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Location Analysis Model for Belgian Intermodal Terminals: towards an integration of the modal choice variables

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Abstract

Intermodal transport, the combination and integration of several transport modes, with the use of loading units, is in most cases more environmentally friendly than unimodal road transport for the carriage of goods. The LAMBIT-model (Location Analysis Model for Belgian Intermodal Terminals) has been developed to analyse the market areas of intermodal terminals and potential ones. In the LAMBIT model, barge/road and rail/road intermodal chains can be compared to unimodal road transport within Belgium. In this paper we show how to include, next to market prices the value of time in the model and how to integrate other cost factors, such as congestion, the possibility to use the terminal as an empty depot function and the distance of the post haulage section.

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Keywords: Intermodal transport, GIS network model, modal choice variables

1. Introduction

Intermodal transport is the combination of at least two modes of transport in a single transport chain, without a change of container for the goods, with most of the route travelled by rail, inland waterway or ocean-going vessel and with the shortest possible initial and final journeys by road (Macharis and Bontekoning, 2004). Intermodal transport may include various types of transport modes. In this paper we concentrate on the combination rail/road and waterways/road using containers as loading units. As noted by Bontekoning et al. (2004), intermodal transport gets growing recognition as well from policy makers, practionners and academics as an important alternative transport mode that can help tackle the congestion and environmental problems caused by our transport system.

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Good decision support systems need to be developed in order to understand the intermodal transport system better and to find ways to stimulate it (Macharis et al. 2008).

As several transport modes are included in an intermodal transport chain, intermodal transport costs involve a variety of transport activities. Figure 1 represents the intermodal cost function. Taking a door-to-door intermodal transport chain, the function allows calculating total intermodal transport cost between an origin and a destination.

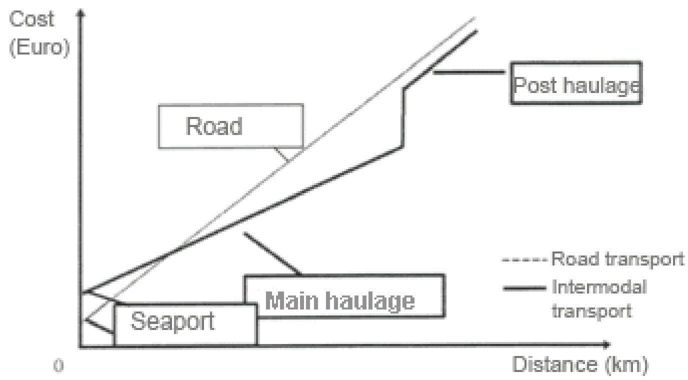

Figure 1: Intermodal cost function Source: Pekin, 2010

At the port intermodal barge transport has larger handling costs compared to unimodal road transport. This is due to the cranes that are being used for the transhipment of containers on barges. The main haulage is carried by barge. The advantage of intermodal transport lies in the smaller variable costs during main haulage, as a result of the scale economies that are obtained by the large capacities that can be used. Scale economies, gained by the main haulage leg of an intermodal transport chain, can further be increased by the introduction of larger vessels. As the variable costs of barge transport is cheaper compared to road-only transport, longer distance covered by the intermodal leg will make intermodal barge transport more efficient than road-only transport. At the end of the chain, this advantage is partly compensated by the extra handling cost that has to be paid for the terminal handling. Terminal operations necessary to tranship the goods from one mode to another imply a vertical leap in the cost curve. Reliable terminal operations will contribute to prevent costs that take place in transhipping a container from the main haulage to the drayage. In order to achieve reliable operations and optimise the terminal processes, ICT applications will be needed. Special attention for empty containers is also required. The post haulage in the intermodal transport chain is performed by road. The cost curve of intermodal freight transport thus runs parallel to unimodal road transport. Once the total intermodal cost is calculated, it is possible to make comparisons with road-only transport, opening the way to a series of possible scenarios that can be assessed using an appropriate set of tools.

