

**Inter-modal freight terminal location in Europe: a strategic model**

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**Abstract**

The political pressure in favour of multi- and inter-modal transport has oriented the focus on sustainable transport solutions. Inter-modal transport is one of the possible solutions, but its efficiency strongly depends on the places where the container terminals are located.

The number of possible locations on large scale networks becomes rapidly too large to be taken as input by exact location methods. That's why the first goal of this paper is to outline a method that helps to identify the best potential locations out of the thousands of potential nodes. The basic idea is to use the flows of commodities and their geographic spreading as input to determine a set of good potential locations for transfer inter-modal terminals. This set can, in a second step, be used as input for already well known optimal location models in order to identify the optimal locations for container terminals in Europe.

The methodology is illustrated over the whole trans-European networks. The paper concludes with a discussion of the results: the model predicts a reduction of the total transportation costs on the network and a modal shift from road to rail. It also evaluates the new modal shift and other indicators.

**KEYWORDS**

Location, Terminals, Hub-and-Spoke, Network, Inter-modal, Transport

## **Introduction**

The optimal location of terminals and logistic centres are an up-to-date research topic. The political pressure in favour of multi- and inter-modal transport has indeed oriented the focus on sustainable transport solutions.

Even if the problem could appear to be rather trivial and well documented, it is not easy to solve on large real networks such as a digitalized European network, as the number of possible locations becomes rapidly too large to be taken as input by an exact location method. Therefore, these models have to start with a subset of nodes that can be considered as good potential locations. Unfortunately, in a majority of the relevant literature, the way these potential locations are chosen is not well documented.

In some rare researches (see for instance Macharis, 2004), the potential locations are determined using common sense reflections and a lot of data collected on the field. If such an approach can be suitable on rather small geographical areas, it becomes much more difficult to implement on the whole European territory, where a much more systematic approach is needed.

Some kind of systematization can be found in the work provided by Arnold (2002) in which three different approaches are presented: a Belgian case study for which the potential locations are just the nodes where both railroads and highways are available, an Iberian case based on a “grid” approach (the territory is divided in 200km grids, in which the most accessible point is kept as potential location), and a European exercise for which the already existent terminals are considered as the set of potential locations.

In addition to this first aspect, it is worthwhile to note that most of the known location methods are “node” based, in the sense that they use the locations of the demands and the supplies as main input. Doing so, they ignore the network effects that can only be captured if the flows of commodities and their geographic spreading are taken into account.

The basic idea of this paper is to use the flows of commodities as input to determine a set of potential locations for transfer inter-modal terminals. This set can then be used in conjunction with already known optimal location models.

Several kinds of approaches exist to solve the optimal location problems, and some of them will be presented in this paper.

A complete exercise, based on real-life data will also be presented and argued. Therefore, a typology of different types of terminals will be discussed. This will be followed by a presentation of the used data, network model and the way the demand can be assigned on the latest, as the assigned flow will be used as main input to compute a set of potential locations.

The case study concerns multi-modal transport over the whole trans-European networks and some results obtained by means of the proposed location methodology is presented at the end of the paper.

## The location problem

Mathematical models were developed and used to quantitatively solve optimal location problems. The location-allocation models provide facilities to customers dispersed over space and assign them to these facilities in order to optimize one or more criteria. The location theory was initially developed by Weber (1909), which considered the location of a service as a minimization problem of transport costs. From a general point of view, mathematical location models are designed to address a number of questions, among which:

- How many terminals are needed and should be located?
- Where should each terminal be located?
- What is the size and shape of their service areas?
- How should the demand for terminals' services be allocated to the terminals?

The answers to these questions depend on the objectives underlying the location problem.

In this section, four basic facility location models, and some variations, will be presented: the  $p$ -median problem (p-MP); the  $p$ -centre problem (p-CP), the uncapacitated facility location problem (UFLP) and the fixed charge location problem (FCLP). In all these approaches, the network and a set of potential locations of facilities are given. Moreover, distances (or some other kind of weight such as travel time or cost) are a fundamental data to solve these problems. Note that, for the exercise presented in this paper, generalized costs, combining out of pocket costs and time related costs, are used.

In the p-MP, the locations of  $p$  facilities on a network have to be found so that the total cost on the system is minimised. Note that the number of facilities to locate must be given as input.

The p-CP differs from p-MP. Indeed, whereas the p-MP is a minimization problem, the p-CP has a minmax objective: open  $p$  facilities and assign each customer to exactly one of them in order to minimize the cost from any open facility to any of the clients assigned to it. The number of facilities to be located must also be given. For the UFLP, the total installation costs of the facilities and all the travel cost must be minimized. In this case, the number of facilities is determined endogenously.

Note that p-MP and p-CP also assume that the facilities to be located don't have any capacity restriction.

For a given set of potential facilities, the p-MP has to find the optimal locations of  $p$  facilities in order to minimize the total cost. The model can be formulated as follows:

### Inputs:

$m$ : the number of clients indexed by  $i, i \in I = \{1, \dots, m\}$

$n$ : the number of sites for potential facilities indexed by  $j, j \in N = \{1, \dots, n\}$

$p$ : the number of facilities to be opened or established,  $1 \leq p \leq n$ .

$h_i$ : demand at node  $i$

For each of the  $mn$  facility-client pairs, define

$c_{ij}$ : the total variable cost to satisfy the total demand of all the clients  $i$  associated to facility  $j$ .

