Models of intermodal node representation

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Abstract

This paper analyses three different approaches of supply representation for intermodal nodes and proposes some functional and topological models for the representation of ports and Freight Villages. Besides in the paper functional and topological representation of container port and freight village are proposed.

Further research is directed to the specification and calibration of cost functions, useful for cost estimation for different components of node network, with a view to facilitate the analyses of freight mobility on multimodal large networks.

Keywords: Intermodal node; Supply representation; Functional representation; Graph; Cost functions.

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1. Introduction

Intermodal nodes, which are different in structure and functions, are essential elements of the transport network and their functionality considerably affects the overall efficiency of the intermodal chain.

A basic element for the implementation of procedures to optimize the global processes of intermodal logistic node management is supply representation.

In particular, intermodal terminals can be represented following three different approaches: functional, topological (graph theory) and analytical (cost functions).

This paper analyses the three different approaches of supply representation for intermodal nodes and proposes certain functional and topological models for the representation of ports and of the Freight Villages.

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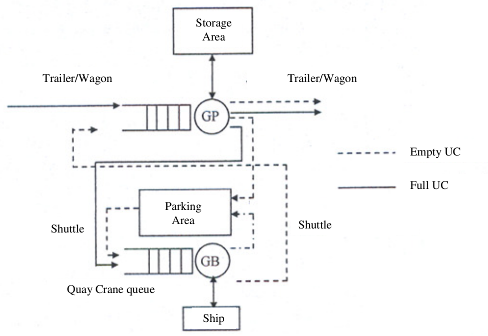
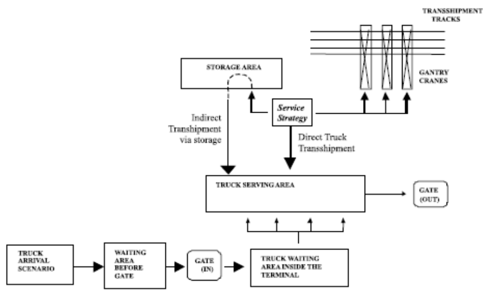
2. Functional representation

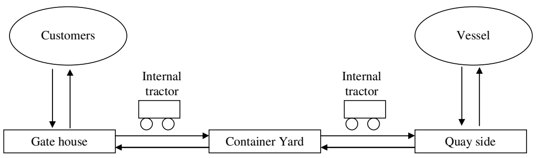
Node functional representation aims to show the terminal functional components as well as their existing relations. It can meet various requirements, such as analyses and assessments of the node spatial, organizational and relational structure. The functional representation is carried out through the use of block diagrams which show the typical utilities of the terminal and the connections between the different areas composing the node. This kind of representation allows to describe the different operations by means of flow charts, where the various phases of goods handling and the conditions to observe are represented by model symbols, called building blocks and connected with each other by arrows.



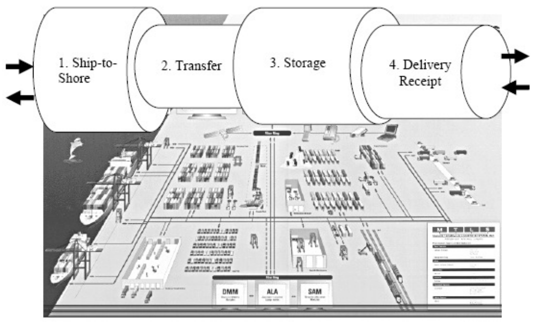
Container Port (Gambardella et al., 1998)



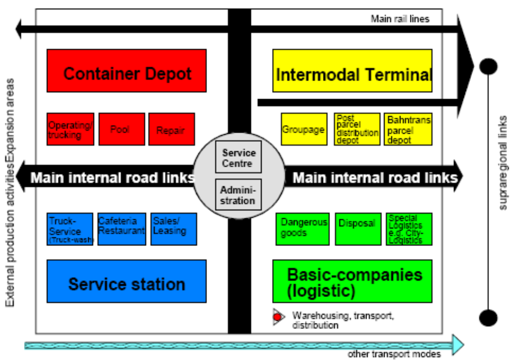
Rail/Road Terminal (Ballis and Golias, 2002)



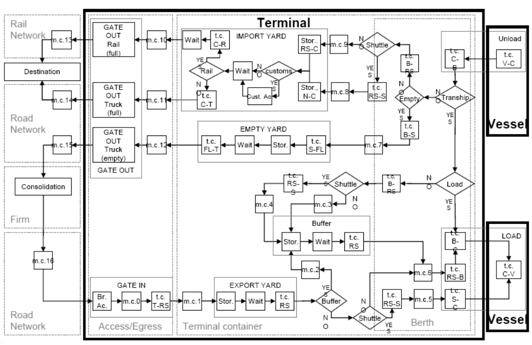
Container Port (Cheung et al., 2002)



Container Port (Henesey, 2004)



Freight Village (SUTRANET Project, 2007)



Container Port (Cantarella et al., 2007)

Figure 1: Models of functional representation of intermodal nodes.

Sector literature includes several examples of functional representation for intermodal nodes (Gambardella et al., 1998; Ballis and Goulias, 2002; Cheung et al., 2002;

Henesey, 2004; Cantarella et al., 2007; SUTRANET, 2007). Figure 1 shows a synthesis of certain functional representations found in sector literature and specifies the represented type of node. Besides goods flows, the so-called "immaterial flows" have also become more and more significant, particularly information exchanges between the subjects within the node and between them and the outside (Gattuso et al., 2005). Figure 2 shows a model of representation of information flows within a port area.

