38TH CONGRESS OF THE
EUROPEAN REGIONAL SCIENCE ASSOCIATION

28 AUGUST-1 SEPTEMBRE 1998 IN VIENNA

Impacts on Modal Choice of New Generation Terminals : Performance Analysis of a Hub-and-Spoke Network

Laurent DEMILIE
GTM-FUCaM

Bart JOURQUIN
GTM-FUCaM
& Limburgs Universitair Centrum

Michel BEUTHE
GTM-FUCaM

Group Transport & Mobility (GTM), Facultés Universitaires Catholiques de Mons (FUCaM),
151 Chaussée de Binche, B-7000, Mons, Belgium.
Tel . : +32 (65) 32.32.11, Fax. : +32 (65) 31.56.91, e-mail : gt&m@fucam.ac.be

Abstract

This paper presents a new methodology for dealing with bundling problems, embedded in a software similar to a GIS software. It was developed as a contribution to the TERMINET project funded by the European Commission as a part of the Fourth Framework Program for Research and Development.

The network model methodology outlined in the paper allows, among other features, to analyze the impacts of the new terminal concepts, both at the node and the link level, throughout the complete space of the multimodal European freight networks. The model deals with different modes (road, rail and inland waterways) and means of transportation (barges of different sizes, intermodal unit and classical trains and trucks, ...) and is based on the concept of « virtual network », that decomposes in a systematic way all the successive operations involved in multi-modal transport. It also includes a detailed analysis of all the costs involved.

In order to illustrate this methodology, a complete exercise based on a potential hub nearby Paris is also presented.

1. Introduction

Intermodal transport, and particularly combined transport by rail and road, is often presented as a promising means to alleviate the ever increasing pressure of road freight transports on congested networks. However, the competitiveness of intermodal transport is hindered by several factors : not only the cost of the transhipment between modes, but also the loss of time and reliability resulting from this operation, the increased risk of damages, and the loss of control of the shipment which is passed along from an operator to another. Combined transport involves necessarily a more complex transport chain which may lead to savings in some respects but also to some additional costs.

In order to solve these problems new generation terminals (NG) are proposed by railways and transport operators. According to their planners, they would provide safer and quicker transhipping, and allow the reorganisation of freight flows around bundling terminals to reduce the number of transhipments and marshalling operations, and benefit from more efficient large volume transport operations. However, this transport strategy raises a lot of questions : where are the best locations for NG terminals, which type of bundling network is the most suitable, what will be their impacts on the freight flows over the network, what will be their attractiveness compared to their cost?

This paper presents a methodology for dealing with some of these questions for the case of a hub-and-spoke network which would be implemented within a real multimodal network. It is based on the multimodal freight transport network software NODUS developed by Jourquin (1995), and proposes a comprehensive and systematic method to assess the attractiveness of a NG hub and its impacts on the flows over a network. It permits also an analysis of the best configuration of such a bundling network.

Obviously, efficient transport solutions and configurations of bundling networks depend on the topology of the basic transport network as well as on the volumes to be transported from origins to destinations. Thus, the proposed method will be applied as an illustration to the case of a railway hub which would be located in the Parisian region. On the basis of a digitised model of the main links of the trans-European network of railways, roads and inland waterways, the more promising spokes of the hub will be identified, the new service will be defined and modelled and, finally, its impacts all over the network and on the other modes and means of transportation will be computed.

The paper starts with a short presentation of the used multimodal transport network model and explains in detail how to use its features to model a specific hub-and-spoke bundling network within an overall network. The proposed methodology uselfulness is then demonstrated by applying it to the case of a fictitious railway hub which would be implemented in the vicinity of Paris. First, it is shown how the promising spokes to Paris can be identified before assessing the hub attractiveness by a set of cost scenario simulations. A number of impacts on some global indicators are also proposed which could be used to assess the usefulness of such a bundling network.

2. Methodology

2.1 NODUS and the concept of « virtual network »

Transportation of goods on a real geographic network may be realised by various means on the same infrastructure. For instance, an electrified rail track can be used by both diesel and electric powered trains. Moreover, transportation involves a chain of operations which do not appear in a normal geographic representation of a network : loading, unloading, transhipping and transiting. A rigorous analysis of efficient transport solutions over a network requires all these operations to be identified separately. This can be achieved by creating a virtual network where specific virtual links are associated with each specific transport operation. In particular, it allows the explicit introduction of transhipping operations which link the different modes' sub-networks. Hence, it offers a convenient approach to analyse the problems of intermodality.