**Decision Variables:**

$y_{ij} =$  1 if demand node  $i$  is assigned to a facility at node  $j$   
0 if not

**Minimize:**

$$\sum_{i \in I} \sum_{j \in J} h_i c_{ij} y_{ij} \quad (1)$$

**Subject to:**

$$\sum_{j \in J} x_j = p \quad (1.1)$$

$$\sum_{j \in J} y_{ij} = 1 \quad \forall i \in I \quad (1.2)$$

$$y_{ij} - x_j \leq 0 \quad \forall i \in I, j \in J \quad (1.3)$$

$$x_j \in \{0,1\} \quad \forall j \in J \quad (1.4)$$

$$y_{ij} \in \{0,1\} \quad \forall i \in I, j \in J \quad (1.5)$$

The objective function (1) minimizes the total cost. Constraint (1.1) stipulates that  $p$  facilities are to be located. Constraint (1.2) requires that each demand node is to be assigned to exactly one facility. Constraint (1.3) restricts demand node assignments to open facilities only. Constraint set (1.4) established the binary location decision variables. Constraint set (1.5) can be replaced by  $y_{ij} \geq 0 \quad \forall i \in I, j \in J$  because constraint set (1.3) guarantees that  $y_{ij} \leq 1$ . This formulation assumes that the potential facility locations are nodes on the network. Hakimi (1964) proved that relaxing the problem to allow facility locations on the edges of the network would not reduce the total travel cost. Consequently, this formulation will yield an optimal solution, even if the facilities could be located anywhere on an edge.

For a given set of potential facilities, the p-CP has to minimize the maximum distance from each demand to its closets facility. Given the previous definitions and:

$W =$  the maximum distance between a demand node and the facility to which it is assigned

The p-CP can be formulated as follows:

$$\text{Minimize } W \quad (2)$$

**Subject to:**

$$\sum_{j \in J} x_j = p \quad (2.1)$$

$$\sum_{j \in J} y_{ij} = 1 \quad \forall i \in I \quad (2.2)$$

$$y_{ij} - x_j \leq 0 \quad \forall i \in I, j \in N \quad (2.3)$$

$$W - \sum_{i \in I} \sum_{j \in J} h_i c_{ij} y_{ij} \geq 0 \quad \forall i \in I \quad (2.4)$$

$$x_j \in \{0,1\} \quad \forall j \in N \quad (2.5)$$

$$y_{ij} \in \{0,1\} \quad \forall i \in I, j \in N \quad (2.6)$$

Constraints (2.1), (2.2), (2.3), (2.5) and (2.6) are identical to (1.1), (1.2), (1.3), (1.4) and (1.5) of the p-MP. Constraint (2.4) defines the lower bound of the maximum cost, which has to be minimized.

The UFLP takes into account the fixed cost  $f_j$  of establishing a facility at candidate location  $j$ . Thus, the objective function to minimize can be rewritten as:

**Minimize:**

$$\sum_{i \in I} \sum_{j \in J} h_i c_{ij} y_{ij} + \sum_{j \in J} f_j x_j \quad (3)$$

The constraints (1.2) through (1.5) remain unchanged. This formulation involves the cancellation of constraint (1.1), since the number of facilities to establish is not predetermined, but is part of the solution.

The solution given to a p-CP tends to favour efficiency, as the problem formulation tries to minimize distances for all the customers to the terminal they are assigned to. This can obviously result in a solution that appears to be less effective than the ones that result from a p-MP (or a UFLP) which tends to favour equity.

These location problem formulations are rather simplistic as they only minimize the total costs or the maximal distance between facility-client pairs. To achieve these goals, minimsum or minimax criteria are used. Neither of these criteria alone, however, captures all essential elements of a location problem, for which it is important to consider both the total "costs" of serving clients as well as the service provided to those clients who are located far away from a facility.

In order to take these considerations into account and obtain a good way to trade-off minimsum (efficiency) and minimax (equity) approaches; bi-criteria models were developed. Halpern (1976, 1978, 1980) introduced the cent-dian model. This term refers to location models where the objective is to minimize a convex combination of the objective functions of the center and the median problems.

Another example is a set of algorithms for hybrid problem: for selected values of parameter  $\lambda$ ,  $0 \leq \lambda \leq 1$ , and for all values of  $p$  within a specified range  $p' \leq p \leq p''$ , determine the location of  $p$  facilities such that each client is assigned to one of these and that the convex combination

$$\lambda(\text{minisum criterion of UFLP}) + (1 - \lambda)(\text{minimax criterion of p-CP})$$

is minimized.

Special cases of this hybrid model include:

p-MP:	$\lambda=1$	$p'=p''=p$ , all fixed costs=0
p-CP:	$\lambda=0$	$p'=p''=p$
UFLP:	$\lambda=1$	$p'=1, p''=n$ .

These kinds of problems make three important assumptions:

- they assume that each potential location has the same fixed installation costs (except UFLP);
- they assume that the facilities being located do not have capacity restrictions;
- they assume, with the noticeable exception of the UFLP, that the number of facilities to open is known *a priori*.

The fixed charge location problem (FCLP) relaxes these assumptions. The objective of the FCLP is to minimize the total facility and transportation costs. During the process, it also determines the optimal number of facilities and their location, as well as the demand to be assigned to each facility. Since the facilities have capacity constraints, the total demand for a given node may not be assigned to its closest facility only, which was the case in the previous described models.

Given the previous definitions and  $\Gamma_j$ , the capacity of a facility at candidate location  $j$ , the following constraints must be added:

$$\sum_{j \in J} h_i y_{ij} - \Gamma_j x_j \leq 0 \quad \forall i \in I$$

This prohibits the total demand assigned to a facility to exceed the capacity of the facility,  $\Gamma_j$ .

Relaxing constraint set:  $\forall i \in I, \forall j \in N, y_{ij} \in \{0,1\}$  allows the total demand at a node to be assigned to multiple facilities, because this binary constraints required that the total demand at a particular location was assigned to one facility. Note that, due to the limited capacities of the facilities, the demand may be deserved by a facility which is not the closest one.

## The Hub-Location Problem

In multiple-hub networks, it is assumed that all the hubs are connected directly to each other, and that the spoke cities are connected to a single hub. The hub-to-hub links consolidate the total flow originating from a hub and its spoke nodes and be sent to the destination hub (and its spoke nodes). If there are economies of scale associated to the transport system, the operating costs per t.km may be significantly reduced on the hub-to-hub links.