In order to have such a tool to analyse the location of intermodal terminals and the effect of different policy measures, a Location Analysis Model for Belgian Intermodal Terminals (LAMBIT) has been set up (see Macharis, 2000 Macharis et al., 2010). This GIS-based model shows the market area of the intermodal terminals on the basis of the market price of each transport alternative. The market area is constituted of the municipalities in which the market price for intermodal transport is cheaper than for road-only transport. As such it takes an All-Or-Nothing (AoN) approach for highlighting a specific municipality. The aim of this paper is to show how in the LAMBIT model the value of time and other cost factors can be integrated. In section 2 we review the literature on value of time and come to a new definition of the cost function to be adopted in the LAMBIT model. We also show how the AoN approach can be relaxed. The model will be further explained in section 3. In section 4, the new approaches are shown.

2. Value of time and cost factors

Next to the market price other modal choice criteria, such as reliability, time, frequency, safety and customer satisfaction play a role in the choice of the shippers or shipping companies for using intermodal transport or road transport. In this paper we focus on the variable of time. In order to integrate this variable in a generalised cost function, the value of time is used. This enables the integration of time within the cost function as a common denominator.

This section presents the literature on value of time to set the context in which this component can be integrated in the LAMBIT model. In the third section, other cost related factors are integrated, such as congestion, the possibility to use the terminal as depot for empty containers and the distance of pre-and post-haulage.

2.1. Value of time

Studies which investigate the importance of variables that are affecting modal choice, show that time-related factors are ranked highest in many studies (see Ribbink et al., 2005). This section aims to provide a literature overview to position value of time (VOT) for examining intermodal freight transportation.

Especially when considering the total logistics costs, transport time clearly plays a critical role in the evaluation of transport alternatives. Woxenius (2006) argues that despite a rather wide use in modelling of transport time, the different elements of time are rarely clearly defined in the transportation literature. Speed is not enough if the service must be ordered far in advance, if the departure or arrival time does not fit, or if the service is not executed within agreed time or is irregular. Woxenius (2006) defines the following major time related components in transportation in order to investigate the VOT, as also shown in Figure 2:

- Transport time: the transit time and duration of transport which is a proportional function of distance. Factors that are affecting the transport time include geographical constraints or technical limitations of the transport network. From the perspective of intermodal transport these limitations include speed limits and drive bans for road transport, interoperability obstacles for railway transport and schedules of canal lock systems for barge transport.
- Order time: the preparation time required before departure of transport to reserve capacity, transport rate and an itinerary.
- Timing: the scheduled point of time for departure and arrival for shipments. Depending on the transport mode used, timing corresponds to a degree of flexibility. Here road transport clearly has an advantage as it can adapt their schedule compared to other transport modes. For post-haulage operations with shorter distances, timing is a critical requirement for the customers and thus more important than speed.
- Punctuality: the ability to keep to the schedule, meaning transport or transit time reliability. Average deviation from scheduled arrival time can be used to calculate punctuality.
- Frequency: the number of departures during a certain time. Frequency is related to timing and punctuality. The size of transport mean used will define the degree of frequency. For example rail transport will have lower frequency compared to road transport.

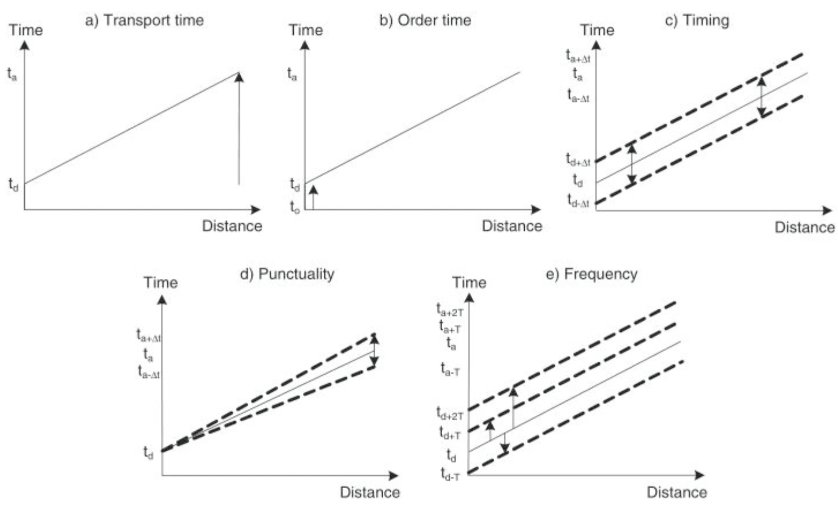

Figure 2: Components of transport time, to = time of order, td = time of departure, ta = time of arrival are points of time; the elements relate to duration. Source: Woxenius, 2006

