National and Local Factors Affecting Ship Time in Container Ports: System of Models at Country and Port Levels

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| Abstract | Ship time in port may be considered as an indicator of the performance of a port, and of a country, in order to compete in the international trade challenge. The general objective of the research concerns the development of a system of models that correlates the average ship times in port with various factors, or attributes, related to the port or to the country that hosts the port.<br>The attributes are related, in general, to the position and role of the ports; the organization of the maritime services; the administration and legislation of the country to which the port belong; the material and immaterial infrastructures of the port; the port accessibility of the land side. The system of models proposed include models to evaluate maritime services, based on a network approach; to evaluate path choices of commercial vehicles travelling to/from the ports, based on discrete choice models; and to evaluate land use of the port hinterland, according to the smart paradigm. The developed models rely upon the Transport Systems Models theory, that in general simulate the interaction between transport users and (congested) networks generating flows and costs. The paper presents the methodological background and the expected results of the proposed system of models implemented inside the research project. |
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| Keywords<br>(separated by '-') | commercial ports - times of ships in container ports - Transport System Models (TSMs) - Spatial Economic Models (SEMs) - quantitative models |

# National and Local Factors Affecting Ship Time in Container Ports: System of Models at Country and Port Levels

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**Abstract.** Ship time in port may be considered as an indicator of the performance of a port, and of a country, in order to compete in the international trade challenge. The general objective of the research concerns the development of a system of models that correlates the average ship times in port with various factors, or attributes, related to the port or to the country that hosts the port.

The attributes are related, in general, to the position and role of the ports; the organization of the maritime services; the administration and legislation of the country to which the port belong; the material and immaterial infrastructures of the port; the port accessibility of the land side. The system of models proposed include models to evaluate maritime services, based on a network approach; to evaluate path choices of commercial vehicles travelling to/from the ports, based on discrete choice models; and to evaluate land use of the port hinterland, according to the smart paradigm. The developed models rely upon the Transport Systems Models theory, that in general simulate the interaction between transport users and (congested) networks generating flows and costs. The paper presents the methodological background and the expected results of the proposed system of models implemented inside the research project.

**Keywords:** commercial ports · times of ships in container ports · Transport System Models (TSMs) · Spatial Economic Models (SEMs) · quantitative models

## 1 Introduction

Commercial ports are classified according to different criteria in the scientific and technical literature. The challenge in establishing a universally accepted classification is due to their heterogeneous nature. UNCTAD introduced the concept of port-generation and sketched three generations of port in 1994 [1]. Port belonging to the first generation are historic multipurpose/multifunction ports that are located close to the urban centres. The second generation includes industrial ports strategically located in proximity to great power and steel production facilities. The third generation includes ports which handle relevant volumes of containerized traffic and increase the added value of freight


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in transit. UNCTAD later sketched the characteristics of the fourth-generation ports [2], which change their attitude with closer ports from a competitive into a cooperative one. The study in [3] introduces a theoretical model that allow to evaluate the competitive and/or cooperative attitudes among two ports Lastly, the fifth-generation port was introduced which incorporate emerging information and communication technology that acts as integrator for different port actors and functions. Some details about the above scientific debate may be found in several publications of the authors ([4–8], and references included).

The research on ports belonging to the third-generation focused on the port areas, where handling and transport operations take place, and the port hinterland, where manufacturing activities may be located increasing the added value of handled freight inside the port. Two recent studies [9, 10] compare some aggregate characteristics of different countries showing relevant differences in import/export times, as reported in the study [11]. The case of Europe is emblematic, where the export times of goods show a great variability between countries compared to the average value of 10 days. Afterwards, the Italian Prime Minister presented an analysis of the time components related to export procedures: documentation, customs, handling and transportation [12]. The analysis showed that differences in average export times of freight depend on documentation and handling times in each country, while times for custom operation seem to be similar in the examined countries.

Given the above context, two main research questions arise: which are the determinants that affects time of ships in container ports? Is it possible to estimate models that relate time of ships in container ports to national and local factors?

The main objective of the ongoing research project aims to respond to the above research questions by providing a spatial analysis of ship times across container ports of the world. The methodologies that are used in the research project have their theoretical background in Transport Systems Models (TSMs) and Spatial Economic Models (SEMs) ([13–17]; among the others).