The p-Hub Median Problem (p-HMP) was first formulated as a quadratic integer program by O'Kelly (1987). Campbell (1994) formulates this problem as a mixed integer linear programming problem. This formulation is used in the majority of location's studies. Campbell formulation is:

### Inputs:

$p$  = number of hubs to be opened

$W_{ij}$  = flow from origin  $i$  to destination  $j$

$C_{ij}^{km}$  = unit cost between origin  $i$  and destination  $j$  when going via the hubs located at nodes  $k$  and  $m$

$$= \chi C_{ik} + \square C_{km} + \delta C_{mj}$$

where :

$\chi$  is the relative cost collection (in Campbell's original formulation,  $\chi=1$ );

$\square$  is the inter-hub discount ( $0 \leq \square \leq 1$ );

$\delta$  is the relative cost distribution (in Campbell original formulation  $\delta=1$ )

$C_{ij}$  = unit travel cost on link between origin  $i$  and destination  $j$ .

### Decision Variables:

$Z_{ij}^{km}$  = fraction of the flow from origin  $i$  to destination  $j$  that is routed via hubs  $k$  and  $m$ .

$Y_k = 1$  if location  $k$  is a hub and 0 otherwise.

**Minimize:**

$$\sum_i \sum_j \sum_k \sum_m C_{ij}^{km} W_{ij} Z_{ij}^{km} \quad (4)$$

**Subject to:**

$$\sum_x Y_k = p \quad (4.1)$$

$$\sum_k \sum_m Z_{ij}^{km} = 1 \quad \forall i,j \in N \quad (4.2)$$

$$Z_{ij}^{km} \leq Y_k \quad \forall i,j,k,m \in N \quad (4.3)$$

$$Z_{ij}^{km} \leq Y_m \quad \forall i,j,k,m \in N \quad (4.4)$$

$$Y_k = 0,1 \quad \forall k \in N \quad (4.5)$$

$$0 \leq Z_{ij}^{km} \leq 1 \quad \forall i,j,k,m \in N \quad (4.6)$$

The objective function (4) minimizes the total cost. Constraint (4.1) stipulates that exactly  $p$  hubs should be located. Constraints (4.2) assures that the flows for every origin/destination pair  $(i,j)$  is routed via a pair of hubs. Note that since  $k$  may be equal to  $m$ , the flow between origin  $i$  and destination  $j$  can be routed through a single hub only. In this case,  $\alpha c_{km} = \alpha c_{kk} = 0$ . Constraints (4.3) and (4.4) assure that flows are routed via locations that are hubs. Constraints (4.5) restrict  $Y_k$  to be binary and constraints (4.6) limits the range of  $Z_{ij}^{km}$ . Note that in the absence of capacity constraints on the links, an optimal solution will have all  $Z_{ij}^{km}$  equal to zero or one since the total flow for each  $(i,j)$  pair should be routed via the cheapest pair of hubs. Note that Goldman (1969) showed that, for the  $p$ -HMP, a solution found somewhere on a link is never better than a solution found at one of its end nodes. Each  $(i,j)$  pair in a  $p$ -HMP is analogous to a demand point in a  $p$  median problem ( $p$ -MP) and the formulation of the  $p$ -HMP is analogous to the one used for the  $p$ -MP. In the  $p$ -MP, the demand nodes are assigned to the nearest facilities. However, in the  $p$ -HMP, it may not be optimal to assign demand nodes to the nearest hub.

The major difficulty to solve  $p$ -HMP is that the number of assignment variables ( $Z_{ij}^{km}$ ) can be very large. Indeed, the  $p$ -HMP involves  $(n^4+n)$  variables where  $n$  is the number of candidate hubs and requires  $(1+n^2+n^4)$  linear constraints. Ernst *et al* (1996) propose a new formulation to solver larger problems. They remove the  $Z_{ij}^{km}$  variables and define  $Y_{km}^i$  as the traffic emanating from node  $i$  that is routed between hub  $k$  and  $m$ . If the total flow out of node  $i$  is denoted by  $O_i$ , the total flow originating at node  $i$  is  $O_i = \sum_{j \in N} W_{ij}$  and if the total flow into node  $i$  is denoted by  $D_i$ , the total flow destined for node  $i$   $D_i = \sum_{j \in N} W_{ji}$ , the formulation is:

**Decision Variables:**

$x_{ij} \in \{0,1\}$  be 1 if node  $i$  is allocated to a hub located at node  $j$  and 0 otherwise  
 $Y_{km}^i \geq 0 \quad \forall i,k,m \in N$

**Minimize:**

$$\sum_i \sum_k C_{ik} Z_{ik} (\gamma O_i + \delta D_i) + \sum_i \sum_k \sum_m \alpha C_{km} Y_{km}^i \quad (5)$$

**Subject to:**

$$\sum_x X_{kk} = p \quad (5.1)$$

$$\sum_k X_{ik} = 1 \quad \forall i \in N \quad (5.2)$$

$$X_{ik} \leq X_{kk} \quad \forall i, k \in N \quad (5.3)$$

$$\sum_m Y_{km}^i - \sum_m Y_{mk}^i = O_i X_{ik} - \sum_j W_{ij} X_{jk} \quad \forall i, k \in N \quad (5.4)$$

The above formulation decreases the problem size, because the flows between pairs of nodes are not treated separately anymore. This problem involves  $(n^3+n^2)$  variables and requires  $(I+n+2n^2)$  linear constraints. The problem size has thus been reduced by a factor  $n$ .

The uncapacitated hub location problem (UHLP) differs from the p-HMP in that a fixed cost is associated to each potential hub location. This is analogous to the UFLP discussed earlier. The UHLP can be formulated as:

**Minimize:**

$$\sum_i \sum_k C_{ik} Z_{ik} (\gamma O_i + \delta D_i) + \sum_i \sum_k \sum_m \alpha C_{km} Y_{km}^i + \sum_k F_k X_{kk} \quad (6)$$

Constraints (4.2) through (4.5) remain unchanged, constraint (4.1) on the number of hubs to be located is removed and  $F_k$  is the fixed cost to establish a facility at location  $k$ .

## The Intermodal Terminal Location Problem

Intermodal transport is “*The movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes*” (European Conference of Ministers of Transport (ECMT) and the European Commission (EC) terminology on combined Transport, 2001). Intermodal transport requires particular infrastructures for the transshipment operations. The competitiveness of intermodal transport strongly depends on the localization of these intermodal terminals.