An accurate estimation of VOT based on the above components is required in assessing transport alternatives both for passenger and freight transport. VOT can be interpreted as a problem not only in evaluating modal choice decisions but also in assessing the impact of transport policies and infrastructure investments. Various estimation methods can be used to compute the VOT. One of the techniques most commonly used is the revenue model which is based on the assumption that resources freed by the time savings are used to supply additional output. Another technique is cost savings method in which VOT is determined by the costs that are saved due to the time reduction. Thirdly, willingness to pay methods are discrete choice models that require extensive data input from questionnaires. These latter models are used to examine the VOT for users where there are more than one mode of travel existing. Two types of willingness to pay methods exist depending on the data collection: data can either be collected through direct observation (revealed preference models) or through questionnaires (stated preference models). Bruzelius (2001) concludes after reviewing the existing literature on the VOT that sensitivity of estimations are higher for willingness to pay methods.

Scientific interest in estimating VOT for freight transportation can be charactersied as under-researched (Kopp, 2005) compared to passenger transportation. Jong (1996) examines a number of European studies by comparing their results. His literature review is not focused on methodology as most previous studies were not based on theoretical frameworks (Bergkvist, 2001). It can be concluded that only a few studies are made in Europe to estimate VOT in freight transport. A common methodology has thus not yet been reached. Therefore attention should be paid when comparing average VOT estimates for freight transport in European countries. Winston (1979) suggested a cost minimising model for a company with the aim of measuring the value of quality factors among transport firms. Ogwude (1993) and Jovicic (1998) developed studies based on revealed and stated preference models to estimate the value of freight transport time.

The study of Beuthe and Bouffioux (2008) estimates the value of transport qualitative factors for shippers. In their calculations the authors partitioned the data according to type of goods such as food products, minerals, materials and chemical and pharmaceutical products. They conclude that the shippers of different commodities also show different preference profiles for modal choice variables. The time attribute is defined as door-to-door transport time, including loading and unloading. Since their paper is based on experiments with Belgian transport shippers, we have decided to use the outcomes of this study for adapting the LAMBIT cost functions. As summarised in Table 1 there is a huge difference of the VOT for different transport modes. This is mostly related to the value of the goods themselves. High value goods are usually transported by road; whereas low value goods are transported by barge or possibly by rail. This explains the huge differences in the VOT-values as shown below. If we would use in LAMBIT the values of time as indicated in this table and by transport mode, this would not give a correct image of the VOT of container transport as different types are goods can be stuffed in containers. That is why we prefer to use the highest value as an estimation for the VOT of high value goods (stuffed in containers) and the lowest for low value goods (again stuffed in containers).

Table 1: Value of time per hour in € per TEU for transport modes

	Road	**Rail**	**Inland navigation**
High-value goods	0.576	1.382	3.142
Middle-value goods	0.034	0.082	0.185
Low-value goods	0.002	0.004	0.01

Source: Own setup based on Beuthe and Bouffioux, 2008

2.2. *Other cost factors*

The above VOT values should be used in combination with the distance travelled and the speed of a certain transportion mode. For road transport, an average speed of 60 kilometers per hour can be used. For inland waterways and rail, we adopt speeds of 11 and 25 kilometers per hour respectively (ECMT (2006) and Janic (2007)). Multiplying the VOT values with the speed and the distance will give the time cost for a specific trajectory and this for low, medium and high value goods.

Several further refinements are possible:

Belgium, and in particular the ring around Antwerp and Brussels, is very congested area. We can introduce the congestion levels in the model, by decreasing the speed for road transport.

Next, intermodal terminals often serve as a depot for empty containers. Shipping companies are leaving the empty containers on the terminals, which saves a return trip to the sea terminal. This cost decrease should also be incorporated in the cost function. As shown in Figure 3, this leads to the elimination of return journey by barge or rail transport, which can make intermodal transport more competitive as with road transport this return trip is always necessary. The empty containers can be refilled for the export of goods within the same area. The latter holds true when the flows between origin and destination are reasonably balanced. In case of structurally unbalanced relationships between origin and destination, the empty container has to be returned anyhow.

