

An economic logistics model for the multimodal inland distribution of maritime containers

by

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Abstract

“Interports” are defined as common-user facilities located in the hinterland of one or several seaports. They represent an innovation posing challenges and opportunities for operators involved in freight transport, freight forwarding, value-adding logistics, manufacturing and trade.

At the interports a range of services may be offered beyond both the simple multimodal switching of load-carrying units from one type of carrier to another and the warehousing of goods. Examples are customs operations and technical controls, cargo consolidation/deconsolidation, advanced quasi-manufacturing and distribution logistic services, and even wholesale and retail trade. Customs services contribute to seamlessly integrated operations between seaports and interports (the “extended gateway” concept).

Mathematically, we identify the “*interport model*” as an extension of the conventional multimodal and multicommodity transshipment problem. Main purpose of the network model is to highlight and measure the advantages that logistic agents can enjoy in routing maritime containers through the interports. The model minimizes the sum of all container-related logistic costs throughout the entire port-hinterland distribution network, subject to balancing conditions at all nodes and capacity constraints over railway links. The logistic costs include transportation costs (by road and railway), terminal and customs operation costs, and inventory in-transit holding costs.

We present an empirical application portraying the intermodal and logistic “first-tier” network in the Campania region, Southern Italy. Naples and Salerno are the container seaports of the region; the relatively recently constructed terminal, customs, warehousing and processing facilities at Nola and Marcianise are recognized as interports. Major Italian regions and cities are the other inland destinations for the container traffic handled in the Campania seaport cluster. Interports face a local demand for containers, and they can perform intermodal and customs functions. Both interports and locations endowed with a railway terminal can serve as intermediate transshipment nodes for traffic towards other inland destinations.

The numerical prototype was programmed and solved using the GAMS (General Algebraic Modeling System) computer code. The results confirm the importance of the regional off-dock and inland logistic system for the inland distribution of international maritime containers flowing through the Campania seaport cluster. The future competitiveness of the regional seaports and their hinterland distribution system will depend on a further improved supply of interport services.

Key words: inland container logistics, interports, multimodal transport, customs, mathematical programming, virtual nodes

1. Introduction

The containerization and evolution of the transportation industry have made off-dock terminals and inland ports increasingly popular as means for boosting seaport capacity¹. Non-essential terminal activities such as customs clearance and controls, storage, sorting and distribution of load-carrying units can be transferred from seaports to off-dock and inland sites. Customs services, in particular, contribute to seamlessly integrated operations between seaports and such intermodal sites (the “extended gateway” concept²). As a result, container dwell times³ and congestion at the seaports can be dramatically reduced. In addition, off-dock terminals and inland ports make it possible to shift cargo away from congested roads to railways (or inland waterways, where available) through frequent, fast, reliable, cost-effective and large capacity shuttle services.

Italy was the first European country to legally conceive of and financially support inland ports as first-tier and common-user facilities in sea-land intermodal logistic networks. The term used to indicate an inland port is that of “interport”, as an abbreviation of “interior port”. Some Italian interports serve in the double role of satellite terminals and inland ports (e.g. the interports of Nola and Marcianise in Campania region, as well as the interport of Cervignano in Friuli Venezia Giulia region).

Interports represent an innovation posing challenges and opportunities for operators involved in freight transport, freight forwarding, value-adding logistics, manufacturing and trade. At the interports a range of services may be offered beyond both the simple intermodal switching of load-carrying units and the warehousing of goods. Examples are customs operations and technical controls, cargo consolidation/deconsolidation, advanced quasi-manufacturing and distribution logistic services, and even wholesale and retail trade.

In the pages to follow, we formulate and solve an economic optimization model for the inland logistics of containers imported through the seaports located in Campania region in Southern Italy. The containers can transit both through the regional interports and extra-regional locations equipped with a railway terminal before reaching their final destinations.

Naples and Salerno are the container seaports of the region; the relatively recently constructed terminal, customs, warehousing and processing facilities at Nola and Marcianise are recognized as interports. Major Italian regions and cities are identified as the final destinations for the container traffic handled in the Campania seaport cluster. Our work aims at measuring the logistic advantages and/or drawbacks arising from both shifting the seaport exit of imported containerized cargoes to regional interports, and employing intermodal solutions for the hinterland distribution.

The *interport model* should be understood as a novel extension of the conventional mathematical programming network model. It is a large-scale, linear, static, multimodal and multicommodity⁴ transshipment model with capacity constraints that identifies possible optimal choices concerning the regional off-dock and inland logistics economy. The programming problem minimizes the total logistic cost of the distribution operations over the inland network, subject to flow balancing conditions at all origins, intermediate and destination nodes, as well as to capacity constraints over the railway links. Total logistic cost includes transportation costs (by road and railway), terminal and customs operation costs, and inventory in-transit holding costs.

The construction of interports and other off-dock facilities is intended to reduce the build-up of cargo at the ports, and to reduce queuing times. The time dimension is accounted for in several ways in our work, through the consideration of:

- average dwell times for empty containers at seaports and interports;
- average dwell times for full containers by customs control type (automated computerized control, documentary control, physical inspection, X-ray scanning) at seaports and interports;
- average dwell times at seaports for full containers to be cleared by customs at interports;

¹ It is possible to distinguish on-dock, near-dock, off-dock and inland sites according to the relative location of such intermodal sites in relation to a seaport terminal (Ashar, 2004). Instead, Rodrigue and Notteboom (2009) distinguish satellite terminals and inland terminals (or inland ports), the former being located in the immediate vicinity of seaport terminals, while the latter are closer to the market, i.e. they are located in more remote areas and linked to long distance corridors.

