

State of the Art of Factors Affecting Times of Ships in Container Ports: Characteristics Identification of Port Generations

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Abstract. Several classifications of ports were proposed in the literature, but there is no single established or accepted framework or taxonomy due to the complexity and diversity of the port entities. UNCTAD introduced a classification based on the definition of port-generation, according to which a prevalent port's characteristics could be associated to each port, the so-called generation. UNCTAD fully defined the characteristics of three generations of ports, while the fourth-generation of ports was less specified. Later, several researchers criticized the definition of port-generation and proposed new elements of classification, mainly of qualitative nature. Today five generations of ports may be identified. The paper proposes a set of characteristics to identify each port-generation. Several ports were object, in the time, of a process of hybridization. They were born with specific characteristics and, later, they evolved in acquiring new ones. The paper de-build the hybridization offering the possibility to identify the operative single generation. The paper introduces a set of material and immaterial characteristics to identify the port generation and then the correct tools to support planning and evaluation activities.

Keywords: commercial ports · port-generation approach · time of ships in port · port classification

1 Introduction

There have been different attempts to establish categorizations for ports in various scientific and technical works. The challenge in identifying universally accepted classifications arises from the complex and diverse nature of port systems. In 1994, UNCTAD [1] introduced the notion of "generation" and outlined the distinctive characteristics of three generations of ports. The characteristics of the three generations are summarized below; it should be noted that these have had, and have, a wide sharing in international literature.

First generation ports are those located just near cities and are an integral part of urban areas. These ports essentially give rise to cities, with urban centres evolving alongside port development [2–4]. Cities rely on their ports to receive supplies of goods consumed within them; the goods produced are transported to other cities via maritime

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routes. Initially, ships arriving in these ports handled both freight and passenger traffic indiscriminately. Today the two traffics are mainly segmented with ships specifically destined for each type of traffic.

Second generation ports developed in line with the significant industrial advances of the 20th century. Key industries of economic development, such as steel, petrochemicals and energy, have played a fundamental role in the creation of these ports. The physical and technological infrastructures differ significantly from those of first-generation ports. Second generation ports are characterized by large yards adjacent to the docks, or oil terminals, or more generally energy terminals, equipped with advanced security measures and directly integrated with oil pipelines and electricity networks [5–7]. In territorial development, priorities are reversed: industrial plants are built first, and then ports are built, to support large energy and metallurgical plants. The ships that call at these ports are always specialized, in particular oil and gas tankers.

Third generation ports emerged with the advent of containerized shipping during the second half of the 20th century. Since then, container shipping has increasingly become the most efficient way of transporting goods [8, 9], using a structure of service defined hub and spoke. The importance of the generic port as a hub of a system depends on its degree of centrality [2, 10–12]. These ports are equipped with well-defined technical and operational characteristics, including long quays, deep drafts, large container yards. Furthermore, these ports are equipped with a specific fleet of machines linked to their main functions: rail-mounted quay cranes over 50 m high; straddle carriers for distribution in yards; wheeled convoys serving the cranes; reach stackers for stacking empty containers. Unlike other, third generation ports not only serve as hubs for containerized transport, but they are often vital nodes within the global supply chain; that is, in these ports a significant added value is generated on freight in transit. The ability to generate added value distinguishes them from first- and second-generation ports, which functioned primarily as cost centers, even if costs are highly optimized. Third generation ports have required the development of significant research which has focused on two key territorial elements [12]: the areas internal to the port, which are important for the efficiency of handling, loading and unloading, and transportation [13, 14]; the port hinterland, where activities related to the handling of freight develop and where the increase in added value of the freight passing through is therefore obtained [15–17].

UNCTAD subsequently [18] introduced the concept of fourth generation ports [19, 20], further proposals have been made to define the characteristics of fifth generation ports [21–23], but the technical and scientific debate is still ongoing, on these last two generations [24, 25], and there is no single shared definition. The evolution of port-generation is depicted in Fig. 1, where it is possible to identify a historical period in which each generation of ports was born.

The paper presents a state of the art on the port-generation approach and proposes a set of characteristics to identify each port-generation. The work is part of an ongoing research project titled “National and local factors affecting times of ships in container ports” composed of different research lines. Among them, it is worth recalling the Automatic Identification System (AIS) data for maritime transport and ports applications [26] and for building a transport supply network [27].

