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AN ECONOMIC LOGISTICS MODEL FOR THE MULTIMODAL INLAND DISTRIBUTION OF MARITIME CONTAINERS

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Abstract: "Interports" are defined as common-user facilities located in the hinterland of one or several seaports. Mathematically, we identify the *"interport model"* as an extension of the conventional multimodal and multicommodity transhipment problem. The 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 generalized logistic costs throughout the entire port-hinterland distribution network, subject to balancing conditions at all nodes and capacity constraints over railway links.

We present empirical applications (baseline scenario, ideal scenario, pessimistic scenario) 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 constitute the other inland destinations for the container traffic handled in the Campanian seaports.

The numerical prototypes were 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 distribution of international maritime containers flowing through the Campanian 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.
JEL Classification: C61, L91, O21, R48.

1. Introduction

The containerization and evolution of the transportation industry have made off-dock terminals and inland ports increasingly popular as means

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for boosting the seaport capacity.[1] 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 contribute to seamless integrated operations between seaports and such intermodal sites (the "extended gateway" concept[2]). As a result, container dwell times[3] 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".[4] Some Italian interports

[1] Ashar (2004) classified on-dock, near-dock, off-dock and inland sites according to the relative location of such intermodal sites in relation to a seaport terminal. Roso (2007) and Roso *et al.* (2009) introduced the concepts of distant, mid-range and close dry ports. Finally, Rodrigue and Notteboom (2009) proposed a distinction between 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. Adopting a functional perspective, one may make the distinction between facilities providing only intermodal and cargo handling services, and those operating as broader logistic zones supplying a range of value added services.

[2] The extended gateway concept is based on the idea of moving some container seaport functions, in particular customs control and clearance, to an off-dock or inland location that becomes an integral part of the seaport itself, thus 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 (op. cit.), 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 same 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 capacity both at seaports and other intermodal nodes. It is affected by customs and other technical and administrative control procedures, by the terminal operators' service level, and by supply chain management strategies. Relevant issues were dealt with by Merckx (2006) and Rodrigue and Notteboom (op. cit.).

[4] The term "interport" referring to a port-hinterland freight village was informally introduced in 1970 during a round table on "Land, maritime, rail and air freight centres" held in the city of Padua in the Veneto region, Northern-Eastern Italy (Iannone *et al.*, 2007). The first Italian interport was put into operation in 1966 in Rivalta Scrivia (in the Piedmont region) with the aim of accommodating traffic leaving or entering the port of Genoa (in Ligu-

serve in the double role of satellite terminals and inland ports (e.g. the interports of Nola and Marcianise in the Campania region, as well as the interport of Cervignano in the 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 the simple intermodal 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.

Our study deals with the inland multimodal distribution of maritime containers through a regional load center network system encompassing seaport and interport nodes. 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 the Campania region in Southern Italy. The containers can transit through both the regional interports and extra-regional locations equipped with a railway terminal, before reaching their final destinations. The interports and the other railway locations have a local container demand as well.

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 other inland destinations for the container traffic handled in the Campanian seaport cluster. Our work aims at measuring the logistic advantages and/or drawbacks arising from shifting the seaport exit of imported containerized cargoes to regional interports, and from employing intermodal solutions for port-hinterland distribution.

The *interport model* should be understood as a novel extension of the conventional mathematical programming network modeling to conform with

ria). Other interports followed in 1970s: Bologna (in the Emilia Romagna region), Verona and Padua (in Veneto). Subsequently, article 1 of the Law No. 240 voted by Italian Parliament in 1990 ("Italian State support for building Interports and developing intermodality") established a legal definition of such facilities as well as an early classification of their activities and functions. The law defines the interport as "*an organic complex of integrated facilities and services providing for the exchange of goods between various transport modes, including a railway yard capable of composing and accommodating complete trains and linked to seaports, airports, and highways*". Legally, interports may be realised either as public companies or as a Public-Private Partnerships (P.P.P.). In retrospect, this legislation sought to stimulate rail freight transport in the country and contributed to increase the range of interport logistic services.

logistic theory and evidence related to "port regionalization",[1] "supply chain terminalization",[2] and the extended gateway concept. It is a large-scale, linear, static, multimodal and multicommodity transhipment model with capacity constraints that identifies possible optimal choices concerning the regional off-dock and inland container logistics economy.

The programming problem minimizes the total generalized logistic cost of the container distribution operations over the inland network, subject to flow balancing conditions at all origin, intermediate and destination nodes, as well as to capacity constraints over railway links. The model solves for the annual multimodal inland traffic demand among different nodes (seaports, interports, etc.) for full and empty units disembarked in Campania, and more generally it estimates the modal split of inland distribution traffics of containers imported in Italy by sea through the Campanian seaports. Total logistic cost includes transportation costs (by road and railway), terminal operation costs, customs control costs, in-transit inventory holding costs, and container leasing costs.

The model examines the possibility of different types of customs control (AC, DC, PI, SC[3]) on full containers both at seaport and interport nodes, as well as the possibility to shift the container releasing seaport operations to regional interports through an extended gateway system based on container carrier haulage by railway under customs bond en route between seaports and interports, and on customs clearance at the interports. If an interport has an authorized customs area, the same interport may be indicated in the bills of lading as the final destination of the international multimodal trans-

[1] Notteboom and Rodrigue (2005) identified a "port regionalization" phase representing a new stage in port development featured by a strong functional interdependency and even joint development of specific seaports and selected multimodal logistic platforms in their hinterland.

[2] Rodrigue and Notteboom (op. cit.) introduced the concept of "supply chain terminalization" to underline the high integration of intermodal terminals in commodity supply chain management practices, which goes well beyond the conventional role of the terminals. Shippers have begun to use seaports and inland terminals as places for storing goods at low cost. It gives the commodity supply chain a higher level of flexibility, allowing to lower the warehousing costs for consignments. Long dwell times can therefore be also increasingly associated with deliberate supply chain management strategies. On their part, terminal companies, especially in the seaports, tend to react to this phenomenon by imposing restrictions on the permitted free time and increasing storage charges. Consequently, the operators who need prolonged storage have to go look for facilities outside the marine terminals, because the seaports should be employed only as transit facilities.

[3] AC stands for Automated Computerized Control, DC for Documentary Control, PI for Physical Inspection, and SC for X-ray Scanning.

port, and the railway transfers between the container seaport and the interport will occur under customs bond on behalf of shipping lines. Under such a system, the shipping lines assume full responsibility for transportation costs and conditions between the point of origin and the interport, and they do not have to wait for customs officials either to release the containers at the seaport of disembarkment or to issue inland transit documents.[1] Transport operations between the sea terminal and the inland port becomes like an internal transport system, i.e. a kind of "conveyor belt" system. In compliance with the customs regulations currently in force in Italy, only railway transport permits the necessary conditions of fiscal safety related to the inland carrier haulage without any accompanying inland transit document for maritime containers not yet cleared by customs.[2]

The construction of interports and other off-dock facilities is intended to reduce the build-up of cargo at the seaports, and to reduce queuing times. 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 at seaports and interports by customs control type (automated computerized control, documentary control, physical inspection, X-ray scanning) and transport mode employed for inland distribution (road, railway);
- average dwell times at seaports for full containers to be cleared at interports, and to be carried from seaports to interports by railway under customs bond (without any accompanying inland transit document) and on behalf of shipping lines (carrier haulage);
- free-of-charge container storage times at seaports and interports;
- average demurrage charges incurred at seaports and interports;[3]
- time duration of multimodal transport operations over the network;
- opportunity costs and economic-technical depreciation costs for the containerized goods (in-transit inventory holding costs);
- container leasing costs.

The most crucial elements in this list are the port dwell times. At Naples they vary from 9.3 days to 23.9 days in the case of imported full containers

[1] Naturally, the inverse process applies for export flows.

[2] Furthermore, due to an ancient customs legal regime still in force, at the moment the incumbent Italian State-owned Trenitalia is the only company authorized to provide rail traction services under facilitated conditions for customs bonded containers travelling under steamship bills of lading from/to the Italian seaports.

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

cleared by customs. Customs procedures are the most important factors determining such figures. Comparisons can be made with the port of Rotterdam, where the release of a container takes 3-7 days at most.

Interports are examples of Schumpeterian innovations dramatically changing the layout and flows of the logistic networks (Thore, 2007). They involve huge investments and relieve congestion at seaports. As presented here, the *interport model* provides a mathematical description and an analytical tool for such innovation. The equilibrium flows of containers are determined by capacity constraints, as well as by supply chain terminalization strategies, and definitively by the performances in terms of generalized logistic costs of both the container releasing operations at the nodes and multimodal transportation over the port-hinterland network.

This model could be a useful tool supporting industrial and territorial logistic decisions, particularly within a strategic planning context. The program can simulate long term alternative scenarios in terms of infrastructure and services supply, demand characteristics, and government and industrial policies. It can also be adapted and employed to identify the most appropriate distribution location solutions in relation to one or several seaports and specific inland trade basins.

For the present work we created a baseline model to represent the existing network in 2007. The results are compared to the observed traffic flows in the same year, thus permitting us to assess the optimality of actual traffic flows. In addition, we developed two different policy scenarios: an "ideal" scenario and a "pessimistic" one. The results from the ideal scenario address questions of possible over-all policies to be pursued. In the baseline scenario, customs clearance and controls are not allowed at the interport of Marcianise; furthermore, the rail services taken into consideration are those which were effectively available in 2007 at the Campanian seaports and interports. In the ideal scenario, customs clearance and controls are allowed at both interports of Nola and Marcianise; furthermore, the rail links included are those which were available at the Campanian seaports and interports during the years 2005-2007. Finally, in the pessimistic scenario, customs clearance and controls are not allowed at neither interport, and the rail links included in such scenario are the same of those included in the baseline scenario.

The numerical solution to the *interport model* for the Campania region pinpoints many current shortcomings of the regional 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 Campanian logistic system for the importation of maritime containers, and to propose possible steps of improvement.

The remainder of the paper is organized as follows. Section 2 presents a literature review, mainly devoted to some optimization models in the field of container logistics. Section 3 introduces the network for imported containerized goods through the Campania region: the seaports, the interports, and the railway and truck connections with other Italian nodes. Section 4 describes the *interport model* by way of a somewhat stylized example. Section 5 indicates the nature of the quite large mathematical programming problems that we actually solved with real data, while also presenting some of the main input data employed. Section 6 reports on the obtained numerical solution in different scenarios compared with the real situation observed in 2007; furthermore, the results of some sensitivity tests are also given. Section 7 sums up the results and introduces several extensions of the model.

