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Location of mid-range dry ports in multimodal logistic networks

Daniela Ambrosino, Anna Sciomachen*

Department of Economics and Business Studies, University of Genoa,Via Vivaldi 5, 16125 Genoa, Italy

Abstract

In the recent literature a lot of attention has been given to intermodal transportation networks, mainly related to inland freight mobility. In particular, the landside distribution of maritime containers from/to seaports has been the focus of many research works. In fact, seaports are now suffering the lack of space at maritime terminals and the growing congestion on their access routes with the inland connections. In this regard, a well established strategic choice for maritime terminals is to perform gateway operations at inland dry ports, especially when topological and environmental constraints prevent terminals from expanding.
Following this idea, in this paper we deal with the problem of locating dry ports for freight mobility in intermodal networks. In particular, the containerized flows originating at the maritime terminals of the port of Genoa, Italy, towards inland destinations throughout rail and road itineraries are examined. The present problem fits in the class of capacitated multiple hub location problems. We give a mathematical programming model for the problem, which is modelled on a two level weighted multimodal graph. Computational experiences based on randomly generated instances of different size are reported together with results related to the case study rail–road logistic network.

Keywords: Maritime logistics; Multimodal transportation networks; Capacitated hub location problem; Dry ports.

1. Introduction

Nowadays, the transportation research community is moving towards sustainable freight logistics, looking not only at cost minimization, but also at the wider effects on the negative externalities, such as congestion, pollution and other ecosystem damages deriving from transport. The goal is to minimize these impacts while achieving

* Corresponding author. Tel.: +39-10-2095484; fax: +039-10-2095243.
E-mail address: sciomach@economia.unge.it

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logistics benefits in terms of reduction of the generalized ditribution cost and improvement of the service level. In this regard, much attention has been recently devoted to intermodal transport, and, in particular, to inland freight mobility, for which the movement of standardized loading units, e.g. containers, is performed using two or more transportation modes. In terms of inland logistics, the landside distribution of maritime containers from/to seaports is particularly critical. In fact, expecially in the last decade, within the whole logistics chain maritime containerized transport has increased its performance significantly, while the size of containerships is doubled, up to 18,000 Twenty Foot Equivalent Units (TEU). Consequently, one of the main problems seaports face today is the lack of space at maritime terminals, long dwell times and the growing congestion in their access routes to inland connections, especially considering the road modality. Furthermore, environmental factors, regulation plans and topological constraints often prevent maritime terminal from expanding. For this reason, the hinterland forwarding of containers has recently been the focus of many research works (Ambrosino and Sciomachen, 2012a; de Langed and Chouly, 2004). Connection with inland transportation often becomes a potential weak point for a port, thus making fruitless the efforts of the terminal operator in the quay-side and yard operations (Stahlbock and Voss, 2008).

All these criticalities generate a need for new port hinterland distribution solutions, mainly based on the combination of different transport modes and multimodal interchange nodes. In this regard, it is common opinion that a strategic choice for maritime terminals is to perform gateway operations at inland multimodal interchange nodes, most frequently denoted dry ports (Cullinane and Wilmsmeier, 2011, Jarzemskis and Vasiliauskas, 2007; Roso and Lumsden, 2010; Veenstra, Zuihwijk and van Asperen, 2012). Dry ports aim at reducing the traffic on the roads and moving it onto the rail networks, so that they are particularly suggested when terminals are located close to urban and suburban areas, characterized by heavy traffic (Roso,Woxenius and Lumsden, 2009).

The location of the site where the modal transshipping takes place is one of the most important elements when evaluating the competitiveness of intermodal transport. The problem of evaluating possible locations for dry ports can be considered as a particular case of the hub location problem, which has recently received a lot of attention in the scientific literature. Initially formulated by O'Kelly (1987), hub location problems have seen several theoretical developments (see, e.g., Campbell, Ernst and Krishnamoorty, 2002, and Alamur and Kara, 2008, for a review) as well as an increasing diversification of their applications. Most of these extensions deal with the definition of the location of hubs as intermodal terminals for collecting, dispatching and redistributing flows. Arnold, Peters and Thomas (2004) gave an idea of the most typical situations encountered in intermodal spatial transportation problems. Hub location problems in rail–road intermodal network are faced in Ishfaq and Sox (2011) and in Limbourg and Jourquin (2009), while a problem modeled on a hub and spoke network is faced in Racunica and Wynter (2005), with the aim of increasing the modal split in favor of the rail mode. A hub location problem for freight mobility in urban multimodal networks is presented in Ambrosino and Sciomachen (2012b). Alamur, Kara and Karasan (2012) address a more general hub location problem where multi-criteria aspects concerning transportation costs and service level are considered.