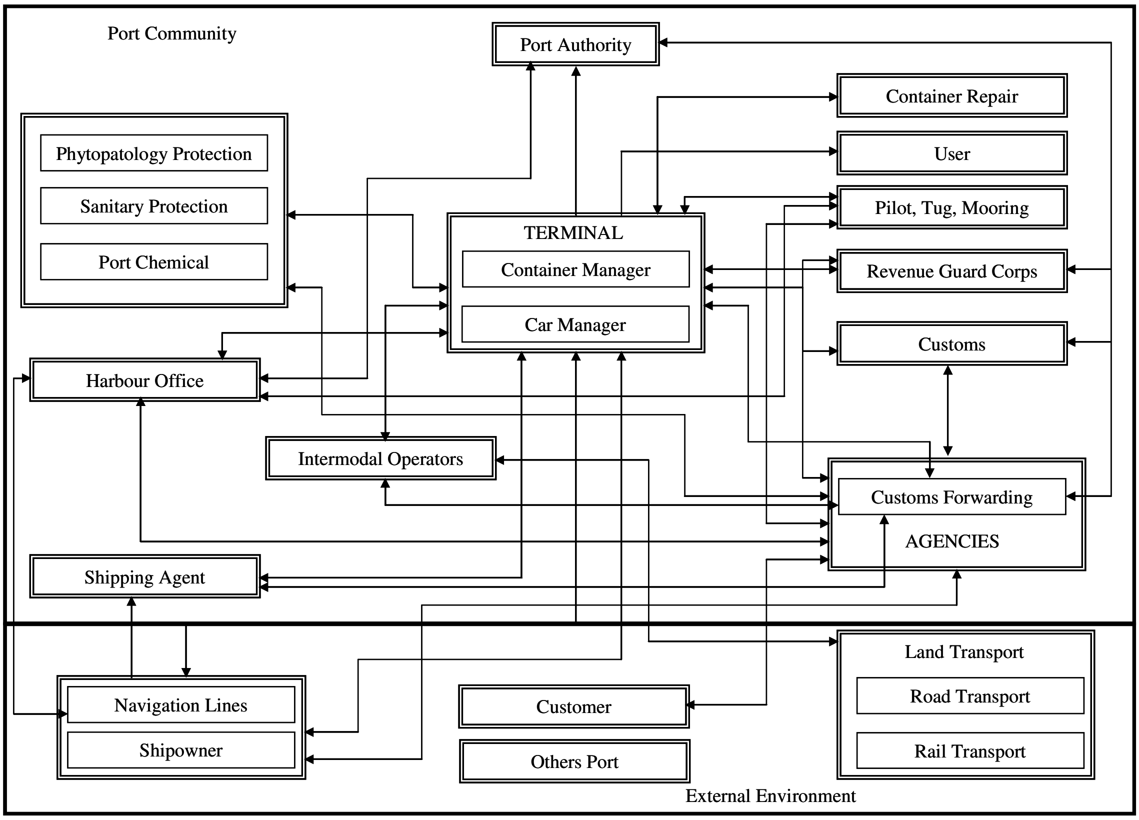


Figure 2: Information flows in the port of Gioia Tauro (Gattuso et al., 2005).

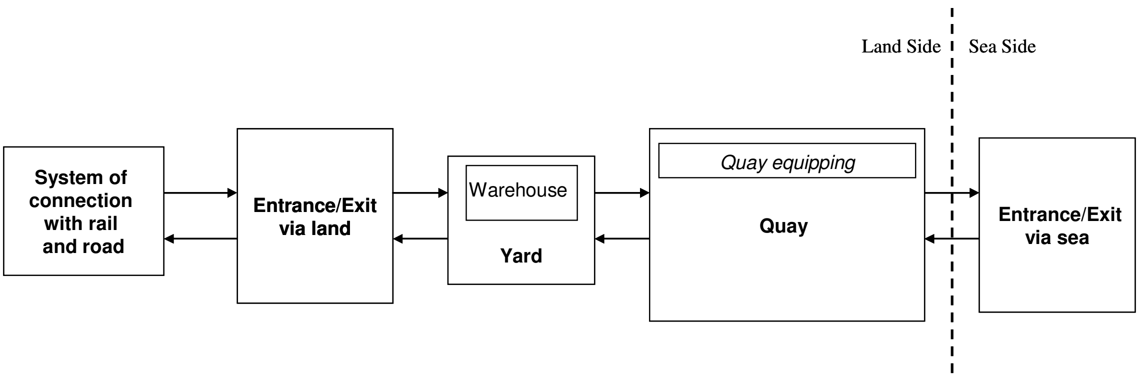


Figure 3: Functional representation of a port.

Ports are intermodal nodes where the waterway transport network is connected with the land transport network. Generally, the port structure can be divided into two macro-blocks: the first identifying sea side activities, the second including land side operations; it is possible to distinguish five functional blocks where different activities are carried out (Figure 3): an entrance via sea; one or several mooring docks; equipment for goods load/unload operations; a yard for goods handling and/or storage with possible sheltered warehouses/depots; an exit gate via land; a system of connection with land transport systems (road and rail).

The functional scheme can be organised depending on the demanded level of detail and on the type of port to represent. Figure 4 shows a proposal of functional representation of a container port. Symbols belong to an international standard language and have specific meanings.

