Freight Transportation Planning on the European Multimodal Network

The case of the Walloon region

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This paper presents a methodology that can be used for long-term planning of freight transportation on multimodal networks. It is illustrated by research carried out for the Belgian Walloon Ministry of Transport between 1997 and 1999. Its aim was to provide a tool for measuring the impacts of different kinds of policies and/or new infrastructures on freight transport flows in and through Wallonia.
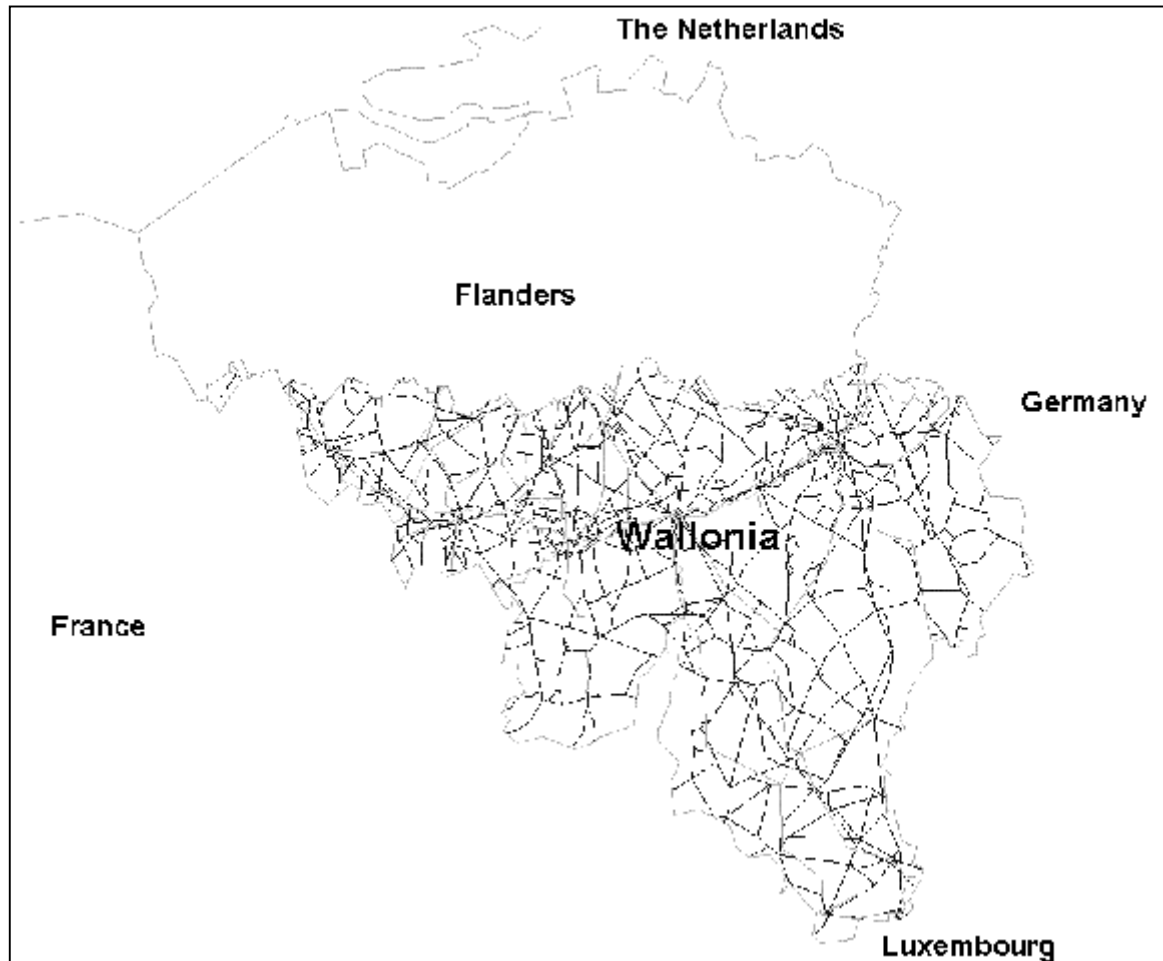*The work started with the setting up of a calibrated multimodal and multi-products reference scenario for the year 1995. This reference scenario was then used as a basis to create a projection for the year 2010: in order to make this projection as realistic as possible, all the decided new infrastructures in Belgium and in the border countries that will be effective in 2010 were introduced in the model. Moreover, expected changes in the O-D matrixes were also introduced at a very detailed level. Then, a set of scenarios was build: one for each transportation mode in which specific changes for that mode were introduced, and one in which the external costs of transport were taken into account.*
On the basis of the obtained results, a 'transportation plan' was built, in which the most promising changes in the different networks and policies were chosen. A sensitivity analysis (low and high economic activity) was finally performed.

1. Introduction

Medium and long-term transportation plans at the level of a whole country or region are seldom discussed in detail. This paper presents a methodology that can be used for long-term planning of freight transportation on multimodal networks. It is illustrated by research that was carried out for the Belgian Walloon Ministry of Transport between 1997 and 1999. Its

aim was to provide a tool for measuring the impacts of different kinds of policies and/or new infrastructures on freight transport flows in and through Wallonia.

Map 1. The Walloon region

The work started with setting up a calibrated multimodal and multi-products reference scenario for the year 1995. This reference scenario was then used as a basis to create a projection for the year 2010, for which already decided new infrastructures were introduced in the network along with a forecast new set of O-D matrixes. Then, a set of specific scenarios was built to measure the impact of several new infrastructures or policies. On the basis of the obtained results, a 'transportation plan' was built, in which the most promising changes in the different networks and policies were chosen.