In the present paper we propose a new hub location model for evaluating the best site for locating dry ports, taking into a proper account the flow of containers, arriving via sea, and their final destination, to be reached on either rail or road network (and viceversa). In this context, the mid-range dry port model, that is a dry port usually located halfway between the port and the inland, where it is possible to provide port services (Roso and Lumsden, 2009), seems to be particularly interesting. We focus our analysis on the logistics network of the Italian north-western regions, and evaluate suitable sites to serve the containerized flows originating at the maritime terminals of the port of Genoa, towards inland destinations throughout rail and road itineraries.

The present problem is formulated on a capacitated multimodal network. The innovative aspect of the proposed mixed integer linear programming (MILP) model is that the containerized flow demand from an origin node to a destination one can be split along its way, also allowing different travelling modes. The location and shipping costs are our objective function to be minimized.

The remaining of the paper is organized as follows. In Section 2 we present a MILP model for dealing with the capacitated hub location problem under consideration. In Section 3 we present the main characteristics of the containerized maritime terminals serving the port of Genoa, giving some information about the volume of import/export containerized flows as well as their inland rail and road connections; the concept of mid-range dry port is also introduced, along with some proposals for dry port sites suitable for efficiently managing the container traffic throughout the port of Genoa. Results of a computational experimentation, related to both test bed random instances and the real data of the case study, are reported in Section 4. Finally, some conclusions are drawn in Section 5.

2. Problem definition and its formulation

Our focus is to locate mid-range dry ports within a multimodal logistic network, which, by definition, have to be located between maritime terminals and inland nodes, towards final destination/origin nodes, not farther than a given distance from the seaside, usually set to about 100 kilometers.

In this work we consider only single hub itineraries, namely origin-hub-destination paths, thus excluding direct connections between origin-destination nodes and between hubs. We adopt this assumption following the suggestions reported in Racuna and Wynter (2005), related to the maximum number of hubs in a single path; the authors indicate single hub itineraries as the most efficient choice in the case of short distance to cover. Moreover, this choice is justified because we aim at increasing the usage of the rail mode and making the railway system as efficient as possible, by using the existing infrastructures and rules, as it will be described in the next Section. Note that we include in the analysis a capacity on the transport modality; the capacity of each potential hub node is considered too.

As a novel aspect of this study, we analyze multimodal itineraries, including rail and road modalities, and admit to split origin–destination demand between different modalities as well as different hubs. As an example, containers leave their origin node by truck and reach a hub node, where a change of modality can occur; if this is the case, containers continue their journey by train. Further, containers can leave their origin node and reach independently different hub nodes, from which a modal split can occur. This possibility allows us to optimize the containerized flow splitting the total demand at each origin node and collecting it at each hub node. In *Fig.* 1a and 1b different possibilities for satisfying a demand of 40 units from port 1 to inland node 1 are depicted: note that in *Fig.* 1a different modalities are used passing through hub 1, whilst in *Fig.* 1b the demand is satisfied by splitting it on two itineraries passing thought two different hubs (i.e. 20 units are shipped through hub 1 and 20 units through hub 2).

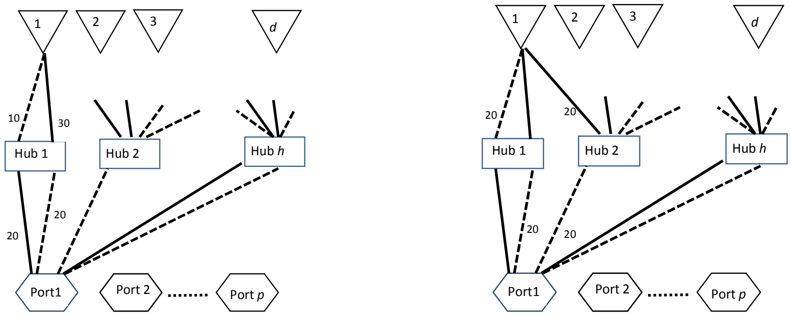

Fig. 1. (a) split demand on different modalities; (b) split demand among hubs

Note that, as a consequence of this multimodal split hub itineraries, not always an origin-destination demand is shipped on the same path with the same transport mode.