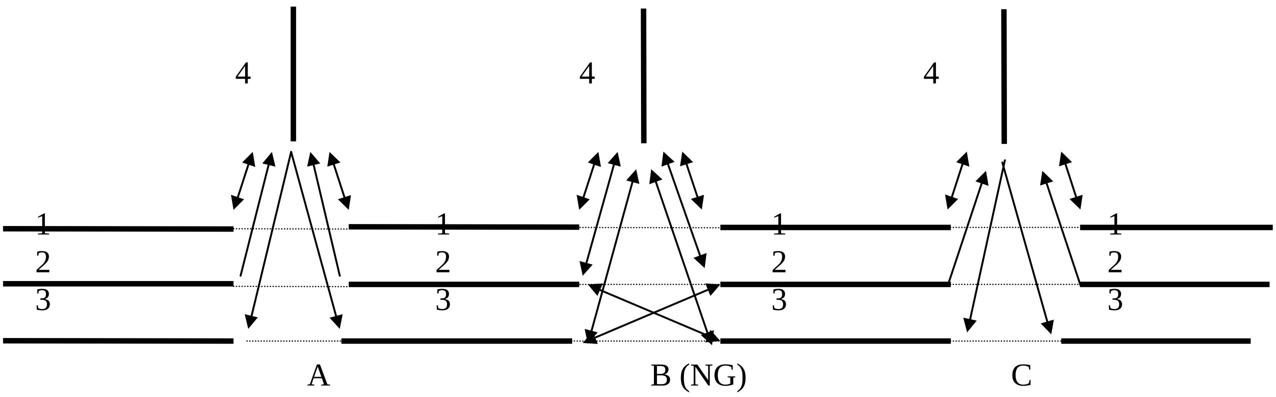
The concept of virtual link was initiated by Harker (1987), and further developed by Crainic et al. (1990). With NODUS, Jourquin (1995) proposes an automatic generation of all the relevant virtual links on the basis of a structured notation of the real nodes and links. This notation provides at the same time a convenient matching of each specific virtual link with the appropriate weight or cost functions. The method makes it possible to deal rather easily with very large networks like the trans-European one. It allows the search over the network of efficient transport solutions which minimise the generalised cost of a transportation task defined by a matrix of origins and destinations, and facilitates greatly sensitivity analyses on the network parameters and cost functions. The reader will find a complete technical explanation of the NODUS model in Jourquin (1995), Jourquin et *al.*(1996 and 1998) and in two reports to the EU Commission (TERMINET D3 and D5, 1998). The subsequent sections and the case of application presented in this paper will also provide insights on its working.

2.2 The methodology to model a hub-and- spoke bundling network

The modelling of a specific hub-and-spoke network competing with other modes and means over a general network raises some particular problems. The main function of the hub is to efficiently tranship containers brought into it by trains coming from some spokes on other trains which will leave it, travelling on different spokes. These trains are dedicated to the hub operations and must be operated efficiently, since such a bundling network imposes in many cases a longer transport trip. Efficiency is a necessary condition of its successful operation. As a consequence, they do not serve all the intermediate points between a spoke's end node and the central hub, like an ordinary railway service would. Moreover, when they do serve an intermediate station, they often can only load containers if they are travelling towards the central hub, while they can only unload containers on their way from the central hub towards the spoke's end. Hence, they cannot carry containers from an intermediate point to another intermediate point. Such an organisation implies naturally that it can only be applied to high volume flows.

It appears, then, that the trains on a particular spoke may not be operated in the same way in both directions like an ordinary freight train. In the framework of a virtual network where all different operations are identified separately, the trains in the two directions on a spoke must therefore be introduced like two different new means : the first new transportation means can only load and carry containers towards the hub, and the second new means can only unload containers brought from the hub. The only node where loading, unloading and transhipping between the two new means are allowed is the central hub. This set-up guarantees that a transhipment operation on the hub-and-spoke network can only take place at the hub. Naturally, this specification affects only the bundling network : none of the traditional means of transporting goods, like trucks and ordinary freight trains, which are operated on the overall network within which the hub-and-spoke is embedded, are affected by these restrictions. Figure 1 illustrates this particular way to model a hub-and-spoke network.