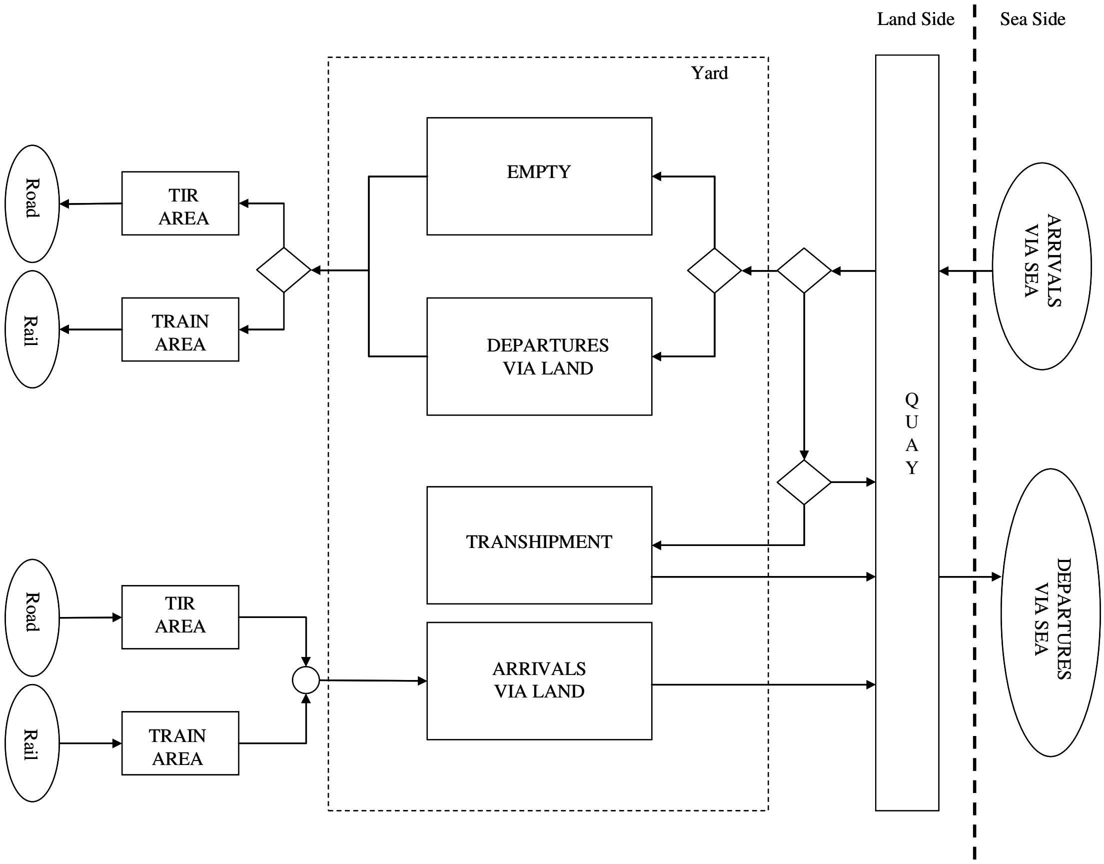


Figure 4: Functional representation of a container port.

The Freight Village is a well organised set of structures and integrated services for the exchange of goods between the different transport modes, which includes, however, a railway station that can form or receive complete trains and is connected with ports, airports and highways (Italian Law n. 240/90).

A Freight Village is a typical infrastructure destined to:

- host transport and logistics companies, as well as product processing businesses;
- integrate the different modes of transport, both in a structural way and through information exchange;
- provide services to the hosted businesses, to goods and people, with a view to enhance the intermodal transport and the storage of products, as well as to assure the control of common areas, the Freight Village entrance and exit, the regular functioning of the technological plants.

On the basis of the above-mentioned functions, as a general rule, it is possible to define 5 functional macro-areas within a Freight Village:

- *the intermodal terminal*: it is the heart of the Freight Village, the place where shunting, change between the different modes of transport (usually road-rail) and load/unload handling occur; it includes a railway station and special warehouses for the temporary storage of goods,
- *the logistic area*: where industrial and productive facilities are located; in this area products are processed/manipulated to gain added value, goods are consolidated/deconsolidated, distributed and collected, or simply stored;
- *administrative area*: it has a central position which is easily accessible by visitors and includes the administrative offices of the Freight Village, of customs and of the fire brigade;
- *commercial area and services to personnel*: it offers tertiary and commercial services to the personnel (restaurant, hotel, bank, post office, etc.);
- *services to vehicles*: where there are parking facilities, assistance to vehicles and repair shops for transport units and unit loads.