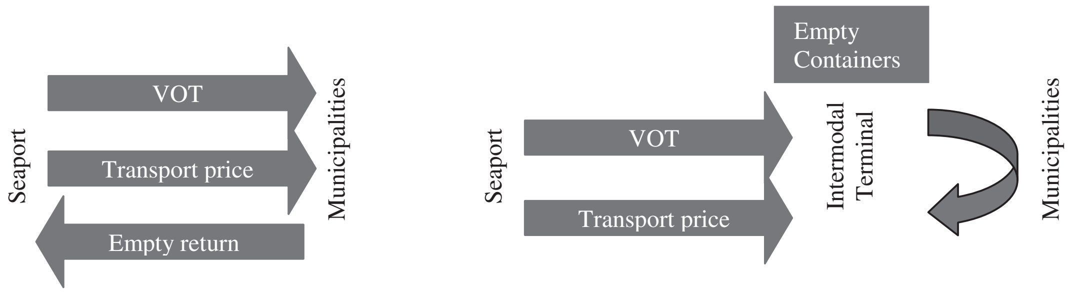

Figure 3: Management of empty container returns

Third, the distance of the pre-and posthaulage by road has an important impact on the total cost. The costs of pre- and end haulage has an important share of the total costs (Bontekoning & Priemus, 2004). The break even distance is largely affected by this pre-and posthaulage (PPH). When the distance decreases, PPH becomes more crucial (Bärthel & Woxenius, 2004). At this moment we are using in LAMBIT an All-Or-Nothing approach: a municipality is either cheaper reachable by road or by a specific intermodal terminal. In order to show possible more advanced visualisations of the market area, a price ratio analysis has been performed. For each municipality, the ratio of intermodal transport market price and unimodal road transport market price is calculated. A ratio analysis can be used to visualise the market area of each terminal with gradual shades and by doing so, the cost of pre and endhaulage is also visualised.

3. LAMBIT: Location Analysis Model for Belgian Intermodal Terminals

Our GIS based location analysis model is built upon two pillars: setting up the network and including the cost function (Macharis, 2000). The network exists of four different layers: the road network, the inland waterways network, the rail network and the (post)final-haulage network (See Figure 4). Also the geographic locations of the intermodal terminals and the municipality centers are defined and connected to the network layers by their corresponding nodes.

As a second step, the transport prices are calculated based on the real market price structures for each transport mode. The variable costs are depending on the distance travelled and the fixed costs are related to the nodes in the network.

The total cost of intermodal transport is composed of the transhipment cost in the port of Antwerp to a barge or a wagon, the cost of the intermodal main haul (by barge or by rail), the transshipment cost in the inland terminal to a truck and the cost of post-haulage by truck. The total intermodal transport cost is obtained by adding all of these mentioned fixed and variable costs.