² The extended gateway concept is based on the idea of moving some container seaport functions, in particular customs inspection and clearance, to an off-dock or inland location which becomes an integral part of the seaport itself, freeing up additional space and capacity to be employed for on-dock and other priority port activities. A theoretical analysis of the extended gateway concept is provided by Rodrigue and Notteboom (2009), and Visser *et al.* (2007). The contributions by the China Intermodal Transport Services to the Interior Project – ITSIP (2003), Hayut (1980), Tioga Group (2006), and UNCTAD (1991) clarified important aspects related to the concept.

³ Dwell time is the length of time a container remains at a terminal before being loaded onto a transportation vehicle (ship, train, truck, barge) for further distribution. It can be a large proportion of the total transit time in a door-to-door multimodal distribution process, and it is a critical factor influencing the node infrastructure capacity. It is affected by customs and other technical and administrative control procedures, as well as by both the terminal operators’ service level, and supply chain management strategies based on the employment of the terminals as places for the low-cost warehousing of goods.

⁴ The model considers the traffics of both full and empty containers.

- free-of-charge container storage times at seaports and interports;
- demurrage charges incurred at seaports and interports⁵;
- the time duration of multimodal transport operations over the network;
- opportunity costs and economic-technical depreciation costs for the containerized goods⁶.

The most crucial element in this list is the average dwell time at the seaports. At the port of Naples it varies from 9.4 days to 23.8 days in the case of full containers cleared at the seaport (averages between values for full load units leaving out by road and values for full load units leaving out by rail). Customs clearance and controls are among the most important factors determining such figures. Comparisons have been made with the port of Rotterdam, where the release of a container may take 3-7 days at most.

The extensive customs controls in the port of Naples are associated with information contained in the customs declaration bills that signal a potential high risk. A large volume of containerized cargo arrives here from China and South-East Asia, mainly textiles, footwear, leather goods. At least 70% of total textile imports from China to Italy transit through the port of Naples. Large quantities of counterfeit goods coming from China have lately been seized at major Italian ports. Campania is the Italian region mainly affected by this phenomenon.

Interports are examples of Schumpeterian innovations dramatically changing the layout of the logistic networks. They involve huge investments and relieve congestion at seaports. The purpose of the *interport model*, as presented here, is to provide a mathematical description and analytical tool for such innovation. Actually, as we shall see, the numerical solution to the *interport model* for the Campania region pinpoints many current shortcomings of the Campania logistic system, for instance: lacking customs facilities at the interport of Marcianise, suspension of railway connections at the port of Salerno, congestion and high container dwell times at the port of Naples, and low rates of utilization of the existing railway capacity from seaports and interports. It will also provide clues for the improvement of current performance. We shall thus be able to make an overall diagnosis and assessment of the current situation of the Campania logistic system for the importation of maritime containers, and to propose possible steps of improvement.

Section 2 maps the flow of imported containerized goods throughout the Campania transportation network: the seaports, the interports, and the railway and truck connections with other Italian nodes. Section 3 describes the mathematical interport model by way of a somewhat stylized example, and indicates the nature of the quite large mathematical programming model that we have actually solved. Section 4 reports on the numerical solution of the model, and Section 5 sums up the results.

1.1. Antecedents

Spatial optimization models available in the literature that can be employed for the containerized traffic industry are not numerous. Examples are the works of Aversa *et al.* (2005), Crainic (2003), Crainic and Kim (2007), Cullinane *et al.* (2002), Deidda *et al.* (2008), Kim *et al.* (2008a; 2008b), Lee *et al.* (2006), Luo (2002), Luo and Grigalunas (2003), Racunica and Winter (2005), Rahimi *et al.* (2008), and Van Duin and Van Ham (2001).

Our present work builds on earlier researches reported in Iannone (2006a; 2006b), Iannone *et al.* (2007), Thore (2007), Thore and Iannone (2005). From a mathematical point of view, the *interport model* hereinafter proposed to analyze the container logistics of the Campania “seaport-interport” system represents an adaptation to the inland container traffic industry of the hub-and-spoke model identified in Thore and Iannone (2005)⁷.

The present version of this paper was prepared for presentation at the ICTPI conference at Porto, July 12-13 2009. For the full version, see www.stenthore.info. For complete background materials, see the doctoral dissertation of Iannone (2008).

2. The Campania regional logistic system, and functional and topological features of the investigated network

Campania is a region located in the Southern Italy, the Italian “*Mezzogiorno*”. It is endowed with an extensive road and railway network. The first-tier sea-land intermodal logistic system in Campania is currently based on the Tyrrhenian regional seaports of Naples and Salerno, and on the interports of Nola and Marcianise. Figure 1 depicts a conceptual schema of the set of nodes, multimodal links, and containerized logistic processes that form the Campania regional logistic system for the importation of maritime containers.

⁵ Demurrage is the daily charge for terminal storage of a container beyond the agreed free time.

⁶ These are inventory in-transit holding costs depending on the value of the containerized goods (expressed in Euros/full TEU), as well as on both the time duration of the logistic operations and a reference interest rate. By taking into consideration the average customs declared value of imports in Campania in the first half of 2007 (equal to 15,934 Euros/TEU, based on data provided by the Italian Customs Agency), and a yearly rate of 35%, we estimated inventory in-transit holding cost for full containers handled in the seaports equal to 15.3 Euros/full TEU/day or 0.64 Euros/full TEU/hour.

⁷ Thore and Iannone (2005) outlined the principal properties of the transshipment problem in a hub-and-spoke type network configuration, with particular reference to its primal and dual mathematical formulations, its economic interpretation, and the complementary slackness conditions. The analytic techniques presented were linear programming and mixed integer programming, the latter employed for formulating and solving an airport location problem.