The multimodal logistic network under investigation can be represented by a weighted digraph $G = (V, E)$, where V is the set of n nodes and E is the set of m arcs, connecting pairs of nodes.

Now we introduce more formally the problem, giving first the required notation.

Notation

V	set of nodes
$V_H \subset V$	set of possible dry ports
$V_P \subset V$	set of maritime terminals / ports
$V_D \subset V$	set of inland nodes
$V \supset V_N = V_P \cup V_D$	set of origin and destination nodes
E	set of arcs
E_k	set of arcs traveled in G using the k-th transportation modality
$k=\{L,R\}$	*L=long vehicles, R=rail*
$E = E_L \cup E_R$	set of arcs traveled by long vehicles and set of arcs traveled by trains
$E = E^F \cup E^S$	set of arcs of the first (F) and second (S) leg
$E^F = E^F{}_L \cup E^F{}_R$	set of arcs $(i,h), \forall i \in V_N, \forall h \in V_H$
$E^S = E^S{}_L \cup E^S{}_R$	set of arcs $(h,i), \forall h \in V_H, \forall i \in V_N$
$w_{ij}(k)$	cost for moving from i to j using transportation modality k
$q_{ij}(k)$	flow capacity along arc (i,j)
cz_h	opening costs at hub node $h, \forall h \in V_H$
ch_h	operative costs at hub node $h, \forall h \in V_H$
k_h	capacity of hub $h, \forall h \in V_H$
M	set of couples of modalities that can be used in the itineraries *o-h-d*
d_{ij}	demand from node i to node j, $\forall i,j \in V_N, i \neq j$, s.t. $i \in V_P$ and $j \in V_D$ (or vice-versa)
$c^m{}_{ijh}$	containerized unit transportation cost from node i to node j through hub h with modality $m, \forall i,j \in V_N$, such that $i \neq j, i \in V_P$ and $j \in V_D$ (or vice-versa), $\forall h \in V_H, \forall m \in M$
decision variables used in the MILP formulation	
$x_{ijhm} \geq 0$	$\forall i,j \in V_N, i \neq j$, such that $i \in V_P$ and $j \in V_D$ (or vice-versa), $h \in V_H$, $m \in M$
$y_h \in \{0,1\}$	$\forall h \in V_H$

For what concerns the network connections, we have to note that the inland nodes V_D represent either the main destination nodes for the import containers, or the origin nodes for the export ones. Since we are involved with the import /export containerized flow from/to maritime terminals, here we consider only rail and road modalities, thus arcs of E_L are travelled by long vehicles, or trucks, mainly on the highway, while arcs belonging to E_R represent the railway connections. Moreover, we have to distinguish between arcs representing the first and the second leg of the paths; thus E^F is the set of arcs connecting nodes belonging to V_N to potential dry ports V_H (first leg) by road ($E^F{}_L$) and by rail ($E^F{}_R$), whilst E^S is the set of arcs connecting hub nodes of V_H to nodes belonging to V_N (second leg) by road ($E^S{}_L$) and by rail ($E^S{}_R$).

Finally, note that the unit cost ch_h for handling goods at dry port h strongly depends on the infrastructures and the equipment held in h. As in Racuna and Wynter (2005), we consider three classes of opening and operating cost of a hub, namely high, medium and low.

2.1 The multimodal single hub itineraries

Starting from the network defined above, here we describe the multimodal single hub itineraries and compute the related cost. Since we consider two travelling modalities, that is road and rail ($E = E_L \cup E_R$), we have four possibilities for transferring goods in each *o-h-d* itinerary, namely:

truck-truck (m_1): from node o to dry port h goods are sent by truck and then, from dry port h to destination node d, are sent, again, by truck;

truck-train (m_2): from node *o* to dry port *h* goods are sent by truck and then, from dry port *h* to destination node *d,* are sent by train;
train-train (m_3): from node *o* to dry port *h* goods are sent by train and then, from dry port *h* to destination node *d,* are sent, again, by train;
train-truck (m_4): from node *o* to dry port *h* goods are sent by train and then, from dry port *h* to destination node *d* are sent by truck.