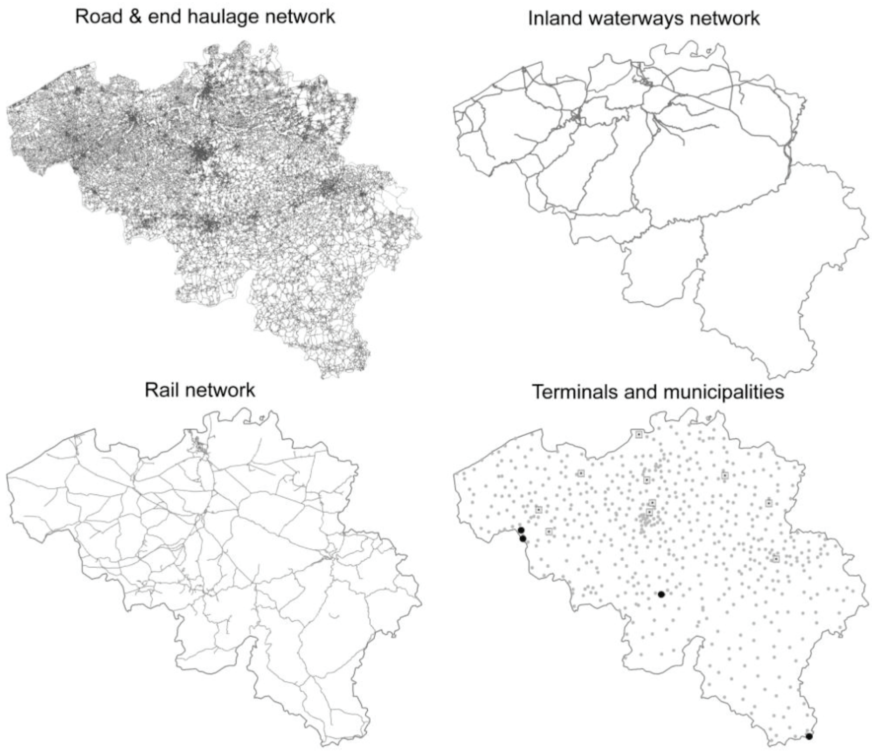

Figure 4: The LAMBIT network

Access to reliable data is essential in order to achieve accurate results from the location analysis model. In this respect, the network for Belgium was obtained from the maps of ESRI and TELE ATLAS. The transport prices for inland waterways and unimodal road transport, are calculated as averages from the market prices, which were obtained from transport companies, inland barge terminals and rail operators.

Only the freight flows of the port of Antwerp to the different municipalities are considered in the model, as this port is connected to all the terminals with daily shuttles. A shortest path algorithm allows calculating the paths that should be considered for further comparisons amongst modes. The costs for unimodal road, inland waterways/road and rail/road transport are compared in each municipality and the cheapest option is selected. The market areas of each inland terminal is then highlighted in the model. As a further step, the potentials of the inland terminals are derived by aggregating the number of containers that are currently transported to/from the municipalities by road (based on data of the National Institute of Statistics).

The model enables to assess different policy options. First of all, the current terminal landscape is obtained, which can be used as a reference point in the policy analysis. As a second step, new terminals can be added into the network to study their effects on the market area of the existing terminals. Furthermore, different policy options can be simulated such as subsidy schemes, oil price increases, internalisation of external costs scenarios, etc. (see Macharis and Pekin, 2009). The LAMBIT approach can easily be applied to other countries as we did already for Turkey (see Pekin and Macharis, 2009).

4. Implementation in LAMBIT and results

As mentioned in the previous section, LAMBIT can be used as a tool to evaluate intermodal transport policies. In Figure 5 an outcome of the LAMBIT model is depicted. The municipalities are highlighted, when intermodal transport has a more attractive transport price compared to unimodal road transport based on the current market prices. The green market areas belong to barge terminals, the yellow-red ones are those of a rail/road terminal. The terminals which are located far from the port of Antwerp, benefit more from the lower variable costs of intermodal transport compared to unimodal road transport and they have larger market areas. This is explained by the intermodal cost structure (see section 1). The longer the distance travelled, the greater the extent to which the lower variable costs of intermodal transport can compensate for the extra transhipment costs at the terminals. This figure will serve as a reference case in order to compare it with the new output of the model with the enhanced LAMBIT model. Implementation of the new methodology is built on two steps: first the value of time is integrated in LAMBIT with some extra simulations, second, a ratio-analysis is performed to visualise the market area.

