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

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The Campania regional container seaport and interport system: main features and criticalities 1/7

Campania region in the Italian "*Mezzogiorno*"

The Campania regional container seaport and interport system: main features and criticalities 2/7

Campania regional logistic system configuration
(including Capodichino airport, and Battipaglia interport under costruction)

The Campania regional container seaport and interport system: main features and criticalities 3/7

Criticalities:

- Saturation of the container terminal capacity at the ports

- Severe congestion and high dwell times at the Naples port also due to slow customs procedures

- Suspension of the railway connections from/to the Salerno port

- Congestion over the urban road systems due to the container port traffics

- Low share of the railway transport on the total port hinterland traffic

- Commercial-geographical inland basin of the ports limited exclusively at a national scale

- No authorized customs bonded area available at the intermodal terminal of the Marcianise interport

- Low share of the railway transport on the total traffic from/to the interports (low utilization of the intermodal handling capacity at the interports)

One of the solutions identified by the regional policy makers is a public grant scheme for funding intermodal shuttle trains between the port of Naples and the interport of Nola.

The Campania regional container seaport and interport system: main features and criticalities

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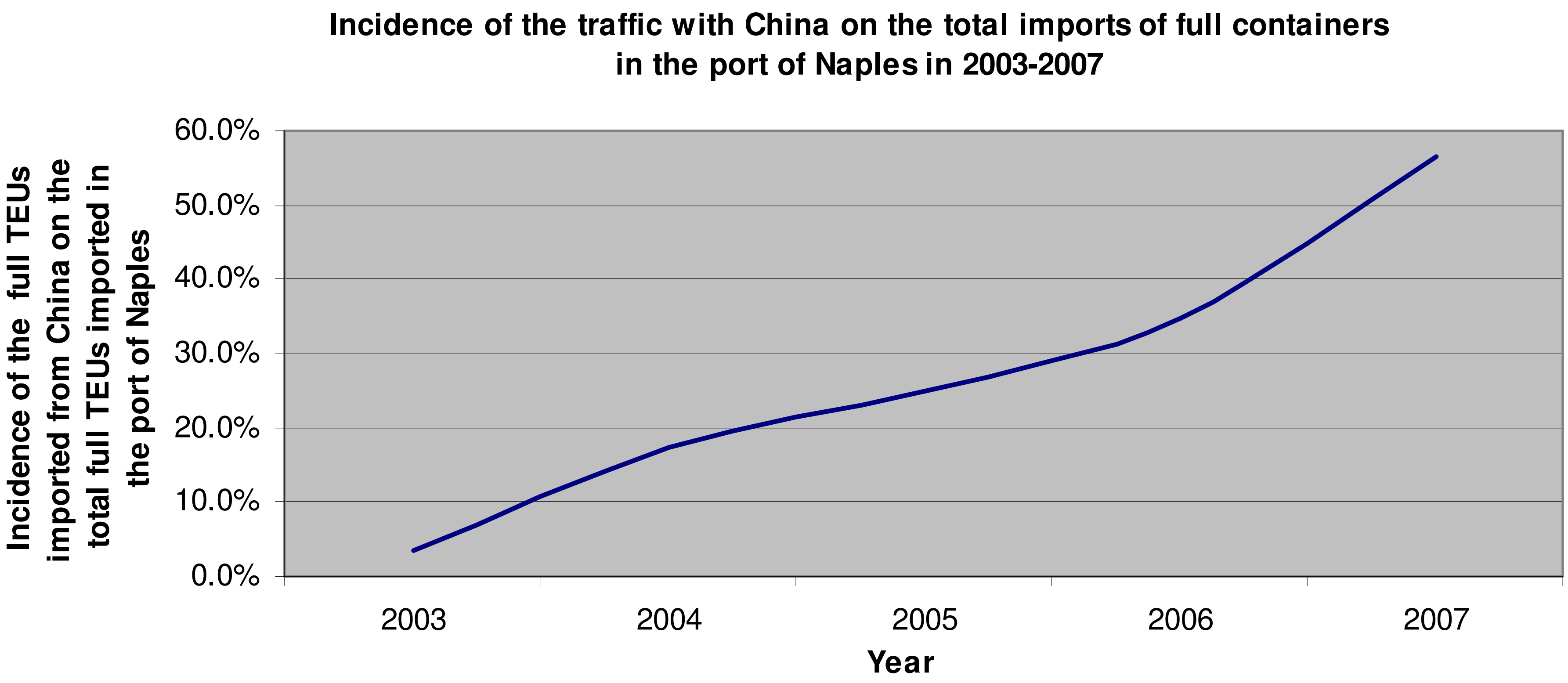
Incidence of customs controls on import-export container traffics
at the ports of Naples and Salerno in 2007