Thus, for each multimodal single hub itinerary we compute the following costs:

$c^{m1}_{ijh} = w_{ih}\,(L) + w_{hj}\,(L)$
$c^{m2}_{ijh} = w_{ih}\,(L) + w_{hj}\,(R)$
$c^{m3}_{ijh} = w_{ih}\,(R) + w_{hj}\,(R)$
$c^{m4}_{ijh} = w_{ih}\,(R) + w_{hj}\,(L)$

2.2 The proposed proposed MILP model

In this Section we propose a MILP model, denoted IDPL (Intermodal Dry Port Location), for the selection of mid-range dry ports within multimodal logistic networks.

Referring to the specificity of the present problem, the main decisions concern the number of dry ports to locate and their location, together with the modalities of transport to use for moving the required quantities of goods from origin-destination pairs through the selected dry ports. Dry ports belonging to V_H are all intermodal nodes able to receive/leave containers either by train or truck, even if not every node is connected to all hubs with all modalities.

The variables defined for model IDPL are flow variables ($x_{ijhm} \geq 0$), indicating the flow of goods from origin node *i* to destination node *j* passing through dry port *h* and transferred by any combined modality *m,* and hub location variables ($y_h \in \{0,1\}$), indicating which nodes are chosen as dry ports in the network.

The proposed MILP formulation is then the following:

$$\min \sum_i \sum_j \sum_h \sum_m c^m_{ijh} x_{ijhm} + \sum_h cz_h y_h + \sum_h ch_h \sum_i \sum_j \sum_m x_{ijhm} \tag{1}$$

subject to

$$\sum_i \sum_j \sum_m x_{ijhm} \leq k_h y_h \quad \forall h \in V_H \tag{2}$$

$$\sum_h \sum_m x_{ijhm} \geq d_{ij} \qquad \forall i, j \in V_N, i \neq j, s.t.\, i \in V_P \text{ and } j \in V_D \text{ (or vice-versa)} \tag{3}$$

$$\sum_j x_{ijhm_1} + \sum_j x_{ijhm_2} \leq q_{ih}(L)\, y_h \quad \forall h \in V_H, \forall i \in V_N \tag{4}$$

$$\sum_j x_{ijhm_3} + \sum_j x_{ijhm_4} \leq q_{ih}(R)\, y_h \quad \forall h \in V_H, \forall i \in V_N \tag{4'}$$

$$\sum_i x_{ijhm_1} + \sum_i x_{ijhm_4} \leq q_{hj}(L)\, y_h \quad \forall h \in V_H, \forall j \in V_N \tag{5}$$

$$\sum_i x_{ijhm_2} + \sum_i x_{ijhm_3} \leq q_{hj}(R)\, y_h \quad \forall h \in V_H, \forall j \in V_N \tag{5'}$$

$$x_{ijhm} \geq 0, \forall i, j \in V_N, i \neq j, s.t.\, i \in V_P \text{ and } j \in V_D \text{ (or vice-versa)}, \forall h \in V_H, \forall m \in M$$

$$y_h \in \{0,1\}, \forall h \in V_H \tag{6}$$

Objective function (1) minimizes the traveling, location and handling costs at hubs, which depend on the selected dry port nodes. (2) are the capacity constraints of the hubs, while (3) represent the demand constraints for each origin-destination pair of nodes. Constraints (4) and (5) are the arc capacity constraints; more precisely, (4) and (4') are the capacity constraints for the arcs connecting origin nodes $i \in V_N$ to hubs $h \in V_H$ by truck and train, respectively, while (5) and (5') are the truck and train capacity constraints for the arcs connecting hubs $h \in V_H$ to destination nodes $j \in V_N$. Note that all capacity constraints in the model are active only if the corresponding hub h is selected, that is if y_h is set to 1; otherwise, no flow can enter or leave hub h. In (6) our decision variables are defined.

3. The maritime terminals serving the port of Genoa and their inland connections

The port of Genoa is the natural access to the sea of the northern most industrialized Italian counties. Its surface is about 7 km^2, while the costal linear extension is about 20 km. The main terminals are located between the east side of the port, in the heart of the city, and the western side. *Fig.*2 gives an overview of the sites where the main container terminals are located.