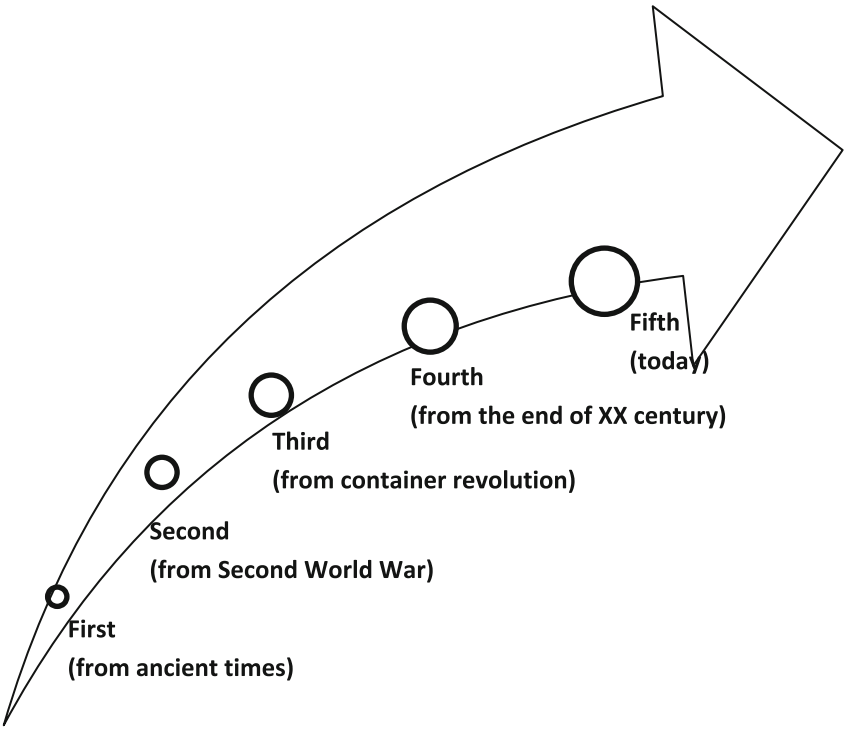

Fig. 1. Evolution of port generations

The paper consists of four sections. After the introduction, Sect. 2 examines the state of the art related to the classification of ports by generation, as initially proposed by UNCTAD and then developed in the international literature. In Sect. 3, a systematization of the different generations of ports is proposed, introducing the physical infrastructures, ships and equipment connected with each generation of ports. In the conclusion, the main results are summarized, outlining what are the guidelines for the development of ports that can now be evidenced from some paradigmatic elements.

The work is useful for both technicians and planners of the port authorities and relevant ministries. It is useful for researchers because it allows them to develop adequate forecasting models by clearly identifying the type of ports of reference.

2 Port-Generations: State of the Art

Although several classifications of ports have been proposed, there is no single established or accepted framework or taxonomy. The major obstacle against this is due to the complexity and diversity of the port entities. The study in [28] pointed out the main four differences among ports: organizational, issues of ownership (public versus private), institutional status (landlord/tool versus service), social arrangements (labour and manpower); operational, types of cargo handled, ships serviced, terminals operated; physical and spatial, location, access, connectivity, available capacity; legal and regulatory,

trade and transport policy, administrative procedures, safety and security regulations, environment.

In 1994 UNCTAD [1] introduced the definition of port generations and coined the term "third generation ports", as the product of the unitization of sea-trade and multimodal cargo packaging, mainly in the form of containers [29]. They led to the development of ports as logistics and intermodal centres offering value-added services, with technology and know-how being the major determining factors. In 1999, UNCTAD [18] suggested the arrival of the "fourth generation ports" as a result of vertical and horizontal integration strategies, and they are identified as being separated geographically but with common operators or administration.

The idea of a fourth generation port was introduced in an earlier work [30], which documented functions and roles of ports from the first to the fourth generation under the category of external environment, functional organization, spatial organization and port organization and strategy.