All the above discussed network location models were considered in an unimodal context. Arnold *et al* (2004) propose a formulation of the rail/road intermodal terminal location problems by considering a terminal as an edge in a graph, rather than a vertex. The authors have defined two networks, corresponding to two different transportation modes, i.e. road and railway transport. Each network is represented by a directed graph. A directed super-graph was build on top of these two first networks, containing a special subset of transfer edges that represent the potential intermodal operations. This solution was inspired from the concept of “virtual network” proposed by Jourquin (1995) and Jourquin and Beuthe (1996). This particular methodology is implemented in the Nodus software (Jourquin and Beuthe, 2004), that will be used for the application that will be presented later in this paper.



A main feature of hub and spoke networks is the ability to bundle flows on the inter-hub links. In most existing models, travel across the inter-hub links is discounted (relative to the travelling cost on the spokes or non inter-hub links) by an exogenously determined value (the inter-hub discount factor  $\alpha$ ) and the same discount is assumed to be applied to all the inter-hub links in the network, regardless of the differences in the flow volumes. The optimization model presented in Racunica *et al* (2005) is a generalization of the hub location problem. In their application, the threshold at which inter-hub link becomes cost efficient is a very important feature of the model; linear functions do not capture this threshold effect. Consequently, non-linear and concave increasing costs on certain links are required to model economies of scale. The resulting model is a non-linear, mixed-integer program.

## Types of hubs networks

These different mathematical formulations make it possible to compute optimal locations for terminals. But all the terminals are not identical, because they can handle different types of volumes or can be connected to different network typologies. It makes thus sense to try to categorise the intermodal terminals. This will help to better focus the applications of the location problems, knowing that our main interest goes to hub and spoke networks, for which it is assumed that:

- all hubs are fully interconnected;
- all non-hub nodes are connected to only one hub;
- there is no direct connections between non-hub nodes

O’Kelly and Miller (1994) convert these three assumptions in three binary decision variables:

1. hub interconnection : either full or partial;
2. node assignment: either one hub assignment or multi-hub assignment;

direct node-node: either full or partial.

These three binary decision variables produce  $2^3=8$  hub network classes (see Table 1).

Class	Node-hub assignment	Inter-modal connections	Inter-hubs connectivity
A	Single hub only	Not allowed	Full
B	Single hub only	Not allowed	Partial
C	Single hub only	Allowed	Full
D	Single hub only	Allowed	Partial
E	Multiple hubs allowed	Not allowed	Full
F	Multiple hubs allowed	Not allowed	Partial
G	Multiple hubs allowed	Allowed	Full
H	Multiple hubs allowed	Allowed	Partial

Table 1. Classification of hub networks

The design problem for container transport in a European network is very complex and corresponds to class H which is the most complex hub network. To our knowledge, this problem, based on real life data, has not yet completely been discussed in the literature and/or no computer model exists that gives an optimal solution for the trans-European networks when multiple hubs and intermodal connections exist. In this paper, a “classical” hub and spoke network will firstly be considered as an approximation in order to design the transport network. The three assumptions will then be relaxed by means of a network model. Indeed, the location model will find optimal places for the terminals, but the assignment of the real-world demand to the hubs cannot be forced, as the users are free to choose or not combined transport.

## Terminals Typology

It is also necessary to give a container terminal classification because they don't all serve the same market with the same set of services. The most general characteristics that are used to classify terminals are (Bowersox, 1996 and de Wit and van Gent, 1996):

- transport modes (rail, road, barge, short-sea, deep-sea);
- terminal operating time;
- activities terminal area (transshipment, storage, building, ...);
- transport units (rail wagon, truck, semi-trailer, container, ship, barges, swap bodies, trailers, ...);
- cranes (rail-road cranes, bridge cranes, Panamax cranes, ...).

Wiegmans *et al* (1998) distinguish five types of container terminals, according to the treated volume (expressed in TEU), infrastructure and terminal area.

An alternative classification can also be found in Wiegmans (2003). It is based on the characteristics of freight flows (Bowersox, 1986), combined with the four types of bundling networks defined in TERMINET (1996, 1997a-c): point to point network, trunk line with collection/distribution network, line network and hub-and-spoke network. This leads to four container terminal types:

1. Bulk terminal: it is also known as “main port”: large volumes and world connections for freight. Incoming freight is divided into smaller flows for further transport. These smaller flows however have enough volume to fill a barge, a train or a whole boat. These terminals have large storage areas, fast loading and unloading facilities and point-to-point consolidations (Ex: Singapore, Hong Kong, Antwerp ...).
2. Transfer terminal: almost exclusively dedicated to the transshipment of continental containers. There is almost no collection and distribution in the area where the terminal is located. Container arrivals and departures involve huge volumes. The terminals are characterized by large areas which allow direct transshipments between trains and/or barges on hub-and-spoke networks. (Ex: Duisburg, Felixstowe ...)
3. Distribution terminal: also called “intelligent terminal”, because extra services are provided to create added. Flows arrive from several origins and are consolidated before to be sent to the final customer. These terminals are mostly connected to line networks. (Ex: MTC Valburg ...).
4. Hinterland terminal: small continental shipments are brought to the hinterland terminal and consolidated into bigger consignments before being transported by larger vehicles such as trains or barges on trunk line with collection/distribution consolidation networks. The reverse operation (unbundling) is performed at the destination terminal. (Ex: UCT, Frankfurt ...).

Further, in “Inventory and Expert System on New Technologies in Intermodal Transport” of the “Innovative Technologies for Intermodal transfer Points” project (Ballis, 2002), a hierarchical system with three levels of operation is defined:

- level 1: Direct and feeder trains between main terminals and ports ; Europe-wide high-quality service with shortest carriage times at lowest cost for haulage transport ;
- level 2: Hub and spoke and liner trains; mainly for national transport but also useful for international transport and for distribution of overseas containers in a large regions or countries.

- level 3: Full-load traffic; for all the flows that cannot be covered by special inter-modal trains.