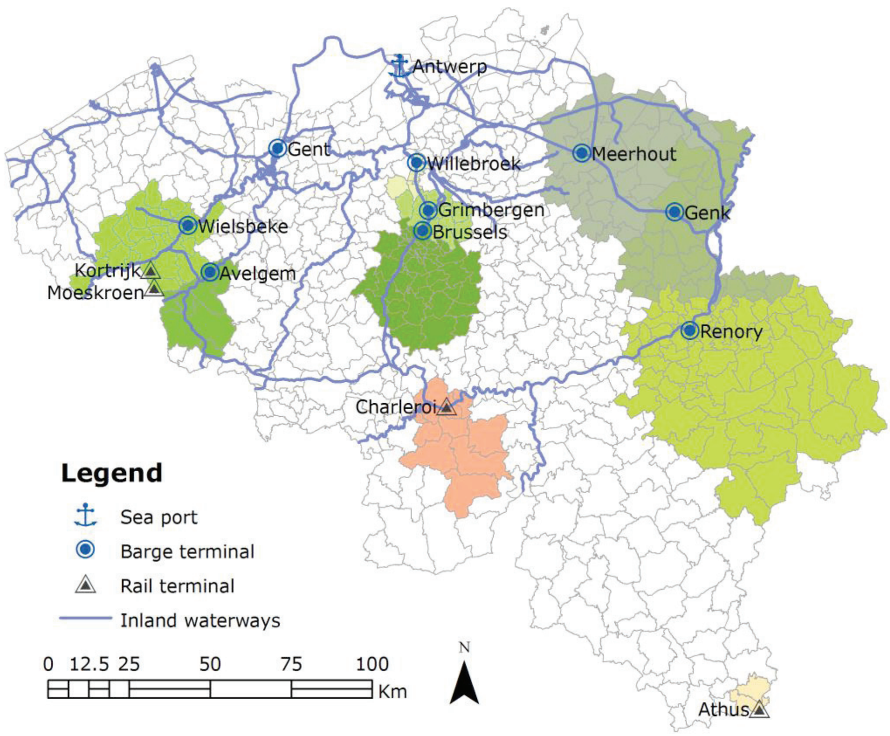

Figure 5: LAMBIT reference output

The first step is to develop a new cost function for the LAMBIT model, which currently uses market prices. The following formula explains the calculation of total costs for intermodal transport:

$$TC = P_M + P_T \quad (1)$$
$$P_M = T_s^i + p_m^i(d)\, d_m + T_t^i + P_p^i + p_p^i(d_r - d) \quad (2)$$
$$P_T = (d)\, d^i v V_T \text{ (i: road, barge or rail)} \quad (3)$$

Where:

- P_M: price of intermodal transport;
- P_T: value of time. This is in function (per kilometer) of a distance d;
- T_s^i: price of container transhipment in the seaport;
- $p_m^i(d)$: price of main-haulage by barge or rail transport. This is in function (per kilometer) of a distance d;
- T_t^i: price of container transhipment in the inland terminal;
- P_p^i: fixed costs of post-haulage by road transport;
- p_p^i: price per kilometer for post-haulage by road transport;
- d: the distance between the seaport and an inland terminal;
- d_r: distance by road transport;

- d_m:distance by main haulage;
- d_r - d: distance of post-haulage by road transport;
- v: average speed for each transport mode;
- V_T : value of time for containers;

As discussed above we use the data of Beuthe and Bouffioux (2008) for the VOT. For an estimation on speed, an ECMT report is consulted for the average speed of rail and inland navigation. For road transport data from Janic (2007) is used. Average speed makes a distinction for short distance road transport (post-haulage) which is slower compared to longer distance main-haulage (See Table 2).

Table 2: Average speed in km per hour for transport modes

Transport mode	Average speed
Unimodal road	60 km/h
Post haulage	35 km/h
Rail	25 km/h
Inland navigation	11 km/h

Source: Own calculations based on Janic (2007) and ECMT (2006)

If we now take our normal cost function and we add the information on VOT together with average speed, we can see how the time factor impacts the market area of the terminals. In Figure 6, the output of LAMBIT with low value of time is presented. This scenario leads to a slight decrease for the market area of intermodal terminals, which can be expected as the speed of road is better than the ones of inland navigation and rail. With a high value of time, intermodal transport cannot compete with unimodal road transport thus no market area for the inland terminals can be shown. Also a medium value of time results in only a small market area for the inland terminals.

In order to investigate the high value of time further, we have developed two additional scenarios.