2. Initial motivation and planning of the research

In the second half of the 1990s, the Ministry of Infrastructures and Transport (M.E.T.) of the Walloon Region (RW) was concerned with the development of a transportation plan for 2010 in Wallonia, the French-speaking part of Belgium. Both passenger and commodity transport were to be analysed, but it was decided to separate both models. The freight

transportation model was entrusted to a team of consultants (STRATEC S.A. and A.D.E.) and researchers (F.U.Ca.M. – G.T.M.) who also had to provide a software tool to be used at the M.E.T.
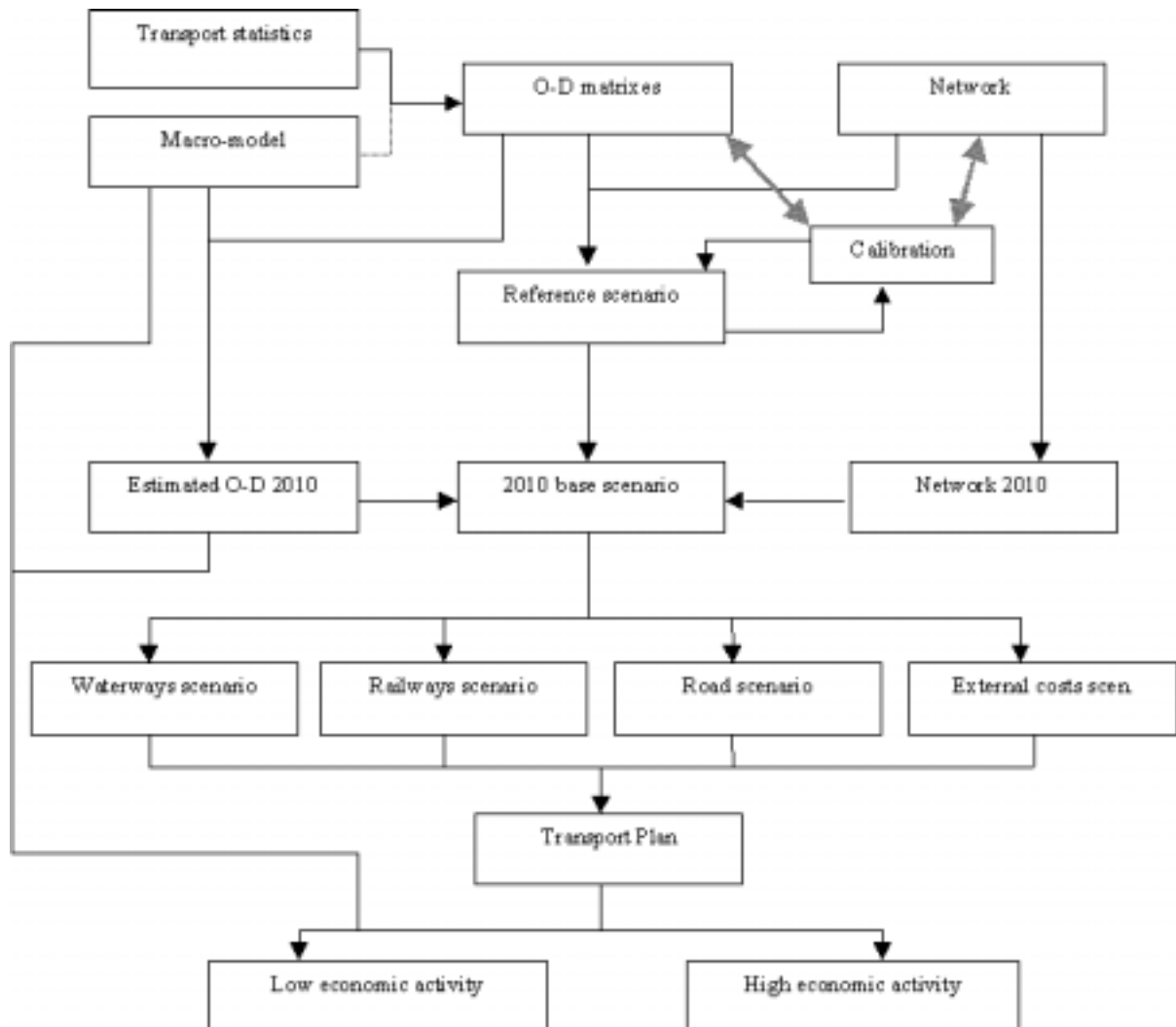

Figure 1. General view of the project

The developed model had to correctly assign flows of freight onto the Walloon network on the basis of a demand specified in a set of origin-destination (O-D) matrixes. It had also to perform a satisfactory modal split. Thus, an important part of the study was devoted to gathering relevant data to build the O-D matrixes, to specifying the network itself, and to developing meaningful transportation cost functions.

On this basis, a reference scenario was built, which had to give a good insight into the flows on the network. Once this first scenario had been calibrated on the observed flows in 1995, the actual 'planning' part of the work could begin.

The reference scenario was used in a first step to create a projection for the year 2010: in order to make this projection as realistic as possible, all decided new infrastructures in Belgium and in the border countries that will be effective in 2010 were introduced in the

network model. Moreover, expected changes in the O-D matrixes were also introduced in great detail. The scenario has to be interpreted as a *ceteris paribus* situation in which no new political decisions influence the level of the flows or the modal split.

In a second phase, a set of scenarios was created, each one introducing new policies, new infrastructures, or a combination of both. During this phase, a scenario was proposed for each transportation mode taken separately: road, rail and inland waterways. An additional scenario was concerned with the internalisation of external costs.

Finally, the M.E.T. had to decide which elements of the different scenarios developed during the second phase were to be introduced in the final transportation plan. During this last step, sensitivity analyses were also performed on the final plan in order to measure its stability against a change in demand.

It is worth noting that the whole model is installed at the M.E.T. and that several officials were trained to be able to create and analyse new scenarios.

3. Building the reference scenario

3.1 Macro-economic indicators and demand estimation

The main goal of the macro-economic model, developed by A.D.E., is to provide a good insight into the evolution of demand between the different main subdivisions of the Belgian provinces[1], per category of goods in the middle and long term. This model, which involves both a spatial and sectorial breaking-up of the macro-economic projections given by the Belgian Planning Office, can be outlined in five steps:

• As the available projections at the macro-sectorial level were only available up to 2005, additional work was done to extend them to 2010.
• Input-Output matrixes were used to split these macro-sectorial projections into sector specific data, by means of a techno-behavioural approach.
• Once all these projections were available, they had to be distributed geographically over the ten Belgian provinces. This was done by using observed flows and production locations between 1980 and 1994.
• The data were further distributed over the 'arrondissements', using national statistics on sectorial employment at this particular geographic level.
• Figures on loaded and unloaded quantities per category of commodity were finally obtained at 'arrondissement' level when a set of ratios was applied to the above data.