Figure 1: NG terminal hub-and-spoke model



Railways

- means 1 : ordinary railways,
- means 2 : « unload only » means
- means 3 : « load only » means

Road

- means 4 : truck

In Figure 1, A and C represent traditional terminals and B the hub. In terminal A and C, it is possible to load only on means 3, and to unload only from means 2. These restrictions are simply obtained by setting the cost of the forbidden operation at a prohibitive level. Both loading and unloading operations are still possible for the means 1. Transhipment from means 3 to means 2 is only possible at the NG terminal. Given the cost functions attached to the different virtual links, it is clear that, between A and C, the hub terminal will only be used if the loading cost at the origin, plus the transhipment cost at the NG terminal, plus the unloading cost at the destination terminal, plus all other shipping costs is lower than the sum of the loading, unloading and shipping costs for means 1.

Given a technical specification of a hub-and-spoke network, with all its associated transport cost functions, this hub model can be introduced at any feasible point in a multimodal network digitised according to the NODUS conventions. Then, the hub attractiveness can be assessed by its impacts on the modes and means' transport flows over the general network and by a number of global indicators which can be computed from the minimum cost solution : total cost of the transportation task, total tons and tons-km transported by each mode, number of movements at the hub, energy consumption and wage cost per mode. Solutions at different hub locations as well as different hub specifications can be compared on that basis. In the following application, the proposed methodology will be used to select the spokes which could be implemented around a possible Parisian hub.

3. The Case of a Paris hub

3.1 The reference scenario

The performance of a possible Parisian hub implemented within the actual West European multimodal networks of railways, inland waterways and roads will be now examined with the proposed methodology. Two first preliminary steps are necessary before introducing the hub in the overall network. First, a point to point origin-destination (O-D) matrix must be generated. On that basis, a calibrated reference scenario (without the new hub in Paris) must be built, which corresponds to the present situation on the trans-European network.

The digitised map was based on the 'trunk lines of communication of international importance' defined by the European Conference of Ministers of Transport for the Western European countries. The map is made of three layers for the three modes included in the analysis : roads, inland waterways and railways. The three layers are interconnected at many nodes, corresponding to cities, terminals and ports. The total 'real' geographic network has about 10,000 nodes and 13,000 links. The corresponding virtual network is about 60,000 nodes and 250,000 links large.

The « combined modes », which are characterised by the use of multimodal transport units, and the « traditional modes », which do not carry such units, that are included in the model are presented in Table 1.

Table 1 : Mode and means modelled in the reference scenario

Inland Waterways	**Railways**	**Road**
300T barge	Traditional train	Traditional truck
1350T barge	« Combined » train	« Combined » truck
Traditional barge (2200T)		
« Combined » barge (2250 t)		

For each of these means, cost functions are defined for every types of operation, i.e. loading, unloading, transiting, transhipping and moving. Some costs are constant, some others are linear with respect to distance, but, in all cases, they are complex functions depending on time, wages, fuel price, maintenance and insurance cost, average value of the goods transported and their time opportunity cost, and tolls. Full details on these costs can be found in Jourquin and Beuthe (1996) and in the two TERMINET reports.

The transportation task to be analysed is defined by a point to point O-D generated by a weighted stochastic assignment between pairs of nodes for numerous small bundles of goods up to the total flows transported throughout Europe in 1993 according to EUROSTAT statistics. The weighting was made with respect to the population at the nodes and took also into account the major importance of the main European harbours.

This O-D matrix was then assigned to modes, means and routes on the basis of the minimisation of the total generalised cost of the transportation task. This minimisation gives a unique ’all or nothing’ solution for each transport flow between a specific origin and destination. Then, the cost functions were adjusted in order to obtain a better fit between the observed modal split given by the EUROSTAT statistics and the estimated one. These cost adjustments were made separately for national and international flows and for short and long distance (above 500 km). The resulting new assignments form the reference scenario on the basis of which the performance of the new hub-and-spoke network will be assessed.

3.2 The promising spokes for the hub

The first objective is to find the railways links which could form an attractive bundling network around a hub located at the North East of Paris. In order to find these promising links, the methodology proposed above will be followed and four steps will be successively taken :

- a new hub-and-spoke network around Paris will be specified which will include all the possible spokes and their associated terminals,
- the cost advantage of the new network will be computed,
- the variations of tonnage transported by each mode/means will be analysed,
- a selection of promising spokes will be made on that basis.