These different classifications can help us to specify the type of terminal we want to locate. Indeed, the largest terminals (size, volume ...) have maritime connections and are located in ports such as Rotterdam, Antwerp, Hamburg, Le Havre, Marseille, Algeciras ... They can be referred to as “XXL”, “XL” or “consolidation” terminals. The amount of goods that are to be transported through these facilities is large enough to organize full-loaded trains or barges, without any further consolidation.

The smallest facilities are called “M”, “S”, “distribution” or “hinterland” terminals. They are sometimes also referred to as national or regional terminals. They need a line or a collection/distribution consolidation of the transported commodities.

Finally, the so-called “L” or “transfer” terminals can be considered as mid-size facilities, and are mostly devoted to huge transshipment operations for continental freight flows. These terminals are embedded in “hub & spoke” network organisations. That’s why we will simply refer to “hubs” when this type of terminals will be further discussed in this paper. According to Ballis (2002), hubs are now located in Metz, Villeneuve St. George, (nearby Paris), Schaerbeek (Brussels), Koln, Hannover and Mannheim, thus in the North of Europe. He also points out that a hub nearby Milan would be useful. The exercise that will be presented later in this paper will try to find optimal locations for this kind of terminals.

## **Determining the demand**

The goal of this research is to apply some of the location problems on the trans-European inter-modal freight transport network. The first question that arises is obviously the pattern of the supply and the demand on such a huge territory. In other words, a detailed matrix of origins and destinations (OD) is needed, but unfortunately not (publicly) available.

We had the opportunity to use, in the framework of this research, the freight OD matrixes for the year 2000, produced by NEA Transport Research and Training. The matrices are available for road, rail, inland waterway, sea, air and pipeline transport, but our network model will only cope with roads, rails and inland waterways. The matrices give information about the type of transported commodities, using the 10 NST-R main chapters. The exercise that will be presented later in the paper will only take the demand for NST-R chapter 9, because it contains the demand for containers, among other manufactured products.

The database contains region-to-region relations at the NUTS 2 level, for the enlarged European area (EU15, Norway, Switzerland and Candidate countries).

## **The assignment problem**

A lot has already been written on the assignment problem, and it goes beyond the scope of this paper to present an in-depth review of the existent methods.

An assignment problem is the distribution of traffic in a network considering a demand between locations and the transport supply of the network. Assignment methods are looking for a way to model the distribution of traffic in a network according to a set of constraints, notably related to transport capacity, time and difference of cost. This type of problem can be solved using optimization methods.

The assignment methods can be grouped in four categories, Table 2, depending on their ability to take capacity constraints into account or the way they consider the perception the users have of their traveling costs.

Capacity constraint	Variable perception of the costs	
	No	Yes
No	All or Nothing	Stochastic (multi-flow)
Yes	Equilibrium	<i>Stochastic equilibrium</i>

Table 2: Assignment methods

The results of the assignment, which depend on the sophistication of the implemented method, include an estimate of flows, travel duration and/or corresponding costs, for each link of the network.

The different assignment techniques can be used on so called “virtual networks” (Jourquin and Beuthe, 1996) , in which a geographic network with multiple transportation modes and means can be represented by a unique but more complex network in which each link corresponds to a unique operation with a specific cost. Note that the stochastic equilibrium is not yet implemented in Nodus, the software tool that implements the “virtual networks” methodology.

An interesting feature of this particular representation is that the different operations can be performed at the “node” level of a geographic network, i.e. (un)loading, transshipments and simple transit are also represented by virtual links, making it very easy to evaluate the flow at the node level. This feature will now be used to determine a set of potential good locations for terminals.

The “virtual networks” approach opens interesting perspectives. Both the modal choice and the assignments steps of the classical four stages approach (in which generation, distribution, modal-split and assignment are seen as separated steps) are performed at the same time. Unfortunately, these virtual networks contain a hidden trap, as it’s nearby impossible to calibrate the models on both the transported quantities and the flows (expressed in tons.km). This problem can be solved if the flow that must be sent from an origin point to some destination is spread over several routes and transportation modes.

It appears (Jourquin, 2006), that the use of equilibrium assignment procedures doesn’t give an adequate answer to the trap on large scale networks such as the trans-European multi-modal freight network. This is essentially due to the fact that equilibrium models are only efficient at a local level, and where congestion, or at least heavy flows, are observed. But origin-destinations matrixes for long distance transport are often built on a yearly basis only, and it is thus difficult to estimate what happens during the peak hours. Even more problematic is the fact that long distance transport last several hours, or even days, and it is not possible, with static models, to know where a vehicle is located at a given moment.

Obtaining a set of credible alternative routes, i.e. (nearby) non overlapping routes, is only possible if multi-flow algorithms are used. A simple and pragmatic algorithm is proposed in Jourquin (2006), which ensures that the computed set of paths contains both different itineraries and the use of different transportations modes. Finally, the method to spread the flow over the different routes uses the relative weights of the different paths in the set of alternative routes. The results (see Table 3) for the trans-European network clearly show that it is possible to obtain a calibrated model on both the transported tons and the flows expressed in tons.km, using an assignment on a virtual network, without the use of a modal split module.

## Determining the network

A reasonable detailed representation of the networks for the different transportation modes (road, railroads and inland waterways) is also needed. Therefore, the railroads and roads networks were taken from the Digital Chart of the World.

The Digital Chart of the World (DCW) is an Environmental Systems Research Institute, Inc. (ESRI) product originally developed for the US Defense Mapping Agency (DMA) using DMA data. The DMA data sources are aeronautical charts, which emphasize landmarks important from flying altitudes. ESRI, in compiling the DCW, also eliminated some detail and made some assumptions for handling tiny polygons and edge matching. Anyway, for the European networks, the proposed data can be used for our needs, after some manipulations in order to obtain a coverage that corresponds to the European countries.

The inland waterways network doesn't exist in the DCW. There is a "drainage" layer, but that is much too detailed, and doesn't correspond to the waterways on which barges can be used. Therefore, we decided to digitize the corresponding network ourselves.

In addition to these main layers, the ferry lines (and the Channel) were also collected and digitized. Finally, the borders of the Nuts2 regions were freely obtained from GISCO (although this data is not public). This data set was used to compute the centroid of each region that will then be used as starting and/or arriving node for the commodities. Using the algorithm proposed by Bourke (1988).