In addition to the procedure outlined above, the loaded and unloaded quantities at the different centroïds[2] were also estimated by using transport statistics that were made available by the national railway company, the national office for statistics and the inland waterways administration. This second approach was needed for the transport model, which has much more centroïds than existing 'arrondissements'.

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[1] Known as 'arrondissements' in Belgium.
[2] A centroïd is a centre of gravity of industrial activity. Using centroïds makes it possible to have only one node, and thus one entry in the O-D matrixes. In this model, a centroïd corresponds to a city within Belgium, but to larger areas outside the country.

In effect, the transport matrixes were built mode by mode before being merged. Modal transfer (combined transport) is allowed in the model for multi-modal units only and not for inland bulk transport.

- The matrix for the inland waterways could rather easily be built from a database in which all movements of barges during the year of reference are recorded. The more than 180,000 records were split into five categories of boats. The database contains precise information on the loading/unloading ports located in Belgium. Unfortunately, and this is also the case for the other transportation modes, origins and destinations located outside Belgium are only available at the NUTS2[3] level. As, in many cases, our network contains more than one centroïd per NUTS region, the relevant amounts of goods were distributed over the centroïds of a same NUTS2 region by a Monte-Carlo procedure.

- The work was much more difficult for the railways, as information on loaded and unloaded goods was only available at the level of administrative railway regions in Belgium, which sometimes contain more than one centroïd. A lot of 'manual' disaggregation was needed, based on the level of activity of the different firms connected to the railway network. Unfortunately, this procedure lead to some loss of information. Indeed, we had no information about flows where both the origin and the destination are located in the same administrative region. As the origin and destination could very well be located in two different cities, we know that, in some cases, our O-D matrixes underestimate inter-urban railway transport[4].

- Truck transport was estimated by using various statistics collected at national and international levels. The National Office for Statistics continuously collects information about all trucks registered in Belgium. Some difficulties had to be solved for data collected in foreign countries as the geographic levels used did not always correspond from country to country. Finally, as no precise information was available for empty vehicles, the corresponding matrix was obtained for these countries by means of ratios obtained for Belgian traffic. The latter matrix was then tuned using a procedure of matrix-estimation performed after the comparison of the assigned flows on the network with numerous counts made along the Belgian roads.

- A matrix for combined transport was developed from both the number of containers handled at the different terminals and the road traffic observed around these terminals.

- Finally, an existing matrix of origins and destinations for private cars was used. The pre-load of the network with this matrix will be used later to estimate the level of congestion on the network.

For different reasons, for instance, a difference between the NACE nomenclature used in the macro-economic model and the NST-R nomenclature used in the transport model, the output given by both approaches gave frequent divergences. As the final output of the research was to provide a GIS transport model, the O-D matrixes obtained by the second approach were used for the assignments. The first matrixes and the macro-economic model were used in a second step to evaluate the impact of the economic activity on the demand: once the impacts

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[3] The NUTS nomenclature is defined by the European Union, but corresponds to already existing entities. In Belgium, for instance, NUTS3 regions correspond to small 'arrondissements', while NUTS2 larger regions correspond to 'provinces'. NUTS3 data were used for border regions around Belgium.

[4] This is mainly the case for transport of metal products in the administrative districts of Liège and Charleroi.

have been evaluated on the 'macro' O-D matrixes, they are introduced in the 'transport' matrixes.

3.2 Network model

Once the aggregated O-D matrixes are set-up, they have to be assigned on a network. As was already pointed out in the previous section, it is important to model the Walloon network as an enclave in the European one. The complete European network of 'Trunk lines of International Importance' as defined by the European Conference of Ministries of Transport (E.C.M.T.) was digitised. For Belgium, this network was encoded in a more detailed way in order to have the complete networks of railways and inland waterways along with all the roads that have a width of at least seven metres. Map 2 gives a partial illustration of the map[5]. The digitised network has about 13,000 nodes and 17,000 links.

The modal choice and assignment of the flows on routes were performed in a single step on what can be called a 'virtual network'. Indeed, a geographic network doesn't provide an adequate basis for a detailed analysis of the different kinds of transport operations (loading, transhipping, transit, …) that can be performed on a given infrastructure To solve this problem, the basic idea, initially proposed by Harker and Crainic *et al.*, is to create a virtual link with specific costs for each particular use of an infrastructure. The NODUS software, developed at F.U.Ca.M.-G.T.M. proposes a methodology and an algorithm which creates, in a systematic and quasi-automatic way, a complete 'virtual network' with the virtual links corresponding to the different operations which are feasible on each real link or node of a geographic network. The software and its underlying methodology are discussed in Jourquin (1995) and Jourquin & Beuthe (1996).

The freight network was set up with its attributes defining the characteristics of the links and terminals (capacity, speed, terminal facilities, etc.). The data collected to build the O-D matrixes was also useful to limit the (un)loading of the different categories of commodities to the ports and railway station in which they are effectively handled. Moreover, inter-modal transport was only allowed for the commodities that belong to NST-R 9.