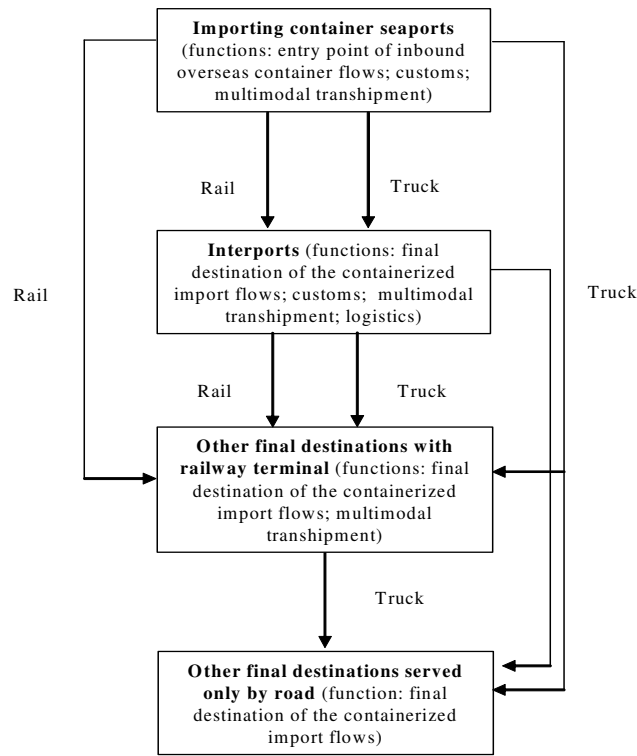


Figure 1. Distribution of maritime containers imported through the Campania regional logistic system: a conceptual schema

This schema can be translated into Figure 2 which is a topological representation of the containerized inland logistic network investigated by the *inward interport model*. The network features the following nodes:

- (i) Seaport nodes at Naples and Salerno. They serve as entry points for full and empty containers imported by sea, to be distributed by road and railway over the national hinterland. Each seaport node has terminal and customs functions.
- (ii) Interport nodes at Nola and Marcianise. They are served by truck and rail, and have a local demand of containers disembarked in the seaports. Furthermore, they may provide customs clearance services and can serve as transshipment nodes for some traffic relations from the seaports towards other inland final destinations. Finally, the interports may provide quasi-manufacturing value-adding logistic services⁸.
- (iii) Final destination nodes with railway terminal which are served by truck and rail from the Campania logistic system. They can also perform the role of intermediate transshipment nodes (railway-to-truck and truck-to-truck) for some traffic relations from both the seaports and interports towards other inland final destinations.
- (iv) Final destination nodes served by truck only.

The seaports at Naples and Salerno are connected by truck to all the inland locations of the network. Naples is connected by railway to the interports and to some final destinations with a railway terminal; Salerno is connected by rail to the Nola interport and to Bari city/terminal. There is no rail connection between Salerno and Marcianise. The interports are connected by road to all the other inland locations of the network, and by railway to some final destinations with a railway terminal.

Customs clearing may take place either in the seaports of Naples and Salerno themselves or in the interports of Nola and Marcianise. The Campania network of imported maritime containers thus forms an extended gateway system based on railway connections under customs bond and under the full responsibility of the shipping lines (carrier haulage) over the routes Naples-Nola, Naples-Marcianise, and Salerno-Nola.

Currently, carrier haulage under customs bond is possible only towards/from Nola interport. In the future, a fully operational customs status of Marcianise interport is expected as well.

⁸ The quasi-manufacturing value-adding logistic function of the interports can be dealt within an interport model with a maximizing objective function.

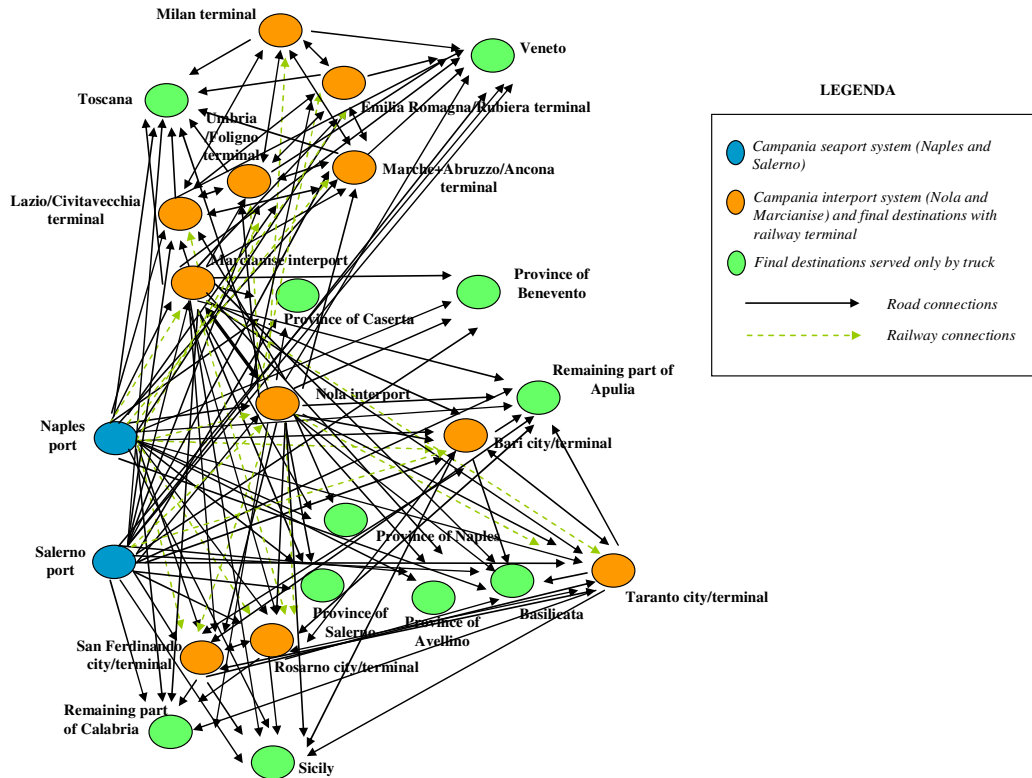


Figure 2. Configuration of the inland distribution network investigated by the interport model

Since December 2005 the rail freight services from/to Salerno have been suspended due to a serious accident that happened on the urban segment of the railway connection between Salerno city and the port rail terminal. In the mathematical *interport model* there are railway connections from Salerno both towards the interport of Nola and the city of Bari (Apulia region, Southern Italy), thus simulating the operational situation prior to the accident. But at the interport of Marcianise it is not possible to clear full containers disembarked in the port of Salerno because of the unavailability of a railway connection between the two nodes.