2. Antecedents and original features of the interport model

Spatial optimization models available in the literature dealing with the containerized traffic industry are not numerous. For instance, Aversa *et al.* (2005) employed a multicommodity mixed integer hub-and-spoke model identifying the optimal location of a hub port on the East Coast of South America. Crainic (2003) dealt with the planning and management issues and models for long haul freight transport systems. Crainic and Kim (2007) illustrated several issues related to the containerized intermodal transport, as well as several applied mathematical modelling methodologies. Cullinane *et al.* (2002) employed a single commodity, multimodal and multiobjective mathematical programming capacitated model to simulate, based on time and cost criteria, the optimization of the flows of full containers imported in China. Deidda *et al.* (2008) developed an integer programming model concerning the so-called "street-turn" or "triangulation" strategy of a shipping line. Kim *et al.* (2008a) developed a multimodal mixed integer programming model to optimize the flows of full containers imported and exported in Korea. Kim *et al.* (2008b) developed a multimodal linear programming model to optimize the flows of full containers imported and exported in Korea. Lee *et al.* (2006) developed a capacitated multicommodity linear programming network model to analyze the containerized maritime flows between Asian ports and over the two-way USA-Far East and Europe-Far East routes. Luo (2002) and Luo and Grigalunas (2003) developed a spatial economic, multimodal simulation model dealing with the containerized transport of 30 cargo categories imported and exported through US container seaports. Racunica and Winter

(2005) developed an optimization model to tackle the problem of increasing the share of rail in intermodal transport through the use of hub-and-spoke networks. The model is a generalization of the hub location problem with non-linear and concave cost functions on different segments. Rahimi *et al.* (2008) investigated the inland port location problem in the five counties surrounding Los Angeles. Van Duin and Van Ham (1998) presented a three-level modeling approach for the design and organization of intermodal transport services, taking into account the different perspectives of shippers, terminal operators, agents, consignees and carriers. They developed, among the others, a linear programming model for a network optimization based on cost and whose results indicate opportunities for inland terminal development in Utrecht and Leiden/Alphen.

Our present work builds on earlier researches reported in Iannone (2006a; 2006b), Iannone *et al.* (op. cit.), Thore (op. cit.), Thore and Iannone (2005). Complete background materials can be found in the doctoral dissertation of Iannone (2008).

The *interport model* represents an adaptation to the port-hinterland container traffic industry of the multi-page hub-and-spoke model presented in the tutorial by Thore and Iannone (op. cit.).[1] Some specific features distinguish it from other spatial models available in the literature. In particular, the customs issues and the container releasing operations at the nodes of the investigated regional load center network system are explicitly modelled. Furthermore, the model also features a road supply sub-model for the quantification of the road transport times at national scale according the Road Code regulations.

3. Inland container distribution through the Campanian regional logistic system: functional and topological features

Campania is a region located in the Southern Italy, the Italian "*Mezzogiorno*". It is endowed with an extensive road and railway network, and it is crossed by the Berlin-Verona/Milan-Bologna-Naples-Messina-Palermo TEN-T railway axis planned at European Union level. Also, Campania is expected to play a significant role in the future Euro-Mediterranean Free Trade Area, by es-

[1] In such tutorial, the principal properties of transhipment problems in a hub-and-spoke type network configuration were outlined, with particular reference to primal and dual mathematical formulations, their economic interpretation, and the complementary slackness conditions. Possible scale economies phenomena related to the massification of flows were not taken into consideration. Multi-page models feature demand vectors specified by origin-destination (O/D) pairs.

tablishing easy interconnections between European industrial and consumer areas, and the shores of the Northern Africa and Middle East. 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 (FIG. 1).

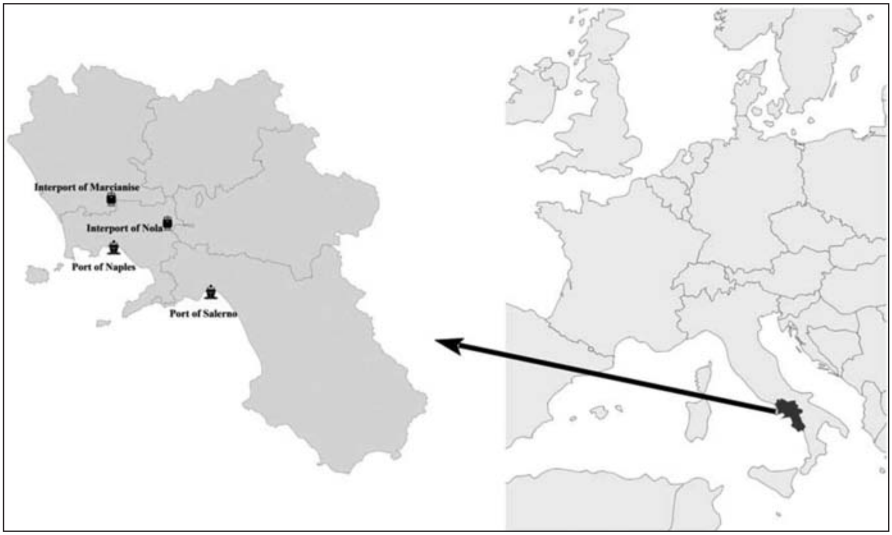

FIGURE 1. The Campania region and its "first-tier" sea-land intermodal logistic system.

FIGURE 2 depicts a conceptual schema of the sets of nodes, multimodal links, and logistic processes that features the import container distribution through the Campanian regional logistic system. This schema can be translated into FIGURE 3 which provides a theoretical topological representation of the distribution network investigated by the *interport model*. Finally, FIGURE 4 exhibits a detailed map of the full real network for the inland distribution of containers disembarked in Campania. Such network features 24 nodes and 163 links (road and railway). It includes the following nodes:

- The seaports at Naples and Salerno.[1] 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.

[1] In the model, they are respectively indicated as NAP and SAL.

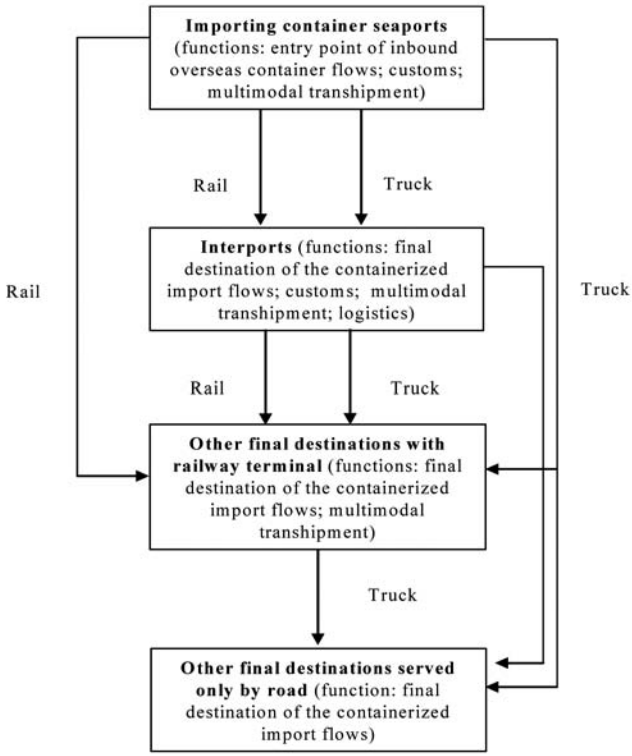

FIGURE 2. Inland distribution of maritime containers imported through the Campanian regional logistic system: a conceptual schema.

- The interports at Nola and Marcianise.[1] They are served by truck and rail, and have a local demand of containers disembarked in the seaports. Furthermore, they may provide terminal and customs services, and can serve as transhipment nodes (railway-to truck, railway-to-railway, truck-to-railway,

[1] As will be explained in the main text in a moment, in the model, each interport is assumed to be composed of a pair of "virtual" nodes. One node performs intermodal and logistic warehousing functions, and has a local demand of full and empty containers arriving from the seaports. The other virtual node has intermodal and customs functions, and is connected to seaports exclusively by railway and for the transportation of full containers under customs bond on behalf of shipping lines. The virtual interport nodes without customs function are indicated as NOL and MAR, while the virtual interport nodes with customs function are indicated as NCC and MCC. NOL and NCC refer to the Nola interport, while MAR and MCC refer to the Marcianise interport.

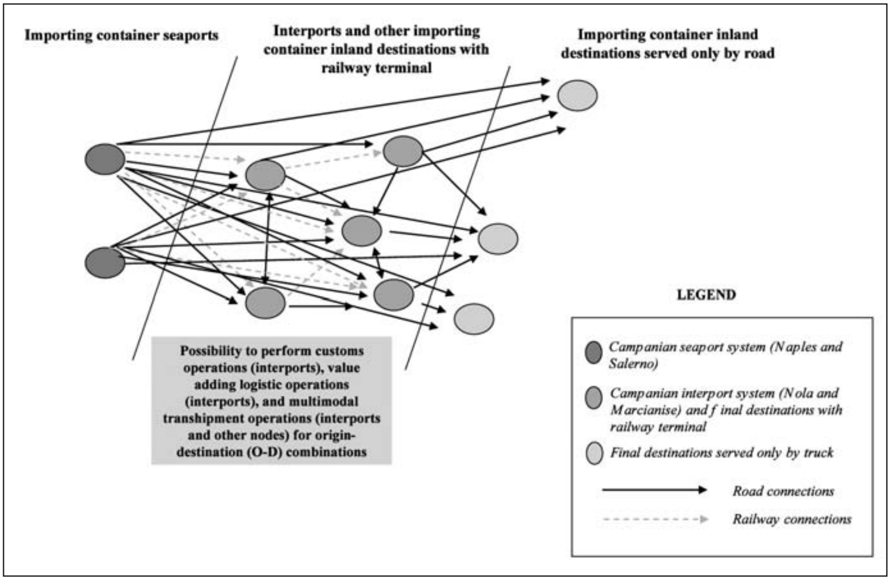

FIGURE 3. Inland distribution of maritime containers imported through the Campanian regional logistic system: theoretical topological features of the investigated network.

truck-to-truck) for some traffic relations from the seaports towards other inland final destinations. Finally, the interports may provide quasi-manufacturing value-adding logistic services.[1]

- The extra-regional final destinations with railway terminal that are served by truck and rail from the Campanian logistic system.[2] They can also perform the role of intermediate transhipment nodes (railway-to-truck and truck-to-truck) for some traffic relations both from the seaports and interports towards other inland final destinations.

- The regional and extra-regional final destinations served by truck only.[3]

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

[2] Taranto city/rail terminal (TAR), Bari city/rail terminal (BAR), Rosarno city/rail terminal (ROS), San Ferdinando city/rail terminal (SAN), Lazio region/Civitavecchia rail terminal (LAZ), Abruzzo+Marche region/Ancona rail terminal (ABR), Umbria region/Foligno rail terminal (UMB), Emilia Romagna region/Rubiera rail terminal (EMI), Lombardia region/Segrate Milan rail terminal (MIL).