Customs controls on imported containers	**Naples port**	**Salerno port**
Automated computerized control (AC)	59.0%	84.0%
Documentary control (DC)	11.0%	11.0%
Physical inspection (PI)	25.0%	4.0%
X-Ray scanner control (SC)	5.0%	1.0%
Customs controls on exported containers		
Automated computerized control (AC)	71.3%	87.0%
Documentary control (DC)	10.0%	10.0%
Physical inspection (PI)	15.6%	2.5%
X-Ray scanner control (SC)	3.1%	0.5%

Source: Italian Customs Agency - Rome, Campania-located terminal operators and freight forwarders, 2008

The Campania regional container seaport and interport system: main features and criticalities 5/7



Source: Eurostat, 2008

The Campania regional container seaport and interport system: main features and criticalities 6/7

Total logistic cost of the releasing operations at seaports and interports (Euros/TEU) - Year 2007

	Empty TEUs leaving out the node by road or railway	Physically inspected (PI) full TEUs leaving out the node by road	X-Ray scanned (SC) full TEUs leaving out the node by road	Documentarily controlled (DC) full TEUs leaving out the node by road	Automatically controlled (AC) full TEUs leaving out the node by road	Physically inspected (PI) full TEUs leaving out the node by rail	X-Ray scanned (SC) full TEUs leaving out the node by rail	Documentarily controlled (DC) full TEUs leaving out the node by rail	Automatically controlled (AC) full TEUs leaving out the node by rail	Full TEUs leaving out the seaport by railway for customs clearing in interports ("extended gateway" concept)	WEIGHTED AVERAGE - Full CLEARED TEUs leaving out the node by road	WEIGHTED AVERAGE - Full CLEARED TEUs leaving out the node by rail
Naples port	540.0	1,133.8	1,238.1	662.0	431.1	1,142.8	1,247.2	671.1	440.2	186.0	672.5	681.6
Salerno port	185.0	265.0	291.1	176.4	168.8	272.0	298.1	179.5	171.8	126.0	174.7	177.9
Nola interport	122.5	215.0	241.1	126.4	118.8	222.0	248.1	129.5	121.8	-	137.2	141.0
Marcianise interport	122.5	215.0	241.1	126.4	118.8	222.0	248.1	129.5	121.8	-	137.2	141.0
Nola/Marcianise interport (containers from Naples)											**149.8**	**154.0**
Nola interport (containers from Salerno)											**124.7**	**127.9**

The total logistic cost for the releasing operations concerning the full containers includes direct costs and inventory-in transit holding costs. Direct costs have been computed through the following formula: *[(Dwell time – demurrage free time) * demurrage charge] + terminal handling charge + [additional Customs costs (only for physically inspected and X-Ray scanned containers)].* Data for the computation of inventory-in transit holding costs are reported in the following table:

Customs declared unit value of containerized goods imported in Campania in the first half of 2007	**Annual Interest rate (opportunity cost of capital + economic/technical depreciation of goods)**	**Daily Interest rate**	**Daily opportunity cost of capital + economic/technical depreciation cost per container (Euros/TEU/day)**	**Hourly opportunity cost of capital + economic/technical depreciation cost per container (Euros/TEU/hour)**
15,933.9	0.35	0.0010	15.28	0.64

In a preliminary way, the total logistic cost for the releasing operations concerning the empty containers include only direct costs.

Source: Italian Customs Agency - Rome, Campania-located terminal operators and freight forwarders, 2008

The Campania regional container seaport and interport system: main features and criticalities 7/7

Effective origin/destination inland demand of full and empty containers disembarked in the Campania seaport cluster in 2007 (excluding transit traffics at the interports, and independently from the transport mode)

Demand at inland locations for containers originating from Campania seaports
INWARD FULL+EMPTY TEUS from Na+Sa

🟦	0 to 8
🟦	9 to 19
🟩	20 to 999
🟩	1000 to 9999
🟨	10000 to 13999
🟥	14000 to 293000

0 50 100 150
Miles

Source: Port authorities of Naples and Salerno, Co.Na.Te.Co., S.C.T., Campania-located freight forwarders and third party logistics providers, 2008

General presentation of the proposed analysis model 1/2

- **Theoretical definition and numerical implementation** of a multimodal and multicommodity economic linear model for the optimization of the inland distribution logistics of the containerized import traffics through the Campania seaport and interport system ("***interport model***").
- Purposes of the *interport model*: 1) **identification of the multimodal transport flows minimizing the total logistic cost of the inland container distribution** (optimal nodal and modal choices); 2) **evaluation of long term alternative scenarios** in terms of infrastructural and service supply, demand characteristics, industrial and governmental policies.
- Extension of the conventional network (mathematical programming) models to the logistic and transportation theories and evidences related to the "***Port regionalization***", the "***Supply chain terminalization***" and the "***Extended gateway concept***" (Notteboom and Rodrigue, 2005, 2009; Rodrigue and Notteboom, 2009; Visser *et al.*, 2007).

General presentation of the proposed analysis model 2/2

- **Mathematical representation of the possibility to shift the container releasing and seaport exit operations to the regional interports through an extended gateway system** based both on the container carrier haulage by railway under customs bond between seaports and interports, and on customs clearance at interports.