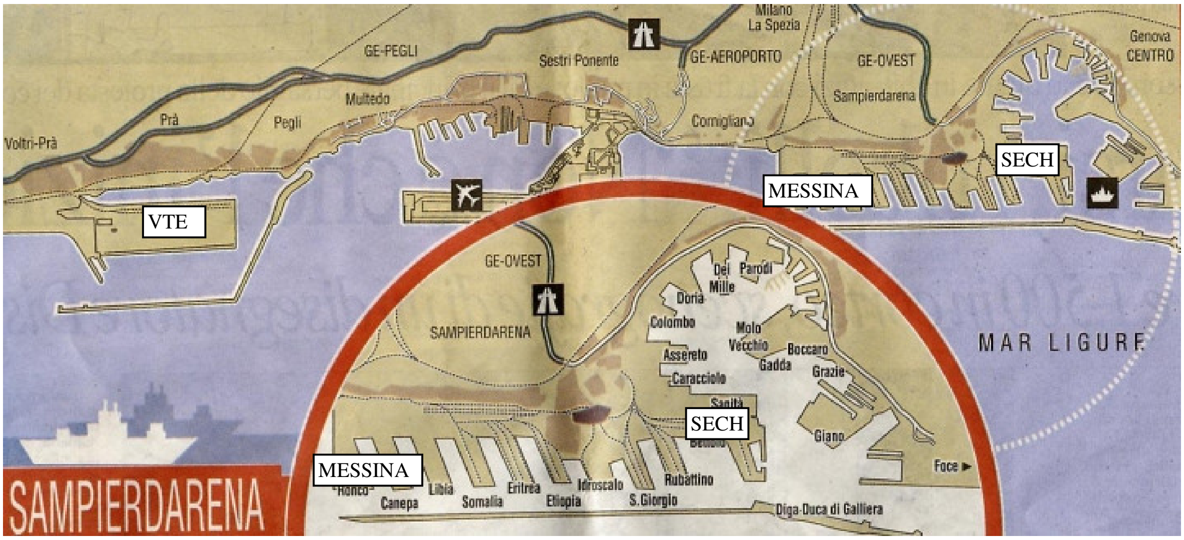

Fig.2 Aerial view of the maritime terminals of the port of Genoa

As far as container transport is concerned, the main terminals are the Voltri Terminal Europe (VTE), the Southern European Container Hub (SECH) and the Messina terminal. Note that the development and consolidation, in the last five years, of these terminals, made the port of Genoa one of the most important container hubs, both in terms of imports and exports, from a technological and infrastructural point of view.

According to data provided by the Port Authority of Genoa (Genoa Port Authority, 2013), in 2012 the containerized port traffic was almost 2 million TEUs. In the last five years, road transport served most of the container traffic to/from the port; in fact, referring only to the road-rail imbalance, the percentage of containers shipped by rail was sensibly less than that shipped by road, that is about 80%.

The main road connections from/to the port of Genoa (see *Fig*. 3 (a)) are represented by two highways going north, one going west towards France and another one going east and further towards the south of Italy. These highways allow the connection to the main European corridors, from Lisbon to Kiev and from Berlin to Palermo.

Another road with heavy traffic is the costal one, in both east and west direction, towards France. The average daily traffic flow at the highway barrier of Genoa, nearby the site of the VTE terminal, of the last six years is more than 2,500 vehicles. Moreover, in the last three years, the daily average number of vehicles circulating around the port of Genoa is about 3.600, 2.000 of them coming from VTE. Presently, the container traffic originating from the port of Genoa going on the road network is about 55% of the overall heavy traffic travelling on the motorway, mainly routed through the highway entrances; this implies that about 3.600 long vehicles departing from the port are moving towards the highway connections, which are within the urban territory.

The railway network from Genoa to the inland is depicted in *Fig.* 3 (b). Readers can see that there are two main lines, one of them is in turn split into two branches. Note that *Line* 1 is a single track electrified one; in some parts the slope of this line is 1.6%, thus presenting a weight limit for the composition of the freight cars. All galleries along the line allow high cube transport. Both branches of *Line* 2 are double track electrified lines; they serve both freight and passenger mobility to/from the north-western part of Italy.