All these separate layers (roads, railways, inland waterways, ferries and centroids) were then connected together, using "connectors" from each centroid to each modal layer located not further than a given distance. A "geographic graph", illustrated by Figure 1, is obtained, on which different algorithms can be applied. Even if not completely up-to-date, this complete pan-European network has certainly enough details to make our simulations realistic.

However, used "out of the box" during the assignment procedure, our detailed cost functions don't give a correct modal split, because some elements such as service quality are not taken explicitly into account. There is thus a need for calibration. The final results, obtained by a "deterministic multi-flow assignment with forced modal split" (Jourquin, 2006) with 6 paths, are illustrated by Table 3.

		<b>Data</b>	<b>Model</b>
<b>Tons</b>	<b>Barges</b>	2.19 %	1.99%
	<b>Trains</b>	8.46 %	9.63 %
	<b>Trucks</b>	89.35 %	88.38 %
<b>Tons.km</b>	<b>Barges</b>	2.12 %	3.50 %
	<b>Trains</b>	12.74 %	13.73 %
	<b>Trucks</b>	85.14 %	82.77 %

Table 3: Assignment performances after calibration

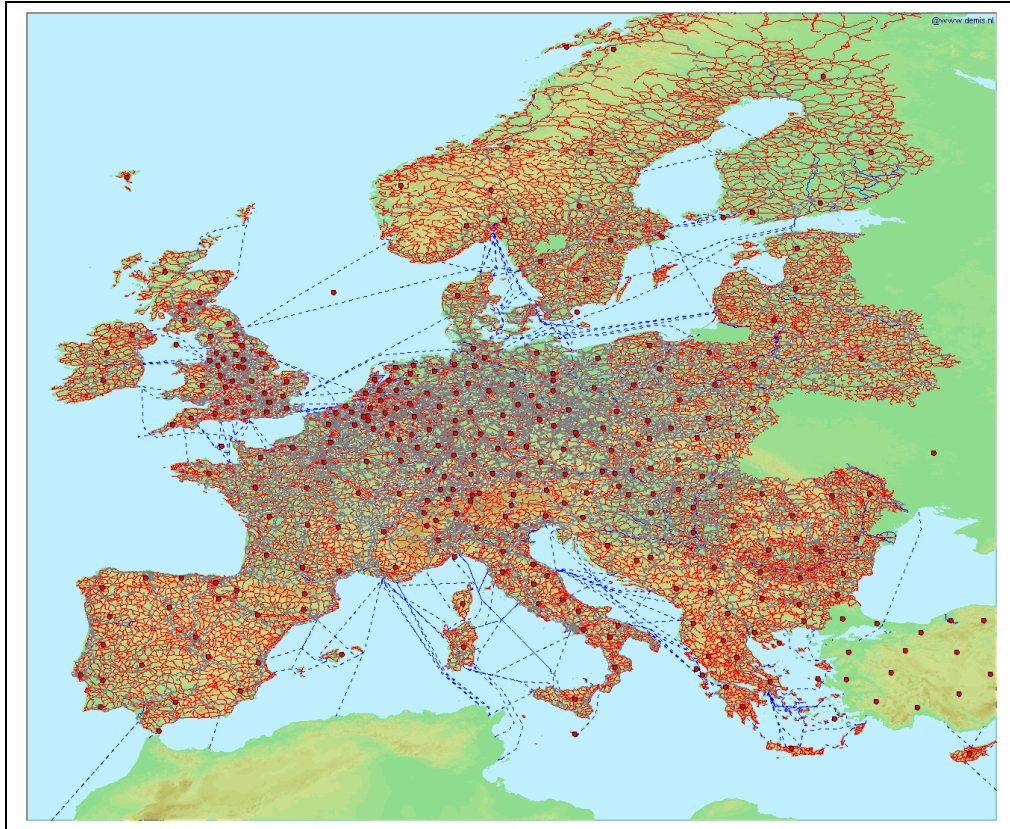


Figure 1: Detailed European networks

### Using flows to determine a set of potential locations

The assignment of the OD matrixes over the network gives information about the flow of commodities that comes along each node of the network. This information is useful to determine a set of potential locations because the flow gives a good idea of the attractiveness of each node. However, this rough information is not enough and needs to be refined.

A first selection of potential locations can be performed, keeping the nodes with a higher weight than a given threshold that will be outlined later. The selection can be further reduced using one or more of the following criteria:

- A minimum distance from an already existent;
- A minimum distance from a port;
- A maximum distance to the waterway network;
- A maximum distance to the railway network.

In the exercise presented in this paper, the maximum distance to water infrastructure and the minimum from a port was ignored. The maximum allowed distance to rail infrastructure was set to 20 km.

The intermodal rail-road transport is competitive only for long distances, more than 500-600 km. However the ECMT in the report of 1998, estimate that the shortest distance on which the offer of transport combined rail-road is competing could be of 300 km. Among UIRR statistics, 92% of the TEU travel between terminals distant of more than 300 km. This last value, initially, will be used as outdistances minimal for which combined transport can be competitive compared to the road. In order to consolidate the flows on some corridors, a AoN method is used, the obtained results are represented on Figure 2.



Figure 2. All or Nothing Assignment

As stated earlier, we are trying to locate “transfer terminals” operating at the country level in Europe. Wiegman (2003), estimated that the annual volume for this kind of terminals must be at least 100000 TEU. As we try to locate big terminals, we fixed this threshold to 150.000. The average payload of a TEU is about 15 ou 16 tons, according to the statistics of the UIRR. KombiConsult (2002) gives the flows (in tons) handled by the principal terminals for the year 2000. These flows make it possible to estimate that, on average, the ratio between the flows obtained along the nodes where are the principal terminals by the AoN assignment and the flows handled by these principal terminals is about 21%. This thus implies that the threshold of minimum flow to consider is approximately 11000000 tons.