In addition, the network investigated by the model also includes the following rail connections operated in years preceding 2007: Naples-Foligno, Nola-Foligno, Nola-Rubiera, Marcianise-Taranto, Marcianise-Rosarno, and Marcianise-Civitavecchia. Definitively, the rail container services included in the model are all those operated in Campania during the years 2005-2007.

A novel aspect of our present work is the use of “virtual nodes” for modeling the whole range of container traffic related functions which can be performed by each interport. Virtual nodes have identical geographical location but involve different interport processing activities. We identify two virtual nodes at each interport:

- (i) the processing of containers arriving from the seaports by road or railway as either full cargo units already cleared by customs or empty cargo units;
- (ii) the customs clearance and processing of full containers arriving from the seaports by railway under customs bond and on behalf of the shipping lines (carrier haulage).

Both nodes perform an intermediate intermodal function. But only one of them performs a customs function as well. It can be reached only by railway. Instead, only to the other virtual node is attributed the local interport demand of full and empty containers arriving from the seaports. Both virtual nodes have the same outbound inland multimodal connections. Finally, in order to model the eventual possibility of clearing in each interport the full containers originating in a regional seaport and destined to importing operators located in the interport itself, it is admitted the one-way road transport at a nil generalized cost between the virtual node with customs function and the other one without customs function.

3. Mathematical formulation of the interport model: a stylized example

We construct a large-scale transshipment model for the economic analysis and strategic planning of the distribution of maritime containers transiting through the seaports and interports of the Campania region. The model is multimodal, allowing for both road and rail transportation, and multicommodity, covering both full and empty containers. It features capacity constraints explicitly formulated for railway links. The objective of the mathematical program is the minimization of all container-related logistic costs throughout the entire port-hinterland distribution

network. The model takes into consideration transportation costs, inventory holding costs, terminal and customs operation costs.

We present a stylized example of an *interport model*. The shipments in the model flow along the arcs of the network, from origin seaports to inland demand points. The demand requirements are then not just that a certain total arrives at each destination irrespective of its origins (as in the conventional transportation and transshipment models), but that all individual customers are satisfied, both at the origins and at the destinations⁹.

There are two originating nodes 1 and 2 (conveniently identifiable as the port of Naples and the port of Salerno, respectively), and an interport featuring two virtual nodes 3 and 4 (node 3 representing the processing of containers that have already been cleared by customs at the seaports, node 4 representing the customs clearance and processing of containers arriving from the seaports under customs bond). There are three distant final destinations: nodes 5, 6, 7. Only the nodes 5 and 6 have a railway terminal. The virtual interport node 3 has a local demand for containers as well; therefore it is also a final demand node of the model.

The simple example shown here is “unicommodity”, i.e. it involves only the logistics for full containers disembarked in the seaports and to be distributed overland. The generalization to multiple container types is immediate and need not delay us here. Introduce some mathematical notation as it follows:

I : set of all the nodes of the network = $\{1, 2, 3, 4, 5, 6, 7\}$

$L(I)$: set of the first-tier intermodal nodes of the regional load center network for containers cleared in the seaports = $\{1, 2, 3\}$

$P(L)$: set of the seaport nodes of the regional load centre network = $\{1, 2\}$

$Q(L)$: set of the “virtual” interport nodes without customs function = $\{3\}$

$D(I)$: set of the “virtual” interport nodes with customs function = $\{4\}$

$Z(I)$: set of all the inland locations demanding containers imported through the origin seaport nodes = $\{3, 5, 6, 7\}$

$E(Z)$: set of all the inland locations (excluding the interports) demanding containers imported through the origin seaport nodes = $\{5, 6, 7\}$

$R(E)$: set of all the demanding inland locations not equipped with a railway terminal = $\{7\}$

$H(I)$: set of nodes with function of inland transshipment centre = $\{3, 4, 5, 6\}$

M : set of the admitted inland transportation modes = $\{rail, truck\}$

T : set of the road linear infrastructures = $\{motorways, remaining\ road\ types\}$ ¹⁰

A : set of the railway links = $\{1_ (3+4), 2_ (3+4), 2_5, (3+4)_5, (3+4)_6\}$ ¹¹

$\begin{bmatrix} D_{pi} \end{bmatrix}$: a column vector of container demand specified in number of full TEUs by origin-destination node pair (that is from each seaport node $p \in P$ towards each node $i \in I$)

$\begin{bmatrix} c_{ij}^m \end{bmatrix}$: a row vector of generalized unit transport costs (in Euros/TEU) for mode $m \in M$ between nodes $i, j \in I$ ¹²

$\begin{bmatrix} f_p^m \end{bmatrix}$: a row vector of weighted average generalized unit costs (in Euros/TEU) of releasing operations for imported full containers cleared at seaport node $p \in P$ and leaving out the seaport node itself by the transport mode $m \in M$

⁹ To deal with this situation, one forms a master (or “multi-page”) program that joins together the individual programs for each origin node of the problem, see (Thore and Iannone, 2005).

¹⁰ Such set can be employed with reference to road distance parameters to be considered together with the assumed average road driving speeds in order to compute the road driving times, and definitively the total travel times by road over the links of the investigated network.

¹¹ This set can be employed with reference to the railway capacity constraints of the model. See the column vector $[b_a]$. The capacity constraint of each railway connection from/towards each interport jointly consider the railway links from/towards each of the two corresponding virtual nodes.