The following part of the paper will be articulated as follows. Section 2 reports the state of the art about models composing the modelling framework adopted in the research project. Section 3 briefly sketches each model's characteristics in terms of theoretical background and reference equations. The last section presents the expected results of the project.

## 2 State of the Art

The existing literature reveals the absence of systematic studies where the relationship between the ship times in container ports and national and local factors is analysed. Existing analyses concentrate on individual ports or terminals with few comparative studies [18–21]. In particular, the study in [19] reveals that ship times are influenced by attributes belonging to three homogeneous classes: the size of the ships; the level of the economy, the logistic services and maritime connections.

The literature about freight transport modelling concerns two levels [16, 17, 22, 23]. Commodity-based models estimate the amount of freight produced and consumed, focusing on aggregate costs of production, consumption and trade. Vehicle-based models estimate the mode/service/route used to transport the freight in relation to transportation and logistics costs.

The analysis on the literature about the two above level of model reveals the presence of quantitative methods and models grouped into two frameworks: TSM and SEMs.

TSMs simulate how passengers, or freight transport operators, use the transport infrastructures and services. TSMs are composed by three modelling elements: the supply, the travel demand, and the assignment models.

The supply model calculates the costs of transport connected to the use of infrastructures and services. Transport supply models may be classified in [20, 24]:

- analytic, adopting a representation of maritime and terrestrial infrastructures and services in an aggregate form;
- topologic, adopting a network model by constricting a graph (nodes and links) and relative cost functions.

The supply models allow to study the level of centrality that each port has in the maritime services system at international scale. The study of the different types of centrality is carried out using the formulation produced in the context of network analysis (see [25–27], and references included).

The travel demand models estimate the choices of users based on the transport costs. Freight demand models can be divided into three categories.

- Statistical-descriptive models calculate maritime flows of freight according to attributes connected to the level of service of the existing network and to the level of economy of production-consumption regions.
- Time series models calculate maritime flows of freight by means of historical data about flows and other attributes.
- Partial-share models calculate the structure of choices in terms of trip generation/attraction, distribution, maritime service and port, maritime line (seaside), and path (landside).

In particular, the path choice model evaluates the percentage of choice that the user assigns to each available alternative. Based on the model proposed in [28], the main models proposed belong to the category of random [14], fuzzy [29, 30] and quantum [31] utility models.

The supply-demand interaction models allow the calculation of the interaction between the user's choices and the costs of transport infrastructures and services. The model in urban area and for ordinary conditions generally relies on the concept of equilibrium [14, 32].

SEMs simulate one or more components of the spatial economic system. They generally refer to the so-called production–consumption paradigm, composed of two modelling components.

- The generation models calculate the a-spatial production and consumption levels. They belong to two classes: the microeconomic one calculates the behaviour of individuals though individual demand and production theories; the macroeconomic one calculates the average behaviour of groups of individuals through variables and relationships that exist between them.

- The location models calculate the amount of freight produced and consumed in a region. The location models belong to two main categories: aggregated models are generally based on entropy maximisation theory; disaggregated models may rely to random utility theory.

SEMs and TSMs are jointly used to calculate the relationships between economic and transport systems, which are called Spatial Economic Transport Interactions (SETI) models. The SE component calculates the level and spatial distribution of production-consumption of freight among regions that concur to the configuration of freight flows; while the T component calculates the transport and logistic costs that influences the fright production-consumption location ([14, 15, 17], and references included).

SETI models are grouped into two classes According to the spatial scale examined. National Economic Transport Interaction (NETI) models are used for the country or regional scales, while Land Use Transport Interaction (LUTI) models are used for the urban scale. In particular, land use models developed for port areas support the evaluation of the integration of the port functions with the infrastructural system of the surrounding area. The port has an added value if it speeds up the transit of goods by taking advantage of efficient correlations with territorial system and service facilities, such as dotation of material and immaterial infrastructures and a research centre.

## 3 Methods

The methodologies that are used in the research project have their theoretical background in TSMs and SEMs frameworks, briefly recalled in the previous section.

The methodologies used in the research project operate at country and port levels (Fig. 1).