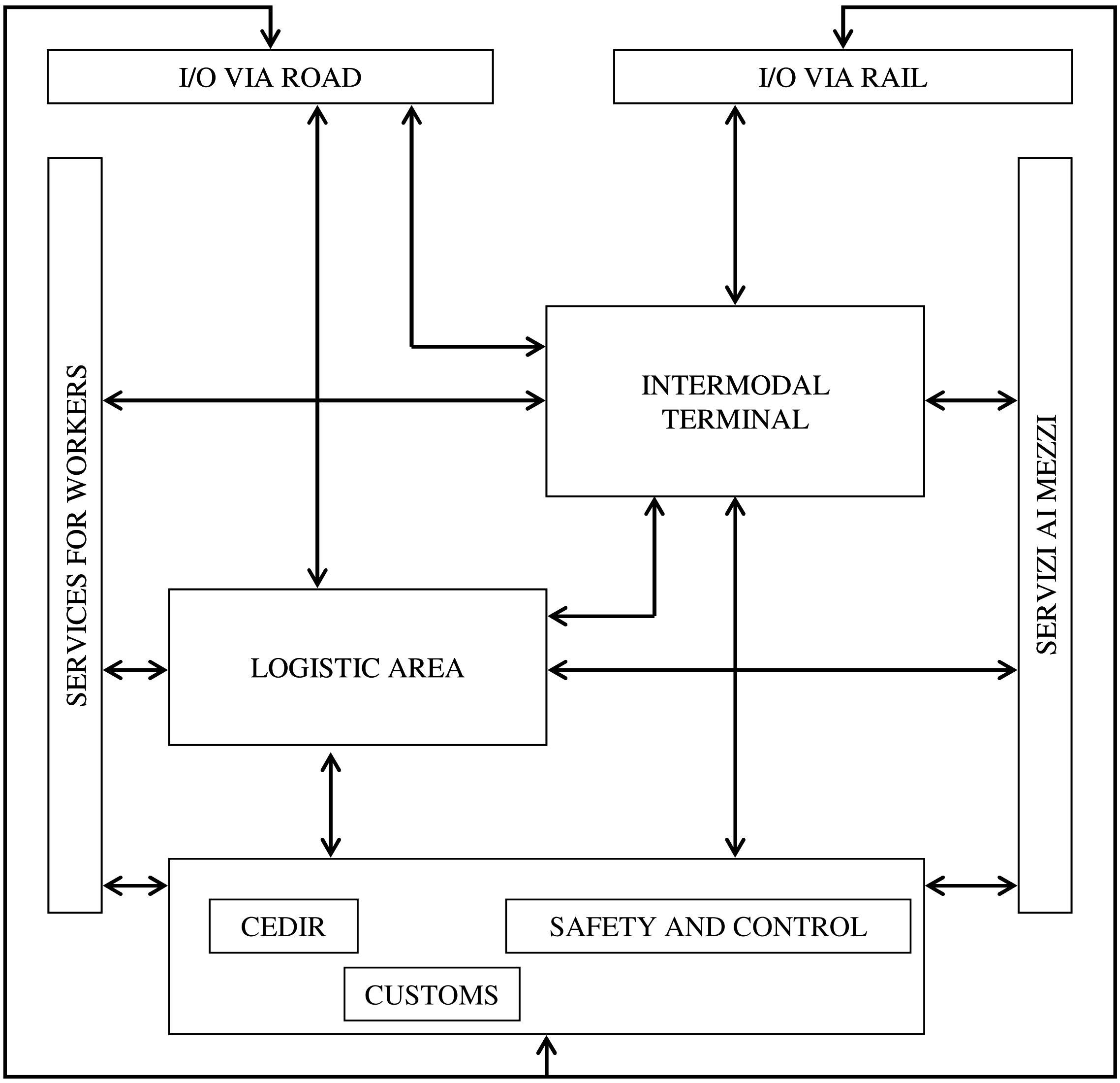


Figure 5: Relations between the areas of Freight Village.

Besides the above-mentioned areas, it is worth mentioning the presence of the road and rail input/output gates. Figure 5 shows the relations between the different functional areas of a Freight Village, while figure 6 proposes a functional representation of the Freight Village node constructed according to the rules of the flow chart theory and taking into account the access/egress functional areas, the intermodal terminal and the logistic area.

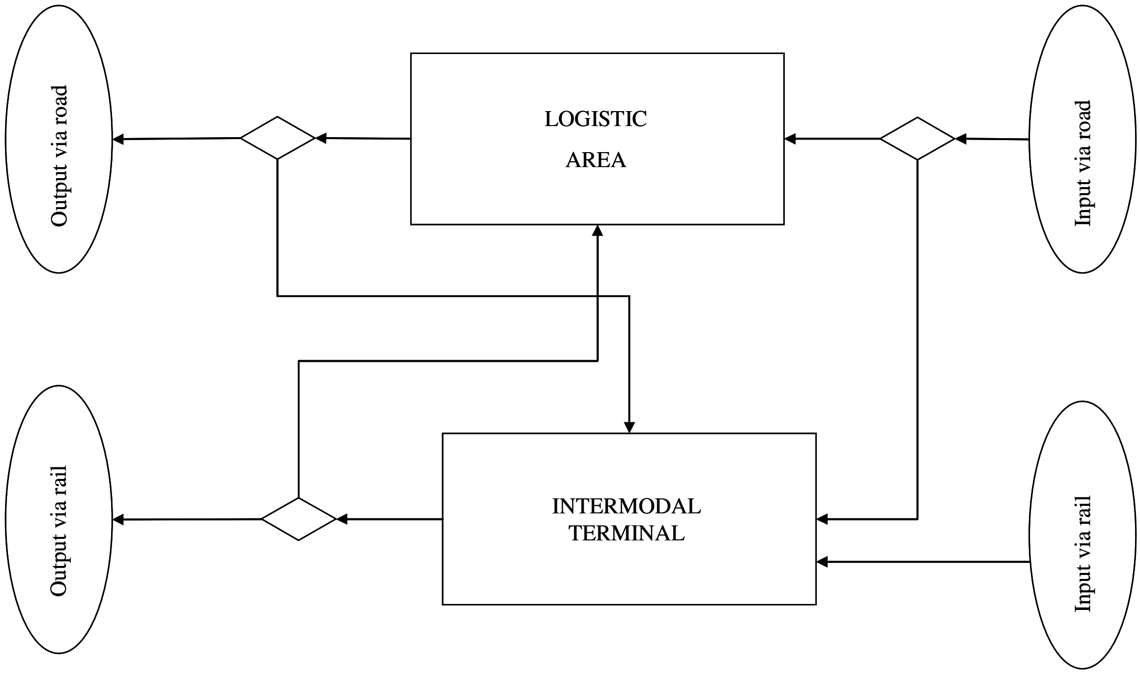


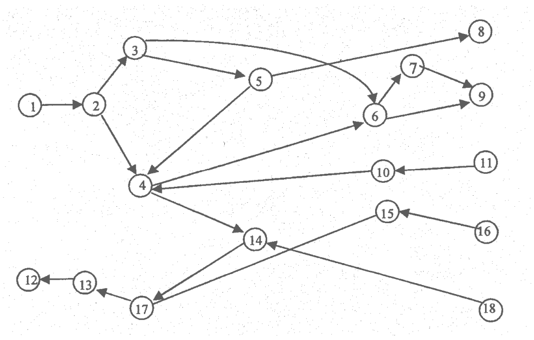
Figure6: Functional representation of a part of Freight Village.