¹² Generalized transport costs include the price of transport plus opportunity costs and economic-technical depreciation costs for the containerized goods during the time needed for transport operations (inventory in-transit holding costs over the links of the network). The price of transport toward a generic node includes the cost of the terminal operation related to the offloading of the container from the vehicle at the end of the trip. Moreover, the price for the road transport from the final destination nodes equipped with a railway terminal (excluding the interport nodes) towards other demanding nodes comprises the cost of terminal operations both at the departure and arrival. Total travel time by road is equal to the driving time plus the time for rests and stops prescribed by Road regulations under the “1 driver on board” hypothesis. The number and time duration of rests and stops to be observed in a container transportation by truck have been calculated in function of the driving time. In particular, the same computational procedure employed by Aponte *et al.* (2009) has been adopted.

$[g_p]$: a row vector of generalized unit costs (in Euros/TEU) of releasing operations for imported full containers leaving out the seaport node $p \in P$ by railway under customs bond and on behalf of shipping lines (carrier haulage) towards a virtual interport node with customs functions

$[h_d^m]$: a row vector of weighted average generalized unit costs (in Euros/TEU) of releasing operations for imported full containers arriving by railway under customs bond and on behalf of shipping lines (carrier haulage) from the seaport of Naples ($1 \in P$) in the virtual interport node (with customs function) $d \in D$, and subsequently cleared and leaving out the virtual interport node itself by the transport mode $m \in M$

$[j_d^m]$: a row vector of weighted average generalized unit costs (in Euros/TEU) of releasing operations for imported full containers arriving by railway under customs bond and on behalf of shipping lines (carrier haulage) from the seaport of Salerno ($2 \in P$) in the virtual interport node $d \in D$, and subsequently cleared and leaving out the virtual interport node itself by the transport mode $m \in M$

$[k_q^m]$: a row vector of generalized unit costs (in Euros/TEU) of releasing operations for imported full containers already cleared in a seaport node and leaving out the virtual interport node (without customs function) $q \in Q$ by the transport mode $m \in M$

$[b_a]$: a column vector of the maximal number of containers which can be transported over the railway link $a \in A$ during the planning horizon

$[x_{ij}^m]$: a column vector of shipments by transport mode $m \in M$ from the origin seaport node $1 \in P$ along the links $i, j \in I$

$[y_{ij}^m]$: a column vector of shipments by transport mode $m \in M$ from the origin seaport node $2 \in P$ along the links $i, j \in I$

The objective of the programming model is:

min $W =$

$$\begin{aligned} & \sum_{i \in I} \sum_{j \in I} \sum_{m \in M} c_{ij}^m \cdot (x_{ij}^m + y_{ij}^m) + \sum_{p \in P} \sum_{z \in Z} \sum_{m \in M} f_p^m \cdot (x_{pz}^m + y_{pz}^m) + \sum_{p \in P} \sum_{d \in D} g_p \cdot (x_{pd}^{rail \in M} + y_{pd}^{rail \in M}) + \sum_{q \in Q} \sum_{e \in E} \sum_{m \in M} k_q^m \cdot (x_{qe}^m + y_{qe}^m) + \\ & + \sum_{d \in D} \left\{ \sum_{z \in Z} \left[(h_d^{truck \in M} \cdot x_{dz}^{truck \in M}) + (j_d^{truck \in M} \cdot y_{dz}^{truck \in M}) \right] + \right. \\ & \left. \sum_{e \in E} \left[(h_d^{rail \in M} \cdot x_{de}^{rail \in M}) + (j_d^{rail \in M} \cdot y_{de}^{rail \in M}) \right] \right\} \end{aligned} \quad (1)$$

The sets Q and D introduce the virtual interport nodes. A full container arriving at a seaport node $p \in P$ can either be cleared by the customs right away, in which case it can proceed to an inland demanding location $z \in Z$, including virtual nodes ($q \in Q \subseteq Z$). Or it can have its customs clearance delayed, in which case it has to proceed by railway to a virtual node $d \in D$. The latter alternative offers the shipper the opportunity to avoid costly delays at a seaport nodes awaiting access to customs clearance.

The weighted average generalized unit costs for container releasing operations both at seaports and interports are computed by taking into consideration direct costs and indirect costs according the different probabilities observed in Campania seaports for the different customs control types (automated computerized control, documentary control, physical inspection, and X-ray scanner control)¹³.

The objective function of the full model is a straight-forward generalization of (1). The full model minimizes the total logistic cost for the distribution of full and empty containers throughout the entire network. It obviously includes more parameters than the mathematical notations presented above, and is subjected to flow conservation constraints at all origin, intermediate and destination nodes, as well as non-negativity constraints on the decision variables and capacity constraints over railway links. Other constraints in the full model: 1) set to zero all variables involving non-existing links over the logistic network; 2) permit one-way road transport with a nil generalized cost for full containers between the two virtual nodes at each interport.

All in all, our complete model features 863 unknowns and 168 constraints. It was programmed and solved with the GAMS (General Algebraic Modeling System) computer code, using the solver CPLEX.

¹³ Direct costs include terminal handling costs, storage costs, and customs operation costs in the case of physical inspection and X-ray scanner control. Instead, indirect costs consist of opportunity costs and economic-technical depreciation costs for the containerized goods during the time needed for the releasing operations (inventory in-transit holding costs at nodes).

4. Optimal solution and discussion

The input data were provided by various bodies and firms involved in the intermodal and logistic industry at regional, national and international level¹⁴. Inputs were also derived from internet web-sites, specialized press, scientific literature, and industrial studies. Generally, excluding some rail links (Salerno-Nola, Salerno-Bari, Naples-Foligno, Nola-Foligno, Nola-Rubiera, Marcianise-Taranto, Marcianise-Rosarno, and Marcianise-Civitavecchia), all the data of the model refer to the year 2007.