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[5] Note that outside Belgium, the network is simplified around the big cities (London, Paris, …) in order to reduce the complexity of the map and the computing times.
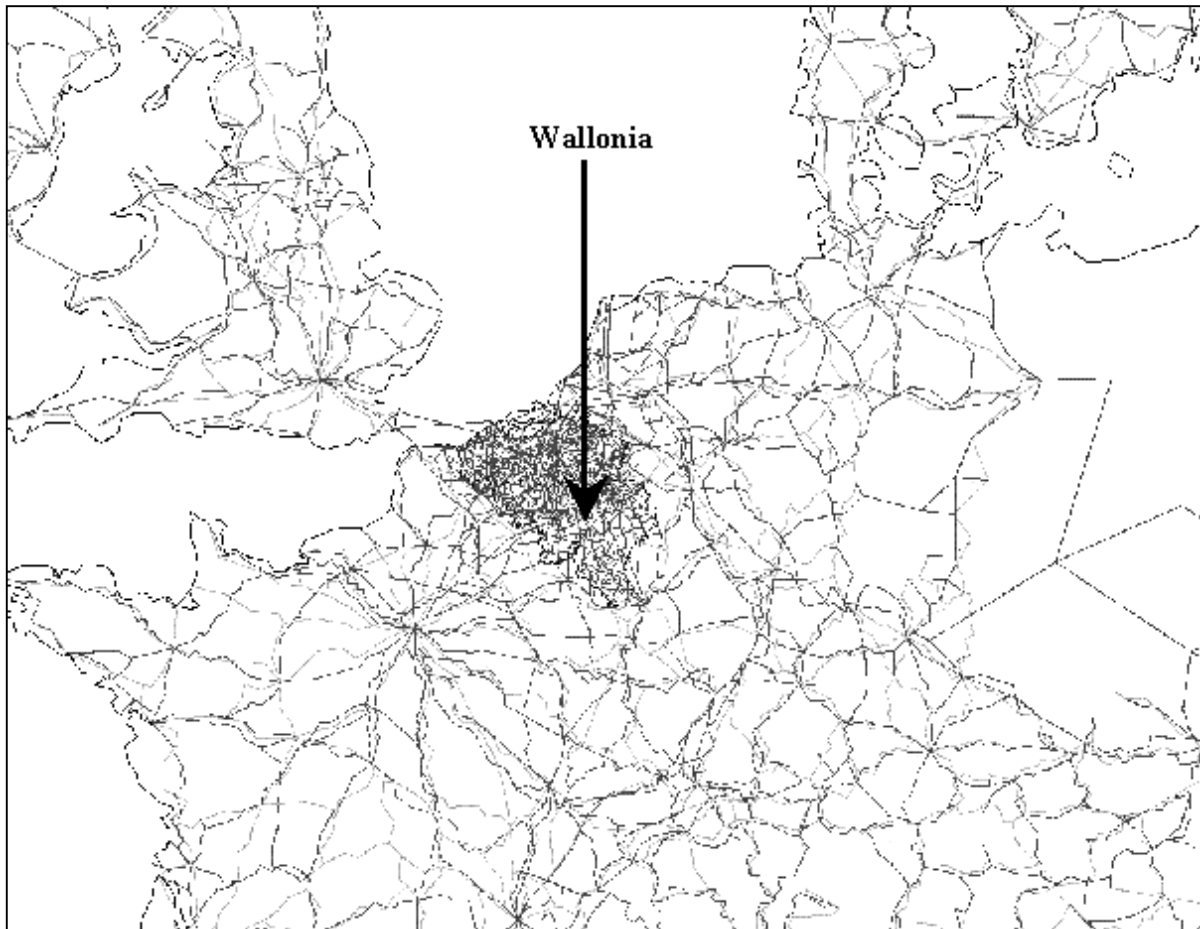
Map 2. Part of the digitised network

As usual in transportation analysis (see, for example, Kresge and Roberts, or Wilson and Bennet), NODUS encompasses the concept of 'generalised cost' which allows for the integration of all factors relevant to transport decision making in terms of monetary units. The virtual network requires the development of four types of cost functions, which are associated with specific virtual links: (un)loading, transit, transhipping, and moving virtual links. The general methodological framework that underlies the development of specific cost functions for the different transportation modes and means can be found in Jourquin & Beuthe (1996).

For this particular model, specific cost functions where developed for five different types of barges (300t, 600t, 1,350t, 2,000t and 4,500t), general cargo trains and large (40t) trucks. The way in which the model copes with block trains and small trucks will be explained later.

The cost functions are composed of the following elements:

- All costs related to moving a vehicle from its origin to its destination, like labour, fuel, insurance or maintenance costs;
- The inventory costs of the goods during transportation;
- Handling and storage costs, including packaging, loading and unloading and services directly linked to a transport;
- All residual indirect costs, like general administrative services, which may be assigned to transports on an average basis.

Besides these costs, a full account of transport costs in a multi-modal multi-means context should include some relative costs of transport quality differences, like differential reliability, safety, information, etc, if it is at all possible. These relative costs may vary from one category of goods to another, since transporting cattle or flowers may require a different type of care than transporting cement or steel beams. Unfortunately, information about these factors is very scarce. They were taken into account to some extent by the adjustment made to cost functions in order to obtain the best fit of the model (calibration) for each category of goods. This calibration of the model, i.e., the comparison between the assigned flows and the observed ones, was performed at three different levels:

- As the O-D matrixes are defined from centroïd to centroïd, an additional cost for initial and final truck traction to and from a railway station or a inland port must be added to the cost functions for trains and barges. It is this additional cost that is adjusted in order to obtain a correct modal shift for each category of commodities.
- Once a correct modal split had been obtained, it could still be found that the assigned flows on the network were sometimes different from the counts. To solve these discrepancies, speeds were modified on some links. For example, where a highway and a traditional road are parallel, too much flow can very well be assigned to the latter. Reducing the speed on it solves the problem.
- As explained earlier, two types of trains can be chosen, but only one cost function was defined because not enough relevant information was available to define two separate consistent cost functions. We decided to consider the cost for a block train as a relative expression of the cost of a traditional train. This percentage was adapted until a correct split between both types of trains was obtained.

A problem remained for trucks as the choice of using a small or a large truck depends much more on the size of the shipment (which is unknown) than on the cost of using either means of transportation. In other words, our cost functions did not discriminate enough to give a satisfactory split. It was decided to solve this problem through 'post-distribution'. The statistics used to build the O-D matrixes where used to estimate, for each category of goods, a distribution of the use of small and large trucks with respect to travel distance, and these distributions were then used to distribute the total quantity assigned to trucks between a given origin and destination among both types of trucks.