3. Topological representation

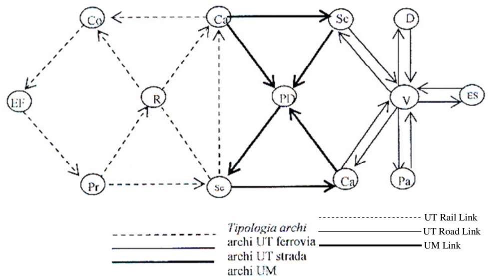
The topological representation of the intermodal logistic node is made through the construction of a graph which allows the precise schematization of its activities. In general, graph nodes represent physical and/or temporal points where an elementary operation, which is part of the transport cycle of goods and of their possible manipulation/processing, starts or finishes; on the contrary, line segments represent goods handling and/or processing operations. After a brief state of the art of the models of topological representation, an alternative network model for a port and a Freight Village is proposed below.

3.1 Literature models

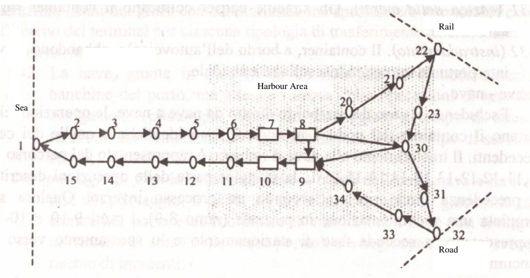
In sector literature there exist several examples of topological representation of intermodal nodes (Pratelli, 2000; Russo, 2000; Gattuso and Musolino, 2002; Gattuso and Chindemi, 2002; Russo and Cartisano, 2005; Gattuso et al., 2008). Figure 7 shows a synthesis of certain topological representations found in Italian sector literature and specifies the represented type of node.



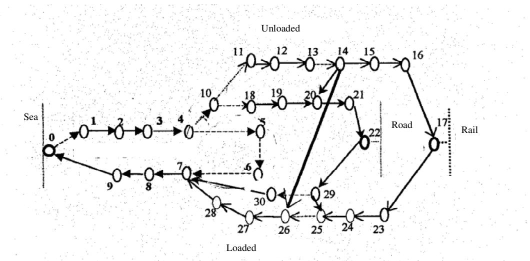
Port (Frankel, 1987)



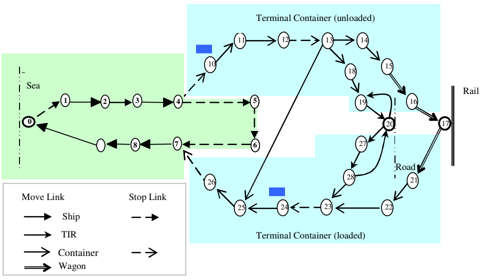
Rail/Road Terminal (Russo, 2000)



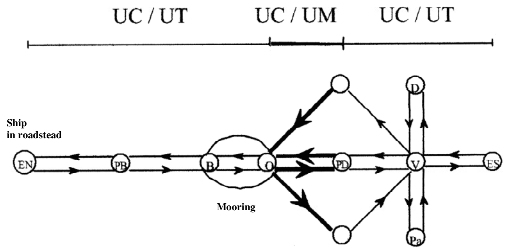
Container Port (Gattuso and Musolino, 2002)



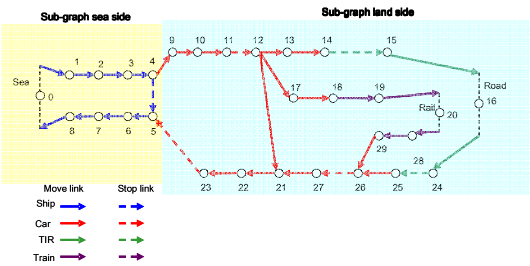
Ro-Ro Port (Gattuso and Chindemi, 2002)



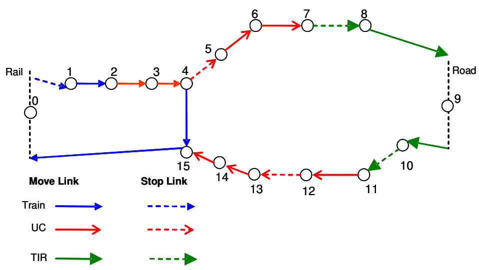
Container Port (Gattuso and Chindemi, 2002)



Ro-Ro Port (Russo and Cartisano, 2005)



Ro-Ro Port (Gattuso et al., 2008)



Rail/Road Terminal (Gattuso et al., 2008)

Figure 7: Models of topological representation of intermodal nodes.

Generally, the schematization of the port functional organization includes the functional relations between dock, goods storage areas (distinguished into import and export areas), intermodal sites, port entrance and exit points. Operations are carried out in the nodes corresponding to exchange relations between different spatial components. The graph can be constructed starting from the hypothesis that the elements, which make up a freight integrated system, can be aggregated into three categories (Russo, 2001): unit loads (UL), handling units (HU) and transport units (TU).

Depending on such elements the port can be divided into three sub-systems: sections where ULs are transported by sea TUs (UL/TU); sections where ULs are transported by HUs within the port (UL/HU); sections where ULs are transported by road TUs (UL/TU). The road-rail intermodal terminal can also be schematised through three sub-graphs: sub-graph of the ULs transported by rail TUs; sub-graph of the ULs transported by road TUs; sub-graph of the ULs transported by HUs. The representation proposed by Gattuso et al. (2002 - 2008) concerns the activities taking place in a Ro-Ro terminal and in a container port. A part of the graph represents seaward operations, the other represents landward handling activities, which are different depending on whether the unit load is a vehicle (lorry, road train or articulated lorry) or a nonmotorised unit (container or semi-trailer).