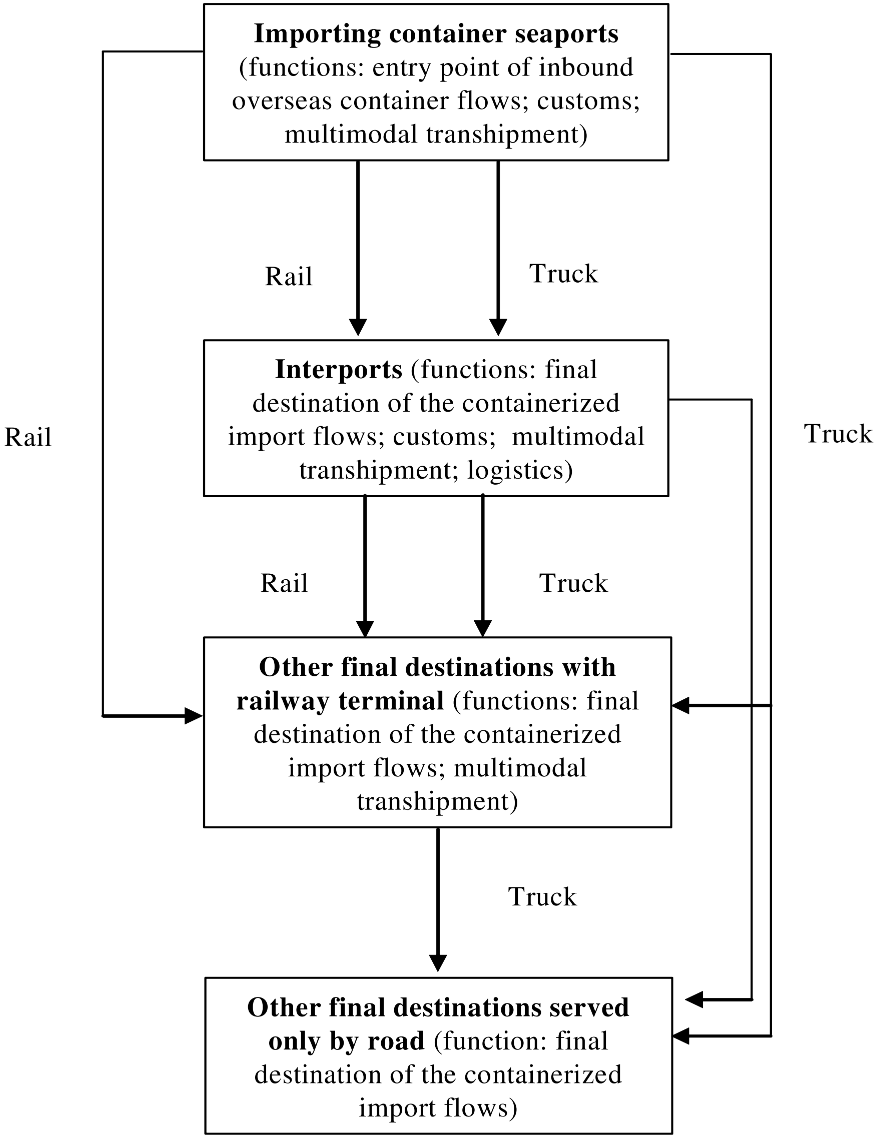
- **Time dimension**: 1) average ***dwell times*** for empty containers, inspected full containers (PI, SC) and non-inspected full containers (AC, DC) at seaports and interports, to be forwarded by road or railway; 2) average ***dwell time*** for full containers to be transferred by railway under customs bond and on behalf of shipping lines from seaports to interports; 3) ***free of charge container storage times*** at seaports and interports; 4) ***demurrage charges*** incurred at seaports and interports; 5) **time duration of multimodal transport operations** over the network; 6) **opportunity costs and economic-technical depreciation costs** for the containerized goods.

Review of some contributions of the reference modeling literature

Authors	Main objective of the paper
Aversa *et al.* (2005)	Identify the optimal location of a hub port on the East Coast of South America through a multicommodity mixed integer hub-and-spoke model.
Crainic (2003)	Illustrate planning and management issues and models for long haul freight transport systems.
Crainic and Kim (2007)	Illustrate several issues related to the containerized intermodal transport, as well as several applied mathematical modelling methodologies.
Cullinane *et al.* (2002)	Develop 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)	Develop an integer programming model concerning the so-called "street-turn" or "triangulation" strategy of a shipping line.
Kim *et al.* (2008a)	Develop a multimodal mixed integer programming model to optimize the flows of full containers imported and exported in Korea.
Kim *et al.* (2008b)	Develop a multimodal linear programming model to optimize the flows of full containers imported and exported in Korea.
Lee *et al.* (2006)	Develop 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); Luo and Grigalunas (2003)	Develop 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)	Develop a non linear optimization model to tackle the problem of increasing the share of rail in intermodal transport through the use of hub-and-spoke networks.
Rahimi *et al.* (2008)	Investigate the inland port location problem in the five counties surrounding Los Angeles.
Thore and Iannone (2005)	Propose a tutorial dealing with the main theoretical and computational elementary aspects related to the employement of both the linear programming and mixed integer programming for solving different transhipment problem types according a hub-and-spoke network configuration.