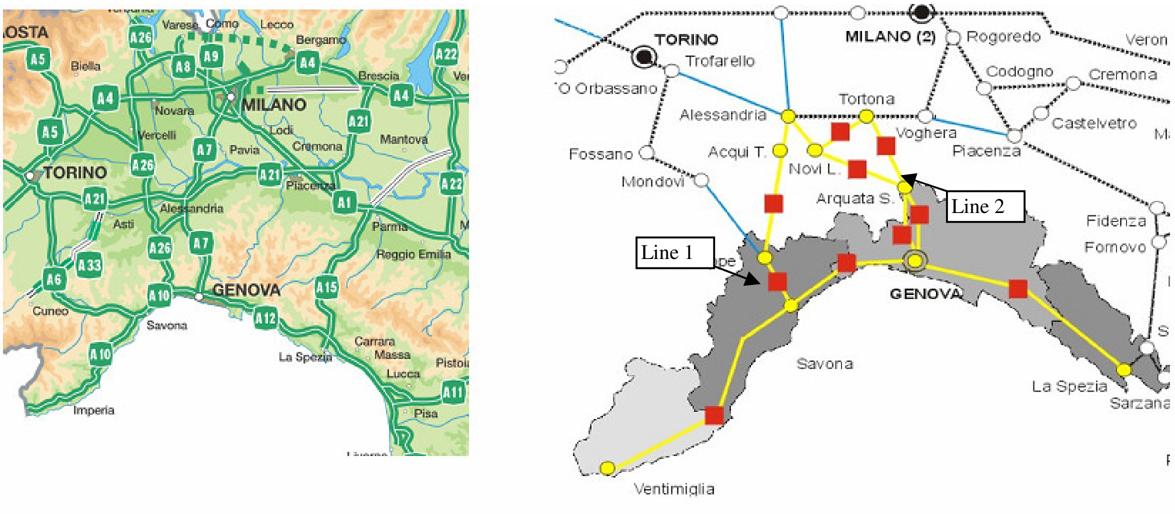

Fig. 3. (a) the highways connections from/to the port of Genoa; (b) the railway network from/to the port of Genoa.

Presently, all the above lines have a capacity of about 450 trains per day. Note that there is no line fully devoted to freight transport. In particular, in some daily time windows *Line* 1 is devoted only to passenger mobility; in fact, regional transportation laws give priority to workers mobility. Nevertheless, the potentiality of the *Line* 1 is much greater than the actual use. It is worth noting that a better organization of the available night shifts could increase up to 30 trains per day the actual capability, so that it could be possible to guarantee rail services more regularly than it is now to/from the port of Genoa towards the Apennines.

There is hence the need of balancing the modal split, in favor of the rail mode, to at least 40-45% in the next five years. This goal can be achieved by planning a number of inland intermodal yards connected with maritime terminals by railway infrastructures; in fact, the development of infrastructures aimed at allowing short distance shuttle trains from the sea side to dry ports, avoiding interferences with the road traffic, is foreseen. In this way, it will be theoretically possible to ship about 5 million TEUs/year along the railway connections, thus removing 35% of the heavy traffic from the port, resulting in a saving of about 1.200 heavy vehicles per day. The resulting great advantages for the whole transport ecosystem are obvious.

Due to the maximum distance of about 100 km from the marine terminals foreseen for mid-range dry ports, the area where dry ports and freight logistics platforms serving the port of Genoa can be usefully located is within the Lombardy and Piedmont regions, better focusing on the south Piedmont zone; only one site is located more than 120 kilometers from the terminals of the port of Genoa (i.e. near Pavia) .

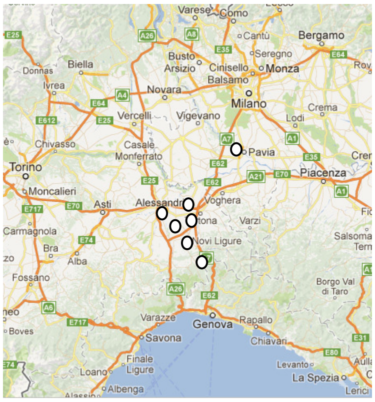

Fig. 4. The map of the area where dry ports are located

In *Fig.* 4 we report the map of the area where the possible dry port sites, enhanced with circles, are located. Note that the selected possible dry ports are all located in plain areas beyond the Apennines. As far as costs are concerned, for the possible dry ports the opening costs per TEU, with respect to their TEU capacity, range from 100 to 170 Euros, while handling costs per TEU range from 8 to 12 Euros. These costs have been derived from an analyses conducted on the network system in the Liguria region by the C.I.E.L.I. (Italian Centre on Integrated Logistics of the city of Genoa) (2012).