The methodologies concern the following elements:

- maritime services, constructing network topology of the main connections provided by the existing container line services;
- port ship times, identifying and calculating the determinants of ship times in container ports based on various attributes on different nature: infrastructural, technological and operational;
- path choice, building path choice models for users that can model and simulate choice behaviour in the road transport system;
- land use, evaluating the land use of the port hinterland, according to the smart paradigm.

### 3.1 Maritime Services Models

Maritime services are represented adopting the topologic approach, supported by the information deriving from AIS data [33]. Maritime transport supply model consists of a network constituted by:

- a set of nodes that represent ports and way points for identify sea routes connecting couple of ports;

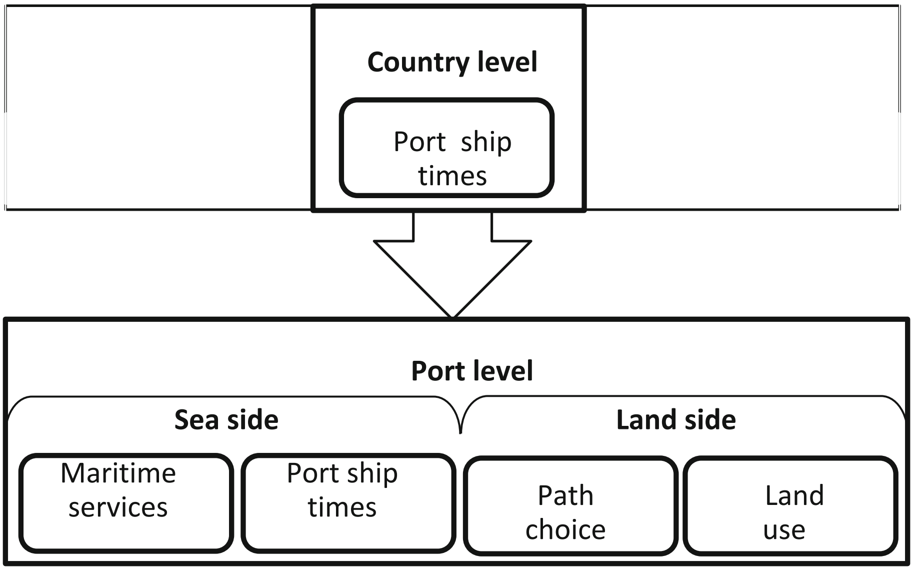


**Fig. 1.** Modelling framework for the evaluation of port ship times.

- a set of links connecting the nodes representing the sea routes or the sequence of nodes that, with a generic service, connects two ports;
- a set of cost functions for representing performances of ports and sea routes (times, costs, …).

By selecting a specific port, AIS data can be used for reconstructing the main maritime services (e.g. containerships lines) that connect the port with other terminals. By using clustering methods, it is possible to individuate nodes and links. Cost functions can be specified and calibrated in relation to the final aim of the applications.

By following the TSM approach, the topology is represented with the following elements [34]:

$\delta_{ak}$, element of the link-path incidence matrix;
$c_a$, cost on link a (e.g. travel time);
$g_k = \Sigma_a \delta_{ak} c_a$, additive cost on path k;
$g_k^{NA}$, non additive cost on path k;
$f_a$, flow on link a;
$h_k$, flow on path k.

According to the above elements, the maritime transport network model is represented with the following formulations.

- Link and path generalized costs:

$$g_k = \Sigma_a \delta_{ak} c_a + g_k^{NA} \tag{1}$$

- Link and path flows:

$$f_a = \Sigma_k \delta_{ak} h_k \quad (2)$$

- Link cost functions:

$$c_a = \gamma(f_a)$$

where
$\gamma(\cdot)$ is the link–cost flow function.

### 3.2 Port Ship Times Models

The models used in the research belong to the class of statistical-descriptive. The relationship defined is supposed to be one-way cause-and-effect.

Ship times in container ports are generally influenced by the following factors:

- role of the port in the supply-chain (e.g. hub port, feeder port) and structure maritime services;
- organization of administration and legislation (e.g. documentation, custom operations);
- port infrastructures (e.g. quays, dock, draught, last-mile connections);
- Information and Communication Technologies (e.g. port community systems, internet-of-things, digital twins).