[3] Province of Naples (NAP2), province of Salerno (SAL2), province of Caserta (CAS), province of Avellino (AVE), province of Benevento (BEN), remaining part of Apulia re-

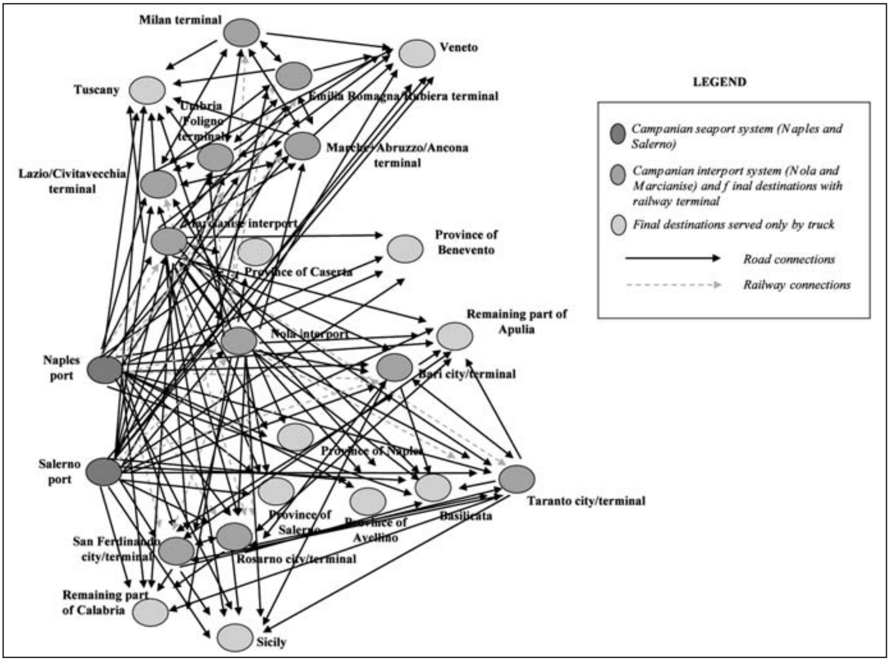

Figure 4. Configuration of the real inland distribution network investigated by the interport model.

The real one-way links of the network are listed below:

- 44 road links in total from the seaports of Naples and Salerno;
- 42 road links in total from the interports of Nola (NOL) and Marcianise (MAR) (that is, by without taking into account connections from the virtual nodes NCC and MCC);
- 58 road links in total from other intermediate transhipment nodes (Taranto, Bari, Rosarno, San Ferdinando, Lazio/Civitavecchia, Abruzzo+Marche/Ancona, Umbria/Foligno, Emilia Romagna/Rubiera, Segrate Milan);
- 10 railway links in total from the seaports of Naples and Salerno (that is, by without taking into account connections towards the virtual nodes NCC and MCC);
- 9 railway links in total from the interports of Nola (NOL) and Marcianise (MAR) (that is, by without taking into account connections from the virtual nodes NCC and MCC).

gion (PUG), Basilicata region (BAS), remaining part of Calabria region (CAL), Sicily region (SIC), Tuscany region (TOS) and Veneto region (VEN).

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 (but not all) final destinations which have a railway terminal; Salerno is connected by rail to the Nola interport and to the Bari city/terminal (Apulia region, Southern Italy). 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 (but not all) final destinations which have a railway terminal. The other container demanding destinations reachable by railway from the nodes of the Campanian regional logistic system can serve by road some inland destinations which could be alternatively served directly from Campania. To sum up, all the inland nodes served by railway can perform a multimodal transhipment function for various O/D combinations, that is for traffic relations from supplying seaports to demanding inland nodes.

Customs clearing may take place either in the seaports of Naples and Salerno or at the interports of Nola and Marcianise. The Campanian network of imported maritime containers thus forms an extended gateway system based on railway connections under customs bond (without any accompanying inland transit document) and under the full responsibility of the shipping lines (carrier haulage) over the routes Naples-Nola, Naples-Marcianise, and Salerno-Nola. Currently, the railway carrier haulage under customs bond is possible only towards/from the Nola interport. In the future, a fully operational customs status of the Marcianise interport is expected as well.[1]

Since December 2005 the rail freight services from/to the Salerno port have been suspended due to a serious accident that happened on the urban segment of the railway connection between the Salerno city and the port rail terminal. In the mathematical *interport model* there are railway connections from the Salerno port both towards the interport of Nola and the city of Bari, 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 real network investigated by the (ideal scenario) model also includes the following rail connections available in years preceding 2007:

[1] Only in February 2010 the intermodal terminal company operating at the interport of Marcianise has been authorized to operate a so called "A3 area", that is a bonded yard for both the handling and storage of imported and exporting containers which can be examined and cleared by customs. However, at the moment, there are no railway connections under customs bond and on behalf of shipping lines from/to the interport. Moreover, in the Marcianise interport there is no currently available X-ray scanner yet. For the calculations of the ideal scenario model, we have nevertheless assumed that customs facilities at Marcianise would parallel those already installed at Nola.

Naples-Foligno, Nola-Foligno, Nola-Rubiera, Marcianise-Taranto, Marcianise-Rosarno, and Marcianise-Civitavecchia.

Finally, a novel aspect of our model is the use of "virtual nodes" for modeling the whole range of container traffic related functions which can be performed by the interports. Virtual nodes have identical geographical location but involve different processing activities. We identify two virtual nodes at each interport:

- 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;

- the customs clearance and processing of full containers arriving from the seaports by railway carrier haulage under customs bond and without any accompanying inland transit document.

Both nodes perform an intermediate intermodal function. But only one of them performs a customs function. It can be reached only by railway. As for the other virtual node, it is the only node which is attributed the local interport container demand. Both virtual nodes have the same outbound multimodal connections. To meet the demand of importing operators located in the interport itself, a one-way road transport between the virtual node with customs function and the one without is permitted at zero cost.

4. Mathematical formulation of the model: a stylized example

We construct a large-scale transhipment model for the economic analysis and strategic planning of the inland logistics 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 all railway links. The objective of the mathematical program is the minimization of all container-related generalized logistic costs throughout the entire port-hinterland distribution network. The costs include transportation costs, in-transit inventory holding costs, container leasing costs, terminal operation costs, and customs control costs.

To introduce matters we present a stylized example of an *interport model* along the lines as the "multi-page" program in Thore and Iannone (op. cit.), that is a model with demand specified by O/D pairs. To deal with this situation, it is possible to formulate as many separate programs as the origin nodes of the problem. Consequently, there will be as much vectors of unknown variables as the origin nodes. The separate programs can be joined together into one "master" program.

The problem is *linear* in both the objective function and the constraints, and it includes the novel concept of "virtual nodes". Furthermore, as presented here, the *interport model* is a static and deterministic problem: all the model's element, from container demands to endogenous variables, cost structure and capacity constraints are for one planning period (which in the empirical applications has corresponded to an operational year), and are assumed not to vary during the planning horizon.

In FIGURE 5 there are two originating nodes *1* and *2* (conveniently identified as the port of Salerno and the port of Naples, respectively), an interport (e.g. Nola) featuring two virtual nodes *3* and *4* (node *3* representing the processing of either empty containers or full containers that have already been cleared by customs at the seaports, node *4* representing the customs clearance and processing of full containers arriving from the seaports by railway carrier haulage under customs bond and without any accompanying inland transit document). Moreover, there are three other distant final destinations, that is nodes *5*, *6*, *7*. Only nodes *5* and *6* have a railway terminal. The virtual interport node *3* has a local demand of containers as well; therefore it is also a final demand node of the model. Node *4* can be reached exclusively by railway from the seaports, and only for the transportation of full containers under customs bond on behalf of shipping lines. It is a pure intermediate transhipment node.

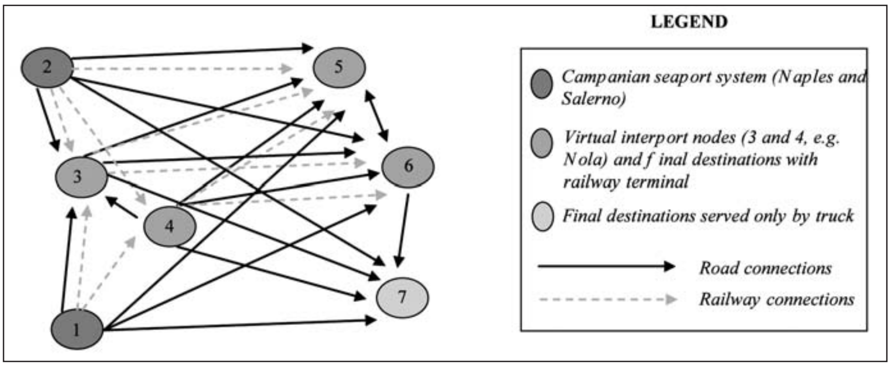

FIGURE 5. Stylized model of multimodal logistic network with interport virtual nodes.

The notations employed in the objective function and in the constraints of the model are shown below.

Indices:

I: set of all nodes of the network = {*1, 2, 3, 4, 5, 6, 7*}
L (I): set of all intermodal nodes of the regional load center network system = {*1, 2, 3, 4*}

N (L): set of intermodal nodes of the regional load center network system excluding virtual interport nodes with customs function = {*1, 2, 3*}
O (L): set of intermodal nodes of the regional load center network system excluding virtual interport nodes without customs function = {*1, 2, 4*}
P (O): set of seaport nodes of the regional load center network system = {*1, 2*}
Q (N): set of virtual interport nodes without customs function = {*3*}
D (O): set of virtual interport nodes with customs function = {*4*}
Z (I): set of all inland locations demanding containers imported through seaport nodes = {*3, 5, 6, 7*}
E (Z): set of all inland locations (excluding the interports) demanding containers imported through seaport nodes = {*5, 6, 7*}
R (Z): set of inland locations without rail terminal and demanding containers imported through seaport nodes = {*7*}
H (I): set of inland locations performing an intermediate multimodal transhipment function = {*3, 4, 5, 6*}
T: set of container types = {*full, empty*}
M: set of admitted inland transportation modes = {*rail, truck*}
A: set of railway services = {*1_(3+4), 2_(3+4), 2_5, (3+4)_5,(3+4)_6*}

Parameters:

[$Demand^{t}_{pi}$]: a column vector of demands specified in number of containers of type $t \in T$ (measured in TEUs) by origin-destination pair (that is from each seaport node $p \in P$ towards each node $i \in I$)
[$Transport\_fare^{m}_{tij}$]: a row vector of unit prices (measured in Euros/TEU) for transport of containers of type $t \in T$ by mode $m \in M$ between nodes $i \in I$ and $j \in I$
[c^{m}_{tij}]: a row vector of total generalized unit costs (in Euros/TEU) for transport of containers of type $t \in T$ by mode $m \in M$ between nodes $i \in I$ and $j \in I$
[f_n]: a row vector of total generalized unit costs (in Euros/TEU) of the releasing operations for empty containers at intermodal node $n \in N$
[g^{m}_{p}]: a row vector of weighted average total generalized unit costs (in Euros/TEU) of the releasing operations for imported full containers cleared by customs at seaport node $p \in P$ and leaving out the same node by transport mode $m \in M$
[k_p]: a row vector of total generalized unit costs (in Euros/TEU) of the releasing operations for imported full containers leaving out seaport node $p \in P$ by railway carrier haulage under customs bond and without any accompanying inland transit document towards virtual interport nodes with customs functions

$[s_q^m]$: a row vector of generalized total unit costs (in Euros/TEU) of the releasing operations for imported full containers already cleared in seaport nodes and leaving out virtual interport node $q \in Q$ by transport mode $m \in M$

$[u_{dm}^p]$: a row vector of weighted average total generalized unit costs (in Euros/TEU) of the releasing operations for imported full containers arriving by railway carrier haulage under customs bond and without any accompanying inland transit document from seaport node $p \in P$ in virtual interport node $d \in D$, and subsequently cleared by customs and leaving out the same virtual interport node by transport mode $m \in M$

$[b_a]$: a column vector of the maximal numbers of containers which can be transported by railway service $a \in A$