3.2 Proposed models

An alternative graph for the representation of the various phases of goods handling in a container port terminal and in a Freight Village is proposed below. The previously described models of node representation have been taken into account as points of reference, yet certain further elements have been added. In accordance with the proposed functional representation, the node supply of a container port terminal can be represented by means of a graph divided into two sub-graphs:

- *Sea Side sub-graph*, which schematises the entrance/exit operations via sea, from the entrance of the vessel in the roadstead up to its dock hauling and viceversa;
- *Land Side sub-graph*, which schematises the vessel load/unload operations, handling and storage activities in the yard, goods routing on land transport networks.

Figure 8 shows the schematised graph of the port; in particular, it is possible to distinguish the two sub-graphs, the entrance/exit paths followed by the vessel, by articulated lorries and by trains within the node, the movements of the unit loads (TEUs), the waiting and handling arcs. Besides, in relation on proposed functional representation, it is possible to distinguish start and finish areas of the activity, processing area of the goods, decision and collection point.

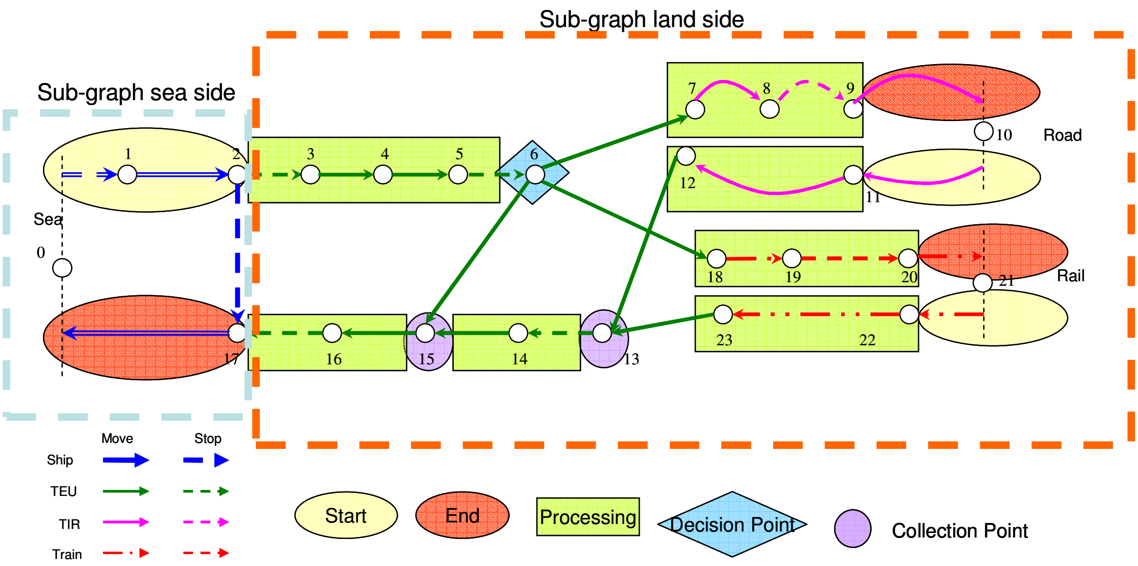


Figure 8: Proposed graph for a container port.

Table 1 shows each arc of the graph with the activity it represents. It is worth noticing that the graph has been constructed considering that the activities of tug and dock mooring are carried out at the same time as pilot activities (from a technical point of view, tug shadows pilot and mooring shadows tug) and that there is no direct ship-ship transhipment.

Table 1: Arcs of the graph of the container port terminal.

Link	*Operation*	*Link*	*Operation*
0-1	Wait in roadstead	12-13	Positioning container in storage area
1-2	Pilot, Tug, Mooring	13-14	Stop container in storage area
2-17	Wait ship for loading/unloading	6-18	Moving container towards train area
2-3	Wait container on the ship	18-19	Loading container on wagon
3-4	Drawing container, positioning in crane buffer	19-20	Formation train
4-5	Positioning container in storage area	20-21	Routing train via rail
5-6	Stop container in storage area	21-22	Entry train to port
6-7	Moving container towards TIR area	22-23	Unloading container to train
7-8	Loading container on TIR	23-13	Positioning container in storage area
8-9	Wait TIR for practices	6-15	Movin container towards quay
9-10	Routing TIR via road	15-16	Loading container on ship
10-11	Entry TIR to port	16-17	Finishing loaded operations
11-12	Unloading Container to TIR	17-0	Unmooring, Pilot, Tug