The solution of the model delivers the optimal flows of full and empty containers along all road links and all rail links. The equilibrating mechanism is governed by the terms of both direct and indirect logistic costs of the releasing operations at the nodes, and therefore by both the capacity of nodes and the supply chain management strategies of the shippers, as well as by the capacity and costs of transport services among nodes.

Our main interest lies with the solution traffic through the two interports at Nola and Marcianise (Table 1). It turns out that the 95% of the demand at Nola interport for full containers disembarked in Naples port is satisfied by road transportation (56,892 TEUs). The containers are cleared by customs in Naples and then transported by truck to Nola. The remaining 5% of the demand at Nola for full containers disembarked in Naples is satisfied by hauling the containers by railway under customs bond from Naples to Marcianise interport (carrier haulage). Here the containers are cleared by customs and then transported to Nola by truck (3,000 TEUs). On the other hand, the whole demand at Marcianise interport for full containers arriving from Naples port (10,890 TEUs) is serviced by carrying the load units by railway under customs bond from Naples to Nola. There the containers are cleared by customs and then transported to Marcianise by truck.

These results may in the first instance seem odd, but can be explained as it follows. The key bottlenecks in the system are the capacity constraints on railway shuttles between the port of Naples and the two interports. For the optimal solution, all available railway capacity from Naples to each of the two interports is utilized. Carrying the containers by railway under customs bond dramatically reduces the generalized cost at the seaport.

The railway services between Naples and Calabria-located destinations (Rosarno and San Ferdinando, that is Gioia Tauro, in Southern Italy) would also operate at the limit of their capacity. Railway-to-railway transshipment through Nola interport is advantageous for full containers imported by sea through Naples and demanded in Milan, Taranto and San Ferdinando. But railway connections from the interports to other national inland locations have low levels of capacity utilization (see Table 2). Such services are also employed for traffic not originating in the Campania seaports.

The results clearly demonstrate the economic and social advantages that would accrue in an extended gateway system based on a fully operational customs status at both Campania interports¹⁵. The model measures the benefits of a regime of customs continuity between seaports and interports. Such a system would be advantageous even for distributing containerized cargoes arriving at Naples and destined to the two interports themselves. For the logistic agent, given the very high generalized unit port cost at Naples, it would at all times be preferable to ship the cargo by railway under customs bond from Naples toward a regional interport, to execute the customs clearance at the interport, and to transport the container by truck towards the other regional interport. There is a huge potential for operational integration between the two different interport sites. This provides an indication of possible industrial, infrastructure and organizational policies that could be pursued by public and private parties.

Next, turning to containers disembarked in the port of Salerno, the situation is different. In Salerno there is not the same customs-induced port congestion as in Naples. Salerno is a typical export port (the import traffic being dominated by empty containers and the export traffic dominated by full containers). In particular, imports arriving from China are low - a situation quite different from that at the port of Naples. Direct and indirect costs incurred at Salerno are also lower than at Naples.

Nevertheless, the railway capacity between the port of Salerno and the inland nodes of Nola and Bari would be fully utilized. The connection to Nola would be employed mainly for transporting full containers already cleared in the port (1,493 TEUs). These containers contribute to the utilization of about 60% of the potential port-interport railway capacity, while a share of 38% would instead be devoted to the re-positioning of empty containers (951 TEUs). The remaining 2% would consist of containers transported by railway under customs bond from Salerno to Nola and destined to the Lombardia market. Once released by customs at Nola, they would be sent by railway from Nola to the Segrate Milan terminal (56 TEUs).

¹⁴ In particular: the Rome-located Italian National Customs Agency, the Nola interport-based Customs Office, the Port authorities of Naples and Salerno, the Centre for Transportation Culture at the Ente Autonomo Volturno (a Campania government-owned holding for regional public transportation planning and management), the management companies of the major maritime container terminals located in Campania (Co.Na.Te.Co. and S.C.T., respectively in Naples and Salerno), the management companies of the Campania-based operational interports (Interporto Campano and Interporto Sud Europa, respectively in Nola and Marcianise interport) and their intermodal terminals (the subsidiaries T.I.N. and NAOS, respectively in Nola and Marcianise interport), the major Italian rail freight companies (Trenitalia and Rail Traction Company), and other Campania region-located operators (FERPORT Napoli, Logship, Italcontainer, DHL Global Forwarding Italy, Schenker, Omnia-logistica, De Crescenzo, and Sticcosped).

¹⁵ In numerical application of the interport model the objective function does not include transport externality costs, but it is clear that transportation by railway adds to social welfare.

Table 1. Optimal inland flows of imported containers through Campania seaports and interports *

	<i>Destinations...</i>				
	<i>NOL</i>	<i>NCC</i>	<i>MAR</i>	<i>MCC</i>	<i>Other inland locations</i>
<i>Leaving the port of Naples (NAP)</i>					
<i>Full TEUs cleared at the port and shipped by road (merchant haulage)</i>	56,892				92,005
<i>Full TEUs cleared at the port and shipped by railway (merchant haulage)</i>					16,725
<i>Full TEUs shipped by railway under customs bond (carrier haulage)</i>		15,000		3,000	
<i>Empty TEUs shipped by road</i>	4,034		772		12,249
<i>Empty TEUs shipped by railway</i>					5,200
<i>Leaving the port of Salerno (SAL)</i>					
<i>Full TEUs cleared at the port and shipped by road (merchant haulage)</i>			302		68,735
<i>Full TEUs cleared at the port and shipped by railway (merchant haulage)</i>	1,493				1,095
<i>Full TEUs shipped by railway under customs bond (carrier haulage)</i>		56			
<i>Empty TEUs shipped by road</i>	149		199		94,762
<i>Empty TEUs shipped by railway</i>	951				1,405
<i>Leaving the virtual interport node with customs function at Nola (NCC)</i>					
<i>Full TEUs from NAP cleared at the interport and shipped by road</i>			10,890		655
<i>Full TEUs from NAP cleared at the interport and shipped by railway</i>					3,455
<i>Full TEUs from SAL cleared at the interport and shipped by railway</i>					56
<i>Leaving the virtual interport node with customs function at Marcanise (MCC)</i>					
<i>Full TEUs from NAP cleared at the interport and shipped by road</i>	3,000				
<i>Leaving the virtual interport node without customs function at Nola (NOL)</i>					
<i>Empty TEUs from SAL and shipped from the interport by railway</i>					58