In the later years a number of papers have criticized the port generation approach defined by UNCTAD, and they have attempted to introduce further elements in order to capture the complexity and diversity of ports. The study presented in [31] argued that the idea of a third generation port could be sufficient if the world economic growth pattern could be forecasted with any certainty; but, this is not the case. The authors claimed that to cope with this uncertainty ports should adopt a new logistics approach based on agility and proposed a methodology for implementing the concept of agile ports. The work in [32] critically examined the UNCTAD generation ports classification and concluded that, rather than developing in discrete steps, ports evolve continuously, adapting to new technologies, evolving legislation, adapting working practices and other influences. They showed that several streams of evolution can be observed simultaneously; the speed of change within each stream can vary substantially. Ports often have several terminals, some operating along traditional lines while others may be leading edge in terms of technology, working practices or other aspects. According to the authors, the UNCTAD model, implying ports development in discrete steps, or generations, is shown to be fundamentally flawed. The study in [33] added on existing models on the spatial and functional evolution of ports and port systems, the paradigm of port regionalization. They showed that the regionalization phase, together with hinterland concepts, demands new approaches to port governance and a functional focus that goes beyond the traditional port perimeter. According to [28], the huge corpus of literature on ports' assets, functions and institutional organizations lie along an ideal line between two extremes. At the one extreme, ports have been defined through a macro-analytical approach as being geographical, physical and corporate assets. This approach is typically illustrated in the study of port aggregate impacts which has proven to be a controversial subject; but also with different methods of assessment and analysis (e.g. added-value, input-output analysis, statistical analysis). The other extreme is to look at ports from a micro-perspective approach in terms of sets of activities and operations shaping a ports' roles and functional dimensions, even this approach has specific methods. An intermediate approach between the two extremes tries to combine both the macro- and

micro-elements through providing a mixed definition of port roles and functions. One of these is the widely cited port generations of UNCTAD.

Port roles and functions, but also institutional structuring, operational and management practices vary significantly from generation to generation. According to [28], the flaws of the generation-type taxonomy outweigh its merits for some aspects. Firstly, it identifies port generations through sea/shore interface developments with little interest in port potential for shore/land-side expansion, as in the case of dry ports and distriparks. Secondly, it applies a rigid categorization far from reflecting the composite reality of ports. Many ports still perform first or second generation-type functions, and even within a single port, there may be a variety of operational and management systems intersecting across different generation categories. Thirdly, it hypothetically equates all cargo/ship type operations and functions under the same generation. In practice, many ports that declared to be fourth generation still carry out activities of first or second generation-types through, for instance, handling first generation-type cargo and ships. The study [34] highlighted the way in which ports and the services they provide develop in an evolutionary rather than a revolutionary way, as defined by the port generation approach by UNCTAD. The political dimension plays a lead role in ports' evolution, as ports are often seen both as a vital part of the supply chain and as a natural focus for regional development and employment. But, where they have been made more responsive is in tailoring services to individual customers' needs, thus becoming more agile.

Table 1 synthesizes the core elements of the main studies present in the literature concerning the port-generation approach, described in this section.

The authors examine the different forms and development process that ports have taken within the supply chain. In the last years some researchers attempted to overcome lacks of the 'fourth-generation ports' definition [35–37]. According to [35], the fourth-generation ports definition proposed in [18] focused on internal efficiency, but it was not sufficient to reflect the port functions required by community stakeholders' requirements and the needs of port users in the rapidly evolving globalised economic system.

They proposed the conceptual framework of the "fifth-generation ports", or Customer-Centric and Community (CCC) port. Key elements of the framework are networking and capacity management between: (1) "customer and port system: customer needs to enlisted as a partner to change certain behaviours in order to optimize work and capacity management"; (2) "commercial and production teams"; (3) "port and intermodal connections: reach a commercial, strategic positioning of the port and national economy, as well as offer an integrated solution".

The works presented in [36] and [37]) examined the competition of four major Asian ports (Shanghai, Singapore, Hong Kong and Busan) based on a revised version of the fifth generation ports framework, previously defined in [35]. They referred to the same factors of fourth generation ports and fifth generation ports, as defined by UNCTAD: service quality, information technology, community environmental impact, port cluster, maritime cluster, logistics hub, inland connection, and waterside connection. They did not explicitly consider in their analysis the vertical and horizontal integration process involving ports.

Recently, an operative basis for the quantitative specification of ports' characteristics according to the port-generation approach was defined [9]. The definition of a specific