Features of the investigated network 1/2

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



Importing container seaports (functions: entry point of inbound overseas container flows; customs; multimodal transhipment)

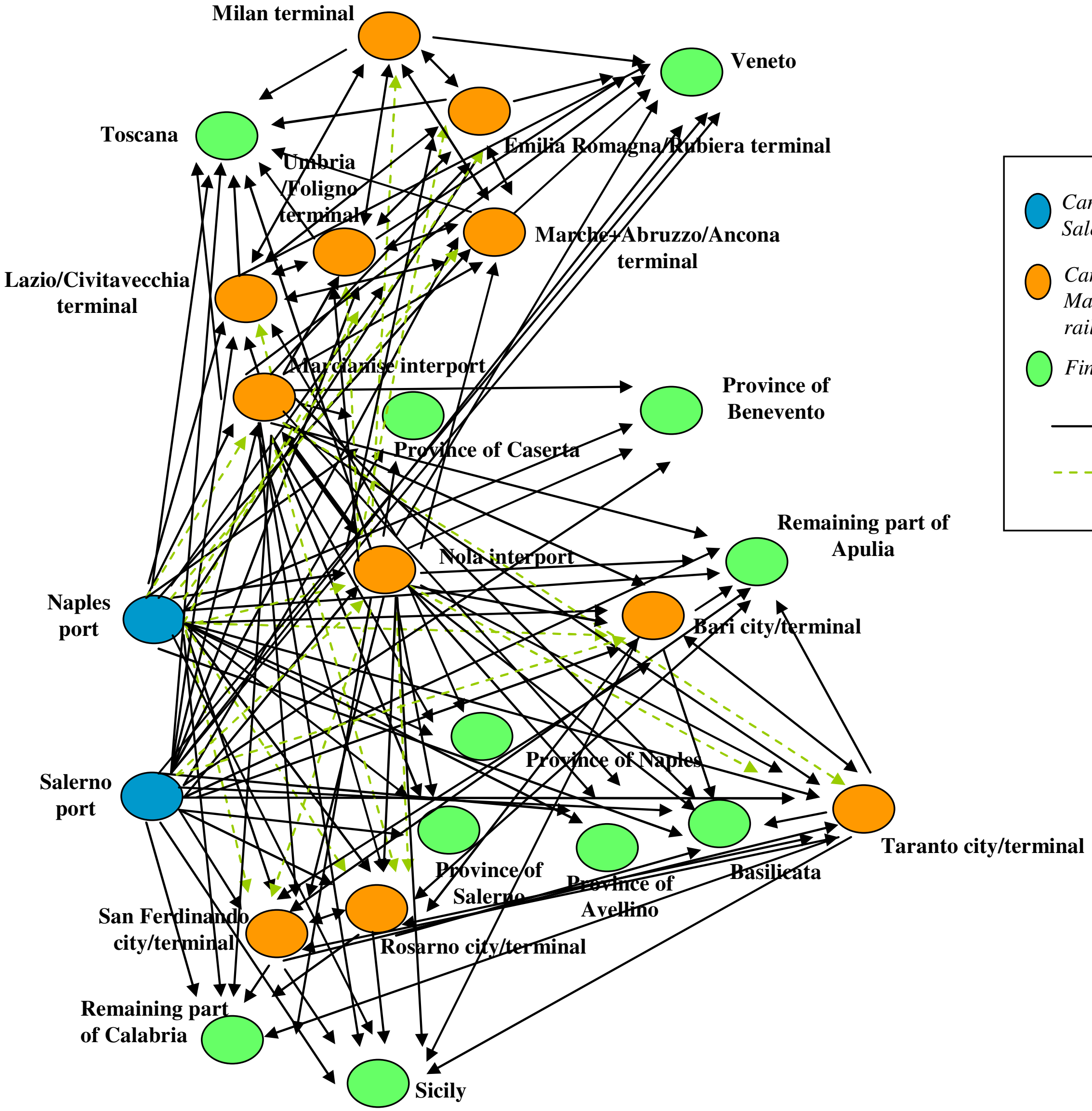
Interports (functions: final destination of the containerized import flows; customs; multimodal transhipment; logistics)

Other final destinations with railway terminal (functions: final destination of the containerized import flows; multimodal transhipment)

Other final destinations served only by road (function: final destination of the containerized import flows)

Features of the investigated network 2/2

Configuration of the inland distribution physical network investigated by the model



LEGENDA

🔵 *Campania seaport system (Naples and Salerno)*

🟠 *Campania interport system (Nola and Marcianise) and final destinations with railway terminal*