3.3 Validation of the reference scenario

Section 3.2 outlined the characteristics of the network model used and the way in which the model was calibrated. Table 1 gives an insight into the performance of the model in terms of estimated market shares expressed in transported tons. The assignments on the most important links were also compared to the observed flows (counts). Correlation factors (r) of

0.91, 0.86, and 0.93, respectively, were obtained on the inland waterway, railway and road networks. Map 3 illustrates the assignment.

Table 1. Assignment performance (tons)

	Observed (1995)		Estimated	
NST-R	**Water**	**Rail**	**Water**	**Rail**
0-9	11.28%	8.99%	11.06%	9.05%
0	7.18%	2.24%	7.56%	1.67%
1	5.06%	2.44%	5.61%	2.13%
2	25.33%	43.51%	25.11%	43.81%
3	28.65%	6.23%	28.89%	9.08%
4	25.06%	49.07%	18.66%	50.24%
5	7.44%	26.22%	7.32%	26.77%
6	15.37%	1.74%	15.44%	1.33%
7	23.70%	5.25%	24.09%	5.39%
8	8.00%	6.56%	7.85%	6.05%
9	0.53%	11.40%	0.88%	11.35%
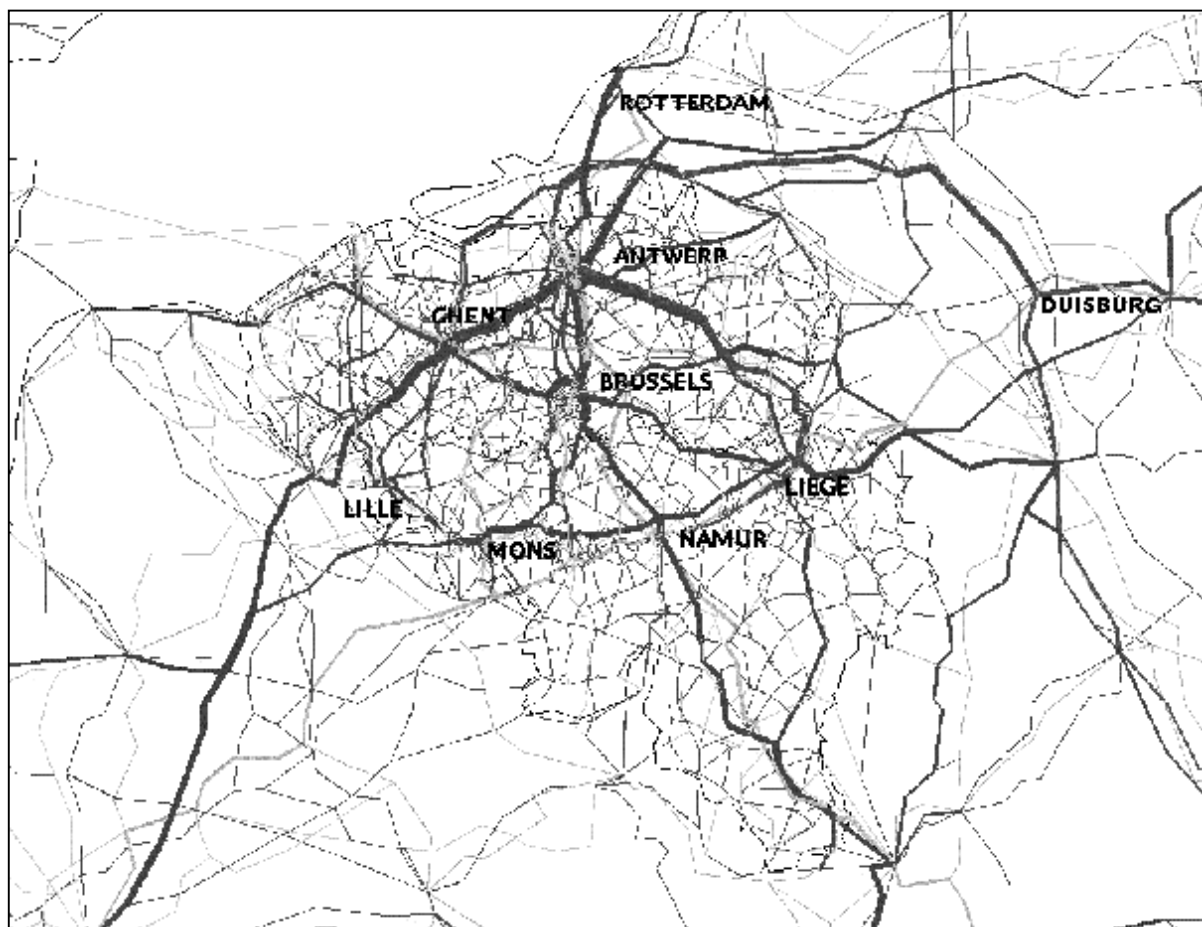
Map 3. Reference scenario

4. The 2010 model

After the work described in section 3 had been completed, a detailed reference scenario was made available which could be used as a starting point for the actual transportation plan.
The first question that needed to be answered at this point was: 'What will happen if no new decisions are taken?'. In order to be able to estimate the flows on the network in 2010, both the demand (the O-D matrixes) and the supply (the transport infrastructures) must be projected.

4.1 Expected demand

As specified in section 3.1, the National Planning Office publishes projected figures for expected changes in production and consumption patterns. These figures were used in the macro-economic model to appraise, per category of commodity, the impact of economic activity on quantities loaded and unloaded per 'arrondissement'. On average, the annual growth in unloaded tons is about 2.40%. An average annual increase of 1.95% is expected for loading. The difference between these two figures can obviously be explained by the nature of Belgian industry, which produces goods with a high added value, using much raw material and energy.
As no precise information was available, the projections for transit flows was based on the observation of these flows between 1982 and 1995. The results of regressions performed on these observations, per NST-R group of commodities, were used to modify the matrixes of the reference scenario.
All this put together, a new matrix could be build for each NST-R group for 2010. These matrixes are completely compatible with those used for 1995, i.e., the same O-D pairs are present in both sets of matrixes.