* NAP = port of Naples; SAL = port of Salerno; NOL = Nola interport (no customs function); NCC = Nola interport (customs function); MAR = Marcanise interport (no customs function); MCC = Marcanise interport (customs function)

Expansion of the customs facilities for the inland container traffic throughout the Campania logistic system, backed up by an efficient railway system, would clearly be an effective means for expanding the commercial and geographical hinterland of the regional seaport system. It would boost the competitiveness of all the first-tier seaport and interport nodes in the region. This holds true also for cargoes destined to Northern Italy and, more generally, to Central and Northern Europe.

Table 2 lists both data and solution values on rail shipments from Campania seaports and interports. The observed data referring to Nola and Marcanise include containers (full and empties) which were not disembarked in the Campania seaports, as well as possible transits from the Campania seaports towards other inland final destinations. The solution figures exclusively refer to containers (full and empties) disembarked at the seaports, including transits towards inland final destinations. The table also exhibits the modelled capacity limits on the various railway links and the solution shadow prices of the capacity constraints.

The shadow prices of the railway capacity constraints (the last column in the table) indicate the imputed value of the objective function arising from an improvement of infrastructure and/or services. They confirm the importance of the off-dock logistic system. In particular, an increase of the railway capacity over the Naples-Nola, Naples-Marcanise, Naples-Rosarno, Naples-San Ferdinando, Salerno-Nola, and Salerno-Bari routes would generate logistic benefits. For instance, the total logistic cost reduction due to a unit relaxation of the capacity constraint on the railway link from Naples to Marcanise equals to 234 euros.

Sensitivity tests. In Figures 3 and 4 the results of some sensitivity tests are reported. We calculated the change of both the objective function and the total generalized average unit port cost that would arise under some alternative values of the parameter measuring the average unit dwell time of full containers cleared by customs at the port of Naples. Compared with the base case, the dwell time variations taken into consideration are: (i) a 50% reduction of the base case dwell time; (ii) a 25% reduction of the base case dwell time; (iii) a 25% increase of the base case dwell time; (iv) a 50% increase of the base case dwell time. As the figures illustrate, a less than proportional change of the optimal value of the objective function occurs, and an almost proportional change of the total generalized average unit port cost.

Table 2. Rail traffics of full and empty containers (observed and resulting from the model), rail capacity utilization (resulting from the model), and shadow values of the rail capacity constraints

Railway link	Number of one-way weekly trains - model	Maximum number of TEUs/train - model	Maximum annual one-way capacity (TEUs) - model	One-way annual shipments in the last observed year (TEUs)	One-way annual shipments resulting from the model (TEUs)	Shadow value of the capacity constraint resulting from the model (Euros/TEU)
Naples-Nola	5	60	15,000	6,707	15,000	203.9
Naples-Marcianise	1	60	3,000	481	3,000	234.1
Naples-Bari	5	50	12,500	6,054	9,408	0
Naples-Rosarno	3	50	7,500	2,408	7,500	169.8
Naples-S. Ferdinando	1	50	2,500	2,410	2,500	187.5
Naples-Ancona	1	50	2,500	44	1,114	0
Naples-Foligno	1	50	2,500	30	1,272	0
Naples-Rubiera	1	50	2,500	129	131	0
Nola-Taranto	3	50	7,500	1,618	2,834	0
Nola-Rosarno	2	50	5,000	1,078	0	0
Nola-San Ferdinando	5	48	12,000	475	597	0
Nola-Foligno	1	50	2,500	51	0	0
Nola-Rubiera	1	50	2,500	66	0	0
Nola-Milano Segrate	5	12	3,000	750	138	0
Marcianise-Taranto	1	50	2,500	24	0	0
Marcianise-Rosarno	1	50	2,500	0	0	0
Marcianise-Civitavecchia	1	50	2,500	0	0	0
Salerno-Nola	1	50	2,500	395	2,500	43.2
Salerno-Bari	1	50	2,500	2,081	2,500	36.1

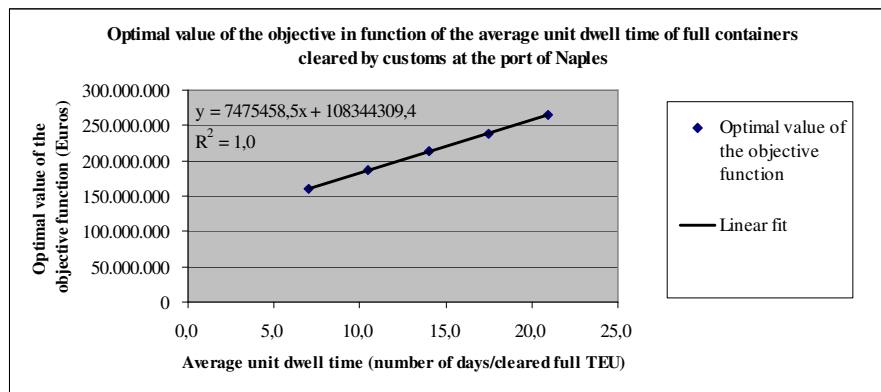


Figure 3. Optimal value of the objective in function of the average unit dwell time of full containers cleared by customs at the port of Naples

Finally, Table 3 reports the results of sensitivity tests calculating the change of the objective function, as well as that of both the rail share of total inland traffic outgoing the port of Naples, and the rail traffic under customs bond and on behalf of shipping lines (carrier haulage) between Naples port and the interports of Nola and Marcianise, that would occur under some alternative values of the parameter measuring the railway capacity over seaport-interport routes. The capacity variations considered were the following: (i) 100% increase of the base case (“ONE”); (ii) 200% increase of the base case (“TWO”).