🟢 *Final destinations served only by truck*

→ *Road connections*

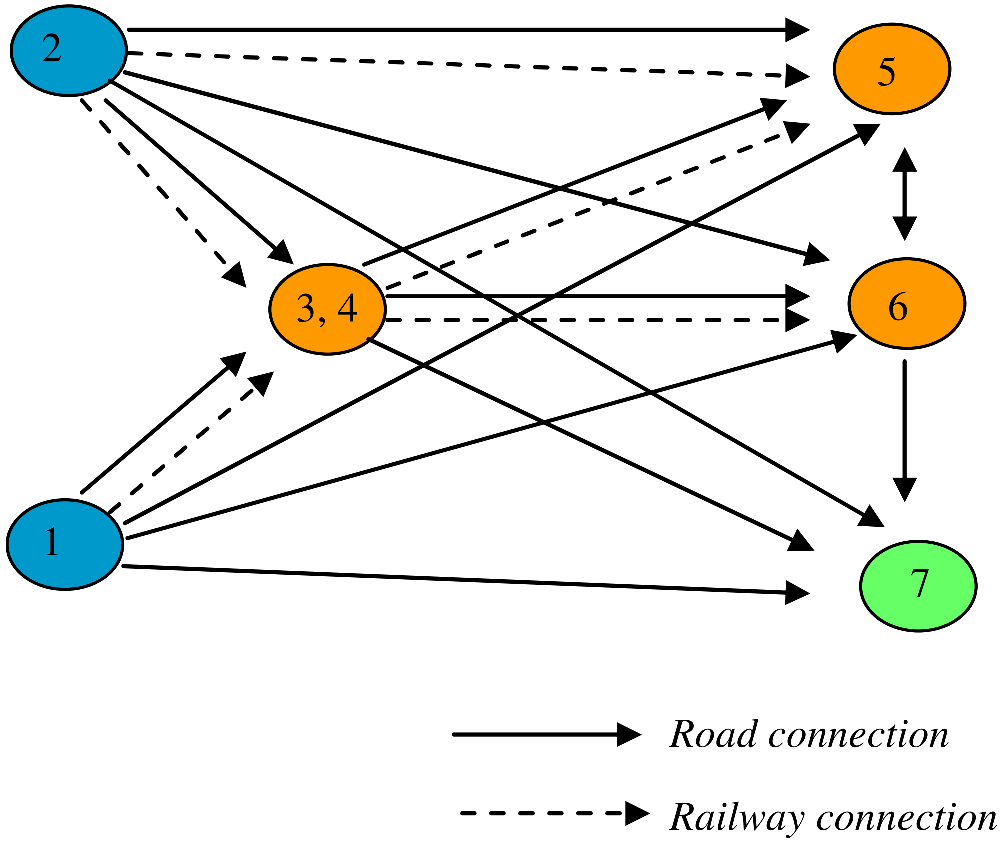
⇢ *Railway connections*

24 real nodes

163 real links (road + railway)

Mathematical formulation of the model: a stylized example 1/7

Stylized model of multimodal logistic network with interport virtual nodes



Mathematical formulation of the model: a stylized example 2/7

Some mathematical notations of the stylized model (unicommodity example) 1/4

Sets:

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

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

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

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

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

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

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

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

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

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

(continued on next page)

Mathematical formulation of the model: a stylized example 3/7

Some mathematical notations of the stylized model (unicommodity example) 2/4

(continued)

Sets:

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

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

Parameters:

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

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

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

(continued on next page)

Mathematical formulation of the model: a stylized example 4/7

Some mathematical notations of the stylized model (unicommodity example) 3/4

(continued)

Parameters:

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

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

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

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Mathematical formulation of the model: a stylized example 5/7

Some mathematical notations of the stylized model (unicommodity example) 4/4

(continued)

Parameters:

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

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

Decision variables:

$\left[x_{ij}^m\right]$: a column vector of inland shipments of containers disembarked in the seaport node $1 \in P$ and forwarded between nodes $i, j \in I$ by transport mode $m \in M$

$\left[y_{ij}^m\right]$: a column vector of inland shipments of containers disembarked in the seaport node $2 \in P$ and forwarded between nodes $i, j \in I$ by transport mode $m \in M$

Mathematical formulation of the model: a stylized example 6/7

Procedure employed to compute times and number of rests and stops prescribed by Italian Road Code regulations under the “1 driver on board hypothesis”

Be $Road\_driving\_time_{ij}$ the expected total road driving time (measured in hours) between a node $i \in I$ and a node $j \in I$, and given:

$$S_{ij} = \text{int}\left(\frac{Road\_driving\_time_{ij}}{9}\right) \qquad (1)$$

$$R_{ij} = Road\_driving\_time_{ij} - 9S_{ij} \qquad (2)$$

It results that:

$$No.\_presc.\_rests_{ij} = \begin{cases} S_{ij} & \text{if } R_{ij} > 1 \\ S_{ij} - 1 & \text{if } R_{ij} <= 1 \text{ and } S_{ij} > 0 \end{cases} \qquad (3)$$

$$No.\_presc.\_stops_{ij} = \begin{cases} No.\_presc.\_rests_{ij} + 2 & \text{if } R <= 1 \text{ and } S > 0 \\ No.\_presc.\_rests_{ij} + \text{int(R/4,5)} & \text{if } R > 1 \end{cases} \qquad (4)$$

Where $No.\_prescrib.\_rests_{ij}$ and $No.\_prescrib.\_stops_{ij}$ are, respectively, the prescribed number of rests and stops provided by the Road regulations.