Table 1. Main scientific publications about the port-generation approach

Author	*Main elements*
UNCTAD (1994; 1999) [1, 18]	• "port-generation" concept under the category of external environment, functional organization, spatial organization and port organization and strategy • "third-generation port "as the product of the unitization of cargo in the form of containers • "fourth generation port" as a result of vertical and horizontal integration strategies
Van Klink (1995) [30]	• Role of ports from first-generation to fourth-generation • Not all ports pass through all stages. Some remain at one stage, others skip one or more steps in their development
Paixao and Marlow (2003) [31]	• Third generation port not sufficient due to uncertainty of world economic growth pattern • New logistics approach based on agility • Methodology for implementing the concept of agile ports
Beresford et al. (2004) [32]	• Ports evolve continuously, rather than in discrete steps • Several streams of evolution can be observed simultaneously; the speed of change within each stream can vary substantially • Additional operational and development issues than UNCTAD
Bichou and Gray (2005) [28]	Limits of port-generation approach: • Focus on sea/shore interface developments with no interest on shore/land-side expansion (dry ports, distriparks); • rigid categorization not reflecting the composite reality of ports • all cargo/ship type operations and functions under the same generation
Notteboom and Rodrigue (2005) [33]	• Paradigm of port regionalization • New approaches to port governance and to functional concern beyond the traditional port perimeter
Flynn et al. (2011) [35]	• Fourth-generation ports focused on internal efficiency, not sufficient to reflect the port functions required by community stakeholders' requirements and the needs of port users • Conceptual framework of fifth generation ports with world-class Customer-Centric and Community (CCC) ports

(*continued*)

Table 1. (*continued*)

Author	*Main elements*
Lee and Lam (2015, 2016) [36, 37]	• Revised concept of fifth-generation port • Empirical comparison of four Asian ports: Shanghai, Singapore, Hong Kong and Busan • Qualitative analysis with sharper demarcation borders of factors
Russo and Musolino (2020) [9]	• Operative basis for quantitative specification of ports' characteristics according to the port-generation approach • Application to Italian ports
Russo and Musolino (2021) [20]	• Description of theoretical approaches to support the evaluation of fourth-generation ports • Case studies of cooperation among ports
Russo and Musolino (2021) [21]	• Benefits and challenges connected with the introduction of shared emerging ICT among stakeholders inside fifth-generation ports

generation for a port highlights its main characteristics, as several ports were object, in the time, of a process of hybridization. The paper proposed some indicators to identify each of the three generations defined by UNCTAD, which were calculated to a set of Italian ports. The paper [20] presents the main theoretical approaches to support the evaluation of fourth-generation ports, which could respond to the new requirements imposed by gigantism, carriers' alliances and land-sea integration. Furthermore, some representative case studies of cooperation among ports are reported and classified, in order to aggregate the observed processes in some macro-classes. The study in [21] presented a framework to evaluate the new benefits and challenges connected with the introduction of shared emerging ICT among decision-makers inside fifth-generation ports. The paper sketched and compared some scenarios with the presence of different level of emerging ICT inside a port (e.g. the presence of a Port Community System). The aim was to estimate the gain in port performance generated by the solution of shared port stakeholders' decisions by means of the emerging ICT.

In relation to the examined literature, it is possible to identify the main characteristic of each port generation. The result of this process is synthetized in Table 2, where a keyword and a main characteristic is reported. It is worth noting that the definition of a specific generation for a port is not an element of ranking; but, expresses its main role in the worldwide transport network. Several ports were object, in the time, of a process of hybridization. They were born with specific characteristics and, later, they evolved in acquiring new ones.

Table 2. Main characteristics port-generations (elaboration from [1, 4, 9].

Port-generation	*Keyword*	*Main characteristic*
First	City	High port-city interactions
Second	Industrial	Heavy industrial plants closer to the port
Third	Container	Container traffic
Fourth	Cooperative	Common public governance with other ports
Fifth	Digital	Emerging ICT (e.g. port community system) with horizontal integration

3 Port-Generations: Identifying Criteria

The section introduces a set of criteria for identifying each generation of port. The issue that arises is to be able to identify a set of characteristics that allows, in a homogeneous way, to identify the generation of a port.

It is necessary to first define two components that identify a port both among those involved in maritime trade, throughout the vertical chain, and among the technicians and researchers who work in this field.

Governance Component. Generally, the ports are managed by a port authority. This authority can have different economic, financial, legal and administrative nature: from completely or predominantly private entities, as in the USA to completely public entities, as in Spain. At the governance level there are therefore a multiplicity of governance structures.

Spatial Component. Inside a harbor space without solution of continuity can be present, more or less contiguous, deeply different commercial functions. From the analysis of the two above elements in the ports of international importance emerge different situations:

- governance and spatial component coincide, that is all the harbor space, continuous, is managed from a single port authority
- governance and spatial components do not coincide, in this case there are two possibilities, the governance entity is unique but the spaces are not continuous, or the space is unique but there are different governance entities.