In order to create a hub in the Parisian region, two new railway means, for transporting containers only, are added to the railway network which connect all the combined rail/road transport terminals to the hub. These new means are characterised by the transhipment possibilities which are presented in Table 2.

Table 2 : Transhipments possibilities of the new railway means

Characteristics	**Train 3**	**Train 4**
Transhipment at terminals	Transhipment only to trucks	Transhipment only from trucks
Transhipment at the hub	Transhipment between trains 3 and 4	Transhipment between trains 4 and 3

As can be deduced from Table 2, all the containers which are transported by the new means are somehow to be handled in Paris. In that hub, the containers can either be transhipped from a type 4 train to a type 3 train, or they can be unloaded on trucks. Containers can also be loaded in the hub, from trucks onto type 3 trains. Moreover, the network is specified in such a way that once the goods are loaded on train 4, no other stop for transhipment or marshalling at intermediate terminals are possible. Finally, note that the hub itself is not a potential point of origin or final destination.

One advantage of a hub is that it increases the commercial speed by decreasing the number of stops for loading/unloading and transhipment operations at the intermediate terminals. As a consequence of this increased speed, the cost per ton km is reduced. In order to model this phenomenon in a new scenario, the moving cost of the new means within France is reduced by 10 % with respect to a regular combined service. Note that, despite the fact that the new service is available from any combined terminal in the European network, the cost per ton/km was reduced only in France. The results of this particular scenario (scenario 1) will now be compared with those obtained in the reference scenario.

It turned out that the new service does not attract any traffic over short distances, presumably because of the additional cost of transhipment in the hub. In contrast, as shown in Table 3, the new service meets some success over distances longer than 500 km.

Table 3: Tonnage variations by means for long distance transports (1000 t)

Mode/Means	**Reference**	**Scenario 1**	**Difference**
300T barge	10645	10215	-430
1350T barge	4765	4765	0
Traditional barge (2200T)	545	545	0
« Combined » barge (2250 t)	10307	10307	0
Inland waterways (total)	26262	25832	-430
Traditional train	14859	14297	-562
« Combined » train	42287	39189	-3098
new service	0	4422	4422
Railways (total)	57146	57908	762
Traditional trucking	193292	192106	-1186
« Combined » trucking	27427	27845	418
Road (total)	220719	219951	-768

This table, in which all the flows over long distance are consolidated, shows that the main impact of scenario 1 is a substitution effect between the existing combined service and the new service. However, three smaller substitution effects can also be observed. Indeed, traditional direct trucking, inland waterways, and traditional railways service lose respectively 1186,000 tons, 430,000 tons and 532,000 tons to the benefit of the new service[1].

Figure 2 shows the traffic attracted by the new service under scenario 1. The width of the links are proportional to the importance of the relative variations. The flows on the different spokes of the network are given in Table 4. On the basis of these results, seven promising spokes have been selected for a hub located in the Parisian region :

- Paris - Calais,
- Paris - Amiens - Dunkerque,
- Paris - Antwerp - Rotterdam,
- Paris - Lyons - Torino,
- Paris - Lyon -Marseilles,
- Paris - Orléans - Narbonnes,
- Paris - Bordeaux - Madrid.

In the following scenarios, the use of the two new means in the network will be restricted to the spokes which have been chosen.

