal locations (e.g. flows between the seaports and the NUTS 3 of Libramont-Chevigny or the flows between Bruges and Maaseik, through the terminal in Zeebrugge). Consequently, the total flows transhipped at Belgian terminals increase by 15.6% with regard to the reference scenario while the flows in non-Belgian terminals hardly change. This means that most of the new flows are flows generated within Belgium. The ports of Antwerp and Ghent would both experience a flow growth of around 13% (Table 2). In addition, the three new terminals would handle 80.2% more freight tonnes than the terminals of Mechelen, Mouscron and Virton in the reference scenario. This increase on flows in terminals also has an impact on the minimum number of trains per week (Fig. 5). There are 21 more trains between the inland terminals and the seaports. There is a concentration of trains to and from the ports, taken the best benefit of the location of the new terminals. With regard to flows between inland terminals, there is only one train per week (running both ways) between the terminals of Arlon and Liège.

#### Scenario 3 – external costs added

The third scenario adds external costs to operational costs and to subsidies and considers the current inland terminals. Surprisingly, the results show a decrease in rail flows (0.74%) and a slight increase in road flows (0.07%), when compared with Scenario 0 (Table 1). The reason for this is that external costs from pre- and post-haulage transport can be too high. For markets not involving long distances by train, these initial and final stages of the intermodal system can result in external costs that are not compensated in the train haulage. This is particularly the case for some Belgian OD markets – the rail market share in Belgium is decreasing from 25.4% to 22.2% while for the entire network the market share is only contracting by 0.01% (to 12.0%). In addition, road flows in Belgium are increasing despite a 0.14% reduction of pre- and post-haulage road flows in Belgium. This means that introducing external costs may have a negative effect for medium-haul markets, shifting the breakeven distance (between only road transport and intermodal options) even further.



**Fig. 4.** Market areas of the Belgian terminals. (a) Scenario 0, (b) Scenario 2.

In terms of subsidies, this solution would reduce the value of subsidies by 12.4% to a total of 15.2 million euros. The external costs in the entire network would only decrease by 0.15%. It is less than the reduction obtained with the optimal location of the terminals (0.29%). With regard to the flows at the terminals, the Port of Antwerp would be the only terminal increasing its flows with this solution (though only by 0.31%). All the other terminals would experience a decrease in the flows transhipped. This is particular evident for the Virton and Mouscron terminals, with a reduction of 30.2% and 18.7% respectively. Nevertheless, this flows reduction at the terminals has a reduced impact on the minimum train services. The only change with regard to the reference scenario would be the inexistence of trains between the inland terminals of Charleroi and Virton.