A *port* could therefore be defined as the intersection of governance and spatial components, i.e. a continuous space managed by a single port authority. Even in the presence of this definition, it appears that the two components, spatial and governance, do not allow us to univocally identify the generation of the port, because over time, radically different port operations have been defined in the same space. The diversity of port operations has led to the hybridizations mentioned above.

The different port operations can be aggregated in relation to the characteristics of:

- *static physical infrastructures* necessary for carrying out port operations;
- *dynamic mechanical infrastructures* that allow the movement of goods;
- *type of ship* that requires the port operations.

In general, a defined combination of these characteristics makes it possible to unequivocally identify the membership to one of the first three generations. Considering that the ships/infrastructures/equipments are internally integrated and therefore fixed, it may be sufficient to know only one of the three characteristics to identify the generation of a port.

Given the components and characteristics, a port is defined as: *the intersection of governance and spatial components in which port operations are carried out with a homogeneous trio of characteristics*, i.e. a continuous space managed by a single port authority in which port operations are carried out with a single homogeneous trio of ships/infrastructures/equipments characteristics.

A highly homogeneous trio, and therefore a strong specialization of the port, implies the handling of very specific loading units.

If this position is necessary, it is also sufficient, i.e. given a type of unitization of the goods, it is possible to know the trio of characteristics necessary for its handling in a port.

A further defining feature of the port is the *territorial scale* at which the goods handled in the ports are distributed. The scale to be considered may be different by considering incoming and/or outgoing goods. In this note, we consider ports that have an intercontinental scale in one or both of the two in/out directions.

Other types of ports, i.e. with in/out directions on a local scale, can have a considerable promiscuity in the use of equipment and therefore the same infrastructures can be destined to significantly different port operations. Obviously, promiscuity does not allow a full identification of generation, which is not necessary because these ports operate on the margins, if not outside, of the global market.

While the first three generations, as mentioned in the introduction, are defined in their components, the fourth and fifth generations are less defined. The fourth generation ports were born because of the significant increase of international trade, that imposed to ports to move from competitive attitudes towards a cooperative one. Fourth-generation ports allow the reduction of the time of ships in transit because they offer greater capacity of both infrastructure and equipment. The fifth generation ports were born with the massive introduction of Information and Communication Technologies (ICT) in port operations. The main characteristics concerns the sharing of ICT among all port operators (i.e. horizontal integration). The systems developed are called Port Community Systems (PCS), which makes it possible to reduce port operations times with a decisive intervention on the information flows connected to the freight handling.

4 Conclusions

The paper reports a state of the art concerning the scientific literature about the port-generation approach and proposes a set of characteristics to identify each port-generation. The different generations are identified and characterized by introducing the physical infrastructures, the ships and the equipment connected with each generation of ports, considered as structural factors of the internal production process of the "port fabric".

From what have been proposed, a first important result emerges: the transition from the first generation to the subsequent, second and third, reduces the time in port for specialized ships, mainly oil tankers and container ships, but requires longer time journeys for the ships compared to first generation ports, because the first generation ports are more present in the regional areas, and are the final destination in the hub and spoke system.

Considering each generation, the relevance of the factors presented in the paper will be validated in the next step of the research by putting them in correlation with the ship times in the ports. With the increase in the size of ships, each hour of stop has a considerable cost, of different types: ship costs due to crews and depreciation of the ship; costs for goods to be loaded/unloaded and for those that remain on board waiting for the next ports. This significant amount of costs can be reduced by optimizing the process of port operations. The type of optimization that can be pursued, depends on the generation of the port in question and therefore with a range of actions ranging from increasing infrastructure capacity to speeding up information flows.

The prospects for sustainable development of ports consider different directions that can contribute to improving the times. These include: lean development, i.e. the elimination of parts of tangible or intangible procedures that weigh down port operations; agile development, i.e. capable of adapting to demand dynamics, both predictable due to seasonal fluctuations, trend fluctuations, and those due to unpredictable random events; resilient development, i.e. the ability to recover after serious unforeseeable events; green development, which is identified as one of the most important frontiers for the development of ports.

The scope defined in this note makes it possible to identify the key factors for the reduction of ship times in port, in relation to the generation of belonging to the port itself. The work can be useful to the technicians and planners of the port authorities and state structures responsible for the financing of ports because it allows them to identify for each port the most important factors on which to act by financing appropriate interventions. The work can be useful to researchers and analysts because it allows to organize statistical-descriptive models that allow to identify in a disaggregated way the major deficiencies of the single port and in aggregate the deficiencies of the set of ports of a country.

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