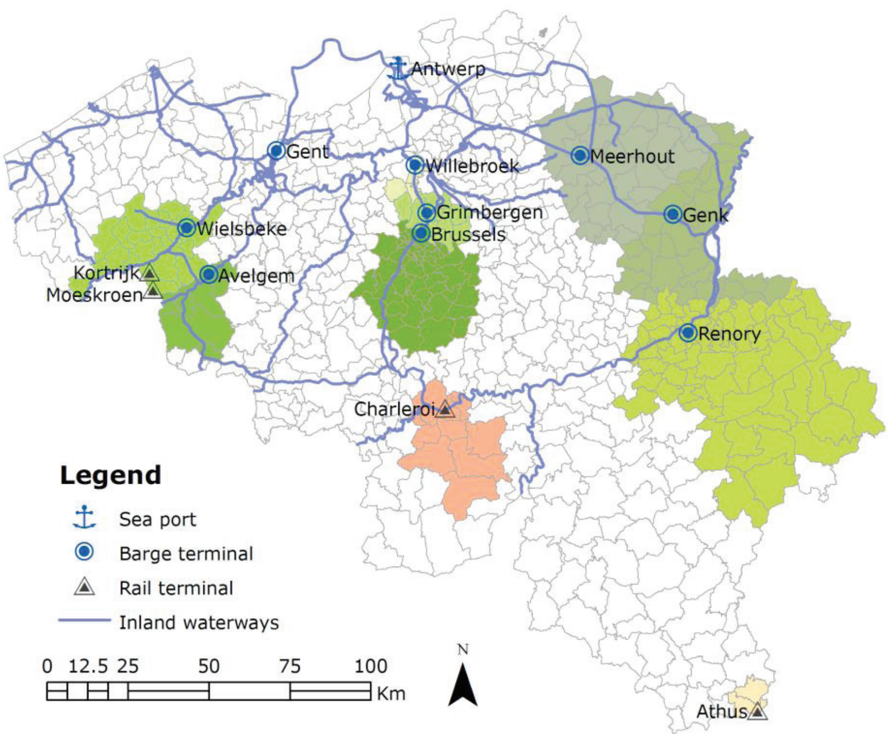

Figure 6: LAMBIT model taking the VOT into account (low value goods)

Figure 7A shows the market areas of the terminals, when these would be used as a depot of empty containers. The figure indicates that intermodal terminals lose market area to road transport even if we take this cost reduction into account. This is due to the negative impact of slower door-to-door transport time for intermodal transport. In total 175 municipalities compared to 227 would be in a favourable condition to let intermodal transport be used by the companies located in that municipality. In Figure 7B, we also take into account congestion by decreasing the average speed for road transport to 40 kilometers per hour instead of 60 km. Lower speed for road transport leads to further opportunities for intermodal transport. Market areas of intermodal terminals are enlarged up to 352 municipalities.

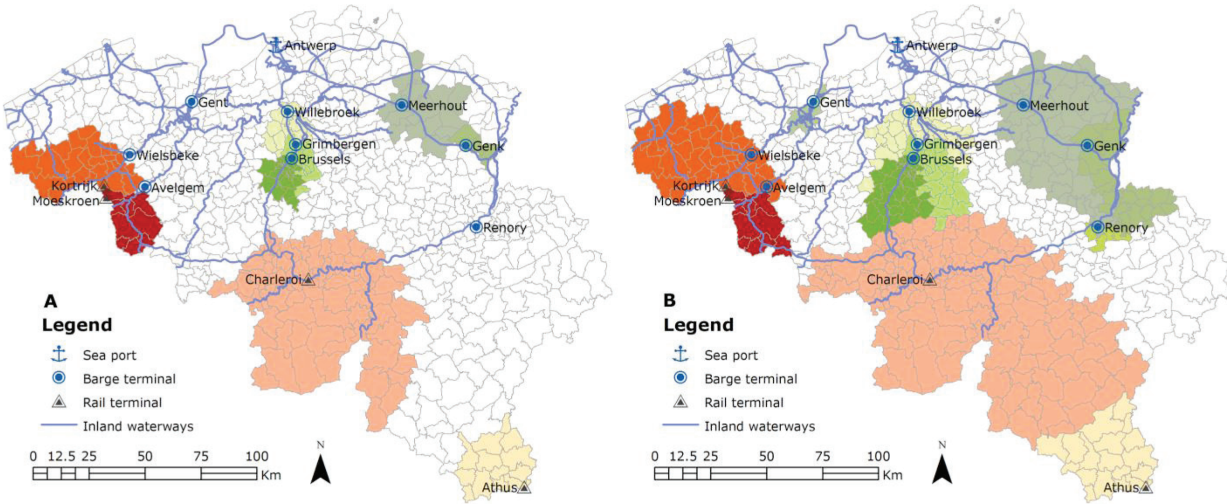

Figure 7A and B: LAMBIT output taking into account the VOT (high value of goods) and a decrease in cost due to the empty depot function of the terminal (A) and congestion (B)