The results demonstrate that even under the hypothetical scenario of a dramatic improvement of the railway capacity between the port and the interports, such increased capacity would still be fully utilized. Shippers would still find it advantageous to relocate customs examination from the seaports to the interports.

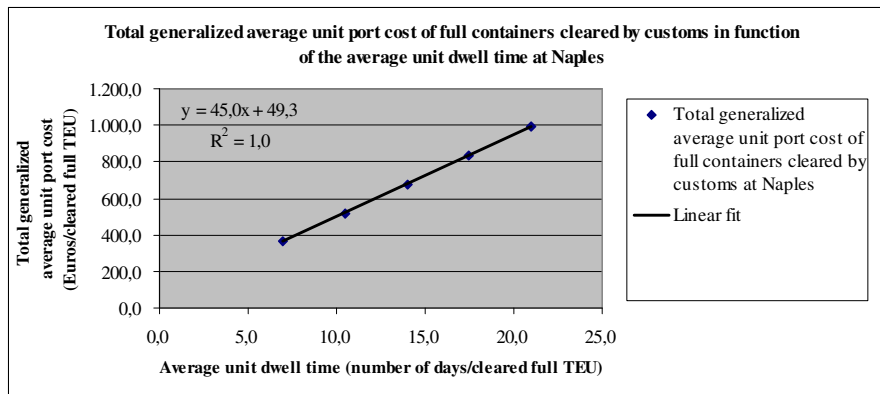


Figure 4. Total generalized average unit port cost of full containers cleared by customs in function of the average unit dwell time at Naples

Table 3. Sensitivity results under alternative assumptions of railway capacity between Naples port and the regional interports

	<i>BASE case</i>	<i>ONE</i>	<i>TWO</i>
No. of one-way weekly trains over the Naples-Nola link	5	10	15
Yearly capacity of the Naples-Nola one-way rail link (TEUs)	15,000	30,000	45,000
No. of one-way weekly trains over the Naples-Marcianise link	1	2	3
Yearly capacity of the Naples-Marcianise one-way rail link (TEUs)	3,000	6,000	9,000
Share of the rail traffic on the total inland traffic from Naples	19%	28%	36%
Optimal value of the objective function (million Euros)	212.9	209.2	205.8
Rail traffic under customs bond between Naples and the interports (TEUs)	18,000	36,000	54,000
Utilization rate of the rail links between Naples and the interports	100%	100%	100%

5. Conclusions

In the pages above we have proposed the interport model as a tool for economic analysis and strategic planning of the inland distribution of imported maritime containers flowing through the Campania seaport-interport system. It should be regarded as a distinct model type, different from other spatial models currently available in the operations research literature devoted to the container traffic industry.

The model solves for the distribution of containers disembarked in the Campania regional seaport cluster. The containers can transit both through the regional interports and extra-regional locations equipped with a railway terminal before of reaching their final destinations. The model is multimodal, allowing for both road and rail transportation, and multicommodity, covering both full and empty containers. It features capacity constraints for the railway links. The objective of the mathematical program is the minimization of all container-related logistic costs throughout the entire port-hinterland distribution network. The model takes into consideration transportation costs, inventory holding costs, terminal and customs operation costs. A main purpose of the model is to measure the advantages that logistic agents can enjoy in routing their containers through the interports according an extended gateway system, i.e. a regime of customs continuity based on the railway transport between seaports and interports.

Our study highlights the benefits of intermodal facilities and customs clearing at the interports. The transfer of customs clearance of containers from seaports to interports expands the hinterland of the Campania container seaports. It enhances their competitiveness for cargoes destined to Northern Italy and, more generally, to Central and Northern Europe.

The numerical solution reveals some of the current deficiencies of the Campania regional load center network in terms of port-interport connections. It also suggests possible policies that would further a better integration between seaports and interports. The future expansion of the Campania container distribution system depends crucially on an improved supply of interport services (at Nola, Marcianise, and Battipaglia, the latter being under construction). Unfortunately, however, new types of freight infrastructures and logistic poles (e.g. distriparks) in Campania region do not seem imminent.

The results demonstrate that it is possible to improve the competitiveness of railway services over short distances (Naples-Nola and Marcianise-Nola) by adopting an extended gateway system based on customs continuity between seaports and interports. This would include granting to the intermodal terminal located at Marcianise a fully operational customs bonded status.

The numerical solution indicates that the choice of one regional interport or the other for containers leaving the port of Naples may be immaterial in terms of costs. Shippers may even consider railway transport under customs bond from Naples toward one interport (Nola or Marcianise) and the subsequent transport by road toward the other. This indicates a possible integration of the use of the two regional interports.

Many inefficiencies could easily be corrected. These include the current suspension of railway connections from the port of Salerno, the absence of a customs bonded area and X-Ray scanner equipment at the Marcianise interport, and the low rates of utilization of existing railway capacity. Limited customs facilities at the port of Naples create severe congestion of containers; this leads to high unit dwell times and excessive generalized port costs.

Some of these shortcomings were recently discussed by the managing director of Co.Na.Te.Co (the major marine terminal company at the port of Naples). Criticizing the Campania regional logistics public policy, he voiced the opinion that local policy makers have failed to integrate the operations between seaports and interports. In his view, the Marcianise interport rather than Nola should become the first off-dock node for containers handled at the port of Naples (Scorza, 2009).

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