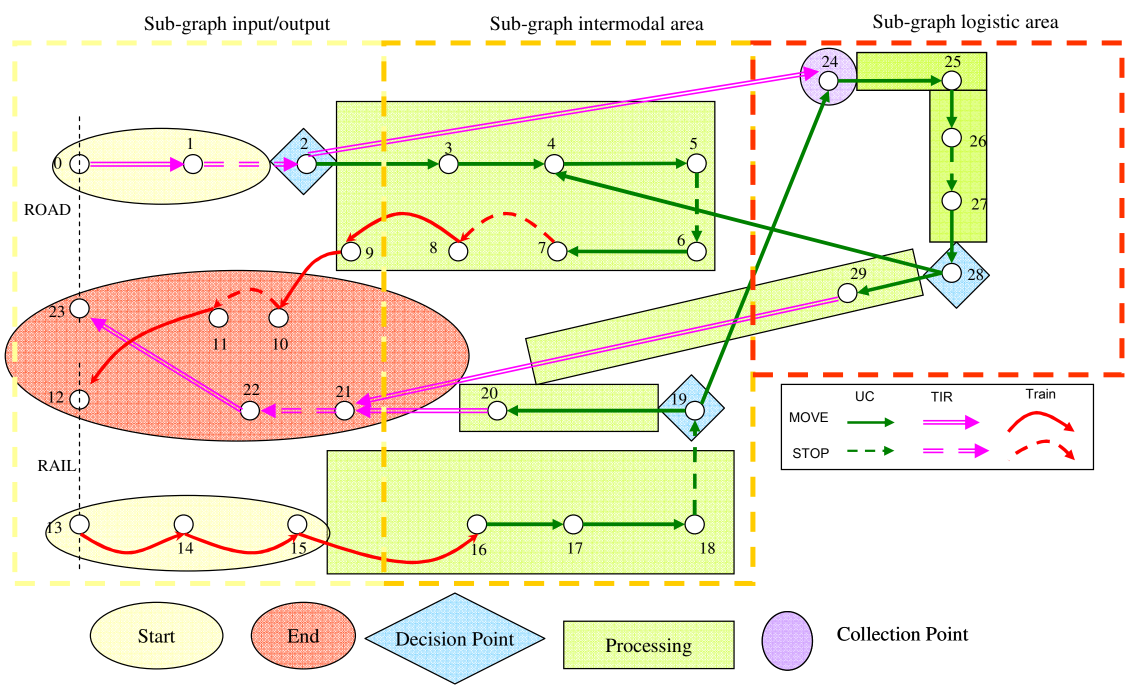


Figure 9: Example of a graph for Freight Village.

In the case of a Freight Village, since its core activities and functions are carried out in the intermodal terminal and in the logistic area, the graph can be divided into 3 sub-graphs:

- *Access/egress sub-graph*, which represents the activities performed at the terminal input/output gates;
- *Intermodal area sub-graph*, which represents the transhipment operations which are carried out in the road-rail intermodal terminal;
- *Logistic area sub-graph*, which represents activities taking place within this area.

Figure 9 proposes an example of graph of a Freight Village where the intermodal terminal is served by transtainer and the length of the operating tracks can assure the handling of a train without sectioning it. Besides, in relation on proposed functional representation, it is possible to distinguish start and finish areas of the activity, processing area of the goods, decision and collection point. Table 2 shows a description of the arcs which form the graph.

Table 2: Arcs of the graph of the Freight Village intermodal terminal.

Link	*Operation*	*Link*	*Operation*
0-1	Entry TIR to freight village	27-28	Loaded preparation
1-2	Check-in operations	28-29	Loading on TIR
2-3	Start TIR towards intermodal terminal	29-21	Start towards exit road gate
2-24	Start TIR towards logistic area	28-4	Start towards intermodal terminal
3-4	Unloading UC to TIR	13-14	Entry train to freight village
4-5	Positioning UC in storage area	14-15	Replacment locomotive
5-6	Wait in storage area	15-16	Start train towards operative railway
6-7	Loading UC on train	16-17	Unloading UC to train
7-8	Finishing train loaded operations	17-18	Positioning UC in storage area
8-9	Start train towards tacking/delivery railway	18-19	Storage
9-10	Replacment locomotive	19-20	Loading UC on TIR
10-11	Wait train	20-21	Start towards exit road gate
11-12	Routine train on railway	21-22	Check-out operations
24-25	Unloading TIRin logistic area	22-23	Introduction on road network
25-26	Treatment, manipulation, manufacturing	19-24	Start UC towards logistic area
26-27	Storage		

4. Analytical representation

To analytically represent an intermodal node means to identify cost functions which allow to evaluate the costs (times) related to the goods transit through that node.

Cost evaluation in intermodal nodes is crucial; in fact, such costs are an important component of the total transport cost. They are costs varying according to the "involved" modes of transport and to the possible storage and processing of the goods in transit.

As a general rule, a cost function can be defined as a function that associates to input and output prices the minimum cost to bear for their production. Formally:

$$C(p,q) = \min_{x}\{p' x : x \in L(q)\}$$

where x is the input vector, p is the vector of the relative prices, q is the vector of productions and $L(q)$ is the input requirement set of the vector of productions q, that is, the set of input combinations which allow the production of q.

From the point of view of a Multimodal Transport Operator (MTO), the monetary cost Cp , associated to the goods transit in the node, can be evaluated as a function of the quantity Q of handled goods through the following expression:

$$C_n = \delta \cdot Q$$

where δ is a unit cost parameter (€/t) which has different values depending on the type of node (Table 3).

Table 3: Values of parameter δ.

Source	*Node*	*δ (€/t)*
SCENES (2000)	Container port	5,6
UIC (2006)	Railway terminal in Europe	3,4
UIC (2006)	Railway terminal in East Europe	6,6

It is possible to evaluate the cost of the transit through the node as a function of the number N of the handled ULs:

$$C_n = \alpha \cdot N$$

where α is expressed in €/UL and varies depending on the type of node and performed operation (Table 4).

Table 4:Values of parameter α (RECORDIT, 2003).

Node	*Operation*	*α (€/UC)*
Railway terminal	Road-Rail Transhipment	32,50
	Rail-Rail Transhipment	27,40
Port	Road-Sea Transhipment	24,00
	Sea-Rail Transhipment	40,00

The cost in the node can be more precisely evaluated as the sum of the costs of the UL entrance/exit operations through the gates ($C_{i/u}$), of the storage in the terminal (C_s), of the transhipment on train or lorry (C_t), of the expenses related to goods delivery and customs operations (C_v), of the expenses of possible manipulation/processing (C_l):

$$C_n = C_{i/u} + C_s + C_t + C_v + C_l \; .$$

Specifically referring to an intermodal port, it is suitable to underline that the entrance/exit cost is generally included in the fare the MTO pays to the shipping company for the sea transport service. If a vessel is taken into account as a transport unit, for a shipping company such a cost is given by the sum of the pilot, tug and mooring costs (Figure 10).