Figure 2: Demand of the new service over long distances

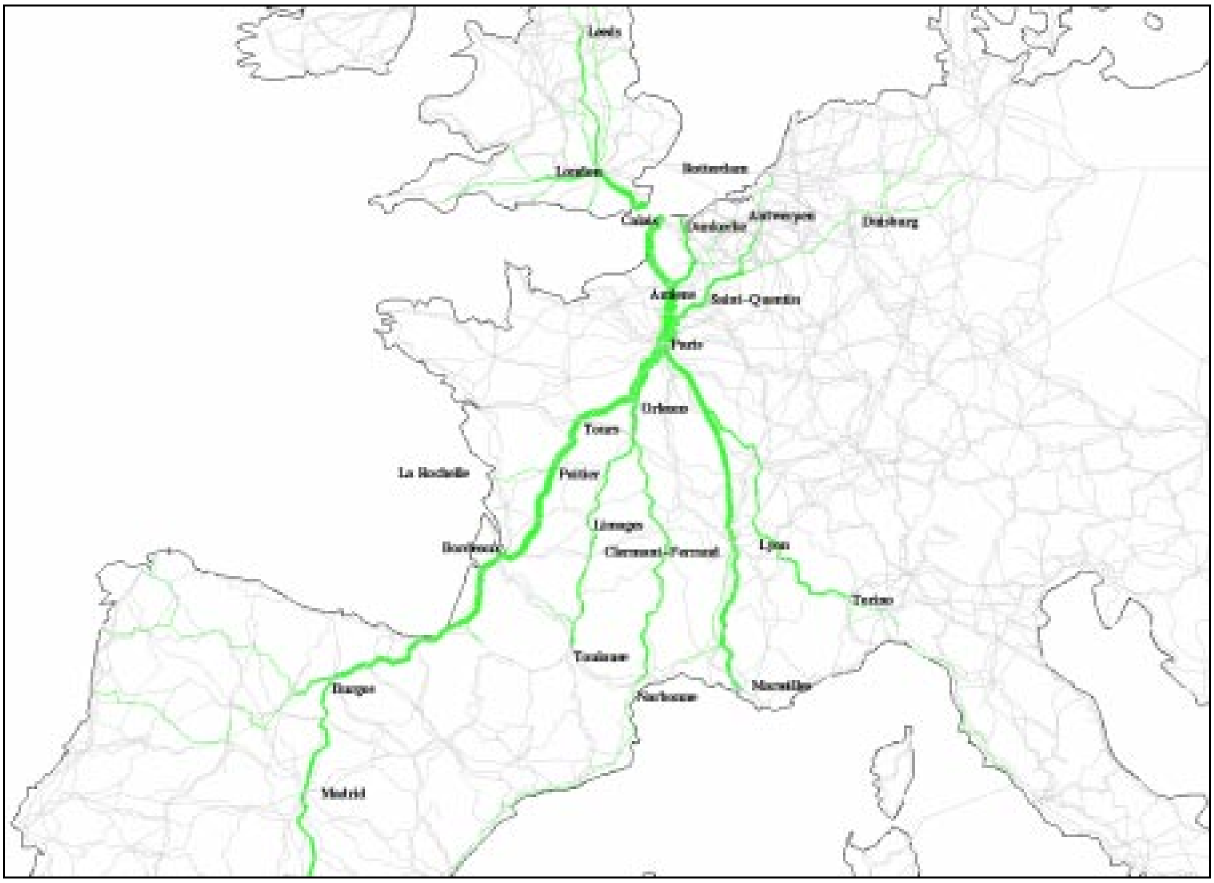


Table 4: Flows given by direction on the spokes (1000T)

Spokes	**To Paris**	**From Paris**
Paris - Calais - Leeds	1393	881
Paris - Amiens - Dunkerque	345	625
Paris - Saint-Quentain - Duisburg	0	213
Paris - Antwerp - Rotterdam	204	210
Paris - Lyons - Torino	210	142
Paris - Lyon -Marseilles	686	555
Paris - Orléans - Narbonnes	271	136
Paris - Orléans - Limoges - Toulouse	67	412
Paris - Tours - La Rochelle	138	0
Paris - Bordeaux - Madrid - Cadiz	970	835

4. The assessment of the new hub-and-spoke network

The impacts of this bundling network will be first analysed by a set of simulations with successive decreased levels of moving costs. These lower levels of generalised moving cost can be interpreted as a result of a higher average speed on the bundling network and as a consequence of a better service quality. In a second set of scenarios, the specific impacts of the NG terminal itself in the hub will be assessed for levels of transhipment costs in the hub decreased by successive steps of 10 %.

4.1 Impact analysis of lower generalised moving costs

An important indicator of a network attractiveness is the tonnage transported on it. The evolution of that indicator for the different means is presented in Table 5 for levels of cost per ton/km decreased successively by 10 % (scenario 1 with restricted spokes) and 20 % (scenario 2). It relates to long distance transports only, because, as mentioned earlier, the new service doesn’t attract any national or international traffic on short distances.