Definitively, it is obtained that:

$$Total\_rest\_time_{ij} = 11 * No.\_prescrib.\_rests_{ij} \qquad (5)$$

$$Total\_stop\_time_{ij} = (45/60) * No.\_prescrib.\_stops_{ij} \qquad (6)$$

Source: Aponte *et al.*, 2009

Mathematical formulation of the model: a stylized example 7/7

The objective of the programming model is:

$$\min \ W =$$

$$\sum_{i\in I}\sum_{j\in I}\sum_{m\in M} c_{ij}^{m}\cdot(x_{ij}^{m}+y_{ij}^{m})+\sum_{p\in P}\sum_{z\in Z}\sum_{m\in M} f_{p}^{m}\cdot(x_{pz}^{m}+y_{pz}^{m})+$$

$$+\sum_{p\in P}\sum_{d\in D} g_{p}\cdot(x_{pd}^{rail\in M}+y_{pd}^{rail\in M})+\sum_{q\in Q}\sum_{e\in E}\sum_{m\in M}k_{q}^{m}\cdot(x_{qe}^{m}+y_{qe}^{m})+$$

$$+\sum_{d\in D}\left\{\sum_{z\in Z}\begin{array}{l}\left[(h_{d}^{truck\in M}\cdot x_{dz}^{truck\in M})+(j_{d}^{truck\in M}\cdot y_{dz}^{truck\in M})\right]+\\ +\sum_{e\in E}\left[(h_{d}^{rail\in M}\cdot x_{de}^{rail\in M})+(j_{d}^{rail\in M}\cdot y_{de}^{rail\in M})\right]\end{array}\right\} \tag{7}$$

The objective function of the full model is a straight-forward generalization of (7). The full model minimizes the total logistic cost for the distribution of full and empty containers throughout the entire network. It includes further parameters, and is subjected to flow conservation constraints at origin, intermediate and destination nodes, as well as to both non-negativity constraints on the decision variables and capacity constraints over the railway links. All in all, the full model features 26 nodes and 219 admitted links (by taking into consideration 2 virtual nodes per each regional interports and their related links), 863 variables and 168 constraints. It was programmed and solved with the GAMS (General Algebraic Modeling System) computer code, using the solver CPLEX .

Main results obtained by the numerical solution of the model 1/5

Optimal inland flows of imported containers through Campania seaports and interports

	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					3,455
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

Example of comparison of the total logistic cost for alternative distribution solutions