Endogenous variables:

$[x_{tij}^m]$: a column vector of inland shipments of containers of type $t \in T$ (measured in TEUs) disembarked in the seaport node $1 \in P$ and forwarded between nodes $i \in I$ and $j \in I$ by transport mode $m \in M$

$[y_{tij}^m]$: a column vector of inland shipments of containers of type $t \in T$ (measured in TEUs) disembarked in the seaport node $2 \in P$ and forwarded between nodes $i \in I$ and $j \in I$ by transport mode $m \in M$

The programming problem now reads:

min $W =$

$$\sum_{t\in T}\sum_{i\in I}\sum_{j\in I}\sum_{m\in M} c_{tij}^m \cdot (x_{tij}^m + y_{tij}^m) + \sum_{n\in N}\sum_{i\in I}\sum_{m\in M} f_n \cdot (x_{empty\in T,ni}^m + y_{empty\in T,ni}^m) +$$
$$+\sum_{p\in P}\sum_{z\in Z}\sum_{m\in M} g_p^m \cdot (x_{full\in T,pz}^m + y_{full\in T,pz}^m) + \sum_{p\in P}\sum_{d\in D} k_p \cdot (x_{full\in T,pd}^{rail\in M} + y_{full\in T,pd}^{rail\in M}) +$$
$$+\sum_{q\in Q}\sum_{e\in E}\sum_{m\in M} s_q^m \cdot (x_{full\in T,qe}^m + y_{full\in T,qe}^m) +$$
$$+\sum_{d\in D}\left\{\sum_{z\in Z}\begin{bmatrix}\left[(u_{d,truck\in M}^{1\in P} \cdot x_{full\in T,dz}^{truck\in M}) + (u_{d,truck\in M}^{2\in P} \cdot y_{full\in T,dz}^{truck\in M})\right] + \\ +\sum_{e\in E}\left[(u_{d,rail\in M}^{1\in P} \cdot x_{full\in T,de}^{rail\in M}) + (u_{d,rail\in M}^{2\in P} \cdot y_{full\in T,de}^{rail\in M})\right]\end{bmatrix}\right\} \tag{1}$$

subject to:

$$-\sum_{i\in I}\sum_{m\in M} x_{tpi}^m \geq Demand_{1\in P,\, p}^t \qquad \text{for all } p\in P \text{ and } t\in T \tag{2}$$

$$\sum_{i\in I}\sum_{m\in M} x_{tih}^m - \sum_{i\in I}\sum_{m\in M} x_{thi}^m \geq Demand_{1\in P,\, h}^t \qquad \text{for all } h\in H \text{ and } t\in T \tag{3}$$

$$\sum_{i\in I}\sum_{m\in M} x_{tir}^{m} \geq Demand_{1\in P,\, r}^{t} \qquad \text{for all } r\in R \text{ and } t\in T \tag{4}$$

$$-\sum_{i\in I}\sum_{m\in M} y_{tpi}^{m} \geq Demand_{2\in P,\, p}^{t} \qquad \text{for all } p\in P \text{ and } t\in T \tag{5}$$

$$\sum_{i\in I}\sum_{m\in M} y_{tih}^{m} - \sum_{i\in I}\sum_{m\in M} y_{thi}^{m} \geq Demand_{2\in P,\, h}^{t} \qquad \text{for all } h\in H \text{ and } t\in T \tag{6}$$

$$\sum_{i\in I}\sum_{m\in M} y_{tir}^{m} \geq Demand_{2\in P,\, r}^{t} \qquad \text{for all } r\in R \text{ and } t\in T \tag{7}$$

$$\sum_{t\in T} x_{t,\, 1\in P,\, 3\in Q}^{rail\in M} + \sum_{t\in T} x_{t,\, 1\in P,\, 4\in D}^{rail\in M} \leq b_{1\_(3+4)\in A} \tag{8}$$

$$\sum_{t\in T} y_{t,\, 2\in P,\, 3\in Q}^{rail\in M} + \sum_{t\in T} y_{t,\, 2\in P,\, 4\in D}^{rail\in M} \leq b_{2\_(3+4)\in A} \tag{9}$$

$$\sum_{t\in T} y_{t,\, 2\in P,\, 5\in Z}^{rail\in M} \leq b_{2\_5\in A} \tag{10}$$

$$\sum_{t\in T} (x_{t,\, 3\in Q,\, 5\in Z}^{rail\in M} + y_{t,\, 3\in Q,\, 5\in Z}^{rail\in M} + x_{t,\, 4\in D,\, 5\in Z}^{rail\in M} + y_{t,\, 4\in D,\, 5\in Z}^{rail\in M}) \leq b_{(3+4)\_5\in A} \tag{11}$$

$$\sum_{t\in T} (x_{t,\, 3\in Q,\, 6\in Z}^{rail\in M} + y_{t,\, 3\in Q,\, 6\in Z}^{rail\in M} + x_{t,\, 4\in D,\, 6\in Z}^{rail\in M} + y_{t,\, 4\in D,\, 6\in Z}^{rail\in M}) \leq b_{(3+4)\_6\in A} \tag{12}$$

$$x_{tij}^{m} \geq 0 \qquad \text{for all } t\in T,\ i,j\in I \text{ and } m\in M \tag{13}$$

$$y_{tij}^{m} \geq 0 \qquad \text{for all } t\in T,\ i,j\in I \text{ and } m\in M \tag{14}$$

$$x_{tij}^{m} = 0 \qquad \text{if } Transport\_fare_{tij}^{m} = 0 \text{ for all } t\in T \text{ and } i,j\in I \tag{15}$$

$$y_{tij}^{m} = 0 \qquad \text{if } Transport\_fare_{tij}^{m} = 0 \text{ for all } t\in T \text{ and } i,j\in I \tag{16}$$

$$x_{full\in T,\, 4\in D,\, 3\in Q}^{truck\in M} \geq 0 \tag{17}$$

$$y_{full\in T,\, 4\in D,\, 3\in Q}^{truck\in M} \geq 0 \tag{18}$$

The sets Q and D introduce the feature that we have called "virtual interport nodes", which have the same geographical location but offer different services. 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 without customs function ($q\in Q\subseteq Z$). Or it can have its customs clearance delayed, in which case it has to proceed by railway to a virtual node $d \in D$. In this manner, shippers may avoid costly delays at seaport nodes awaiting access to customs clearance. Of course, empty containers do not require customs clearance before being released from intermodal nodes.

The railway services from/to the interport include the connections from/to each of the two corresponding virtual nodes. For instance the rail service from the seaport node *1* to the interport is symbolically represented by '*1_(3+4)*', which means that such service contemporarily carries containers from the node *1* to the node *3* and from the node *1* to the node *4*. In the same manner, the rail service from the interport to the location *5* is symbolically represented by '*(3+4)_5*', which means that such service contemporarily carries containers from the node *3* to the node *5* and from the node *4* to the node *5*.

The demand specified by 'origin node-origin node' pair (i.e. $Demand^{t}_{pp}$ for all $t \in T$ and $p \in P$) indicates the total container supply available at the specific port node $p \in P$, and is entered in the model with the minus sign. This is due to the fact that in a minimizing program it is preferable to write all inequalities with a ≥ sign (see the constraints (2) and (5)).

As it regards the network generalized costs, the critical direct and indirect cost items explicitly taken into account by the model concern:

- container loading and unloading onto/from transportation vehicles at seaports and interports (container handling costs);
- container storage at seaports and interports (demurrage costs in function of the dwell time for full containers transferred by railway under customs bond and on behalf of shipping lines between seaports and interports, and demurrage costs in function of the dwell times for empty containers, automatically controlled full containers, documentarily controlled full containers, physically inspected full containers and X-ray scanned full containers at seaports and interports, to be forwarded by road or railway);
- additional direct costs for possible physical inspections and X-ray scanner controls by customs at seaports and interports (additional direct customs costs);[1]
- in-transit inventory holding costs at seaports and interports, in function both of the customs declared value of cargoes and of the dwell times of full containers;
- in-transit inventory holding costs over admitted road and rail links of the

[1] Since for simplification and illustrative purposes, in the *interport model* it is assumed that all the containers transiting through the Campanian seaports carry legitimate cargoes, and therefore succeed in positively passing the customs controls. Moreover, the model does not take into consideration the payment of customs duties related to the value of the traded goods.

network, in function both of the customs declared value of cargoes and of the time duration of transport operations;

- container leasing costs at seaports and interports, in function both of a container leasing charge and of the dwell times of full and empty containers;

- container leasing costs over admitted road and rail links of the network, in function both of a container leasing charge and of the time duration of transport operations;

- internal direct costs of road and railway transport of full and empty containers over admitted links of the network (see the parameter *Transport_fare* presented above).

In the objective function (1) such cost items are compressed into aggregate costs (c, f, g, k, s, u). For the details of the definitions and calculations of all these aggregated costs, see the Appendix.

The capacity limits of railway services (that is $[b_a]$) are computed by taking into account the number of railway operational weeks in the planning period, as well as the number of one-way weekly trains operated by each rail service $a \in A$, and the maximal number of containers per one-way trip of the same service.

The objective function (1) denotes the total generalized logistic cost for the distribution of imported full and empty containers throughout the hinterland network of the Campanian seaports. The first term represents the total cost for rail and road transportation of full and empty containers over the port-hinterland network. The second term captures the total releasing cost for empty containers at the Campanian seaports and interports, leaving by road and railway. The third term denotes the total releasing cost for full containers cleared by customs at the Campanian seaports and leaving by road and railway. The fourth term indicates the total releasing cost for full containers leaving the Campanian seaports by railway carrier haulage under customs bond (without any accompanying inland transit document) and to be cleared at the regional interports. The fifth term is the total releasing cost for full containers already cleared in the seaports, arriving in the interports, and leaving by road and railway. Finally, the sixth term is the total releasing cost for full containers cleared by customs at the interports and leaving by road and railway.

Flow conservation constraints (i.e. the Kirchhoff conditions) at the origin nodes state that the supply at each node must suffice to cover the flows leaving the node (constraints (2) and (5)).[1] For intermediate nodes the balancing condi-

[1] When the objective function of a linear program is minimizing we say that ≥ inequalities are "right way inequalities" and ≤ inequalities are "wrong way inequalities". For a maximizing objective ≤ are right way inequalities and ≥ are wrong way inequalities. Furthermore, the rules for the sign of the dual variable corresponding to each constraint can be summarized as: the sign of the dual variable of a right way inequality is nonnegative whereas the sign of the dual variable of a wrong way constraint is nonpositive; as for the dual variable of

tions say that the flow entering each node must suffice to cover the flows leaving it (constraints (3) and (6)). Finally, for each destination node, the deliveries forthcoming at the node must suffice to cover demand (constraints (4) and (7)).

Capacity constraints of the railway links are (8)-(12). The limits on each railway connection from/towards the interport jointly considers the railway services from/towards each of the two corresponding virtual nodes (in (8), (9), (11), (12)). The limits of the railway connections from interport nodes, i.e. (11) and (12), are written as "coupling conditions" tying the x-traffic and the y-traffic together.

Non-negativity constraints on the decision variables are (13) and (14). Instead, the constraints (15) and (16) set to zero all variables involving non-existing links over the logistic network.[1] Finally, the constraints (17) and (18) permit one-way road transport with a nil generalized cost for full containers between the two virtual nodes at the interport, that is the road transport between $4 \in D$ and $3 \in Q$.