4.2 New transport infrastructures and flow assignment

As a number of new infrastructures are already decided and will be available in 2010, the network must be updated, both in Belgium and in the surrounding regions. Some new highways will appear, some roads will be broadened, an important new lock will be created, and some tracks will be electrified.
As the 2010 scenario must be considered an 'unchanged' situation, nothing will be changed in the cost functions, to maintain the same relative weight between the use of the alternative transportation modes.
When the assignment of the new O-D matrixes on the 'updated' network are compared with the results of the reference scenario, it comes out that the modal-split remains quite stable as the market share of road transport is only reduced by one percent. In other words, as the total quantity to be transported is increased by 40%, severe congestion problems may appear during peak hours. This is illustrated by Map 4, in which the thick lines represent the roads on which the estimated assigned flow during the peak[6] hours exceeds or reaches at least 80% of the standard capacity of the link.

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[6] The well known method of the 30th peak hour was used to estimate the flows during peak hours. It is also worthwhile to note that the previously discussed matrix of private cars was also assigned on the network so that the estimated flow contains both cars and trucks.
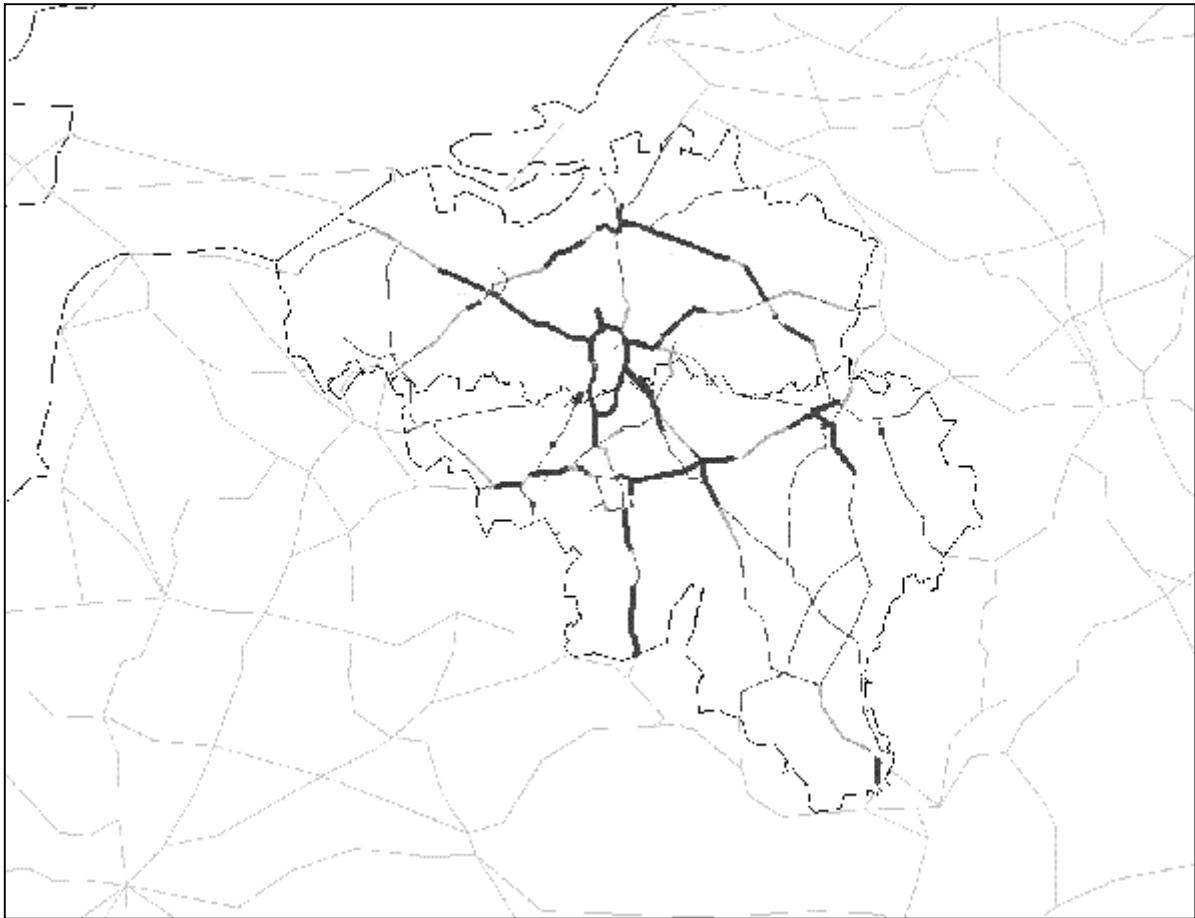
Map 4. Expected congested links

5. Building alternative scenarios

Section 4 indicates that, if no new decision is taken before 2010, the road network will be much more congested than in 1995. It seems worthwhile to consider a set of alternative solutions in order to assess their impact on the entire network. Three of these scenarios are directly related to some changes in the transport conditions for a given mode, the last one tries to measure the impact of some cost internalisations.

5.1 Road

In this first scenario, several new or improved roads are introduced. The list of these investments was gathered through all kinds of studies that were done during the last years in Belgium and its border regions. The definitive list was discussed with (and approved by) officials at the M.E.T. and representatives of other ministries. When the results of the scenario were compared to the initial 2010 scenario, the modal split had hardly changed, but with constant demand more truck transports use highways and assimilated roads. This is an expected result as most of the newly integrated investments are related to the creation of

highways or the broadening of existing roads; as a result, a greater proportion of the road network belongs to the highways.

5.2 Water

As in the case of the 'road' scenario, a list of investments was discussed and approved by officials. In addition to new infrastructures, like a new lock or the broadening of an existing canal, this scenario also allows navigation on Sundays[7]. This scenario has an impact on the modal split as transport by barges increases by 11% in Wallonia as compared to the basic 2010 estimation.