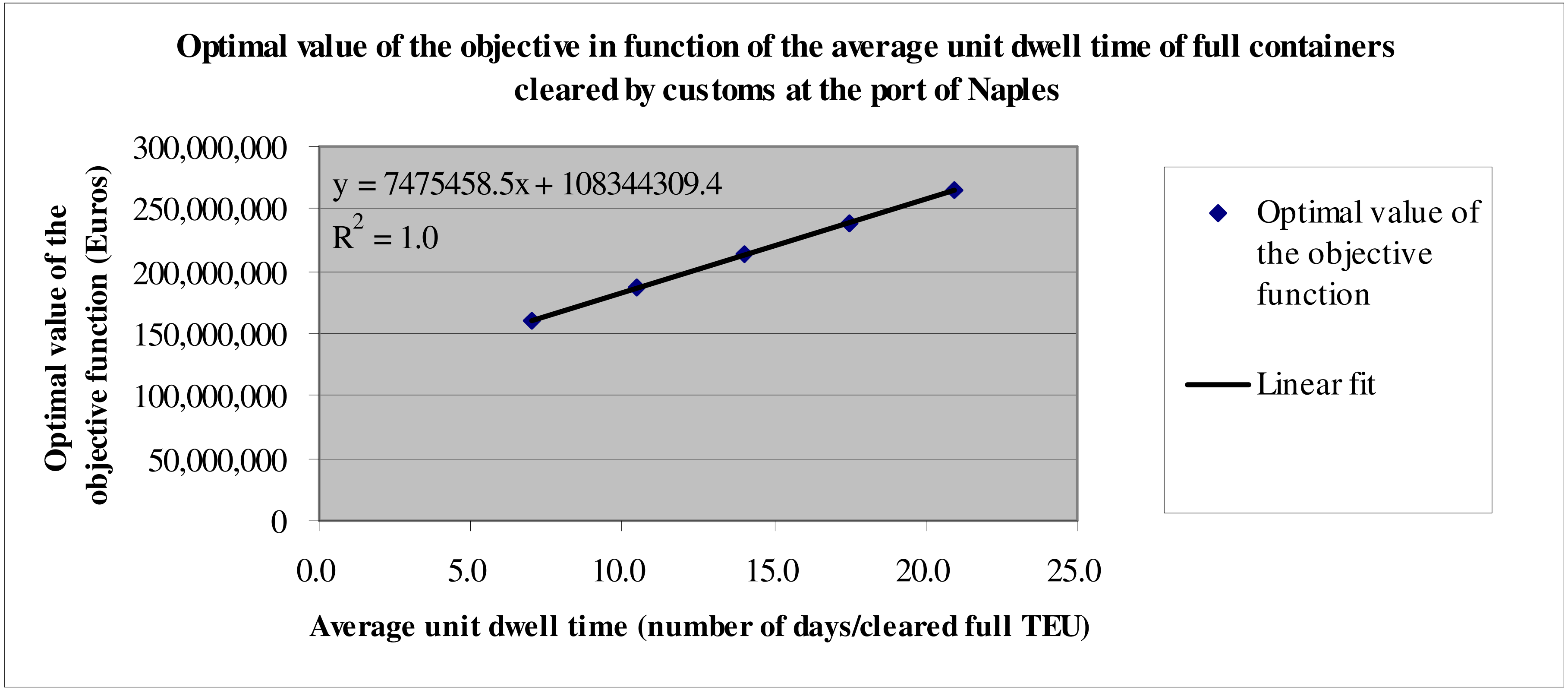
Example: containers disembarked in Naples and demanded by operators located in the interport of Nola	**Total logistic cost (Euros/TEU)**
Full container cleared by customs in Naples and forwarded by railway to Nola	844.2
Full container cleared by customs in Naples and forwarded by road to Nola	852.8
Full container disembarked in Naples and cleared by customs in Nola	498.4
Empty container forwarded by rail from Naples to Nola	668.0
Empty container forwarded by road from Naples to Nola	684.0

Main results obtained by the numerical solution of the model 2/5

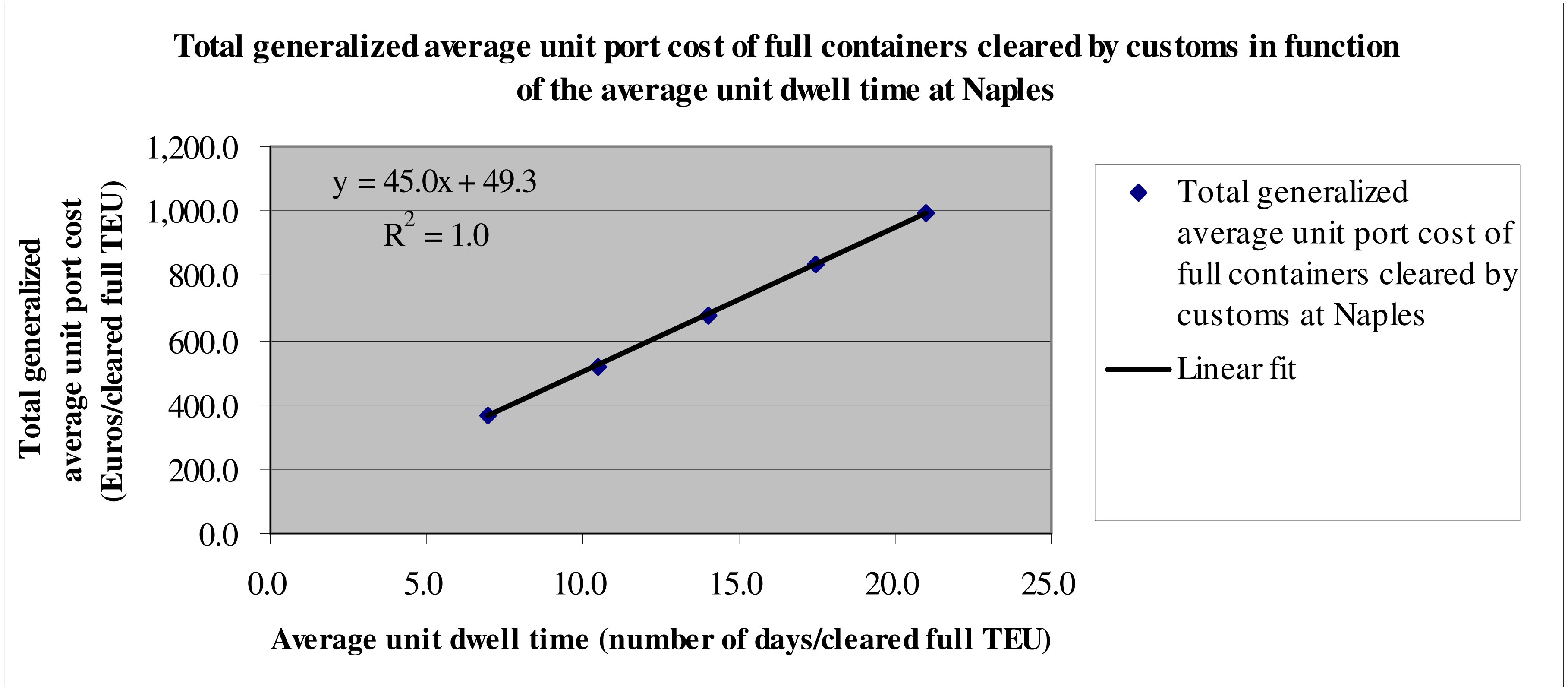
Rail traffics of full and empty containers (observed and resulting from the model), rail capacity utilization (resulting from the model), and shadow values of the rail capacity constraints