4. Computational results

The model proposed in Section 2 has been implemented in C# Visual Studio 2010 and solved by CPLEX 12.5 on a Intel (R) Core (TM) i5 CPU, 2.40GHz, 6.00 GB RAM. The model has been validated by using different sets of randomly generated instances derived by the case study under consideration.

The test bed instances have been categorized in different sets in accordance with the number of nodes and the potential hubs and the ratio δ between the capacity of the hub nodes and the total flow on the network. In particular, the hub capacity has been probabilistically determined among three different values, representing, respectively, high, medium and low capacity, in such a way to grant the desired capacity ratio δ previously defined. The *o-d* demands have been randomly derived from a uniform distribution within a [min, max] interval, specifically defined for the import and export flows.

The in/out connectivity degree of the nodes in V_H with the other nodes of the network has been randomly generated, giving higher probability to road connections than rail ones. Finally, distances between the nodes of the network have been uniformly generated within a range of values different for port-hub connections and inland-hub ones. For what concerns the arc capacities, these are generated in a probabilistic way, distinguishing between road and rail modes. For what concerns the existing train connections, two different probabilities are used for determining capacity values, representing, respectively, high, and medium capacity; whilst the existing road connections have high capacity.

The main characteristics of the generated instances are described in Table 1.

Due to the fact that some connections in *G* are not available, not necessarily any *o-d* demand can visit all hubs via all combinations of travelling modes provided in *M*. Thus, the number of variables x_{ijhm} of model (1)-(6) is less than $2|V_H|*|V_P|*|V_D|*|M|$; in particular, the number of variables depends on the available rail and road connections from/to the hubs. These important data characterizing the networks under investigation are reported in Table 1, where for the hub nodes in V_H we report the connection degree. In particular, columns **H_noL** and **H_noR** report the average number of hubs that are not connected to all o-d nodes of *G* by road and rail modes, respectively. Column **%psaving** gives the percentage of not generated variables x_{ijhm} with respect to that required in a complete graph. The last two columns of Table 1 report the ratio **δ (**total hub capacity/total flow in *G*), and the percentage of the import and export demand on the total one, respectively.

Table 1. Characteristics of the sets of randomly generated instances

Instances	$\|V_H\|$	$\|V_P\|$	$\|V_D\|$	H_noL	H_noR	%psaving	δ	%I - %E
SET A	5	5	10	2.3	4.95	24.1	3.86	37-63
SET B	5	10	10	2.8	4.9	23.5	3.95	37-63
SET C	5	10	20	3.8	5	26.4	3.43	39-61
SET D	10	10	20	6.8	10	22.7	4.92	39-61
SET E	10	10	40	8.2	10	24.3	4.85	40-60
SET F	10	10	60	9.65	10	23.8	4.95	37-63

Each row of Table 1 reports average values of 20 instances, grouped in four subsets according to the ratio δ and the percentage values **%**I - %E. More precisely, in Table 2 instances of set A, having $|V_H| = |V_P|$ 5 and $|V_D|$ = 10 , described in Table 1, are detailed.

Table 2. Characteristics of instances within Set A

Instances	H_noL	H_noR	%psaving	δ	%I - %E
SET A1	3	5	23.75	<3	50-50
SET A2	2.88	4.88	25.88	<5	50-50
SET A3	3	5	25	<3	25-75
SET A4	2	4.67	21.67	<5	25-75

Solutions of model (1)-(6) related to instances described in Table 2 are reported in Table 3, whilst results for the whole sets of instances described in Table 1 are given in Table 4. In particular, for each set of instances we report the average numbers of variables and constraints, the objective function value and the CPU time required for solving them up to optimality. Further, the number of selected hubs (**Y**) and the costs split into hub costs (**CZ+CH**) and transportation costs (**C**) are reported. Finally, the last three columns give the % of different modalities used in the chosen itineraries for satisfying the o-d demands, that is the mono-modal road modality (**m1**), the mono-modal rail modality (**m3**) and the multi-modalities (**m2** and **m4**).

In the performed computational tests, we have noted that the value of δ generally impacts on the ratio between hub and transportation costs. In particular, higher capacity values induce to obtain solutions characterized by lower hub costs, and consequently, a lower number of selected hubs to be opened.