5.3 Rail

Beside the re-opening of a closed track and the creation of the 'Iron Rhine', this scenario also tries to measure the impact of the opening of a 'freeway' in Belgium and the creation of a big industrial park for logistic-oriented activities. This involves a substantial modification of the O-D matrixes, because some industrial activities are relocated to this new location. This work was based on a previous done by Geerts and Duchâteau (1997).

The freeway was modelled as an additional transportation means with a commercial speed of 50 km/h, that only stops at some selected railway stations: Antwerp (B), Muizen (B), Bettembourg (L), Lyon (F), Torino (I). The new industrial park is also linked to the freeway.

The results of the output of this scenario was discussed with the national railway company in order to compare the needed capacity with the available one on the network.

This scenario increases the tonnage transported by trains by 13% in Wallonia, which represent a reduction of 2% of the road market share.
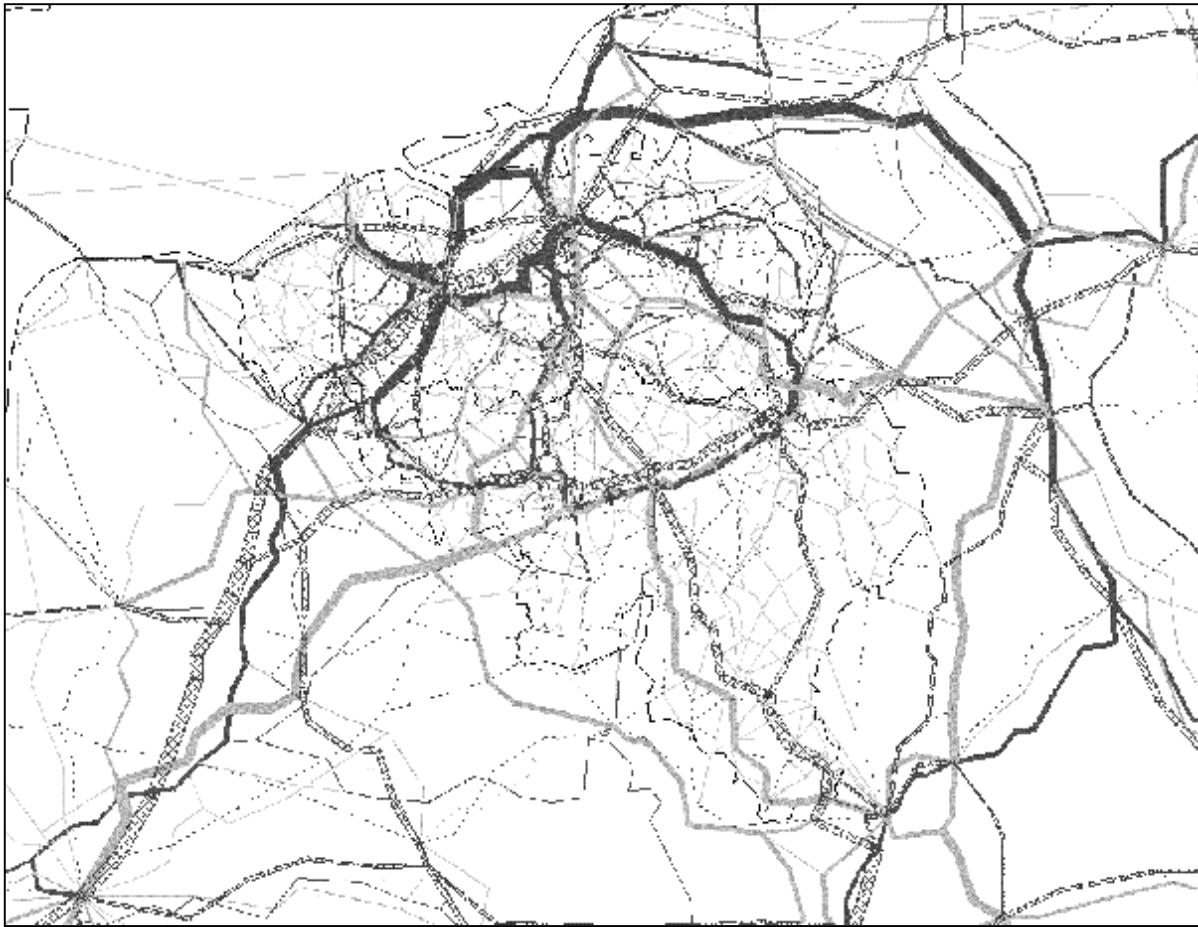
5.4 Internalisation of external costs

The three previously discussed scenarios give interesting results, but none has an important effect on the modal shift: in the best case, a reduction of 2% of the tonnage transported by road can be expected, and that is not enough to reduce the level of congestion. Improving the networks and transport conditions does not seem to be sufficient to substantially influence the modal split.

Alternative political decision can be taken; one of them is the internalisation of the external costs induced by the transport system. It is clear that such a sensitive political decision cannot be taken by the Walloon Government alone, but must be considered in the European context. Nevertheless, it is at least worthwhile to estimate the impact of such a policy.

Obviously, this research was not intended to estimate the value of the different commonly cited external costs such as congestion, emission of pollutants, accidents, noise and road damages, so that recently published values by De Borger and Proost (1997) were used. Two different scenarios were achieved. In the first one, all external costs were internalised. In a second one, inspired by work published by the Economic and Statistic Office of the French Ministry for Infrastructures and Transport (SES 1997), these costs were only partially internalised. The different values that were used can be found in Table 2.

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[7] This was simulated by a reduction of the transport costs by barges.

Dotted lines: Reduction of road traffic
Dark plain lines: Additional waterway traffic
Grey plain lines: Additional railroad traffic

Map 5. New modal split and traffic after total internalisation of external costs

These scenarios have a much greater impact on the modal split. For instance, for a total internalisation, the market share (tons) in Wallonia for road transport is reduced by 10%, which corresponds to an increase of 7% in rail transport and a gain of 3% for the inland waterways. This is very well illustrated by Map 5, in which plain lines represent increases of traffic and dashed lines a traffic reduction. It can easily be observed that the inland waterways and railway transport benefit from the cost internalisation.