Table 5 : Tonnage variations by means over long distances (1000 t)

Means	**Base**	**Scenario 1**		**Scenario 2**	
	Tons	**Tons**	**Variation**	**Tons**	**Variation**
300T barge	10645	10645	0	10507	-138
1350T barge	4765	4765	0	4765	0
Traditional barge (2200T)	545	545	0	545	0
« Combined » barge (2250 t)	10307	10307	0	10307	0
Inland waterways (total)	26262	26262	0	26124	-138
Traditional train	14859	14859	0	13824	-1035
« Combined » train	42287	42011	-276	41183	-1104
Train 3	0	345	345	2966	2966
Train 4	0	345	345	2966	2966
Railways (total)	57146	57215	69	57973	827
Traditional truck	193292	193223	-69	191982	-1310
« Combined » truck	274272	27496	69	29013	1586
Road (total)	220719	220719	0	220995	276

By comparison with Table 3, the flows attracted by the new service, with a 10% decrease of the moving costs are less important than when the new service is not restricted to the more promising spokes. Indeed, the tonnage attracted by the new service is reduced from 4.4 to 0.3 million of tons. This phenomenon could be expected, and shows the specific interaction between the general and the new hub-and-spoke networks. It is also worthwhile to note that most of the tonnage arriving in the hub is transhipped to another direction. Hence, the volumes that appear under the heading "Train 3" are also present under "Train 4".

A second interesting point is that the main substitution effect occurs between the existing combined rail service and the new service. This result, which appeared already when searching for promising spokes, is found in both scenarios 1 and 2. In the later case, i.e. with a 20% decrease, it can be seen that the attractiveness of the new service is dramatically improved. Indeed, the new service increases its traffic by 2.6 million tons.

Figure 3 compares the traffic pattern obtained without the new service with the pattern obtained when the hub-and-spoke is implemented with a 20% reduction of moving cost. The solid lines correspond to an increased flow, the hashed lines correspond to negative variations. It should be pointed out that the substitution between two means inside one mode (e.g. : an ordinary railway service and the new hub-and-spoke service) cannot be observed on that figure. The red colour is associated with roads, while the green colour is associated with the railways. It is seen that the four main corridors affected by this new service are Paris - Bordeaux - Burgos, Paris - Marseilles, Paris - Narbonne, Paris - Calais and Paris - Dunkerke.

4.2 Impact analysis of the NG terminal.

In order to examine how the introduction of a NG terminal would affect the various flows, the impact of cost variations of the bundling operations in the hub must be analysed. The transhipment costs are reduced successively by 10 %, 20 % and 30 %. For each of these scenarios, it is also supposed that the cost per ton/km is reduced by 20 %.

Table 6 suggests that a reduction of 10 % of the transhipment cost provokes a small increase of attractiveness of the new service at the expense of the traditional direct trucking and the traditional train service. This phenomenon is reinforced for direct trucking when transhipment costs are decreased by 20 % and 30 %.