5. Features and main data of the numerical models

The numerical models that we constructed and solved are straight-forward generalizations and adaptations of the program presented in the previous section. The baseline model features 25 nodes and 182 admitted links (including two virtual nodes at Nola interport and their related links), 755 unknowns and 162 constraints. The ideal scenario model features 26 nodes and 219 admitted links (including two virtual nodes at each regional interport and their related links), 863 unknowns and 168 constraints. The pessimistic scenario model features 24 nodes and 159 admitted links (no virtual interport customs nodes and related links), 645 unknowns and 158 constraints. All the models were programmed and solved with the GAMS (General Algebraic Modeling System) computer code, using the solver CPLEX.

Main empirical input data were directly provided by various bodies and firms involved in the intermodal and logistic industry at regional, national and international level.[2] Other input data were derived from internet web-

an equality constraint, this is unconstrained regardless of whether the objective function is maximizing or minimizing (Thompson and Thore, 1992; Thore and Iannone, op. cit.).

[1] Similarly to all the large-scale network models, also the *interport model* uses a sparse data structure, that is a structure based on data matrices with relative few non-zero entries. It seems appropriate to remember and highlight that (road and/or railway) connections are not allowed between some nodes of the network investigated by the model. Therefore, a value equal to zero has to be assigned to the spatial, temporal and economic attributes of the forbidden links, and appropriate constraints have to be formulated accordingly.

[2] In particular: the Rome-based Italian National Customs Agency, the Nola interport-based Customs Office, the Port authorities of Naples and Salerno, the Centre for Transportation

Table 1. Container supply at the Campanian seaports and inland origin-destination demand in 2007.

Node	*Imports from the port of Naples (NAP)*		*Imports from the port of Salerno (SAL)*	
	Full TEUs	*EmptyTEUs*	*Full TEUs*	*EmptyTEUs*
NAP	-183,622	-22,255	0	0
SAL	0	0	-71,681	-97,466
NOL	59,892	4,034	1,493	1,042
MAR	10,890	772	302	199
NAP2	55,946	7,510	2,636	4,689
SAL2	2,918	592	43,740	59,474
CAS	7,071	898	5,074	7,110
AVE	3,313	428	2,494	3,392
BEN	2,000	294	1,714	2,329
PUG	9,173	1,050	3,362	5,064
TAR	2,834	189	1,041	894
BAR	5,198	4,210	1,095	1,489
BAS	2,880	303	2,917	3,967
CAL	3,086	326	17	23
ROS	3,481	119	42	8
SAN	3,398	187	21	9
SIC	0	0	43	58
LAZ	9,359	985	3,770	5,127
ABR	1,008	106	1,835	2,495
UMB	1,151	121	14	19
TOS	0	0	7	10
EMI	0	129	43	58
MIL	24	2	13	0
VEN	0	0	8	10

Source: own elaboration on data provided by the Campanian Port Authorities, Campania-based marine and inland terminal companies, freight forwarders, third-party logistics providers, and national railway companies.

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 SCT, respectively in Naples and Salerno), the management companies of the Campanian operational interports (Interporto Campano and Interporto Sud Europa, respectively at Nola and Marcianise) and their intermodal terminals (the subsidiaries TIN and NAOS, respectively at Nola and Marcianise), the major Italian rail freight companies (Trenitalia and Rail Traction Company), and other Campania region-based operators (FERPORT Napoli, Logship, Italcontainer, DHL Global Forwarding Italy, Schenker, Omnialogistica, De Crescenzo, and Sticcosped).

sites, specialized press, scientific literature, and industrial studies. Apart from data for some rail links (Salerno-Nola, Salerno-Bari, Naples-Foligno, Nola-Foligno, Nola-Rubiera, Marcianise-Taranto, Marcianise-Rosarno, and Marcianise-Civitavecchia) all data of the model refer to the year 2007.

In the present section, some of the more significant input data are listed and briefly commented. Detailed information concerning can be obtained from the authors upon request.

Container supply at the origin seaport nodes, i.e. $Demand^{t}_{pp}$ (for $t = full$, $empty$ and $p = NAP, SAL$), as well as container demand at the inland destination nodes, i.e. $Demand^{t}_{pz}$ (for all $t \in T$, $p \in P$, and $z \in Z \subseteq I$), are listed in Table 1. In particular, $Z = NOL, MAR, NAP2, SAL2, CAS, AVE, BEN, PUG, TAR, BAR, BAS, CAL, ROS, SAN, SIC, LAZ, ABR, UMB, TOS, EMI, MIL, VEN$.

The observed data on container supply in 2007 diffused by the Port authorities of Naples and Salerno were employed, that is: 183,622 full TEUs and 22,255 empty TEUs imported through the port of Naples; 71,681 full TEUs and 97,466 empty TEUs imported through the port of Salerno. As already previously indicated, the container supply available at each port node $p \in P$ is entered in the model with the minus sign. For final demands, observed origin-destination road and railway sample traffic data were employed. Because of possible transit traffics via the interports from the seaports to other inland locations, the data concerning the flows between seaports and interports were corrected based on specific information provided by the companies managing the intermodal terminals located in the regional interports. The origin-destination railway data were provided by the railway companies, while the origin-destination road data were estimated using average samples provided by other transport and logistic companies operating in the Campania region.

Table 2. Incidence of customs controls on imported full containers cleared at the ports of Naples and Salerno in 2007.

Customs controls on imported full containers in 2007	**Naples port (NAP)**	**Salerno port (SAL)**
Automated computerized control - AC	59.0%	84.0%
Documentary control - DC	11.0%	11.0%
X-ray scanner control - SC	5.0%	1.0%
Physical inspection - PI	25.0%	4.0%

Source: Italian Customs Agency - Rome, Campania-based marine terminal operators and freight forwarders.

Table 2 shows the incidence of customs controls on imported full containers cleared at the Campanian seaports. The corresponding parameters in terms

Table 3. Average dwell times of imported containers cleared at the ports of the Naples and Salerno in 2007 (sample data).

Average dwell times of imported containers cleared at the Campania seaports	Number of days/ TEU
Automated computerized control (AC) - cleared containers leaving the Naples port by road	9.3
Documentary control (DC) - cleared containers leaving the Naples port by road	14.4
Physical inspection (PI) - cleared containers leaving the Naples port by road	22.5
Scanner control (SC) - cleared containers leaving the Naples port by road	23.7
Weighted average - cleared containers leaving the Naples port by road	**13.9**
Automated computerized control (AC) - cleared containers leaving the Naples port by railway	9.5
Documentary control (DC) - cleared containers leaving the Naples port by railway	14.6
Physical inspection (PI) - cleared containers leaving the Naples port by railway	22.7
Scanner control (SC) - cleared containers leaving the Naples port by railway	23.9
Weighted average - cleared containers leaving the Naples port by railway	**14.1**
Automated computerized control (AC) - cleared containers leaving the Salerno port by road	4.5
Documentary control (DC) - cleared containers leaving the Salerno port by road	5.0
Physical inspection (PI) - cleared containers leaving the Salerno port by road	7.0
Scanner control (SC) - cleared containers leaving the Salerno port by road	7.4
Weighted average - cleared containers leaving the Salerno port by road	**4.7**
Automated computerized control (AC) - cleared containers leaving the Salerno port by railway	4.7
Documentary control (DC) - cleared containers leaving the Salerno port by railway	5.2
Physical inspection (PI) - cleared containers leaving the Salerno port by railway	7.2
Scanner control (SC) - cleared containers leaving the Salerno port by railway	7.6
Weighted average - cleared containers leaving the Salerno port by railway	**4.9**

Source: own elaboration on data provided by the Italian Customs Agency-Rome, Campania-based marine terminal operators and freight forwarders.

of model notation do not explicitly appear in the objective function (1), but are instead internalized in the parameters g and u. The higher incidence in the port of Naples typically arises from information contained in the customs declaration bills that prompt a need for inspection. A high number of customs controls takes place of containerized cargoes from China and South-East Asia, mainly textiles, footwear, leather goods - cargoes that directly compete with Italian industry.

Table 3 lists the average unit dwell times for full containers cleared at the Campanian seaports in 2007, broken down by different customs control types (AC, DC, SC, PI) and inland transport modes. The data refer to container dwell times by various types of customs controls occurring in combination with other types of technical and administrative controls (veterinary controls, sanitary controls, etc.). The weighted average times were computed by taking into consideration the probabilities observed in the Campanian seaports for the different customs control types on imported containers (see Table 2). Dwell times and weighted average dwell times of full containers cleared at the regional seaports do not explicitly appear in the objective function (1). In particular, weighted average port dwell times are internalized in the parameter *g*.

Furthermore, an average dwell time of 1.7 days may be assumed for full containers disembarked in Campania seaports and carried by rail under customs bond and on behalf of shipping lines (without any accompanying inland transit document) to the regional interports (see the parameter *k*).

Table 4 lists the dwell times of the imported maritime containers cleared at the Nola interport. The data refer to various types of customs controls occurring in combination with other types of technical and administrative controls (veterinary controls, sanitary controls, etc.). At least the same performance levels are hypothesized for the Marcianise interport when completed. Dwell times of full containers cleared at the regional interports do not explicitly appear in the objective function (1), but are instead internalized in the parameters *s* and *u*.

Table 5 lists data on free storage time and average charges related to terminal operations at the Campanian seaports and interports.[1] These data are internalized in the parameters *f*, *g*, *k*, *s* and *u* appearing in the objective function (1). Table 6 lists the average costs of container releasing operations at the Campanian seaports and interports (parameters *f*, *g*, *k*, *s* and *u*). These generalized cost figures include direct costs and time related costs. Direct costs were computed by the formula: *[(Dwell time – demurrage free time) * demurrage charge] + terminal handling charge + [additional Customs costs (only for physically inspected and X-Ray scanned full containers)]*. Time related costs are the sum of in-transit inventory holding costs and container leasing costs, cal-

[1] Of course, the real terminal pricing structure can be much more articulated and diversified than that one presented in the table. Particularly for demurrage charges, it varies among different terminals located in the same seaport, and also according to specific agreements among the concerned service providers and customers (that is, marine and inland terminal companies, shipping lines and shippers). The *interport model* may easily take into consideration different and more complicated terminal pricing structure types as well.

Table 4. Average dwell times of imported containers cleared at the Nola interport in 2007 (sample data).

Average dwell times of imported containers cleared at the Campania interports	**Number of days/TEU**
Automated computerized control (AC) - cleared containers leaving the Nola interport by road	4.5
Documentary control (DC) - cleared containers leaving the Nola interport by road	5.0
Physical inspection (PI) - cleared containers leaving the Nola interport by road	7.0
Scanner control (SC) - cleared containers leaving the Nola interport by road	7.4
Average - cleared containers leaving the Nola interport by road	**6.0**
Automated computerized control (AC) - cleared containers leaving the Nola interport by railway	4.7
Documentary control (DC) - cleared containers leaving the Nola interport by railway	5.2
Physical inspection (PI) - cleared containers leaving the Nola interport by railway	7.2
Scanner control (SC) - cleared containers leaving the Nola interport by railway	7.6
Average - cleared containers leaving the Nola interport by railway	**6.2**

Source: own elaboration on data provided by Campania-based terminal operators, freight forwarders, and third party logistics providers.