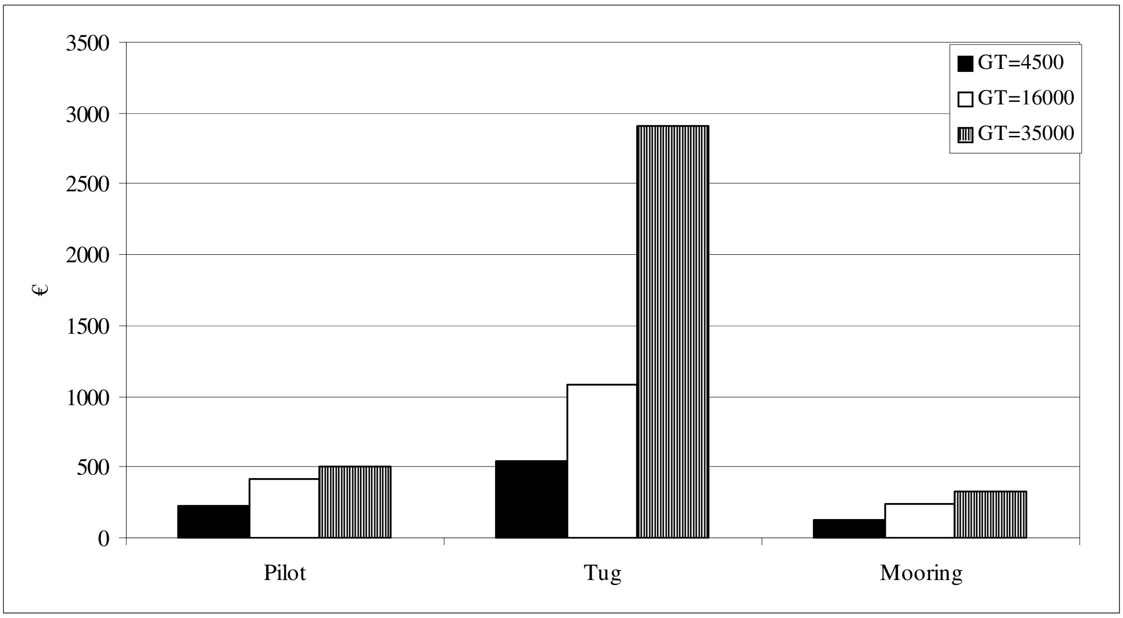


Figure 10: Average cost of port entrance/exit for a vessel.

It can be observed that the vessel entrance/exit cost increases in proportion to the vessel gross tonnage (GT); the tug cost is the most significant. On the contrary, the costs of storage, transhipment, customs and possible processing/manipulation depend on the quantity of goods, that is, on the number of unit loads handled on the land side of the port. Such costs significantly change according to the goods dwell time in the node, to the quantity of goods, to the involved modes of transport.

The temporal cost (T_n) associated to the goods transit through the node can be evaluated as the sum of the node entrance/exit time ($T_{i/u}$), of the time of UL load/unload from the transport unit ($T_{c/s}$), of the UL waiting time and downtime in the node (T_{att}), of the handling time for the transfer of the UL from an area of the node to another (T_{mov}):

$$T_n = T_{i/u} + T_{c/s} + T_{att} + T_{mov}$$

In the case of a port, entrance/exit times depend on the type of port and on its physical characteristics; table 5 shows certain estimations of entrance/exit times for different types of port (Ro-Ro and Lo-Lo).

Table 5: Entrance/exit times.

Source	*Port*	T_{entry} *(h)*	T_{exit} *(h)*
Russo and Cartisano, 2005	Ro-Ro	0,47	0,41
	Lo-Lo	0,40	0,37
Marino S. (2000)	Ro-Ro	0,50	0,50

The time necessary to carry out load/unload operations is a function of the number and type of unit loads to handle, of the type and number of the used handling units and of their net productivity.

In the case of a Ro-Ro port, where semi-trailers are handled, such a time can be evaluated as (Russo e Cartisano, 2005):

$$T_{c/s} = \beta_1 \cdot NT + \beta_2 \cdot NS / NT$$

where *NT* is the number of trailers used for handling, *NS* is the number of handled semi-trailers, β_1 and β_2 are model parameters (Table 6) which can vary depending on whether a load or unload operation is being carried out.

Table 6: Values of parameters β_1 and β_2 (Russo and Cartisano, 2005).

Operation	β_1	β_2
Loading	0,18	0,12
Unloading	0,17	0,16

In the case of a container port, load/unload time can be evaluated as (Russo e Cartisano, 2005):

$$T_{c/s} = \beta \cdot N$$

where *N* is the number of loaded/unloaded containers and β is the model parameter equal to 0.08, if the unload phase is considered, and to 0.07, if the load phase is considered. Table 7 shows certain values relative to the waiting and handling times in a container port according to the modal transfer.

Table 7: Average waiting and handling times in a container port (Gattuso and Musolino, 2002).

	S-S	*S-T*	*T-S*	*S-C*	*C-S*
T_w (h)	146	12	36	12	24
T_{mov} (h)	0,42	0,36	0,71	0,55	0,83

Notes: S= Ship; T= Train; C=Truck.

5. Conclusions

The supply representation for the intermodal node is a fundamental element for the definition of procedures to optimise the performances of the node and of a logistic chain. The functional representation allows analyses of the spatial and organizational structure of the node. The topological representation provides a precise schematization of the activities, which are carried out in the node, through the construction of graphs. The analytical representation allows to evaluate the cost components, related to the goods transit through the node, in temporal and monetary terms.

This paper proposes certain functional and topological representations for intermodal ports and Freight Villages, highlighting the relations existing between the different functional parts of the two terminal systems.

Further research is directed to the specification and calibration of cost functions for the estimation of the costs related to the goods transit through ports and Freight Villages, with a view to facilitate the analyses of goods mobility on multimodal networks.

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