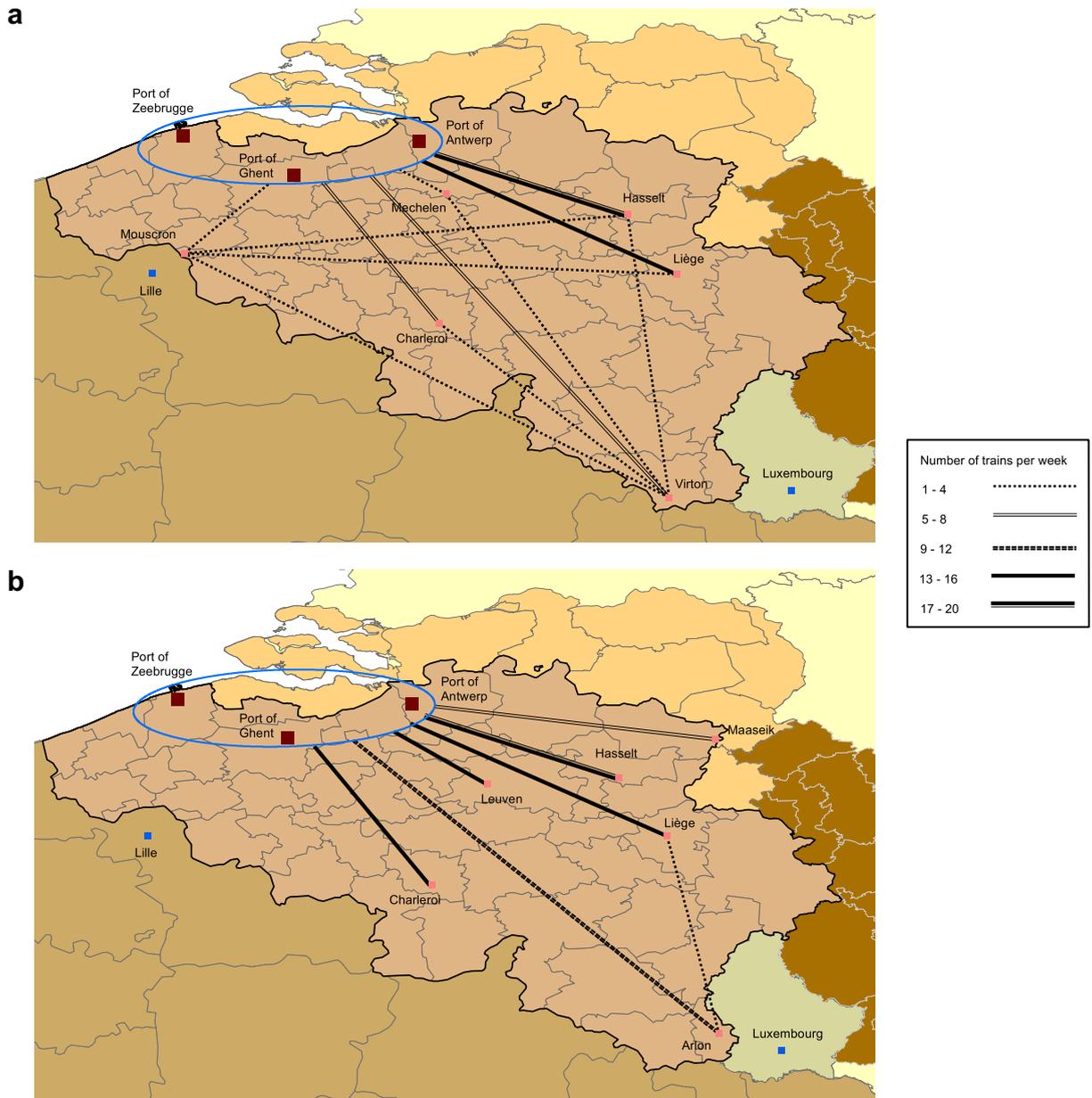


Fig. 5. Number of minimum weekly train connections between terminals. (a) Scenario 0, (b) Scenario 2.

### Summary

Given the assumptions made in this study, the results obtained from this case study yield some interesting conclusions:

- The subsidies provided by the Belgian government are critical to the success of intermodal freight transport in Belgium. Without them, for instance, the flows in Belgian intermodal terminals would be reduced by almost 40%.
- Nevertheless, the provision of subsidies to rail and terminal operators in Belgium seems not the best way to stimulate the shift of freight to transport options with lower external costs. The reduction in external costs is not proportional to the amount of subsidies granted and, when compared with the reference scenario, the scenario without subsidies just slightly decreased the external costs of transport below the reductions verified for the two other scenarios.
- The location of the current six inland terminals in Belgium is not far from optimal. Nevertheless, an optimal location could derive a potential benefit from the subsidies and the large flows between some regions of Belgium and its seaports, thus increasing rail flows in the country by 20.5%.

- Due to the external costs from pre- and post-haulage stage, introducing external costs in the transport cost would result in a decrease of flows by intermodal transport. This suggests that, without an efficient collection and distribution system, internalizing external costs may be negative for the promotion of intermodal freight transport. This is especially the case for medium-haul markets.

The last conclusion is compatible with those drawn by Janic (2007). However, it conflicts with those of Beuthe et al. (2002) and is somehow contradictory with the discussion presented in the last part of Macharis et al. (2010). This divergence can be accounted for by three factors:

- the costs from pre- and post-haulage played a major role in our results and Beuthe et al. do not implicitly model these costs in their analysis;
- in our formulation we consider external costs in both rail and road modes;
- and, we take into account economies of distance when measuring operational and external costs. This differs from the approach of Macharis et al. in which only road transport is associated with an external cost penalty and where this penalty is calculated based on a constant cost (regardless of the distance).

This suggests that including economies of distance and considering the inefficiency of short-haul road transport can have a considerable impact on the analysis of the intermodal freight transport system.

## Conclusions

This paper discusses the impact on the promotion of intermodal freight transport of adopting different transport policies, such as subsidizing intermodal transport operations, internalizing external costs and adopting a system perspective in deciding where to locate intermodal terminals. The case of Belgium is analyzed and an innovative intermodal freight location-allocation model is proposed to solve the optimization problem. The model is based on hub-location theory and it can be used to determine the optimal location of intermodal terminals and the allocation of freight between transport modes. Non-linear transport costs for road and rail modes (proposed by Janic (2007, 2008)) are used to directly model economies of distance.

The results obtained from the case study yield some interesting insights on the potential impact of the policies tested. For instance, policies involving the subsidizing of intermodal transportation largely increase the volume of freight migrating to rail. The same holds, but to a lower extent, if the location of the intermodal terminals is defined according to a system perspective. On the other hand, including externalities in the total cost of transportation results may compromise the competitiveness of intermodal transportation, in particular for small to medium range markets.

Notwithstanding the interest of this discussion, one must remember that its conclusions depend on the Belgian context and on the assumptions made in the modelling framework. Thus, future contributions might analyze the case of another country (or of a set of countries) to examine potential variation between distinct contexts. Besides, an extended modelling framework ought to include the inland waterways systems. Other possible improvements might be to contemplate more efficient alternative collection and distribution transport systems so as to increase the competitiveness of intermodal transport when external costs are considered. Such would be the case, for instance, of collaborative local transport.

## Acknowledgements

The project leading to the results presented was partially supported by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office, Comex, Grant P7/36. The authors are also grateful to the two anonymous referees for carefully reading the paper and for their useful suggestions.

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