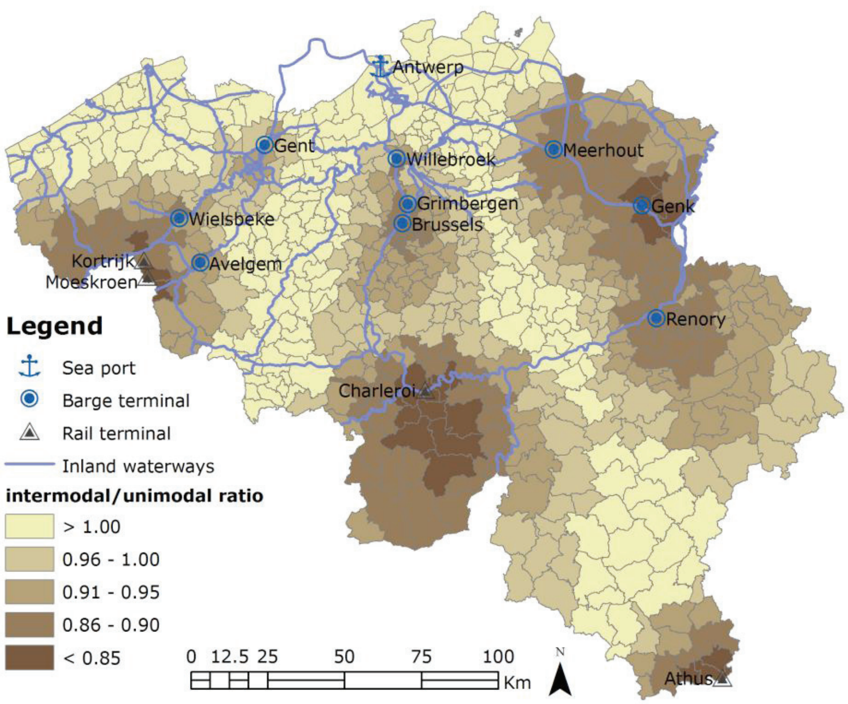

Figure 8: Cost ratio analysis Source: Pekin, 2010

Finally, one can calculate price ratios for each municipality in order to visualise the degree in which intermodal transport is better than road transport. The ratio divides the intermodal transport market price by the unimodal road transport market price. Working with ratios can make it possible to visualise the market area of each terminal with gradual shades. Figure 8 depicts the market area for each terminal based on the cost ratio. A ratio higher than 1 means that unimodal road transport is the most interesting transport mode in that municipality. A ratio lower than one, means that intermodal transport is more attractive. Instead of the All-Or-Nothing approach, we give here an indication in how far intermodal transport is more attractive. Towards the centre of each terminal, intermodal transport becomes relatively cheaper with a lower ratio compared to unimodal road transport. In other words, the further one goes away from the terminal the cost ratio increases.

The ratio analysis introduces a more realistic market area for the intermodal transport. This analysis demonstrates the impact of post-haulage within the intermodal transport chain.

5. Conclusions

In this paper, the location analysis model for intermodal terminals (LAMBIT) has been improved by integrating next to the market price, the value of time. Taking this value of time into account shows that the types of goods in the containers have an important impact. If the values are high, intermodal transport has no market area. If however we have lower values of time for lower value goods or we take into account congestion and the possibility of the empty depot function of the intermodal terminals, we get a clear view of the current situation of intermodal transport in Belgium. Also a further improvement was realised on the visualisation of the market area for intermodal terminals. A refinement of the competitiveness of each municipality can now be better visualised. These adaptations enable to make LAMBIT a more realistic model on which further policy measures are possible to be evaluated. The analysis of the cost function as discussed in this paper, also allow to gain more insight about the importance of each cost element in the total cost of intermodal transport.

Further research will be dedicated to further refine the integration of congestion in the model. In this first attempt, we simply decrease the overall speed of road transport. More accurate data should be collected on the congestion of different segments of the road network in Belgium and by doing so, create a more realistic approximation of the speed on each of the segments.

Another further step would be to integrate other modal choice variables. As no monetary values exist for all these modal choice variables a multi-criteria or multi-objective function approach will be followed. Such an approach would allow to weight the different modal choice variables and to come to a general assessment of a proposed trajectory on the different modal choice variables. As this weighting cannot be done anymore on the basis of a monetary weighting as introduced in this paper, the weights will have to be elicitated from a discrete choice experiment or another type of stated preference elicitation.

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