Table 3. Levels of cost increases

	Increase of transportation cost	
Mode	**Total internalisation**	**Partial internalisation**
Road	40%	15%
Water	20%	10%
Rail	18%	8%

Such a result must be taken with some caution, like the results of the other scenarios, since the model remains 'static' in the sense that there is no feedback about demand[8]. All the assignments are made with fixed demand, as if the demand was perfectly inelastic. If this can be rather easily accepted for the 'infrastructure' scenarios which have only a very limited impact on transportation costs, things are not so clear for internalisation. Indeed, such a policy implies important changes of cost levels, which must have a negative impact on the total demand.

This limitation also implies that organisational aspect, such as changes in the distribution systems, are not explicitly taken into account. For instance, a modification of the transport conditions could be a decisive element for a firm to change its distribution system from a centralised to a decentralised one. This would certainly have an impact on the O-D matrixes. Such a change was only statically introduced in the matrixes for the railway scenario, in which a big distribution centre was created in Wallonia, but is never a dynamic result of the assignments.

6. Final transport plan and sensitivity analysis

The different scenarios proposed in section 5 give a rather large palette of possible measures and decisions that can be taken by the Ministry. Obviously, not all results that were obtained are published here, but enough details were given to the Walloon authorities to enable them to develop a transportation plan from elements from the different scenarios. The final choice included a partial internalisation of the external costs as well as some additional infrastructures.

This final scenario was then compared to the basic 2010 situation. Moreover, low and high economic conjunctures were simulated through changes in the O-D matrixes.

All kinds of indicators can be computed on the basis of the results obtained, among which some kind of accessibility indicators, such as the average cost or time to reach a given city, calculated from the average cost per kilometre and the average speed on the network. So, when compared to the basic 2010 scenario, the average transportation cost in the final plan is increased by 10% and the average speed is reduced by 3 km/h (-8%). In other words, if the different elements put in the scenario would be implemented, sending/receiving some goods from/in Wallonia would cost[9] 10% more than in the present situation. This is obviously linked to the fact that the plan includes a partial cost internalisation and that this internalisation implies a higher usage of slow transportation modes (rail and water).

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[8] Because the transport costs for all modes are higher after internalisation of the external costs, the total demand should be lower. The transportation task generated for this lower demand would generate less externalities, making transport less expensive and so increasing demand. Such an equilibrium model was not implemented in the present research.

[9] Based on generalised costs, including time loss due to a lower average speed.

7. Conclusions

This paper has presented some details of research carried out by STRATEC, F.U.Ca.M.-G.T.M. and A.D.E for the Walloon Ministry of Infrastructures and Transport. The objective of the study was to correctly model the actual flows of freight transport through Wallonia and to analyse the impact of different infrastructure or policy oriented decisions on these flows in order to build a freight transportation plan for the year 2010. In addition to this work, a complete software tool was installed at the Ministry so that the Officials can build and analyse further scenarios.

Important data gathering made it possible to build detailed origin-destinations matrixes for the 10 main NST-R categories of commodities. The European network was also digitised at a rather detailed level. Belgium was even more detailed. Finally, complete cost functions were set up for the different transportation means and operations.

For the network model, the methodology embedded in the NODUS software was used. It makes it possible to build transport models allowing complete and detailed analyses of multimodal freight transportation networks including intermodal solutions. It is based on the concept of 'virtual network' which is applied in a systematic way to model all transport operations: travelling, (un)loading, transhipping, waiting, handling, paying tolls, etc. with several modes and means of transportation. This methodology makes it possible to solve the assignment and modal choice problems in one single step.

The output of the different scenarios was thoroughly analysed and the most promising elements from each of them where bundled into a final transportation plan, of which the robustness was finally tested under high and low levels of economic activity.

Acknowledgements

References

Beuthe, M., L. Demilie, and B. Jourquin (1999) The international impacts of a new road taxation scheme in Switzerland. In: M. Beuthe and P. Nijkamp (eds.) *New contributions to transportation analysis in Europe*, Ashgate.

Crainic, T.G., M. Florian, J. Guélat, and H. Spiess (1990) Strategic planning of freight transportation: Stan, an interactive graphic system. *Transportation research record*, 1283.

Borger, B. de and S. Proost (1997) *Mobiliteit : de juiste prijs*, Garant.

Geerts, J.-F. and H. Duchâteau (1997) *Etude de pré-commercialisation et la plate-forme logistique d'intérêt européen de Dourges*, STRATEC S.A.

Harker, P.T. (1987*) Predicting intercity freight flows*, VNU Science Press.

Jourquin, B. (1995) *Un outil d'analyse économique des transports de marchandises sur des réseaux multi-modaux et multi-produits: Le réseau virtuel, concepts, méthodes et applications*, PhD thesis, Facultés Universitaires Catholiques de Mons.

Jourquin, B. and M. Beuthe (1996) Transportation policy analysis with a geographic information system: the virtual network of freight transportation in Europe, *Transportation Research C*, 4(6), pp. 359-371.

Jourquin, B., M. Beuthe and L. Demilie (2000) Freight bundling network models: Methodology and application. *Transportation Planning and Technology*, forthcoming.

Lippman, J., M. Rouchal, M. Wilck a.o. (2000) Multimodal Freight Networks Analysis with NODUS, a Survey of Several Applications. Submitted to *Transportation Planning and Technology*.

Kresge, D.T. and P.O. Roberts (1971) *Techniques of Transportation Planning: Systems Analysis and Simulation Models*, Brooking Institution, Washington DC.

SES (1997) *La demande de transports en 2015*, French Ministry for Infrastructures and Transport, 1997.

STRATEC-ADE-FUCAM (1997-1999) *Plan multimodal de transport de marchandises de la région wallonne*, several technical reports, Région Wallonne, M.E.T., DG3.

Wilson, A.G. and R.J. Bennet (1985) *Mathematical Methods in Human Geography and Planning*, John Wiley & Sons, New York.