The general functional form of the model is:

$$t = t(\mathbf{x}; \boldsymbol{\beta}) + \varepsilon \quad (3)$$

where
$\mathbf{x}$ is a vector of port and ship attributes, where the port attributes may belong to the different categories described above;
t is the ship time;
$\boldsymbol{\beta}$ is a vector of unknown parameters;
$t()$ is a function;
$\varepsilon$ is the error term.
By assuming that $t()$ is linear, Eq. (3) is specified as follows:

$$t = \beta_0 + \Sigma_j \beta_j x_j + \varepsilon \quad (4)$$

where:
$x_j$ is the generic attribute;
$\beta_0$ and $\beta_j$ are components of vector $\boldsymbol{\beta}$.
The vector of parameters, $\boldsymbol{\beta}$, is calibrated by means of the Least Squares (LS) method. A vector $\boldsymbol{\beta}_{LS}$ is estimated which minimizes the distances between the observed values $t_i$ and the values calculated with (4).

The method may be applied both at country and port levels (see Fig. 1). In case of application at country level, the ship times observed, $t_{obs,i}$, and calculated with Eq. (4), and the attributes, $x_{j,i}$, are average values calculated for each country.

### 3.3 Path Choice Models

Ports can also enable the transfer of goods to and from the mainland. The transfer can mainly take place with the use of two modes of transport: road and rail. Road is used for medium-short distances considering that the mode transfer is more flexible than by rail and, in general, there are no constraints on the use of road infrastructure; rail is used for long distances to allow where possible to amortise the costs of intermodal transfers, the composition and completion of train loads, and the slots available on rail.

The route choice on rail is constrained and decided by the company that organizes the services according to the train paths made available and planned over the long term. Path choice in the road system, on the other hand, is left to the operator who transports the goods, with or without the support of systems that advise or impose the pre-trip and/or en-route. Therefore, it is necessary to build path choice models for users that can model and simulate choice behaviour in the road transport system. These models can support the decision maker in estimating the effects on the road system resulting from freight vehicles with destination or origin in ports [35].

The path choice model considers two levels of choice referred to in this paper as Perception (P) and Choice (C). At each of the two levels, a utility function and a choice model are defined.

For an alternative, the utility function, $\upsilon(\mathbf{x}, \boldsymbol{\beta})$, depends on measurable attributes (vector $\mathbf{x}$) and parameters to be calibrated (vector $\boldsymbol{\beta}$). The utility function is non-deterministic (e.g. random, fuzzy, quantum) considering that the analyst does not know exactly how the users' behaviour and the user and analyst do not know exactly the characteristics of the transport system. It is therefore possible to calculate the percentage of choice, $p()$, of each alternative (probability in the random and quantum case and possibility in the fuzzy case) by comparing the utilities of the different alternatives.

Considering the two levels of choice denoted by subscript P and C respectively, the probability of choice of a k route alternative is obtained using the following model [28]:

$$\mathrm{p}(\mathrm{k}|\boldsymbol{\upsilon}_P(\cdot), \boldsymbol{\upsilon}_C(\cdot)) = \sum\nolimits_{\mathrm{Ii}} \mathrm{p_P}(\mathrm{I_i}|\boldsymbol{\upsilon}_P(\cdot))\cdot \mathrm{p_C}(\mathrm{k}|\mathrm{I_i}, \cdot\, \boldsymbol{\upsilon}_C(\cdot)) \tag{5}$$

having indicated with $\mathrm{I_i}$ the generic perceived set of choice and with $\boldsymbol{\upsilon}(\cdot)$ the vector containing the utility functions, separated for levels P and C.

If only one perceived set is considered, the previous model degenerates into a single level, with only the choice model applied to the only perceived set I:

$$\mathrm{p}(\mathrm{k}|\boldsymbol{\upsilon}_C(\cdot)) = \mathrm{p_C}(\mathrm{k}|\mathrm{I}, \cdot\, \boldsymbol{\upsilon}_C(\cdot)) \tag{6}$$

Starting from path choice models, the land-side accessibility can be evaluated.