Railway link	Number of one-way weekly trains - model	Maximum number of TEUs/train - model	Maximum annual one way capacity (TEUs) - model	One-way annual shipments in the last osbserved year (TEUs)	One-way annual shipments resulting from the model (TEUs)	Railway capacity utilization resulting from the model	Shadow value of the capacity constraint (Euros)
Naples-Nola	5	60	15,000	6,707	15,000	100.0%	203.9
Naples-Marcianise	1	60	3,000	481	3,000	100.0%	234.1
Naples-Bari	5	50	12,500	6,054	9,408	75.3%	0
Naples-Rosarno	3	50	7,500	2,408	7,500	100.0%	169.8
Naples S. Ferdinando	1	50	2,500	2,410	2,500	100.0%	187.5
Naples-Ancona	1	50	2,500	44	1,114	44.6%	0
Naples-Foligno	1	50	2,500	30	1,272	50.9%	0
Naples-Rubiera	1	50	2,500	129	131	5.2%	0
Nola-Taranto	3	50	7,500	1,618	2,834	37.8%	0
Nola-Rosarno	2	50	5,000	1,078	0	0.0%	0
Nola-San Ferdinando	5	48	12,000	475	597	5.0%	0
Nola-Foligno	1	50	2,500	51	0	0.0%	0
Nola-Rubiera	1	50	2,500	66	0	0.0%	0
Nola-Segrate Milan	5	12	3,000	750	138	4.6%	0
Marcianise-Taranto	1	50	2,500	24	0	0.0%	0
Marcianise-Rosarno	1	50	2,500	0	0	0.0%	0
Marcianise-Civitavecchia	1	50	2,500	0	0	0.0%	0
Salerno-Nola	1	50	2,500	395	2,500	100.0%	43.2
Salerno-Bari	1	50	2,500	2,081	2,500	100.0%	36.1

Main results obtained by the numerical solution of the model 3/5



Main results obtained by the numerical solution of the model 4/5



Main results obtained by the numerical solution of the model 5/5

Analysis of sensitivity of some model results after the variation of the capacity of the railway links between 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 (million Euros)	212.9	209.2	205.8
Rail traffic under customs bond between Naples and the interports (TEUs)	18,000	36,000	54,000
Utilization rate of the rail links between Naples and the interports	100%	100%	100%

Percentage variation compared with the BASE case

	BASE case	*ONE*	*TWO*
No. of one-way weekly trains over the Naples-Nola link		100%	200%
Yearly capacity of the Naples-Nola one-way rail link		100%	200%
No. of one-way weekly trains over the Naples-Marcianise link		100%	200%
Yearly capacity of the Naples-Marcianise one-way rail link		100%	200%
Share of the rail traffic on the total inland traffic from Naples		45%	87%
Optimal value of the objective function		-2%	-3%
Rail traffic under customs bond between Naples and the interports		100%	200%
Utilization rate of the rail links between Naples and the interports		0%	0%

Conclusions 1/2

Definitively, through the *interport model* it has been possible to demonstrate that under the hypothesized system (based both on the customs continuity between Campania seaports and interports, and on the restoration of railway connections at Salerno port):

- the whole railway capacity and beyond between Campania seaports and interports can be fully utilized;
- the whole railway capacity and beyond from the port of Salerno can be fully utilized;
- it may be reached an equilibrium in terms of competition between the regional interports for containers arriving from the port of Naples;
- railway-to-railway transhipment through Nola interport is advantageous for containers demanded over the traffic relations Naples-Milan, Salerno-Milan, Naples-Taranto, and Naples-Gioia Tauro;
- strategies of infrastructure capacity improvement should be pursued.

Conclusions 2/2

Further extension of the model could take into consideration, for instance:

- external costs of transport operations;
- safety stocks;
- container leasing costs;
- possibility of performing quasi-manufacturing logistic activities on the containerized cargoes at the interports;
- import and export traffics in a simultaneous manner ("*inward-outward simultaneous interport model*").

THANKS FOR YOUR ATTENTION!