Figure 3: Impacts of a 20% decrease per ton/km

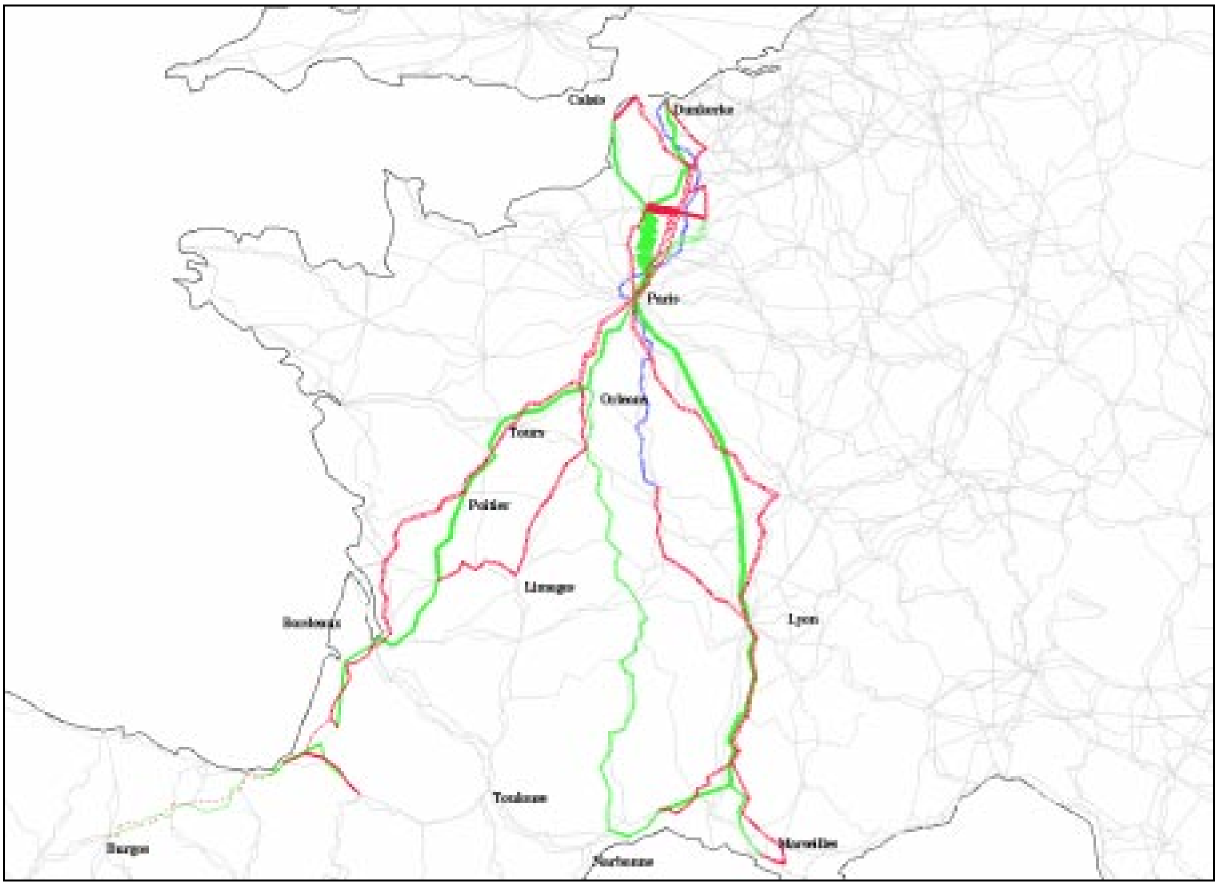


Table 6 : Tonnage variations for transports over long distances (1000 t)

Transhipment cost	**0.9**	**0.8**	**0.7**
300T barge	0	10	10
1350T barge	0	0	0
Traditional barge (2200T)	0	0	0
« Combined » barge (2250 t)	0	0	0
Inland waterways (total)	0	10	10
Traditional train	-68	-68	-68
« Combined » train	0	0	0
Train 3	206	409	547
Train 4	206	409	547
Railways (total)	138	341	479
Traditional truck	-206	-344	-482
« Combined » truck	68	68	206
Road (total)	-138	-276	-276

4.3 Other indicators

Table 7 presents the average distance per means in three scenarios :

- Scenario A : reference scenario without the new service,
- Scenario B : reduction of 20 % of the cost per ton/km on the new service,
- Scenario C : reduction of 20 % of the cost per ton/km and of 30 % of the transhipment costs in the hub .

Table 7: Average distance per means (km)

Means	Scenario A	Scenario B	Scenario C
300T barge	840	843	843
1350T barge	762	762	762
Traditional barge (2200T)	735	735	735
« Combined » barge (2250 t)	638	638	638
Traditional train	1127	1148	1150
« Combined » train	940	942	940
Train 3	-	461	429
Train 4	-	399	414
Traditional truck	784	786	786
« Combined » truck	77	78	78

It seems that the introduction of the new service has almost no impact on the average distance realised with the existing means. For instance, the average distance made by direct trucking is quite constant and is always less important than the distance of the different railway means. It is interesting to note that the total distance covered by the new means, the sum of the distance by trains 3 and 4, is superior to 800 km. This result shows clearly that such a hub-and-spoke service has a good potential only for long distance transports. Table 8 presents another set of indicators.

Table 8: Global indicators

Indicator	Scenario A	Scenario B	Scenario C
Total cost (10^6 ECU)	9643	9638	9635
Total quantity transported, per transportation mode (1000T) :			
• Inland waterways	26262	26124	26134
• Railways	57146	57973	58452
• Road	220719	220995	220719
Total tons-km per transportation mode (10^6 T) :			
• Inland waterways	19547	19471	19471
• Railways	56511	57213	57494
• Road	153694	153091	152803
Energy consumption on the network, per mode (10^6 ECU)			
• Inland waterways	49	49	49
• Railways	302	308	310
• Road	1608	1602	1600
Wages cost, per transportation mode (10^6 ECU)			
• Inland waterways	85	85	85
• Railways	96	97	98
• Road	1891	1884	1881

Total cost, total quantities per mode, total quantities handled at the terminals and total tons-km covered per mode are direct outputs of the software. Energy consumption and wage costs per mode can also be computed, since energy and wages[2] are components of the cost functions

As it appeared already in Table 5, the introduction of the new service with a reduction of 20 % per ton/km increases slightly the tonnage moved by the railways. In Table 6, additional reductions of the transhipment cost were shown to have further positive impacts on the tonnage and tons/km realised by the railways. These increases in the railways' activity are the result of a substitution of rail services to trucking. As a consequence, it is seen in this Table 8 that total cost of transportation decreases. The other indicators translate this substitution effect in terms of labour cost and energy consumption. It is worthwhile to point out that the wages cost and energy consumption are computed at constant unit value, so that the results show how the substitution of the two modes contributes to a saving of energy and manpower in real terms.