The remaining set of nodes after filtering is still rather important, mainly because many of these nodes that are close to each other, as they have about the same characteristics (chain effect). If it is true that, at the micro or regional level, these nodes can be very different (availability of enough ground surface for instance), these considerations are less important at the macro European level for which it is important to know in which (sub-)region a terminal could be helpful. That’s why we only considered the node that has the maximum weighted flows in a chain, keeping only one node by NUTS2 region. This reduction of the number of potential location (Figure 3) can be handled more easily by optimal location models.

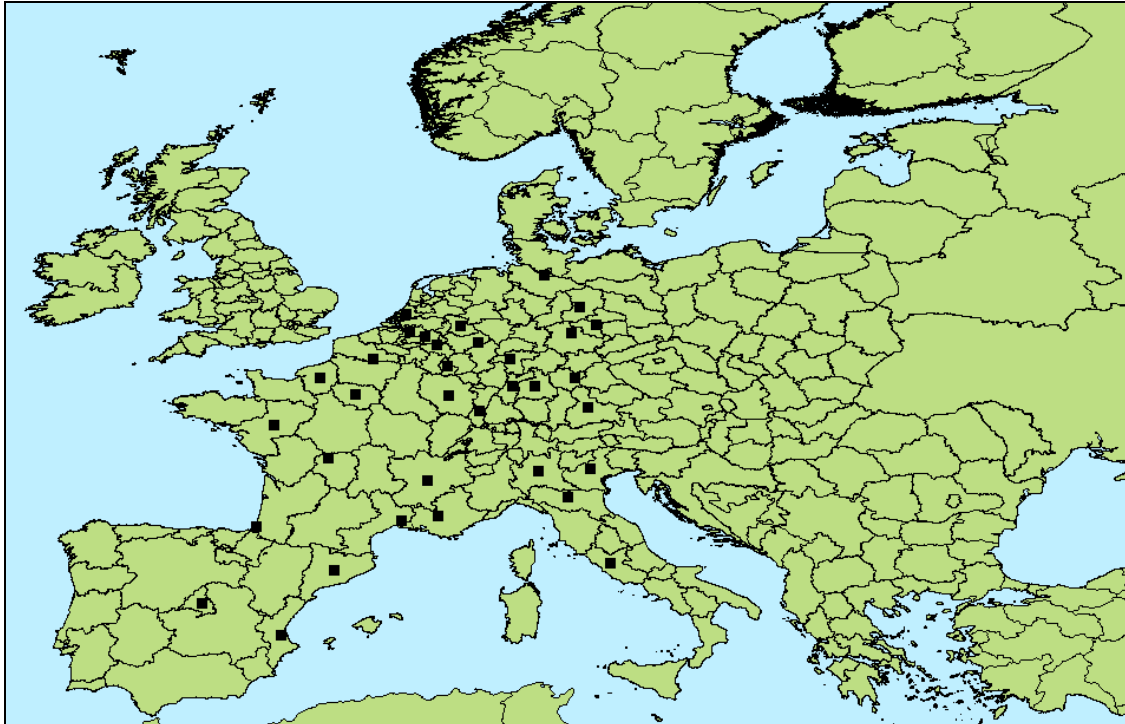


Figure 3: Set of potential location

## Results

Now that a set of potential locations has been defined, a p-hub median problem can be implemented in order to determine which the optimal locations for hubs are. Therefore, the p-HMP formulation proposed by Ernst *et al* (1996) was implemented in the CPLEX software package. For this study, the transshipment cost was set to 3.29 €/ton, the inter-hub discount ( $\alpha$ ) to 10% and the pre- and post-haulage are set to 1.483 times the long haul road cost. Figure 4 illustrates the obtained results when the number of hubs to locate ( $p$ ) varies from 2 to 7.

Now that the optimal locations are determined, they can be integrated in the network and a new assignment will be performed, in which transshipments are now possible at the just located facilities. The demand can be assigned over all the transportation modes, with the possibility (and not the obligation) to use the transshipment facilities. Combined transport is thus considered as one of the possible transport solutions among others.