Table 5. Logistic parameters related to terminal operations at the Campanian seaports and interports in 2007.

	Free of charge storage time (number of days/TEU)	**Average demurrage charge (Euros/TEU)**		**Average terminal handling charge (Euros/TEU)**		**Additional customs charge (Euros/full TEU)**	
		Full containers	**Empty containers**	**Full containers**	**Empty containers**	**Physical inspection**	**X-ray scanning**
Port of Naples	5	30	20	160	140	105	155
Port of Salerno	7	20	15	100	80	58	70
Interport of Nola	7	20	15	50	40	58	70
Interport of Marcianise	7	20	15	50	40	58	70

Source: own elaboration on data provided by Campania-based terminal operators, freight forwarders, and third party logistics providers.

TABLE 6. Total generalized average logistic costs of container releasing operations at the Campanian seaports and interports.

Total generalized average logistic costs of container releasing operations at the Campanian seaports and interports (Euros/TEU) - IMPORT TRAFFICS	Naples port	Salerno port	Nola interport	Marcianise interport
Empty TEUs leaving the node by road or railway	556.3	194.1	130.6	130.6
Automatically controlled (AC) full TEUs leaving the node by road	437.1	171.7	121.7	121.7
Documentarily controlled (DC) full TEUs leaving the node by road	671.4	179.6	129.6	129.6
Physically inspected (PI) full TEUs leaving the node by road	1,148.4	269.5	219.5	219.5
X-Ray scanned (SC) full TEUs leaving the node by road	1,253.5	295.9	245.9	245.9
Automatically controlled (AC) full TEUs leaving the node by rail	446.3	174.9	124.9	124.9
Documentarily controlled (DC) full TEUs leaving the node by rail	680.6	182.8	132.8	132.8
Physically inspected (PI) full TEUs leaving the node by rail	1,157.6	276.7	226.7	226.7
X-Ray scanned (SC) full TEUs leaving the node by rail	1,262.7	303.1	253.1	253.1
Full TEUs leaving the seaport by railway for customs clearing at interports ("extended gateway" system)	187.1	127.1	-	-
WEIGHTED AVERAGE - Full CLEARED TEUs leaving the node by road	681.5	177.7	-	-
WEIGHTED AVERAGE - Full CLEARED TEUs leaving the node by rail	690.7	181.1	-	-
WEIGHTED AVERAGE - Full CLEARED TEUs leaving the node by road (containers from Naples)	-	-	153.2	153.2
WEIGHTED AVERAGE - Full CLEARED TEUs leaving the node by road (containers from Salerno)	-	-	127.7	-
WEIGHTED AVERAGE - Full CLEARED TEUs leaving the node by rail (containers from Naples)	-	-	157.6	157.6
WEIGHTED AVERAGE - Full CLEARED TEUs leaving the node by rail (containers from Salerno)	-	-	131.1	-
Full TEUs cleared at the seaports and leaving the node by road	-	-	121.7	121.7
Full TEUs cleared at the seaports and leaving the node by rail	-	-	124.9	124.9

Source: own elaboration on data provided by Italian Customs Agency - Rome, Campania-based terminal operators, freight forwarders, and third party logistics providers.

culated in function of the dwell times. Anyway, the availability of railway connections at the Salerno port and the availability of a fully operational customs status of the Marcianise interport are only hypotheses of the ideal scenario model. Furthermore, the weighted average costs were computed by taking into consideration the probabilities observed in the Campanian seaports for the different customs control types on imported containers (see Table 2).

By taking into consideration both the average customs declared value of imports in Campania in the first half of 2007 (equal to 15,934 Euros/ full TEU, based on a calculation performed using data provided by the Italian Customs Agency), and an annual interest cost rate of 35% (expressing both opportunity cost of capital tied in containerized goods and economic/technical depreciation of the same goods), one would obtain an in-transit inventory holding unit cost for full containers handled in the Campanian seaports equal to 15.3 Euros/full TEU/day or 0.64 Euros/full TEU/hour.[1] In the model we also assumed a unit container leasing charge figure equal to 0.65 Euros/ TEU/day.[2] All these parameters do not explicitly appear in the objective function (1), but are instead internalized in the parameters *c*, *f*, *g*, *k*, *s* and *u*.

Finally, Tables 7 and 8 are illustrative of the generalized costs of transporting full and empty containers (parameter *c*) between the two sea ports, the two interports and just other four representative inland locations: Taranto city/rail terminal (in the Puglia region, Southern-Eastern Italy), Rosarno city/rail terminal (in the Calabria region, Southern-Western Italy), Emilia Romagna region/Rubiera rail terminal (in Northern Italy), and Segrate Milan rail terminal (in the Lombardia region, Northern Italy). The dash (-) indicates that no direct connection exists or is admitted in the model.

6. Optimal solution and discussion

The aim of the *interport model* consists of measuring the possible benefits resulting from the employment of regional interports and intermodal solutions for the inland distribution of full and empty maritime containers handled in the Campanian seaports.

The solution 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

[1] These are average figures only. There is also the possibility of customs bill declarations which do not match what effectively is transported and thus elude controls. The average value of the containerized import cargoes could then be even higher.

[2] The same figure was employed in the analysis by Notteboom and Wu (2008).

TABLE 7. Generalized road transport costs in 2007 (Euros/full TEU): representative locations in the Campanian port-hinterland.

from/to	**Interport of Nola**	**Interport of Marcianise**	**Taranto city/ rail terminal**	**Rosarno city/rail terminal**	**Emilia Romagna region/ Rubiera rail terminal**	**Segrate Milan rail terminal**
Port of Naples	180.3	180.3	471.2	651.0	1,015.2	1,080.6
Port of Salerno	250.5	250.8	401.2	585.2	1,074.8	1,134.3
Interport of Nola	-	120.3	462.6	642.9	1,011.7	1,079.4
Interport of Marcianise	120.3	-	496.9	675.4	981.8	1,050.3

Source: own elaboration on data provided by Ente Autonomo Volturno, Italian Customs Agency-Rome, freight forwarders, and third party logistics providers, plus data derived from industrial studies, internet web-sites and specialized press.

TABLE 8. Generalized rail transport costs in 2007 (Euros/full TEU): representative locations in the Campanian port-hinterland.

from/to	**Interport of Nola**	**Interport of Marcianise**	**Taranto city/rail terminal**	**Rosarno city/rail terminal**	**Emilia Romagna region/ Rubiera rail terminal**	**Segrate Milan rail terminal**
Port of Naples	162.8	162.8		259.4	568.9	-
Port of Salerno	199.3	-	-	-	-	-
Interport of Nola	-	-	304.3	414.6	693.1	509.3
Interport of Marcianise	-	-	299.2	404.6	-	-

Source: own elaboration on data provided by Trenitalia, Rail Traction Company-RTC, Italian Customs Agency-Rome, plus data derived from industrial studies and specialized press.

at the nodes, and therefore by both the capacity of nodes and the supply chain management strategies of the shippers (reflected in container dwell times), as well as by the capacity and generalized costs of transport services between nodes. Our main interest lies with the solution traffics through the two interports at Nola and Marcianise.

Table 9 presents the observed data on the inland traffics of containers disembarked at the Campanian seaports in 2007. It may be noted that in 2007, for the first time, a volume of approximately 625 TEUs was carried by railway under customs bond (without any accompanying inland transit document) on behalf of the shipping line CMA-CGM from the port of Naples to the interport of Nola. This was equal to the 10% of the total railway traffic of full containers between the same two locations (6.245 TEUs). The remaining import traffic was mainly merchant haulage destined to warehousing facilities located in the interport itself.

Tables 10-12 list the solutions of three alternative scenarios, as signalled earlier:

- A baseline scenario model (optimizing the existing situation in 2007): no customs clearance at Marcianise, and no railway connections over the routes Salerno-Nola, Salerno-Bari, Naples-Foligno, Nola-Foligno, Nola-Rubiera, Marcianise-Taranto, Marcianise-Rosarno, Marcianise-Civitavecchia;
- An ideal scenario model: customs clearance available at both Nola and Marcianise, and all port and interport railway connections operated in 2005-2007 being available;
- A pessimistic model: no customs clearance at neither Nola nor Marcianise, and railway connections as in the baseline model.

Table 13 compares several minimum cost items obtained from the three scenarios and also with actual data for 2007. Note the gratifying result that all optimised costs accumulating for containers imported via Naples are lower than the actual recorded costs (the optimized costs for containers imported via Salerno are at least not greater than the actual costs). Among the three scenarios, the ideal scenario is clearly the winner, but even the pessimistic alternative provides reasonable savings of the order of one percentage point.

Let us now focus on the solution generated by the ideal scenario model (Table 11). It turns out that the 95% of the demand at the Nola interport for full containers disembarked in the 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 (merchant haulage). 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 the Marcianise interport (carrier haulage). Here the containers are cleared by

TABLE 9. Inland flows of imported containers through the Campanian seaports and interports (observed real situation in 2007).

Inland traffics of imported containers: observed real situation in 2007	*Destinations...* NOL	NCC	MAR	Other inland locations
Leaving the port of Naples (NAP)				
Full TEUs cleared at the port and shipped by road (merchant haulage)	56,220		10,757	103,016
Full TEUs cleared at the port and shipped by railway (merchant haulage)	5,620		473	6,912
Full TEUs shipped by railway under customs bond (carrier haulage)		625		
Empty TEUs shipped by road	4,035		772	12,889
Empty TEUs shipped by railway	462		8	4,089
Leaving the port of Salerno (SAL)				
Full TEUs cleared at the port and shipped by road (merchant haulage)	1,579		302	69,800
Empty TEUs shipped by road	1,042		199	96,224
Leaving the virtual interport node with customs function at Nola (NCC)				
Full TEUs from NAP cleared at the interport and shipped by road	367			245
Full TEUs from NAP cleared at the interport and shipped by railway				13
Leaving the virtual interport node without customs function at Nola (NOL)				
Full TEUs cleared at NAP, arriving by railway and shipped from the interport by road				2,203
Full TEUs cleared at NAP, arriving by railway and shipped from the interport by railway				112
Empty TEUs arriving from NAP by railway and shipped from the interport by road				453
Empty TEUs arriving from NAP by railway and shipped from the interport by railway				9
Leaving the virtual interport node without customs function at Marcianise (MAR)				
Full TEUs cleared at NAP, arriving by railway and shipped from the interport by road				340
Empty TEUs arriving from NAP by railway and shipped from the interport by road				8

Source: own elaboration on data provided by the Campanian Port Authorities, Campania-based marine and inland terminal companies, freight forwarders, third-party logistics providers, Trenitalia, and Rail Traction Company-RTC.

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 the Naples port (10,890 TEUs) is serviced by carrying the loading units by railway under customs bond from Naples to Nola (carrier haulage). There the containers are cleared by customs and then transported to Marcianise by truck. In other words, the solution involves a two-way utilization of the connection between the two interports: some containers being shipped from Nola to Marcianise and others being shipped in the opposite direction.

Table 10. Optimal inland flows of imported containers through the Campanian seaports and interports (baseline scenario model).