5. Summary and conclusion

This paper proposed a methodology for analysing the impacts of a hub-and-spoke bundling network implemented in a multimodal network of freight transportation. It is based on a network software called NODUS which decomposes the chains of transportation in all their successive operations by the creation of virtual links corresponding to each of them. This allows in particular the convenient modelling of transhipping operations between modes and means.

In order to demonstrate the usefulness of the method, an application to a fictitious railway hub in the North East vicinity of Paris was realised. In a first step, the best configuration of the hub and-spoke network was analysed by a simulation which identified the railway links which could contribute sufficient flows to the system. The most promising links were found to correspond to long distance transports. After selecting some of these promising links, and implementing the hub-and-spoke network, two set of simulations corresponding to different cost scenarios were realised. In the first set of scenarios, the generalised cost per ton/km of moving the goods were decreased over the new network, in order to examine how an improvement of the transport service, which can be translated in a lower level of generalised cost, affects the various modes, means and paths' chosen. This analysis showed the importance of the network organisation on its performances ; the limitation of the network to the more promising spokes reduces considerably the volume attracted by the new service.

The main substitution effect observed is between the existing « combined » railway transports and the new service. However two others substitution effect are observed between traditional trucking and the new service and between traditional railways and the new service.

In the second set of scenarios, focused on the operation of an NG terminal in Paris, the transhipment costs in the hub were decreased by successive steps of 10 %. Such decreases seem to have a limited impact on the attractiveness of the new service. However, in this case the main substitution effect is between the direct trucking and the new service.

An analysis of the average distance covered by the various means confirms that, for both national and international traffic, such a hub-and-spoke network can only be of interest for very long transport distances ; the average distance of a shipment using the new service appears to be more than 800 km.

Finally, a few indicators were computed which show the various impacts of the different cost reductions. It appears that there is a reduction of the total cost of the transportation task defined by the O-D matrix, which results from the substitution of railway transport to trucking. Finally, it is shown that this substitution contributed to a saving of energy and labour.

Notes :

[1] Note that the given statistics do not record any trucking which is necessary to carry the goods from a point of origin or destination to/from the local loading/unloading station. More precisely, such trucking is not included in the tonnage of "combined" trucking. This explains why, in the present case, there is no variation of combined trucking. However, some "combined" trucking could be used in some other cases to carry goods over longer distances to feed a railway or waterway loading station. These comments have to be kept in mind for a correct interpretation of the different tables presented in this paper.

[2] For railway and road transport, the wages are computed for respective average speeds of 30 and 50 km per hour.

Acknowledgements :

This paper is an output of the TERMINET project funded by the European Commission as a part of the Fourth Framework Program for Research and Development. We wish to acknowledge also the support of the Belgian Services Fédéraux des Affaires Scientifiques,Techniques et Culturelles for the development over a number of years of the basic software.

References :

1. 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.
2. Harker P.T. (1987), *Predicting Intercity Freight Flows*, VNU Science Press, Utrecht.

3. 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*, Ph.D. Thesis, Facultés Universitaires Catholiques de Mons.
4. Jourquin B., M. Beuthe (1996) *Transportation Policy Analysis with a Geographic Information System: The Virtual Network of Freight Transportation in Europe* , Transportation Research C, 1996, Vol 4, No 6, pp. 359-371
5. Jourquin B., M. Beuthe and L. Demilie (1998), *Freight Bundling Network Models: Methodology and Application*, paper presented at the 8th World Conference on Transport Research and forthcoming in Transportation Planning and Technology.
6. TERMINET, deliverable D3 (1998) , *GIS presentation of innovative bundling concepts*, Transport RTD Programme of the 4th framework programme.
7. TERMINET, deliverable D5 (1998) , *Tool : Decision support tool/model for bundling layout*, Transport RTD Programme of the 4th framework programme.