### 3.4 Land Use Models

The literature on examples of ports confirms that an important transport infrastructure, such as the case of the port system, must interact with urban and regional areas to maximize profits [36–38].

The big transport nodes such as high-speed railway stations, international airports, inter-continental ports, are often new constructions that invade an already defined territory. The node overlaps with a pre-existing territorial system with considerable difficulties of integration.

The huge project remains closed inside its own limit, inside a system organized exclusively for the function it performs. Therefore, although it is a production system of considerable value, it is not proactive for the territory. This is a limitation, both for the territory that must suffer a massive structure, and for the node that does not use external service infrastructures.

Not having connections, other to causing a conflict with the territory and a strong negative impact, does not permit to benefit from the fruit of relationships, which would instead transform the productive value into added value, increasing its efficiency.

The closed port in itself does not trigger added value. The activities take place within the boundary of the structure and do not increase the benefits.

It is crucial to create proactive connections between the mega infrastructure and the surrounding territorial system.

The lack of integration, with existing or potential systems, does not allow us to take advantage of the opportunities that the territory owns.

The mega structure, without the smart planning process, is unable to integrate into the territory, use services, trigger new development opportunities.

The input that the territory can give is to provide centralized services, production factors of increase for the development of the port.

The key objectives to consider are:

- agile and frequent connections between the node and the territorial network;
- an intermodal exchange infrastructure;
- ability to trigger new functions;
- offer of services and activities, integrated between the node and the neighboring territorial systems.

## 4 Expected Results and Future Work

Some expected results will be obtained by means of Automatic Identification System (AIS) data, which were initially used to avoid ship collision accidents and, later, their usage expanded to monitor the ships along their maritime routes and inside ports.

The application of AIS data ranges from navigation analysis to ships flow estimation, from pollutant emissions estimation to the evaluation of the ship performances. AIS provides a huge amount of data about ships (e.g., real-time position, route followed) that can be combined with supplementary data (e.g., ports and ships characteristics). AIS data represents the spatial characterization of the trips made by ships. In particular, the AIS provides (among the other ones) the arrival/departure times of the ships from/to the port, allowing to analyse the ship time in port, also called vessel turnaround time, and providing the inputs to define a model able to relate such a time to a set of attributes [39, 40].

The following part of the paragraph reports the expected results in each modelling component of the framework.

The adopted network approach for modelling maritime transport networks, supported by AIS data, will allow to estimate the current performances of port infrastructure and maritime line services. Different configurations of maritime infrastructure and services can be defined by evaluating the main issues of the current network. In the future, it will be possible to experiment different specifications of cost functions of maritime transport networks to better represent current configurations as the volume and variety of AIS big data increases.

The route choice models will make it possible to estimate the percentages of choice in the different alternatives and, thus, also the possibility of estimating the additional load on the road transport network, assuming known travel demand to and from the port broken down by vehicle type and time slot. The route choice model allows also the estimation of the land-side accessibility. The results of the research project concern the type of models to be adopted in the two levels of perception-choice. One could also investigate the possibility of applying different types in the two levels of choice (e.g. quantum and random).

If the port produces value only from transport activities, the convenience will be limited to the supply of the system organized within the limit of its structure. The smart planning process will be tested to plan the integration between the node and the territorial system and to implement the port's supply. The plan proposes useful connections to use existing or potential services and to facilitate port operations. The plan designs new scenarios to meet complex objectives, decisive for integrated opportunities for sustainable development and new smart territories.

Finally, the ship time in port may be a synthetic indicator of the performance of each country and of each container port to compete in the international trade challenges. Specifically, ship times in port are a useful benchmark for evaluating countries and ports' ability to efficiently handle container flows within their terminals. At European level, these times influence competition between Northern and Southern range gateways. The gateways are relevant elements of Trans-European Networks – Transport (TEN-T) and relative infrastructural and commercial corridors (Railway Freight Corridors-RFCs). The research's products contribute to increase knowledge about TEN-T perspectives in terms of effects produced by planned interventions on links (e.g. railway links) and AQ1 nodes (e.g. ports).

The approach proposed in the research project will be also fruitful in terms of knowledge improvements because it will allow to test the level of dependency of ship times in ports upon national and local attributes both at country level and port levels, provided by international institutes.

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