By analyzing the results reported in Tables 3 and 4, it is possible to note that instances of the size similar to that reported in this study can be easily solved (in few seconds) up to optimality by using the proposed model (1)-(6). Moreover, two simple considerations arise: 1) until the rail mode is more convenient, the capacity of the rail paths is saturated; 2) until the transportation costs represent the majority of the costs, the number of selected hub is high; in fact, in this case it is more convenient to open a new hub in order to reduce transportation costs even if the capacity of the selected hubs is not saturated.

Table 3. Results for instances of set A obtained with model (1)-(6)

Inst.	# var.	# const.	Objective	CPU Time (Secs)	Y	CZ+CH (%)	C (%)	m1 (L) %	m3 (R) %	m2 + m4 %
SET A1	1684,20	405,00	819702804,53	0,16	3,20	30,09	69,91	1,17	58,32	40,51
SET A2	1765,60	405,00	457582202,80	0,20	2,60	22,83	77,17	1,68	54,20	44,12
SET A3	1763,40	405,00	498653114,99	0,16	3,20	30,55	69,45	1,93	57,69	40,38
SET A4	1775,80	405,00	800468357,82	0,19	3,40	28,87	71,13	0,00	66,17	33,83
Average	***1747,25***	***405,00***	***644101620,04***	***0,17***	***3,10***	***28,08***	***71,92***	***1,19***	***59,10***	***39,71***

Table 4. Results for instances sets A – F obtained with model (1)-(6)

Inst.	# var.	# const.	Objective	CPU Time (Secs)	Y	CZ+CH (%)	C (%)	m1 (L) %	m3 (R) %	m2 + m4 %
SET A	1747.25	405	644101620	0.17	3.10	28.08	71.92	1.19	59.10	39.71
SET B	3504,70	605,00	677426919	0.21	3,60	30,19	69,81	0,50	69,38	30,12
SET C	6868.4	1005	935403320	0.24	3.2	33.22	69.79	1.04	63.37	33.59
SET D	14067.8	1610	849961347	0.86	4	26.01	74.99	0.02	67.97	32.01
SET E	27837.6	2810	587952509	2.13	4	33.66	66.34	0.71	63.19	36.11
SET F	41909.15	4010	376033137.44	5.37	3.75	30.85	69.15	0.99	82.06	16.95

Results related to the case study of the Ligurian logistic network are reported in Table 5. The real case is characterized by $|V_H|=7$, $|V_P|=3$ and $|V_D|=9$. Only one hub is not completely connected to the node of the network by the rail mode. The % of import and export demand is 50-50, and the ratio δ between the total capacity of the hub nodes and the total demand is 6.23. The optimal solution suggest to open 3 hubs; note that the rail modality is mainly chosen; the existing rail capacity is enough for reducing the impact of heavy traffic on the city center and its surroundings. However, presently the railway network is used very little; the operators justify this fact saying that the freight train does not guarantee a reliable service.

Table 5. Case study results obtained with model (1)-(6)

# var.	# const.	Objective	CPU Time (Secs)	Y	CZ+CH (%)	C (%)	m1 (L) %	m3 (R) %	m2 + m4 %
1373	397	368792328	0.23	3	28.38	71.62	0	58.61	41.39

The selected mid-range dry ports are multimodal hubs located in Novi, Alessandria and near Pavia, respectively 60, 100 and 120 kilometers far from the port of Genoa. In the optimal solution the containerized flows go through two of the three opened hubs using only the mono modal rail modality; the mid-range dry port located in Novi is the only one used as multimodal hub.

5. Conclusions

We have presented an application of the hub location problem aimed at finding optimal configuration of a dry port network for serving the containerized import/export flow of the maritime terminals of the port of Genoa, Italy. The problem is a particular case of the capacitated hub location problem; as a novel issue, we allow the splitting of the origin-destination demand throughout more than one hub, also considering different travelling modes, that in the present case are road and rail ones. We propose a computationally efficient MILP model, tested with randomly generated instances having different capacity and modal split.

Our preliminary results show that the proposed MILP model is very promising. We plan to continue the computational experimentation in order to be able to *i*) better evaluate the impact of these new deliver strategies on both hub and transportation costs; *ii*) solve more complex instances related to larger geographical areas, thus not considering only mid-range dry ports (i.e. deleting the constraints on the maximum distance of 100 kilometers between ports and hubs).

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