Inland traffics of imported containers: baseline scenario model	*Destinations...* NOL	NCC	MAR	Other inland locations
Leaving the port of Naples (NAP)				
Full TEUs cleared at the port and shipped by road (merchant haulage)	59,892		4,680	98,760
Full TEUs cleared at the port and shipped by railway (merchant haulage)				9,790
Full TEUs shipped by railway under customs bond (carrier haulage)		10,500		
Empty TEUs shipped by road	4,065		172	13,033
Empty TEUs shipped by railway			600	4,385
Leaving the port of Salerno (SAL)				
Full TEUs cleared at the port and shipped by road (merchant haulage)	1,549		302	69,830
Empty TEUs shipped by road	1,100		199	96,167
Leaving the virtual interport node with customs function at Nola (NCC)				
Full TEUs from NAP cleared at the interport and shipped by road			6,210	
Full TEUs from NAP cleared at the interport and shipped by railway				4,290
Leaving the virtual interport node without customs function at Nola (NOL)				
Full TEUs cleared at SAL and shipped from the interport by railway				56
Empty TEUs from NAP and shipped from the interport by railway				31
Empty TEUs from SAL and shipped from the interport by railway				58
Leaving other inland locations with rail terminal				
Full TEUs arriving from NAP by railway and shipped by road				2,519
Empty TEUs arriving from NAP by road and shipped by road				326
Full TEUs from NAP arriving from NCC by railway and shipped by road				1,000
Empty TEUs from NAP arriving from NOL by railway and shipped by road				29
Full TEUs from SAL arriving from NOL by railway and shipped by road				43
Empty TEUs from SAL arriving from NOL by railway and shipped by road				58

These results may in the first instance seem odd, but can be explained as follows. The key bottlenecks in the system are the capacity constraints on railway shuttles between Naples and the two interports. For the optimal solution, all available railway capacity from Naples to each of the two interports is utilized (see Table 14). Container carrier haulage by railway under customs bond dramatically reduces the cost of the releasing operations at the seaport, and consequently also reduces the total cost of inland distribution. A comparison of costs of alternative routings between the port of Naples and the interports is presented in Table 15.

The railway services between Naples and Calabria-located destinations (Rosarno and San Ferdinando, which are the rail nodes of the Gioia Tauro port, in Southern Italy) would also operate at the limit of their capacity. Railway-to-railway transhipment through the 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

Table 11. Optimal inland flows of imported containers through the Campanian seaports and interports (ideal scenario model).

Inland traffics of imported containers: ideal scenario model	***Destinations...*** *NOL*	*NCC*	*MAR*	*MCC*	***Other inland locations***
Leaving the port of Naples (NAP)					
Full TEUs cleared at the port and shipped by road (merchant haulage)	56,892				92,005
Full TEUs cleared at the port and shipped by railway (merchant haulage)					16,725
Full TEUs shipped by railway under customs bond (carrier haulage)		15,000		3,000	
Empty TEUs shipped by road	4,034		772		12,249
Empty TEUs shipped by railway					5,200
Leaving the port of Salerno (SAL)					
Full TEUs cleared at the port and shipped by road (merchant haulage)			302		68,735
Full TEUs cleared at the port and shipped by railway (merchant haulage)	1,493				1,095
Full TEUs shipped by railway under customs bond (carrier haulage)		56			
Empty TEUs shipped by road	149		199		94,762
Empty TEUs shipped by railway	951				1,405
Leaving the virtual interport node with customs function at Nola (NCC)					
Full TEUs from NAP cleared at the interport and shipped by road			10,890		655
Full TEUs from NAP cleared at the interport and shipped by railway					3455
Full TEUs from SAL cleared at the interport and shipped by railway					56
Leaving the virtual interport node with customs function at Marcianise (MCC)					
Full TEUs from NAP cleared at the interport and shipped by road	3,000				
Leaving the virtual interport node without customs function at Nola (NOL)					
Empty TEUs from SAL and shipped from the interport by railway					58
Leaving other inland locations with rail terminal					
Full TEUs arriving from NAP by railway and shipped by road					3,387
Empty TEUs arriving from NAP by railway and shipped by road					515
Full TEUs from SAL arriving from NCC by railway and shipped by road					43
Empty TEUs from SAL arriving from NOL by railway and shipped by road					58

national inland locations have low levels of capacity utilization. Such services are also employed for traffic not originating in the Campanian 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 of both the Campanian interports.[1] The ideal scenario model

[1] In addition, although not accounted for in our present formulation of the objective function, it is clear that transportation by railway adds to social welfare.

Table 12. Optimal inland flows of imported containers through the Campanian seaports and interports (pessimistic scenario model).

Inland traffics of imported containers: pessimistic scenario model	Destinations...		
	NOL	*MAR*	*Other inland locations*
Leaving the port of Naples (NAP)			
Full TEUs cleared at the port and shipped by road (merchant haulage)	53,481	10,890	103,026
Full TEUs cleared at the port and shipped by railway (merchant haulage)	6,435		9,790
Empty TEUs shipped by road		172	13,033
Empty TEUs shipped by railway	4,065	600	4,385
Leaving the port of Salerno (SAL)			
Full TEUs cleared at the port and shipped by road (merchant haulage)	1,549	302	69,830
Empty TEUs shipped by road	1,100	199	96,167
Leaving the virtual interport node without customs function at Nola (NOL)			
Full TEUs cleared at NAP and shipped from the interport by railway			24
Full TEUs cleared at SAL and shipped from the interport by railway			56
Empty TEUs from NAP and shipped from the interport by railway			31
Empty TEUs from SAL and shipped from the interport by railway			58
Leaving other inland locations with rail terminal			
Full TEUs arriving from NAP by railway and shipped by road			2,519
Full TEUs arriving from NAP by road and shipped by road			567
Empty TEUs arriving from NAP by road and shipped by road			326
Empty TEUs from NAP arriving from NOL by railway and shipped by road			29
Full TEUs from SAL arriving from NOL by railway and shipped by road			43
Empty TEUs from SAL arriving from NOL by railway and shipped by road			58

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 the port of Naples and destined just to the two interports themselves. For the shipping agent, given the very high port cost at Naples, it would at all times be preferable to choice a container distribution solution based on the carrier haulage by railway under customs bond from the port toward a regional interport. The containers would then be subject to both customs clearance at the interport and final transportation by truck towards the other interport. There thus exists a huge potential for operational integration between the two different regional interport sites. This observation should give 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 here is rather 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, few imports arrive from China – a situation

TABLE 13. Comparison of total generalized costs in observed situation and modelled scenarios.

Comparison of total generalized logistic costs for inland distribution of imported containers disembarked at the Campanian seaports	**Observed real situation in 2007**	**Baseline scenario model**	**Ideal scenario model**	**Pessimistic scenario model**
Total generalized logistic cost for inland distribution of full containers disembarked in Naples (millions of Euros)	158.2	153.2	150.9	156.2
Total generalized logistic cost for inland distribution of empty containers disembarked in Naples (millions of Euros)	15.9	15.8	15.6	15.8
Total generalized logistic cost for inland distribution of full and empty containers disembarked in Naples (millions of Euros)	174.1	169.0	166.5	171.9
Total generalized logistic cost for inland distribution of full containers disembarked in Salerno (millions of Euros)	21.5	21.5	21.4	21.5
Total generalized logistic cost for inland distribution of empty containers disembarked in Salerno (millions of Euros)	28.2	28.2	28.1	28.2
Total generalized logistic cost for inland distribution of full and empty containers disembarked in Salerno (millions of Euros)	49.7	49.7	49.5	49.7
Total generalized logistic cost for inland distribution of full containers disembarked in Naples and Salerno (millions of Euros)	*179.7*	*174.7*	*172.3*	*177.7*
Total generalized logistic cost for inland distribution of empty containers disembarked in Naples and Salerno (millions of Euros)	*44.1*	*44.0*	*43.7*	*43.9*
Total generalized logistic cost for inland distribution of full and empty containers disembarked in Naples and Salerno (millions of Euros)	***223.8***	***218.7***	***216.0***	***221.7***

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 and on behalf of shipping lines 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).

Expansion of the customs facilities for the inland container traffic throughout Campania, 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 first-tier

Table 14. Observed real data and optimization model output data (ideal scenario model) on traffics of full and empty containers, capacity utilization, plus shadow values of capacity constraints over railway connections from the Campanian seaports and interports.

Railway link	Number of one-way weekly trains	Maximum number of TEUs/train	Annual maximum one-way capacity (TEUs)	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	208.3
Naples-Marcianise	1	60	3,000	481	3,000	238.5
Naples-Bari	5	50	12,500	6,054	9,408	0
Naples-Rosarno	3	50	7,500	2,408	7,500	169.8
Naples-San 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-Segrate Milan	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	43.1
Salerno-Bari	1	50	2,500	2,081	2,500	36.0

Source: own elaboration on observed supply and demand data provided by Trenitalia and Rail Traction Company-RTC, plus solution data resulting from the ideal scenario model.

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 14 lists both observed values and solution values on rail shipments originating in the Campanian seaports and interports (see the fifth and sixth columns of the table). The observed data on traffics towards Nola and Marcianise include possible transits from the Campanian seaports towards other inland final destinations. Instead, the observed traffics from Nola and Mar-

TABLE 15. Comparison of costs of alternative distribution solutions for full containers disembarked in Naples and demanded by operators located in the interports at Nola and Marcianise.

Cost comparison example for alternative distribution solutions: full containers disembarked in Naples and demanded by operators located in the interports at Nola and Marcianise	**Total generalized logistic cost (Euros/TEU)**
Full containers cleared by customs in Naples and forwarded by railway to the interports	853.5
Full containers cleared by customs in Naples and forwarded by road to the interports	861.9
Full containers forwarded to the interports by railway carrier haulage under customs bond (without inland transit document), and cleared by customs at the same interports	503.1

Source: own elaboration on data provided by Italian Customs Agency-Rome, Campania-based terminal operators, freight forwarders, and third party logistics providers.

cianise include containers (full and empties) which were not disembarked in the Campanian seaports. The solution figures exclusively refer to containers (full and empties) disembarked at the seaports, including transits towards other inland final destinations. The table also exhibits the capacity limits on the various railway links and the solution shadow prices of such capacity constraints (in the fourth and seventh columns). The shadow prices indicate the imputed value of the objective function that would arise from an improvement of infrastructure and/or services. They confirm the importance of the off-dock logistic system. An increase of the railway capacity over the Naples-Nola, Naples-Marcianise, 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 Marcianise would equal 238.5 Euros per TEU.

The characteristics of the ideal solution now discussed confirm the critical role that would be played by a fully operational customs-authorized Marcianise interport. The solution demonstrates the current presence of a demand deficit and the consequent under-utilization of the intermodal capacity at Marcianise. Thus, Marcianise offers a very considerable potential for improving both its off-dock function and railway connections for the inland distribution of containers handled in the seaport of Naples. A slightly different situation features instead the interport of Nola, whose capacity is more utilized.

Sensitivity tests. In FIGURES 6 and 7 the results of some sensitivity tests are reported. We calculated the change of both the optimal value of the objective function of the ideal scenario 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.