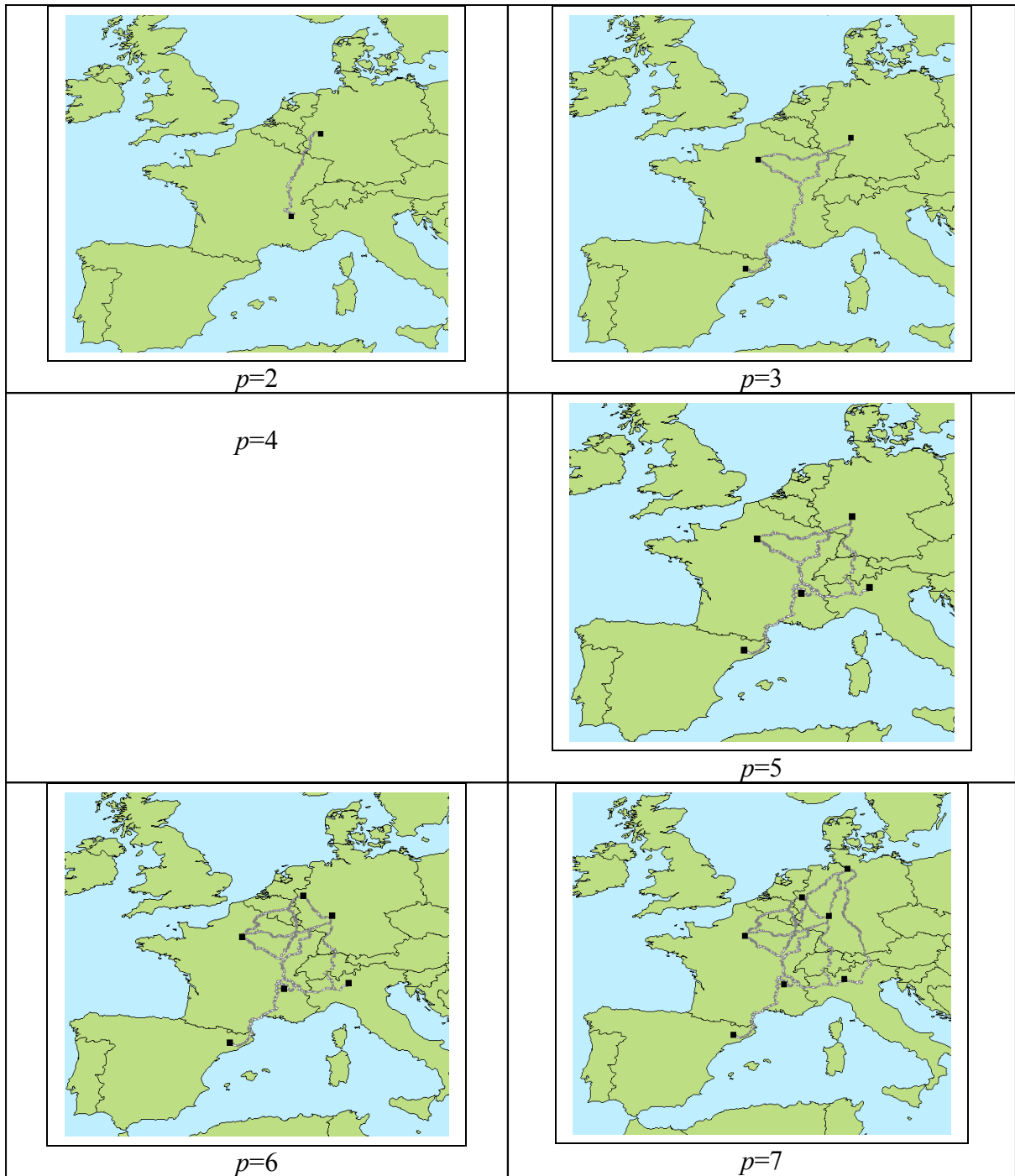


Figure 4: Optimal locations (model)

Table 4 gives modal split comparison of the opening of the seven terminals. Figures are given when the reference scenario (without terminals) is compared to new assignment for the NSTR-9 commodities (which represent 20,60% of the total amount of goods transported on the network). It can clearly be noticed that the possibility to use combined transport at the optimally located terminals decreases the flows by road of 7.59 billions of t.km and the total cost on the networks of 0.63%, if the implantation cost of terminals is taking into account, the diminution of the total cost is only of 0.49%.

	Ton.km		Variation
	Without terminals	With 7 terminals	
<b>Inland Waterways</b>	1,41%	1.41%	
<b>Rail</b>	13,66%	16.14%	+2.49%
<b>Road</b>	84,88%	82.45%	-2.43%

Table 4: Modal split comparison between the optimal 7 hubs solution and the reference scenario

Now, we compare this situation with the existing situation represented in Figure 5; the international hubs mentioned by Ballis (2002): Metz, Villeneuve St. George, (nearby Paris), Schaerbeek (Brussels), Koln, Hannover, Mannheim and Milan. The exercise that will be presented later in this paper will try to find optimal locations for this kind of terminals.

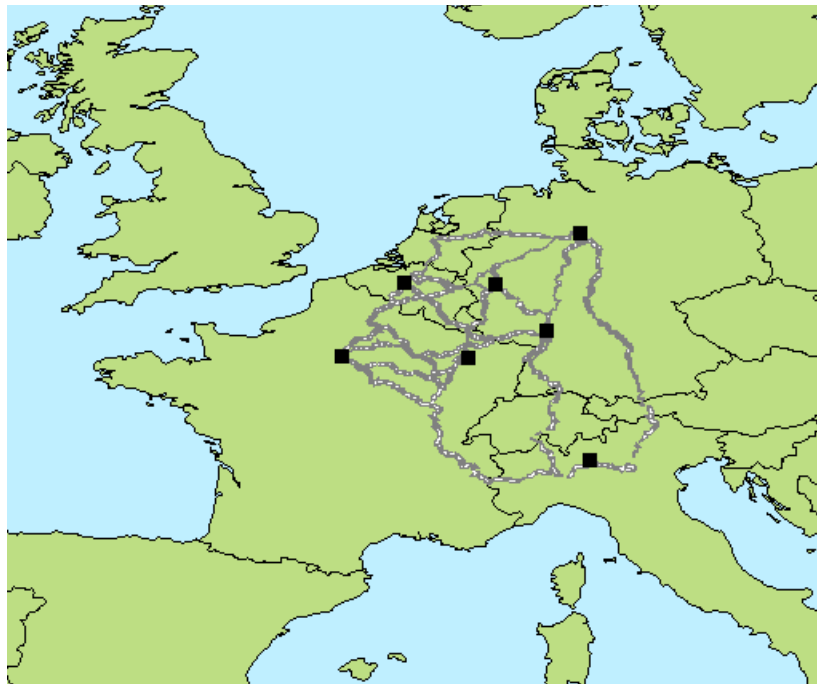


Figure 5: Existing situation

Tables 5 gives a comparison of the modal splits of the existing situation with the one obtained seven hubs optimal configurations.

	Ton.km	
	Ballis	Obtained 7 hubs solution
<b>Eau</b>	1.41%	1.41%
<b>Fer</b>	14.03%	16.14%
<b>Route</b>	84.56%	82.45%

Table 5: Modal split comparison

The existing configuration decreases the flows by road of 1.34 billions of t.km and the total cost on the networks of 0.49%.

## Conclusions

This paper tries to propose a usable optimal localization model for continental transfer terminals (hubs) embedded in hub-and-spoke consolidation networks. The basic idea of this research is to use the flows of commodities as input to determine a set of potential locations, before an actual optimal location method is implemented.

The locations obtained by our methodology are very close to the existing main international hubs. In the case of the location of seven hubs, our model predict a reduction of the total transport costs on the network while the flows in t.km by rail increase, due to a modal shift from road to rail. The optimal situation with seven hubs is five times better in terms of flow reduction per road than the existing situation.

However, we can already conclude that it is possible to implement an (exact) optimal location algorithm on detailed large networks such as the trans-European freight networks, using complete (and complex) demand data.

In the next future, the following additional work will be mainly focused on:

- Testing the sensitivity of the obtained potential location to the chosen “filter” parameters ;
- Taking into account the already existing terminals and ports;
- Evaluating the impact of the inter-hub discount.

## Acknowledgement

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