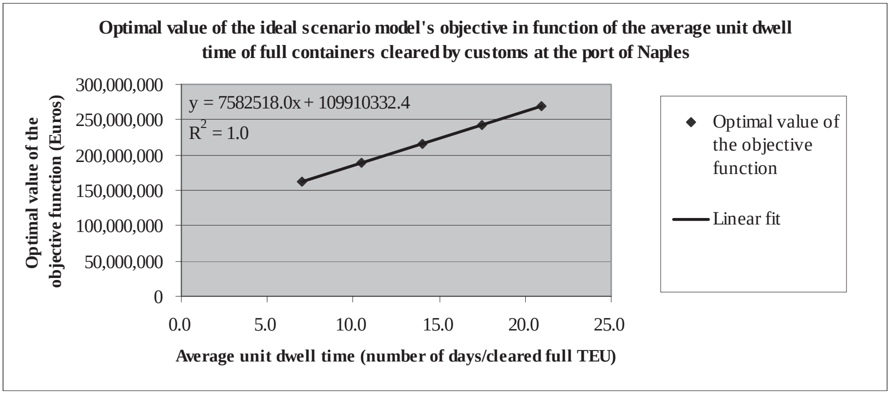

Figure 6. Optimal value of the ideal scenario's objective in function of the average unit dwell time of full containers cleared by customs at the port of Naples.

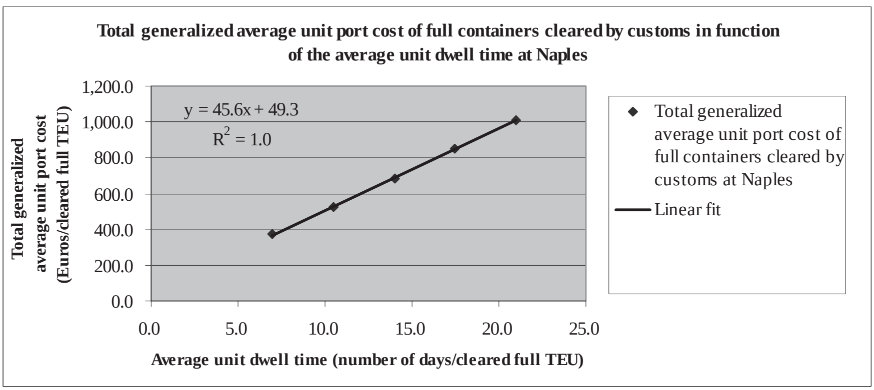

Figure 7. Total generalized average unit port cost of full containers cleared by customs in function of the average unit dwell time at Naples.

Finally, Table 16 reports the results of sensitivity tests calculating the change of the objective function of the ideal scenario, 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 the 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 links in the same scenario. The capacity variations considered were the following: (i) a 100% increase of the base case ("ONE"); (ii) a 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 ports and the interports, such increased capacity would still be fully utilized. Shippers would still find it advantageous to relocate customs clearance procedures from the seaports to the interports.

Table 16. Sensitivity results under alternative assumptions of railway capacity between the Naples port and the regional interports in the ideal scenario.

Analysis of sensitivity of some results of the ideal scenario model after the variation of the capacity of the railway links between the Naples port and the interports of Nola and Marcianise	*BASE case*	*ONE*	*TWO*
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 (millions of Euros)	216.0	212.2	208.7
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%

7. Conclusions

The future expansion of the Campanian container distribution system depends crucially on an improved supply of interport services (at Nola, Marcianise, and Battipaglia, the latter being under construction). New types of freight infrastructures and logistic poles (e.g. distriparks) in the Campania region do not seem imminent.

The numerical results of the *inward interport model* confirm the importance of the regional off-dock and inland logistic system, i.e. of the Campanian interports, for the inland distribution of international maritime containers disembarked in the Campanian seaport cluster. They reveal some of the current deficiencies of the Campanian regional load center network in terms of seaport-interport connections, while suggesting possible policies that would further a better integration between seaports and interports.

The case study highlights the benefits of modern customs and intermodal procedures for inland container logistics, which are currently adopted only in few cases in Campania. The ideal scenario model admits the possibility to employ both the operational Campanian interports, that is Nola and Marcianise, as extended gates of the regional seaport system. Therefore, direct and indirect costs for port releasing operations can be reduced. Such kind of interport-related economic and logistic benefits deserves particular attention.

The results demonstrate that it is possible to improve the competitiveness of railway services over short distances (Naples-Nola and Naples-Marcianise) only by adopting an extended gateway system based both on the possibility of carrier haulage by railway under customs bond without any accompanying inland transit document over seaport-interport routes, and on customs clearance at the interports. By both an adequate regulation and an efficacious organizational system (e.g. extending the possibility of carrier haulage under customs bond also to the Naples-Marcianise railway link), the current railway capacity and beyond can be fully employed over seaport-interport connections.

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

The hypothesized customs facilitations between seaports and interports could prove to be an useful tool to both expand the Campanian container seaports' hinterland and guarantee, through an efficient railway system, the competitiveness of the regional load center network system also for cargoes destined to Northern Italy and, more generally, to Central and Northern Europe.

Many inefficiencies could easily be corrected. These include, for instance, the current suspension of railway connections at the port of Salerno, the lack of fully operational customs equipments at the Marcianise interport, and the low rates of utilization of the existing container railway capacity of the whole Campanian load center network system. Limited customs clearing capacity 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. Criticizing the Campanian 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).

The model formulation and the numerical applications proposed are also featured by some limits however constituting a potential in terms of possible future extensions. For example, time-related safety stock costs can be included among the parameters of the model. Furthermore, the model can also feature the external costs of transport operations, and the possibility of enhancing the value of the containerized goods at the interports through semi-manufacturing logistic services (opening containers and repacking goods together with marketing material, for instance). In this case, the optimization problem will consist in maximizing the value of all "upgraded" containers processed at the interports, calculated net of the internal and external logistic costs throughout the entire port-hinterland network.

Future applications of the *interport model* will take simultaneously into consideration the inland logistics of both import and export containerized trades through the Campania regional load center network *(inward-outward simultaneous interport model)*. Finally, the model could be extended for the investigation of wider territorial logistic systems.

Appendix: definition and calculation of all cost elements

The total generalized unit costs for road and railway transport of full containers (that is $[c^{m}_{full \in T,ij}]$) are calculated as the sum of direct transport costs and time related costs during transport operations. The latter are the sum of in-transit inventory holding costs and container leasing costs. Inventory costs depend on: the customs declared value of the containerized goods (expressed in Euros/full TEU); the time duration of the logistic operations; the reference interest rate employed to calculate both the opportunity cost of the capital tied in goods and the economic-technical depreciation costs of the same goods. Container leasing costs depend both on the time duration of the logistic operations and a reference container leasing charge. Also container leasing costs can be intended as a kind of opportunity costs. As far as the total generalized unit costs for road and railway transport of empty containers (that is $[c^{m}_{empty \in T,ij}]$) are concerned, these are calculated as the sum of direct transport costs and container leasing costs.

The costs of transport either by road or railway toward generic nodes include the costs of the terminal operation related to the offloading of the container from the vehicle at the end of the trip. The costs of road transport from the final destination nodes which have a railway terminal (excluding the interport nodes) towards other demanding nodes comprises the costs of the terminal operations both at the departure and the arrival. Furthermore, total travel times by road over admitted links are equal to the driving time both over motorways and other road types plus the time for rests and stops prescribed by Road regulations under the "1 driver on board" hypothesis. Road driving times are computed by assuming two different admitted truck's average speeds over motorways and other road types. The number and time duration of rests and stops to be observed in a transportation by truck are calculated in function of the driving time. In this respect, the same computational procedure employed by Aponte *et al.* (2009) has been adopted. As for total travel times by rail over admitted links, these are instead exogenous.

The total generalized unit port and interport costs of the releasing operations for empty containers ($[f_n]$) include handling costs, storage costs and container leasing costs. Storage costs are computed in function of unit dwell time for empty loading units, unit free of charge time and unit demurrage charge for empty load units at intermodal node $n \in N$. Container leasing costs are computed in function of both a reference container leasing charge and the unit dwell time for empty units at intermodal node $n \in N$.

The weighted average total generalized unit port costs of the releasing operations for cleared full containers (that is $[g_p^m]$) are computed by taking into consideration both direct costs and time related costs, according to the different probabilities observed in the seaport $p \in P$ for the different customs control types (AC, DC, PI, SC). In particular, direct port costs include handling, storage and customs control costs. Storage costs are computed in function of weighted average unit dwell time for cleared full loading units (also broken down by transport mode $m \in M$ employed for inland distribution), unit free of charge time, and unit demurrage charge for full loading units at port node $p \in P$. Practically, weighted average values are calculated multiplying each container dwell time for different customs control categories by the probabilities of the same control categories. Additional customs cost apply only in the cases of PI and SC. Time related port costs consist of the sum of in-transit inventory holding costs and container leasing costs. The former measure the economic and technical depreciation of the containerized goods, and depend on: the value of the goods; a reference interest rate; the time duration of the logistic operations (in this case, the weighted average unit dwell time at port node $p \in P$ broken down by leaving transport mode $m \in M$ for cleared full loading units). The latter are computed by taking into account both a container leasing charge and the weighted average unit dwell time at port node $p \in P$ broken down by leaving transport mode $m \in M$ for cleared full loading units.

The total generalized unit port costs of the releasing operations for full containers to be cleared at the interports and to be carried by railway under customs bond (and without any accompanying inland transit document) between seaports and interports (that is $[k_p]$) are the sum of handling costs, storage costs, inventory holding costs and container leasing costs. Storage costs are computed in function of unit dwell time for full loading units to be cleared at interports, unit free of charge time, and unit demurrage charge for full loading units at port node $p \in P$. Inventory holding costs and container leasing costs are computed in function of unit dwell time at port node $p \in P$ for full loading units to be cleared at interports.

The total generalized unit interport costs of the releasing operations for full containers already cleared by customs at the seaports (that is $[s_q^m]$) are the sum of handling costs, storage costs, inventory holding costs and container leasing costs. Storage costs are computed in function of unit dwell time at interport node $p \in Q$ for full loading units already cleared at the seaports (also broken down by transport mode $m \in M$ employed for inland distribution), as well as in function of unit free of charge time and unit demurrage charge for full loading units at interport node $p \in Q$. Inventory holding costs and container leasing costs are computed in function of unit dwell time at interport node $p \in Q$ for full loading units already cleared at the seaports (also broken down by transport mode $m \in M$ employed for inland distribution).

The weighted average total generalized unit interport costs of the releasing operations for cleared full containers (that is $[u_{dm}^p]$) are computed by taking into consideration both direct costs and time related costs, according to the different probabilities observed in the seaports ($p \in P$) for the different customs control types (AC, DC, PI, SC). In particular, direct interport costs include handling, storage and customs control costs. Storage costs are computed in function of weighted average unit dwell time for cleared full loading units (also broken down by transport mode $m \in M$ employed for inland distribution), unit free of charge time, and unit demurrage charge for full loading units at interport node $d \in D$. Additional customs cost applies only in the cases of PI and SC. Time related interport costs consist of the sum of in-transit inventory holding costs and container leasing costs, which are computed in function of weighted average unit dwell time for cleared full loading units (broken down by leaving transport mode $m \in M$) at interport node $d \in D$.

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